CIVIL AVIATION
REQUIREMENTS FOR
AERONAUTICAL TELECOMMUNICATION

CAR – 10

(Volume I: Radio Navigation Aids)

Third Edition-March, 2019

Civil Aviation Authority of Nepal

RECORD OF AMENDMENTS

Amendments to CAR-10, VOLUME 1

Amendment	Sources	Subject(s)	Effective Date
First edition, 1st amendment	Annex 10	Aeronautical Telecommunication	2009
Second edition, 1st amendment	Annex 10	Aeronautical Telecommunication	2013
Third edition, 1st amendment	Annex 10	Aeronautical Telecommunication	2019

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Foreword

Article 28 (Air Navigation facilities and standard systems) of the Convention on International Civil aviation requires each contracting state to provide, in its territory, airports, radio services, meteorological services and other air navigation services to facilitate international air navigation, in accordance with the standards and recommended practices established from time to time, pursuant to this Convention. Under Article 37 (Adoption of international Standard and Procedures) of the Convention, each contracting State undertakes to collaborate in securing the highest practicable degree of uniformity in regulations, standards, procedures, and organization in relation to aircraft, personnel, airways and auxiliary services in all matters in which such uniformity will facilitate and improve air navigation. To this end the International Civil Aviation Organization adopts and amends from time to time, as may be necessary, international standards and recommended practices and procedures dealing with air traffic service practices.

In above respect, ICAO Annex 10 Volume I provides the Standard pertaining to the Aeronautical Telecommunication which are required to be adopted by the Contracting States.

This Civil Aviation Requirement for Aeronautical Telecommunication, CAR-10 Vol-I, Third Edition 2019 has been enacted by Civil Aviation Authority of Nepal, pursuant to Clause-5 Sub-Clause “Pha” and Clause-35 of Civil Aviation Authority of Nepal Act, 2053(1996) and Rule-82 Schedule-3 of Civil Aviation Regulation, 2058(2002), in accordance with the Standard and Recommended Practices of Annex-10 “Aeronautical Telecommunication” to the convention of International Civil Aviation for safety, regularity and efficiency of civil aviation in Nepal and incorporates all the provisions of 7th edition of this Annex, and concerning directives time to time issued by CAAN.

This edition supersedes the previous edition of CAR-10 Vol-I.

All earlier national legislations still stand valid as a part of Civil Aviation Requirements for practical purposes.

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CHAPTER 1. DEFINITIONS

Note 1.— All references to “Radio Regulations” are to the Radio Regulations published by the International Telecommunication Union (ITU). Radio Regulations are amended from time to time by the decisions embodied in the Final Acts of World Radiocommunication Conferences held normally every two to three years. Further information on the ITU processes as they relate to aeronautical radio system frequency use is contained in the Handbook on Radio Frequency Spectrum Requirements for Civil Aviation including statement of approved ICAO policies *(Doc 9718).*

Note 2.— CAR 10, Volume I includes Standards for certain forms of equipment for air navigation aids.

Note 3.— The terminology used in this CAR to refer to instrument approach operations is based on a previous version of the FOR classification of instrument approach and landing operations. It can be mapped to the FOR definitions as follows:

Performance requirements in support of instrument approach operations		
CAR 10 system performance		FOR- Aeroplane — Approach operation category
Non-precision approach (NPA)		2D-Type A (1)
Approach with vertical guidance (APV)		3D-Type A (2)
Precision approach (PA)	Category I, DH equal to or greater than 75 m (250 ft)	3D-Type A (3)
	Category I, DH equal to or greater than 60 m (200 ft) and less than 75 m (250 ft)	3D-Type B — CAT I (3)
	Category II	3D-Type B — CAT II
	Category III	3D-Type B — CAT III

(1) Without vertical guidance.
(2) With barometric or SBAS vertical guidance.
(3) With ILS, GBAS or SBAS vertical guidance.

When the following terms are used in this volume, they have the following meanings:

Altitude. The vertical distance of a level, a point or an object considered as a point, measured from mean sea level (MSL).

Area navigation (RNAV). A method of navigation which permits aircraft operation on any desired flight path within the coverage of ground- or space-based navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

Note.— Area navigation includes performance-based navigation as well as other operations that do not meet the definition of performance-based navigation.

Effective acceptance bandwidth. The range of frequencies with respect to the assigned frequency for which reception is assured when all receiver tolerances have been taken into account.

Effective adjacent channel rejection. The rejection that is obtained at the appropriate adjacent channel frequency when all relevant receiver tolerances have been taken into account.

Elevation. The vertical distance of a point or a level, on or affixed to the surface of the earth, measured from mean sea level.

Essential radio navigation service. A radio navigation service whose disruption has a significant impact on operations in the affected airspace or aerodrome.

Fan marker beacon. A type of radio beacon, the emissions of which radiate in a vertical fan-shaped pattern.

Height. The vertical distance of a level, a point or an object considered as a point, measured from a specified datum.

Human Factors principles. Principles which apply to design, certification, training, operations and maintenance and which seek safe interface between the human and other system components by proper consideration to human performance.

Mean power (of a radio transmitter). The average power supplied to the antenna transmission line by a transmitter during an interval of time sufficiently long compared with the lowest frequency encountered in the modulation taken under normal operating conditions.

Note.— A time of 1/10 second during which the mean power is greatest will be selected normally.

Navigation specification. A set of aircraft and flight crew requirements needed to support performance-based navigation operations within a defined airspace. There are two kinds of navigation specifications:

Required navigation performance (RNP) specification. A navigation specification based on area navigation that includes the requirement for performance monitoring and alerting, designated by the prefix RNP, e.g. RNP 4, RNP APCH.

Area navigation (RNAV) specification. A navigation specification based on area navigation that does not include the requirement for performance monitoring and alerting, designated by the prefix RNAV, e.g. RNAV 5, RNAV 1.

Note.1— The Performance-based Navigation (PBN) Manual *(Doc 9613), Volume II, contains detailed guidance on navigation specifications.*

Note 2.— The term RNP, previously defined as "a statement of the navigation performance necessary for operation within a defined airspace", has been removed from this CAR as the concept of RNP has been overtaken by the concept of PBN. The term RNP in this CAR is now solely used in the context of navigation specifications that require performance monitoring and alerting, e.g. RNP 4 refers to the aircraft and operating requirements, including a 4 NM lateral performance with on-board performance monitoring and alerting that are detailed in Doc 9613.

Performance-based navigation (PBN). Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

Note.— Performance requirements are expressed in navigation specifications (RNAV specification, RNP specification) in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

Pressure-altitude. An atmospheric pressure expressed in terms of altitude which corresponds to that pressure in the Standard Atmosphere.

Protected service volume. A part of the facility coverage where the facility provides a particular service in accordance with relevant SARPs and within which the facility is afforded frequency protection.

Radio navigation service. A service providing guidance information or position data for the efficient and safe operation of aircraft supported by one or more radio navigation aids.

Touchdown. The point where the nominal glide path intercepts the runway.

Note.— "Touchdown" as defined above is only a datum and is not necessarily the actual point at which the aircraft will touch the runway.

Z marker beacon. A type of radio beacon, the emissions of which radiate in a vertical cone-shaped pattern.

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CHAPTER 2. GENERAL PROVISIONS FOR RADIO NAVIGATION AIDS

2.1 Standard radio navigation aids

2.1.1 The standard radio navigation aids shall be:

a) the instrument landing system (ILS) conforming to the Standards contained in Chapter 3, 3.1;

b) reserved;

c) the global navigation satellite system (GNSS) conforming to the Standards contained in Chapter 3, 3.7;

d) the VHF omnidirectional radio range (VOR) conforming to the Standards contained in Chapter 3, 3.3;

e) the non-directional radio beacon (NDB) conforming to the Standards contained in Chapter 3, 3.4;

f) the distance measuring equipment (DME) conforming to the Standards contained in Chapter 3, 3.5; and

g) the en-route VHF marker beacon conforming to the Standards contained in Chapter 3, 3.6.

Note 1.— Since visual reference is essential for the final stages of approach and landing, the installation of a radio navigation aid does not obviate the need for visual aids to approach and landing in conditions of low visibility.

Note 2.— It is intended that introduction and application of radio navigation aids to support precision approach and landing operations will be in accordance with the strategy shown in Attachment B. It is intended that rationalization of conventional radio navigation aids and evolution toward supporting performance-based navigation will be in accordance with the strategy shown in Attachment H.

Note 3.— Categories of precision approach and landing operations are classified in FOR- Aeroplane, Chapter 1.

Note 4.— Information on operational objectives associated with ILS facility performance categories is given in Attachment C, 2.1 and 2.14.

2.1.2 Differences in radio navigation aids in any respect from the Standards of Chapter 3 shall be published in an Aeronautical Information Publication (AIP).

2.1.3 Wherever there is installed a radio navigation aid that is neither an ILS nor an MLS, but which may be used in whole or in part with aircraft equipment designed for use with the ILS or MLS, full details of parts that may be so used shall be published in an Aeronautical Information Publication (AIP).

Note.— This provision is to establish a requirement for promulgation of relevant information rather than to authorize such installations.

2.1.4 GNSS-specific provisions

2.1.4.1 It shall be permissible to terminate a GNSS satellite service provided by one of its elements (Chapter 3, 3.7.2) on the basis of at least a six-year advance notice by a service provider.

2.1.4.2 Reserved.

Note 1.—

Note 2.— Guidance material on the recording of GNSS parameters is contained in Attachment D, 11.

2.1.4.3 Reserved.

2.1.5 Reserved

2.1.6 When a radio navigation aid is provided to support precision approach and landing, it shall be supplemented, as necessary, by a source or sources of guidance information which, when used in conjunction with appropriate procedures, will provide effective guidance to, and efficient coupling (manual or automatic) with, the desired reference path.

Note.— DME, GNSS, NDB, VOR and aircraft navigation systems have been used for such purposes.

2.2 Ground and flight testing

2.2.1 Radio navigation aids of the types covered by the specifications in Chapter 3 and available for use by aircraft engaged in international air navigation shall be the subject of periodic ground and flight tests.

Note.— Guidance on the ground and flight testing of ICAO standard facilities, including the periodicity of the testing, is contained in Attachment C and in the Manual on Testing of Radio Navigation Aids *(Doc 8071).*

2.3 Provision of information on the operational status of radio navigation services

2.3.1 Aerodrome control towers and units providing approach control service shall be provided with information on the operational status of radio navigation services essential for approach, landing and take-off at the aerodrome(s) with which they are concerned, on a timely basis consistent with the use of the service(s) involved.

2.4 Power supply for radio navigation aids and communication systems

2.4.1 Radio navigation aids and ground elements of communication systems of the types specified in this CAR shall be provided with suitable power supplies and means to ensure continuity of service consistent with the use of the service(s) involved.

Note.— Guidance material on power supply switch-over is contained in Attachment C, 8.

2.5 Human Factors considerations

2.5.1 Human Factors principles shall be observed in the design and certification of radio navigation aids.

Note.— Guidance material on Human Factors principles can be found in the Human Factors Training Manual *(Doc 9683) and Circular 249* (Human Factors Digest No. 11 — Human Factors in CNS/ATM Systems).

CHAPTER 3. SPECIFICATIONS FOR RADIO NAVIGATION AIDS

Note.— Specifications concerning the siting and construction of equipment and installations on operational areas aimed at reducing the hazard to aircraft to a minimum are contained in CAR 14, Part-I, Chapter 8.

3.1 Specification for ILS

3.1.1 Definitions

Angular displacement sensitivity. The ratio of measured DDM to the corresponding angular displacement from the appropriate reference line.

Back course sector. The course sector which is situated on the opposite side of the localizer from the runway.

Course line. The locus of points nearest to the runway centre line in any horizontal plane at which the DDM is zero.

Course sector. A sector in a horizontal plane containing the course line and limited by the loci of points nearest to the course line at which the DDM is 0.155.

DDM — Difference in depth of modulation. The percentage modulation depth of the larger signal minus the percentage modulation depth of the smaller signal, divided by 100.

Displacement sensitivity (localizer). The ratio of measured DDM to the corresponding lateral displacement from the appropriate reference line.

Facility Performance Category I — ILS. An ILS which provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 60 m (200 ft) or less above the horizontal plane containing the threshold.

Note.— This definition is not intended to preclude the use of Facility Performance Category I — ILS below the height of 60 m (200 ft), with visual reference where the quality of the guidance provided permits, and where satisfactory operational procedures have been established.

Facility Performance Category II — ILS. An ILS which provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 15 m (50 ft) or less above the horizontal plane containing the threshold.

Facility Performance Category III — ILS. An ILS which, with the aid of ancillary equipment where necessary, provides guidance information from the coverage limit of the facility to, and along, the surface of the runway.

Front course sector. The course sector which is situated on the same side of the localizer as the runway.

Half course sector. The sector, in a horizontal plane containing the course line and limited by the loci of points nearest to the course line at which the DDM is 0.0775.

Half ILS glide path sector. The sector in the vertical plane containing the ILS glide path and limited by the loci of points nearest to the glide path at which the DDM is 0.0875.

ILS continuity of service. That quality which relates to the rarity of radiated signal interruptions. The level of continuity of service of the localizer or the glide path is expressed in terms of the probability of not losing the radiated guidance signals.

ILS glide path. That locus of points in the vertical plane containing the runway centre line at which the DDM is zero, which, of all such loci, is the closest to the horizontal plane.

ILS glide path angle. The angle between a straight line which represents the mean of the ILS glide path and the horizontal.

ILS glide path sector. The sector in the vertical plane containing the ILS glide path and limited by the loci of points nearest to the glide path at which the DDM is 0.175.

Note.— The ILS glide path sector is located in the vertical plane containing the runway centre line, and is divided by the radiated glide path in two parts called upper sector and lower sector, referring respectively to the sectors above and below the glide path.

ILS integrity. That quality which relates to the trust which can be placed in the correctness of the information supplied by the facility. The level of integrity of the localizer or the glide path is expressed in terms of the probability of not radiating false guidance signals.

ILS Point "A". A point on the ILS glide path measured along the extended runway centre line in the approach direction a distance of 7.5 km (4 NM) from the threshold.

ILS Point "B". A point on the ILS glide path measured along the extended runway centre line in the approach direction a distance of 1 050 m (3 500 ft) from the threshold.

ILS Point "C". A point through which the downward extended straight portion of the nominal ILS glide path passes at a height of 30 m (100 ft) above the horizontal plane containing the threshold.

ILS Point "D". A point 4 m (12 ft) above the runway centre line and 900 m (3 000 ft) from the threshold in the direction of the localizer.

ILS Point "E". A point 4 m (12 ft) above the runway centre line and 600 m (2 000 ft) from the stop end of the runway in the direction of the threshold.

Note.— See Attachment C, Figure C-1.

ILS reference datum (Point "T"). A point at a specified height located above the intersection of the runway centre line and the threshold and through which the downward extended straight portion of the ILS glide path passes.

Two-frequency glide path system. An ILS glide path in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies within the particular glide path channel.

Two-frequency localizer system. A localizer system in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies within the particular localizer VHF channel.

3.1.2 Basic requirements

3.1.2.1 The ILS shall comprise the following basic components:

a) VHF localizer equipment, associated monitor system, remote control and indicator equipment;

b) UHF glide path equipment, associated monitor system, remote control and indicator equipment;

c) an appropriate means to enable glide path verification checks.

Note.— The Procedures for Air Navigation Services — Aircraft Operations *(PANS-OPS) (Doc 8168) provide guidance on the conduct of glide path verification checks.*

3.1.2.1.1 Distance to threshold information to enable glide path verification checks shall be provided by either VHF marker beacons or distance measuring equipment (DME), together with associated monitor systems and remote control and indicator equipment.

3.1.2.1.2 If one or more VHF marker beacons are used to provide distance to threshold information, the equipment shall conform to the specifications in 3.1.7. If DME is used in lieu of marker beacons, the equipment shall conform to the specifications in 3.1.7.6.5.

Note.— Guidance material relative to the use of DME and/or other standard radio navigation aids as an alternative to the marker beacon is contained in Attachment C, 2.11.

3.1.2.1.3 Facility Performance Categories I, II and III — ILS shall provide indications at designated remote control points of the operational status of all ILS ground system components, as follows:

a) for all Category II and Category III ILS, the air traffic services unit involved in the control of aircraft on the final approach shall be one of the designated remote control points and shall receive information on the operational status of the ILS, with a delay commensurate with the requirements of the operational environment;

b) for a Category I ILS, if that ILS provides an essential radio navigation service, the air traffic services unit involved in the control of aircraft on the final approach shall be one of the designated remote control points and shall receive information on the operational status of the ILS, with a delay commensurate with the requirements of the operational environment.

Note 1.— The indications required by this Standard are intended as a tool to support air traffic management functions, and the applicable timeliness requirements are sized accordingly (consistently with Attachement-C, 2.8.1). Timeliness requirements applicable to the ILS integrity monitoring functions that protect aircraft from ILS malfunctions are specified in 3.1.3.11.3.1 and 3.1.5.7.3.1.

Note 2.— It is intended that the air traffic system is likely to call for additional provisions which may be found essential for the attainment of full operational Category III capability, e.g. to provide additional lateral and longitudinal guidance during the landing roll-out, and taxiing, and to ensure enhancement of the integrity and reliability of the system.

3.1.2.2 The ILS shall be constructed and adjusted so that, at a specified distance from the threshold, similar instrumental indications in the aircraft represent similar displacements from the course line or ILS glide path as appropriate, irrespective of the particular ground installation in use.

3.1.2.3 The localizer and glide path components specified in 3.1.2.1 a) and b) which form part of a Facility Performance Category I — ILS shall comply at least with the Standards in 3.1.3 and 3.1.5 respectively, excepting those in which application to Facility Performance Category II — ILS is prescribed.

3.1.2.4 The localizer and glide path components specified in 3.1.2.1 a) and b) which form part of a Facility Performance Category II — ILS shall comply with the Standards applicable to these components in a Facility Performance Category I — ILS, as supplemented or amended by the Standards in 3.1.3 and 3.1.5 in which application to Facility Performance Category II — ILS is prescribed.

3.1.2.5 The localizer and glide path components and other ancillary equipment specified in 3.1.2.1.3, which form part of a Facility Performance Category III — ILS, shall otherwise comply with the Standards applicable to these components in Facility Performance Categories I and II — ILS, except as supplemented by the Standards in 3.1.3 and 3.1.5 in which application to Facility Performance Category III — ILS is prescribed.

3.1.2.6 To ensure an adequate level of safety, the ILS shall be so designed and maintained that the probability of operation within the performance requirements specified is of a high value, consistent with the category of operational performance concerned.

Note.— The specifications for Facility Performance Categories II and III — ILS are intended to achieve the highest degree of system integrity, reliability and stability of operation under the most adverse environmental conditions to be encountered. Guidance material to achieve this objective in Categories II and III operations is given in 2.8 of Attachment C.

3.1.2.7 At those locations where two separate ILS facilities serve opposite ends of a single runway, an interlock shall ensure that only the localizer serving the approach direction in use shall radiate, except where the localizer in operational use is Facility Performance Category I — ILS and no operationally harmful interference results.

3.1.2.7.1 **Reserved.**

3.1.2.7.2 At locations where ILS facilities serving opposite ends of the same runway or different runways at the same airport use the same paired frequencies, an interlock shall ensure that only one facility shall radiate at a time. When switching from one ILS facility to another, radiation from both shall be suppressed for not less than 20 seconds.

Note.— Additional guidance material on the operation of localizers on the same frequency channel is contained in 2.1.9 of Attachment C and Annex-10, Volume V, Chapter 4.

3.1.3 VHF localizer and associated monitor

Introduction. The specifications in this section cover ILS localizers providing either positive guidance information over 360 degrees of azimuth, or providing such guidance only within a specified portion of the front coverage (see 3.1.3.7.4). Where ILS localizers providing positive guidance information in a limited sector are installed, information from some suitably located navigation aid, together with appropriate procedures, will generally be required to ensure that any misleading guidance information outside the sector is not operationally significant.

3.1.3.1 General

3.1.3.1.1 The radiation from the localizer antenna system shall produce a composite field pattern which is amplitude modulated by a 90 Hz and a 150 Hz tone. The radiation field pattern shall produce a course sector with one tone predominating on one side of the course and with the other tone predominating on the opposite side.

3.1.3.1.2 When an observer faces the localizer from the approach end of a runway, the depth of modulation of the radio frequency carrier due to the 150 Hz tone shall predominate on the observer's right hand and that due to the 90 Hz tone shall predominate on the observer's left hand.

3.1.3.1.3 All horizontal angles employed in specifying the localizer field patterns shall originate from the centre of the localizer antenna system which provides the signals used in the front course sector.

3.1.3.2 Radio frequency

3.1.3.2.1 The localizer shall operate in the band 108 MHz to 111.975 MHz. Where a single radio frequency carrier is used, the frequency tolerance shall not exceed plus or minus 0.005 per cent. Where two radio frequency carriers are used, the frequency tolerance shall not exceed 0.002 per cent and the nominal band occupied by the carriers shall be symmetrical about the assigned frequency. With all tolerances applied, the frequency separation between the carriers shall not be less than 5 kHz nor more than 14 kHz.

3.1.3.2.2 The emission from the localizer shall be horizontally polarized. The vertically polarized component of the radiation on the course line shall not exceed that which corresponds to a DDM error of 0.016 when an aircraft is positioned on the course line and is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.2.1 For Facility Performance Category II localizers, the vertically polarized component of the radiation on the course line shall not exceed that which corresponds to a DDM error of 0.008 when an aircraft is positioned on the course line and is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.2.2 For Facility Performance Category III localizers, the vertically polarized component of the radiation within a sector bounded by 0.02 DDM either side of the course line shall not exceed that which corresponds to a DDM error of 0.005 when an aircraft is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.3 For Facility Performance Category III localizers, signals emanating from the transmitter shall contain no components which result in an apparent course line fluctuation of more than 0.005 DDM peak to peak in the frequency band 0.01 Hz to 10 Hz.

3.1.3.3 Coverage

Note.— Guidance material on localizer coverage is given in Attachment C, 2.1.10 and Figures C-7A, C-7B, C-8A and C-8B.

3.1.3.3.1 The localizer shall provide signals sufficient to allow satisfactory operation of a typical aircraft installation within the localizer and glide path coverage sectors. The localizer coverage sector shall extend from the centre of the localizer antenna system to distances of:

46.3 km (25 NM) within plus or minus 10 degrees from the front course line;

31.5 km (17 NM) between 10 degrees and 35 degrees from the front course line;

18.5 km (10 NM) outside of plus or minus 35 degrees from the front course line if coverage is provided;

except that, where topographical features dictate or operational requirements permit, the limits may be reduced down to 33.3 km (18 NM) within the plus or minus 10-degree sector and 18.5 km (10 NM) within the remainder of the coverage when alternative navigational means provide satisfactory coverage within the intermediate approach area. The localizer signals shall be receivable at the distances specified at and above a height of 600 m (2 000 ft) above the elevation of the threshold, or 300 m (1 000 ft) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher, except that, where needed to protect ILS performance and if operational requirements permit, the lower limit of coverage at angles beyond 15 degrees from the front course line shall be raised linearly from its height at 15 degrees to as high as 1 350 m (4 500 ft) above the elevation of the threshold at 35 degrees from the front course line. Such signals shall be receivable, to the distances specified, up to a surface extending outward from the localizer antenna and inclined at 7 degrees above the horizontal.

Note.— Where intervening obstacles penetrate the lower surface, it is intended that guidance need not be provided at less than line-of-sight heights .

3.1.3.3.2 In all parts of the coverage volume specified in 3.1.3.3.1, other than as specified in 3.1.3.3.2.1, 3.1.3.3.2.2 and 3.1.3.3.2.3, the field strength shall be not less than 40 microvolts per metre (minus 114 dBW/m^2).

Note.— This minimum field strength is required to permit satisfactory operational usage of ILS localizer facilities.

3.1.3.3.2.1 For Facility Performance Category I localizers, the minimum field strength on the ILS glide path and within the localizer course sector from a distance of 18.5 km (10 NM) to a height of 60 m (200 ft) above the horizontal plane containing the threshold shall be not less than 90 microvolts per metre (minus 107 dBW/m^2).

3.1.3.3.2.2 For Facility Performance Category II localizers, the minimum field strength on the ILS glide path and within the localizer course sector shall be not less than 100 microvolts per metre (minus 106 dBW/m^2) at a distance of 18.5 km (10 NM) increasing to not less than 200 microvolts per metre (minus 100 dBW/m^2) at a height of 15 m (50 ft) above the horizontal plane containing the threshold.

3.1.3.3.2.3 For Facility Performance Category III localizers, the minimum field strength on the ILS glide path and within the localizer course sector shall be not less than 100 microvolts per metre (minus 106 dBW/m^2) at a distance of 18.5 km (10 NM), increasing to not less than 200 microvolts per metre (minus 100 dBW/m^2) at 6 m (20 ft) above the horizontal plane containing the threshold. From this point to a further point 4 m (12 ft) above the runway centre line, and 300 m (1 000 ft) from the threshold in the direction of the localizer, and thereafter at a height of 4 m (12 ft) along the length of the runway in the direction of the localizer, the field strength shall be not less than 100 microvolts per metre (minus 106 dBW/m^2).

Note.— The field strengths given in 3.1.3.3.2.2 and 3.1.3.3.2.3 are necessary to provide the signal-to-noise ratio required for improved integrity.

3.1.3.3.3 **Reserved**.

Note 1.— The requirements in 3.1.3.3.1, 3.1.3.3.2.1, 3.1.3.3.2.2 and 3.1.3.3.2.3 are based on the assumption that the aircraft is heading directly toward the facility.

Note 2.— Guidance material on significant airborne receiver parameters is given in 2.2.2 of Attachment C.

3.1.3.3.4 When coverage is achieved by a localizer using two radio frequency carriers, one carrier providing a radiation field pattern in the front course sector and the other providing a radiation field pattern outside that sector, the ratio of the two carrier signal strengths in space within the front course sector to the coverage limits specified at 3.1.3.3.1 shall not be less than 10 dB.

Note.— Guidance material on localizers achieving coverage with two radio frequency carriers is given in the Note to 3.1.3.11.2 and in 2.7 of Attachment C.

3.1.3.3.5 **Reserved**

3.1.3.4 Course structure

3.1.3.4.1 For Facility Performance Category I localizers, bends in the course line shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point “A”	0.031
ILS Point “A” to ILS Point “B”	0.031 at ILS Point “A” decreasing at a linear rate to 0.015 at ILS Point “B”
ILS Point “B” to ILS Point “C”	0.015

3.1.3.4.2 For Facility Performance Categories II and III localizers, bends in the course line shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point “A”	0.031
ILS Point “A” to ILS Point “B”	0.031 at ILS Point “A” decreasing at a linear rate to 0.005 at ILS Point “B”
ILS Point “B” to the ILS reference datum	0.005

and, for Category III only:

Zone	*Amplitude (DDM) (95% probability)*
ILS reference datum to ILS Point “D”	0.005
ILS Point “D” to ILS Point “E”	0.005 at ILS Point “D” increasing at a linear rate to 0.010 at ILS Point “E”

Note 1.— The amplitudes referred to in 3.1.3.4.1 and 3.1.3.4.2 are the DDMs due to bends as realized on the mean course line, when correctly adjusted.

Note 2.— Guidance material relevant to the localizer course structure is given in 2.1.3, 2.1.5, 2.1.6 and 2.1.9 of Attachment C.

3.1.3.5 Carrier modulation

3.1.3.5.1 The nominal depth of modulation of the radio frequency carrier due to each of the 90 Hz and 150 Hz tones shall be 20 per cent along the course line.

3.1.3.5.2 The depth of modulation of the radio frequency carrier due to each of the 90 Hz and 150 Hz tones shall be within the limits of 18 and 22 per cent.

3.1.3.5.3 The following tolerances shall be applied to the frequencies of the modulating tones:

a) the modulating tones shall be 90 Hz and 150 Hz within plus or minus 2.5 per cent ;

b) the modulating tones shall be 90 Hz and 150 Hz within plus or minus 1.5 per cent for Facility Performance Category II installations;

c) the modulating tones shall be 90 Hz and 150 Hz within plus or minus 1 per cent for Facility Performance Category III installations;

d) the total harmonic content of the 90 Hz tone shall not exceed 10 per cent; additionally, for Facility Performance Category III localizers, the second harmonic of the 90 Hz tone shall not exceed 5 per cent;

e) the total harmonic content of the 150 Hz tone shall not exceed 10 per cent.

3.1.3.5.3.1 **Reserved.**

3.1.3.5.3.2 For Facility Performance Category III localizers, the depth of amplitude modulation of the radio frequency carrier at the power supply frequency or its harmonics, or by other unwanted components, shall not exceed 0.5 per cent. Harmonics of the supply, or other unwanted noise components that may intermodulate with the 90 Hz and 150 Hz navigation tones or their harmonics to produce fluctuations in the course line, shall not exceed 0.05 per cent modulation depth of the radio frequency carrier.

3.1.3.5.3.3 The modulation tones shall be phase-locked so that within the half course sector, the demodulated 90 Hz and 150 Hz wave forms pass through zero in the same direction within:

a) for Facility Performance Categories I and II localizers: 20 degrees; and

b) for Facility Performance Category III localizers: 10 degrees,

of phase relative to the 150 Hz component, every half cycle of the combined 90 Hz and 150 Hz wave form.

Note 1.— The definition of phase relationship in this manner is not intended to imply a requirement to measure the phase within the half course sector.

Note 2.— Guidance material relative to such measurement is given at Figure C-6 of Attachment C.

3.1.3.5.3.4 With two-frequency localizer systems, 3.1.3.5.3.3 shall apply to each carrier. In addition, the 90 Hz modulating tone of one carrier shall be phase-locked to the 90 Hz modulating tone of the other carrier so that the demodulated wave forms pass through zero in the same direction within:

a) for Categories I and II localizers: 20 degrees; and

b) for Category III localizers: 10 degrees,

of phase relative to 90 Hz. Similarly, the 150 Hz tones of the two carriers shall be phase-locked so that the demodulated wave forms pass through zero in the same direction within:

1) for Categories I and II localizers: 20 degrees; and

2) for Category III localizers: 10 degrees,

of phase relative to 150 Hz.

3.1.3.5.3.5 Alternative two-frequency localizer systems that employ audio phasing different from the normal in-phase conditions described in 3.1.3.5.3.4 shall be permitted. In this alternative system, the 90 Hz to 90 Hz phasing and the 150 Hz to 150 Hz phasing shall be adjusted to their nominal values to within limits equivalent to those stated in 3.1.3.5.3.4.

Note.— This is to ensure correct airborne receiver operation in the region away from the course line where the two carrier signal strengths are approximately equal.

3.1.3.5.3.6 **Reserved**.

3.1.3.5.3.6.1 The sum of the modulation depths of the radio frequency carrier due to the 90 Hz and 150 Hz tones shall not exceed 60 per cent or be less than 30 per cent within the required coverage.

Note 1.— If the sum of the modulation depths is greater than 60 per cent for Facility Performance Category I localizers, the nominal displacement sensitivity may be adjusted as provided for in 3.1.3.7.1 to achieve the above modulation limit.

Note 2.— For two-frequency systems, the standard for maximum sum of modulation depths does not apply at or near azimuths where the course and clearance carrier signal levels are equal in amplitude (i.e. at azimuths where both transmitting systems have a significant contribution to the total modulation depth).

Note 3.— The standard for minimum sum of modulation depths is based on the malfunctioning alarm level being set as high as 30 per cent as stated in 2.3.3 of Attachment C.

3.1.3.5.3.7 When utilizing a localizer for radiotelephone communications, the sum of the modulation depths of the radio frequency carrier due to the 90 Hz and 150 Hz tones shall not exceed 65 per cent within 10 degrees of the course line and shall not exceed 78 per cent at any other point around the localizer.

3.1.3.5.4 Undesired frequency and phase modulation on ILS localizer radio frequency carriers that can affect the displayed DDM values in localizer receivers shall be minimized to the extent practical.

Note.— Relevant guidance material is given in 2.15 of Attachment C.

3.1.3.6 Course alignment accuracy

3.1.3.6.1 The mean course line shall be adjusted and maintained within limits equivalent to the following displacements from the runway centre line at the ILS reference datum:

a) for Facility Performance Category I localizers: plus or minus 10.5 m (35 ft), or the linear equivalent of 0.015 DDM, whichever is less;

b) for Facility Performance Category II localizers: plus or minus 4.5 m (15 ft);

c) for Facility Performance Category III localizers: plus or minus 3 m (10 ft).

3.1.3.6.2 **Reserved.—**

Note 1.— It is intended that Facility Performance Categories II and III installations be adjusted and maintained so that the limits specified in 3.1.3.6.1 are reached on very rare occasions. It is further intended that design and operation of the total ILS ground system be of sufficient integrity to accomplish this aim.

Note 2.— reserved

Note 3.— Guidance material on measurement of localizer course alignment is given in 2.1.3 of Attachment C. Guidance material on protecting localizer course alignment is given in 2.1.9 of Attachment C.

3.1.3.7 Displacement sensitivity

3.1.3.7.1 The nominal displacement sensitivity within the half course sector shall be the equivalent of 0.00145 DDM/m (0.00044 DDM/ft) at the ILS reference datum except that for Category I localizers, where the specified nominal displacement sensitivity cannot be met, the displacement sensitivity shall be adjusted as near as possible to that value. For Facility

Performance Category I localizers on runway codes 1 and 2, the nominal displacement sensitivity shall be achieved at the ILS Point “B”. The maximum course sector angle shall not exceed six degrees.

Note.— Runway codes 1 and 2 are defined in Annex 14.

3.1.3.7.2 The lateral displacement sensitivity shall be adjusted and maintained within the limits of plus or minus:

a) 17 per cent of the nominal value for Facility Performance Categories I ;

b) 10 per cent of the nominal value for Facility Performance Category II and III.

3.1.3.7.3 **Reserved.**

Note 1.— The figures given in 3.1.3.7.1 and 3.1.3.7.2 are based upon a nominal sector width of 210 m (700 ft) at the appropriate point, i.e. ILS Point “B” on runway codes 1 and 2, and the ILS reference datum on other runways.

Note 2.— Guidance material on the alignment and displacement sensitivity of localizers using two radio frequency carriers is given in 2.7 of Attachment C.

Note 3.— Guidance material on measurement of localizer displacement sensitivity is given in 2.9 of Attachment C.

3.1.3.7.4 The increase of DDM shall be substantially linear with respect to angular displacement from the front course line (where DDM is zero) up to an angle on either side of the front course line where the DDM is 0.180. From that angle to plus or minus 10 degrees, the DDM shall not be less than 0.180. From plus or minus 10 degrees to plus or minus 35 degrees, the DDM shall not be less than 0.155. Where coverage is required outside of the plus or minus 35 degrees sector, the DDM in the area of the coverage, except in the back course sector, shall not be less than 0.155.

Note 1.— The linearity of change of DDM with respect to angular displacement is particularly important in the neighbourhood of the course line.

Note 2.— The above DDM in the 10-35 degree sector is to be considered a minimum requirement for the use of ILS as a landing aid. Wherever practicable, a higher DDM, e.g. 0.180, is advantageous to assist high speed aircraft to execute large angle intercepts at operationally desirable distances provided that limits on modulation percentage given in 3.1.3.5.3.6 are met.

Note 3.— Wherever practicable, the localizer capture level of automatic flight control systems is to be set at or below 0.175 DDM in order to prevent false localizer captures.

3.1.3.8 Voice

3.1.3.8.1 Facility Performance Categories I and II localizers may provide a ground-to-air radiotelephone communication channel to be operated simultaneously with the navigation and identification signals, provided that such operation shall not interfere in any way with the basic localizer function.

3.1.3.8.2 Category III localizers shall not provide such a channel, except where extreme care has been taken in the design and operation of the facility to ensure that there is no possibility of interference with the navigational guidance.

3.1.3.8.3 If the channel is provided, it shall conform with the following Standards:

3.1.3.8.3.1 The channel shall be on the same radio frequency carrier or carriers as used for the localizer function, and the radiation shall be horizontally polarized. Where two carriers are modulated with speech, the relative phases of the modulations on the two carriers shall be such as to avoid the occurrence of nulls within the coverage of the localizer.

3.1.3.8.3.2 The peak modulation depth of the carrier or carriers due to the radiotelephone communications shall not exceed 50 per cent but shall be adjusted so that:

a) the ratio of peak modulation depth due to the radiotelephone communications to that due to the identification signal is approximately 9:1;

b) the sum of modulation components due to use of the radiotelephone channel, navigation signals and identification signals shall not exceed 95 per cent.

3.1.3.8.3.3 The audio frequency characteristics of the radiotelephone channel shall be flat to within 3 dB relative to the level at 1 000 Hz over the range 300 Hz to 3 000 Hz.

3.1.3.9 Identification

3.1.3.9.1 The localizer shall provide for the simultaneous transmission of an identification signal, specific to the runway and approach direction, on the same radio frequency carrier or carriers as used for the localizer function. The transmission of the identification signal shall not interfere in any way with the basic localizer function.

3.1.3.9.2 The identification signal shall be produced by Class A2A modulation of the radio frequency carrier or carriers using a modulation tone of 1 020 Hz within plus or minus 50 Hz. The depth of modulation shall be between the limits of 5 and 15 per cent except that, where a radiotelephone communication channel is provided, the depth of modulation shall be adjusted so that the ratio of peak modulation depth due to radiotelephone communications to that due to the identification signal modulation is approximately 9:1 (see 3.1.3.8.3.2). The emissions carrying the identification signal shall be horizontally polarized. Where two carriers are modulated with identification signals, the relative phase of the modulations shall be such as to avoid the occurrence of nulls within the coverage of the localizer.

3.1.3.9.3 The identification signal shall employ the International Morse Code and consist of two or three letters. It may be preceded by the International Morse Code signal of the letter “I”, followed by a short pause where it is necessary to distinguish the ILS facility from other navigational facilities in the immediate area.

3.1.3.9.4 The identification signal shall be transmitted by dots and dashes at a speed corresponding to approximately seven words per minute, and shall be repeated at approximately equal intervals, not less than six times per minute, at all times during which the localizer is available for operational use. When the transmissions of the localizer are not available for operational use, as, for example, after removal of navigation components, or during maintenance or test transmissions, the identification signal shall be suppressed. The dots shall have a duration of 0.1 second to 0.160 second. The dash duration shall be typically three times the duration of a dot. The interval between dots and/or dashes shall be equal to that of one dot plus or minus 10 per cent. The interval between letters shall not be less than the duration of three dots.

3.1.3.10 Siting

3.1.3.10.1 For Facility Performance Categories II and III, the localizer antenna system shall be located on the extension on the centre line of the runway at the stop end, and the equipment shall be adjusted so that the course lines will be in a vertical plane containing the centre line of the runway served. The antenna height and location shall be consistent with safe obstruction clearance practices.

3.1.3.10.2 For Facility Performance Category I, the localizer antenna system shall be located and adjusted as in 3.1.3.10.1, unless site constraints dictate that the antenna be offset from the centre line of the runway.

3.1.3.10.2.1 The offset localizer system shall be located and adjusted in accordance with the offset ILS provisions of the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS) (Doc 8168), Volume II, and the localizer standards shall be referenced to the associated fictitious threshold point.

3.1.3.11 Monitoring

3.1.3.11.1 The automatic monitor system shall provide a warning to the designated control points and cause one of the following to occur, within the period specified in 3.1.3.11.3.1, if any of the conditions stated in 3.1.3.11.2 persist:

a) radiation to cease; and

b) removal of the navigation and identification components from the carrier.

3.1.3.11.2 The conditions requiring initiation of monitor action shall be the following:

a) for Facility Performance Category I localizers, a shift of the mean course line from the runway centre line equivalent to more than 10.5 m (35 ft), or the linear equivalent to 0.015 DDM, whichever is less, at the ILS reference datum;

b) for Facility Performance Category II localizers, a shift of the mean course line from the runway centre line equivalent to more than 7.5 m (25 ft) at the ILS reference datum;

c) for Facility Performance Category III localizers, a shift of the mean course line from the runway centre line equivalent to more than 6 m (20 ft) at the ILS reference datum;

d) in the case of localizers in which the basic functions are provided by the use of a single-frequency system, a reduction of power output to a level such that any of the requirements of 3.1.3.3, 3.1.3.4 or 3.1.3.5 are no longer satisfied, or to a level that is less than 50 per cent of the normal level (whichever occurs first);

e) in the case of localizers in which the basic functions are provided by the use of a two-frequency system, a reduction of power output for either carrier to less than 80 per cent of normal, except that a greater reduction to between 80 per cent and 50 per cent of normal may be permitted, provided the localizer continues to meet the requirements of 3.1.3.3, 3.1.3.4 and 3.1.3.5;

Note.— It is important to recognize that a frequency change resulting in a loss of the frequency difference specified in 3.1.3.2.1 may produce a hazardous condition. This problem is of greater operational significance for Categories II and III installations. As necessary, this problem can be dealt with through special monitoring provisions or highly reliable circuitry.

f) change of displacement sensitivity to a value differing by more than 17 per cent from the nominal value for the localizer facility.

Note.— In selecting the power reduction figure to be employed in monitoring referred to in 3.1.3.11.2 e), particular attention is directed to vertical and horizontal lobe structure (vertical lobing due to different antenna heights) of the combined radiation systems when two carriers are employed. Large changes in the power ratio between carriers may result in low clearance areas and false courses in the off-course areas to the limits of the vertical coverage requirements specified in 3.1.3.3.1.

3.1.3.11.2.1 In the case of localizers in which the basic functions are provided by the use of a two-frequency system, the conditions requiring initiation of monitor action should include the case when the DDM in the required coverage beyond plus or minus 10 degrees from the front course line, except in the back course sector, decreases below 0.155.

3.1.3.11.3 The total period of radiation, including period(s) of zero radiation, outside the performance limits specified in a), b), c), d), e) and f) of 3.1.3.11.2 shall be as short as practicable, consistent with the need for avoiding interruptions of the navigation service provided by the localizer.

3.1.3.11.3.1 The total period referred to under 3.1.3.11.3 shall not exceed under any circumstances:

10 seconds for Category I localizers;

5 seconds for Category II localizers;

2 seconds for Category III localizers.

Note 1.— The total time periods specified are never-to-be-exceeded limits and are intended to protect aircraft in the final stages of approach against prolonged or repeated periods of localizer guidance outside the monitor limits. For this reason, they include not only the initial period of outside tolerance operation but also the total of any or all periods of outside tolerance radiation including period(s) of zero radiation and time required to remove the navigation and identification components from the carrier, which might occur during action to restore service, for example, in the course of consecutive monitor functioning and consequent changeover(s) to localizer equipment or elements thereof.

Note 2.— From an operational point of view, the intention is that no guidance outside the monitor limits be radiated after the time periods given, and that no further attempts be made to restore service until a period in the order of 20 seconds has elapsed.

3.1.3.11.3.2 **Reserved**.

3.1.3.11.4 Design and operation of the monitor system shall be consistent with the requirement that navigation guidance and identification will be removed and a warning provided at the designated remote control points in the event of failure of the monitor system itself.

Note.— Guidance material on the design and operation of monitor systems is given in Attachment C, 2.1.7.

3.1.3.12 Integrity and continuity of service requirements

3.1.3.12.1 The probability of not radiating false guidance signals shall not be less than $1 – 0.5 \times 10^{-9}$ in any one landing for Facility Performance Categories II and III localizers.

3.1.3.12.2 The probability of not radiating false guidance signals should not be less than $1 – 1.0 \times 10^{-7}$ in any one landing for Facility Performance Category I localizers.

3.1.3.12.3 The probability of not losing the radiated guidance signal shall be greater than:

a) $1 – 2 \times 10^{-6}$ in any period of 15 seconds for Facility Performance Category II localizers or localizers intended to be used for Category III A operations (equivalent to 2 000 hours mean time between outages); and

b) $1 - 2 \times 10^{-6}$ in any period of 30 seconds for Facility Performance Category III localizers intended to be used for the full range of Category III operations (equivalent to 4 000 hours mean time between outages).

3.1.3.12.4 The probability of not losing the radiated guidance signal should exceed $1 - 4 \times 10^{-6}$ in any period of 15 seconds for Facility Performance Category I localizers (equivalent to 1 000 hours mean time between outages).

Note.— Guidance material on integrity and continuity of service is given in Attachment C, 2.8.

3.1.4 Interference immunity performance for ILS localizer receiving systems

3.1.4.1 The ILS localizer receiving system shall provide adequate immunity to interference from two-signal, third-order intermodulation products caused by VHF FM broadcast signals having levels in accordance with the following:

$$2N_1 + N_2 + 72 \le 0$$

for VHF FM sound broadcasting signals in the range 107.7 – 108.0 MHz

and

$$2\,N_1 + N_2 + 3\left(24 - 20 \log \frac{\Delta f}{0,4}\right) \le 0$$

for VHF FM sound broadcasting signals below 107.7 MHz,

where the frequencies of the two VHF FM sound broadcasting signals produce, within the receiver, a two-signal, third-order intermodulation product on the desired ILS localizer frequency.

N_1 and N_2 are the levels (dBm) of the two VHF FM sound broadcasting signals at the ILS localizer receiver input. Neither level shall exceed the desensitization criteria set forth in 3.1.4.2.

$\Delta f = 108.1 - f_1$, where f_1 is the frequency of N_1, the VHF FM sound broadcasting signal closer to 108.1 MHz.

3.1.4.2 The ILS localizer receiving system shall not be desensitized in the presence of VHF FM broadcast signals having levels in accordance with the following table:

Frequency (MHz)	*Maximum level of unwanted signal at receiver input (dBm)*
88-102	+15
104	+10
106	+5
107.9	–10

Note 1.— The relationship is linear between adjacent points designated by the above frequencies.

Note 2.— Guidance material on immunity criteria to be used for the performance quoted in 3.1.4.1 and 3.1.4.2 is contained in Attachment C, 2.2.2.

3.1.5 UHF glide path equipment and associated monitor

Note.— θ is used in this paragraph to denote the nominal glide path angle.

3.1.5.1 General

3.1.5.1.1 The radiation from the UHF glide path antenna system shall produce a composite field pattern which is amplitude modulated by a 90 Hz and a 150 Hz tone. The pattern shall be arranged to provide a straight line descent path in the vertical plane containing the centre line of the runway, with the 150 Hz tone predominating below the path and the 90 Hz tone predominating above the path to at least an angle equal to 1.75 θ.

3.1.5.1.2 The ILS glide path angle shall be 3±10% degrees. For nonstandard glide path shall refer to ICAO DOC 8168.
3.1.5.1.2.1 The glide path angle shall be adjusted and maintained within:

a) 0.075 θ from θ for Facility Performance Categories I and II — ILS glide paths;

b) 0.04 θ from θ for Facility Performance Category III — ILS glide paths.

Note 1.— Guidance material on adjustment and maintenance of glide path angles is given in 2.4 of Attachment C.

Note 2.— Guidance material on ILS glide path curvature, alignment and siting, relevant to the selection of the height of the ILS reference datum is given in 2.4 of Attachment C and Figure C-5.

Note 3. – Guidance material relevant to protecting the ILS glide path course structure is given in 2.1.9 of Attachment C.

3.1.5.1.3 The downward extended straight portion of the ILS glide path shall pass through the ILS reference datum at a height ensuring safe guidance over obstructions and also safe and efficient use of the runway served.

3.1.5.1.4 The height of the ILS reference datum for Facility Performance Categories II and III — ILS shall be 15 m (50 ft). A tolerance of plus 3 m (10 ft) is permitted.

3.1.5.1.5 The height of the ILS reference datum for Facility Performance Category I — ILS should be 15 m (50 ft). A tolerance of plus 3 m (10 ft) is permitted.

Note 1.— In arriving at the above height values for the ILS reference datum, a maximum vertical distance of 5.8 m (19 ft) between the path of the aircraft glide path antenna and the path of the lowest part of the wheels at the threshold was assumed. For aircraft exceeding this criterion, appropriate steps may have to be taken either to maintain adequate clearance at threshold or to adjust the permitted operating minima.

Note 2.— Appropriate guidance material is given in 2.4 of Attachment C.

3.1.5.1.6 **Reserved**.

3.1.5.2 Radio frequency

3.1.5.2.1 The glide path equipment shall operate in the band 328.6 MHz to 335.4 MHz. Where a single radio frequency carrier is used, the frequency tolerance shall not exceed 0.005 per cent. Where two carrier glide path systems are used, the frequency tolerance shall not exceed 0.002 per cent and the nominal band occupied by the carriers shall be symmetrical about the assigned frequency. With all tolerances applied, the frequency separation between the carriers shall not be less than 4 kHz nor more than 32 kHz.

3.1.5.2.2 The emission from the glide path equipment shall be horizontally polarized.

3.1.5.2.3 For Facility Performance Category III — ILS glide path equipment, signals emanating from the transmitter shall contain no components which result in apparent glide path fluctuations of more than 0.02 DDM peak to peak in the frequency band 0.01 Hz to 10 Hz.

3.1.5.3 Coverage

3.1.5.3.1 The glide path equipment shall provide signals sufficient to allow satisfactory operation of a typical aircraft installation in sectors of 8 degrees in azimuth on each side of the centre line of the ILS glide path, to a distance of at least 18.5 km (10 NM) up to 1.75 θ and down to 0.45 θ above the horizontal or to such lower angle, down to 0.30 θ, as required to safeguard the promulgated glide path intercept procedure.

3.1.5.3.2 In order to provide the coverage for glide path performance specified in 3.1.5.3.1, the minimum field strength within this coverage sector shall be 400 microvolts per metre (minus 95 dBW/m^2). For Facility Performance Category I glide paths, this field strength shall be provided down to a height of 30 m (100 ft) above the horizontal plane containing the threshold. For Facility Performance Categories II and III glide paths, this field strength shall be provided down to a height of 15 m (50 ft) above the horizontal plane containing the threshold.

Note 1.— The requirements in the foregoing paragraphs are based on the assumption that the aircraft is heading directly toward the facility.

Note 2.— Guidance material on significant airborne receiver parameters is given in 2.2 of Attachment C.

Note 3.— Material concerning reduction in coverage outside 8 degrees on each side of the centre line of the ILS glide path appears in 2.4 of Attachment C.

3.1.5.4 ILS glide path structure

3.1.5.4.1 For Facility Performance Category I — ILS glide paths, bends in the glide path shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point "C"	0.035

3.1.5.4.2 For Facility Performance Categories II and III — ILS glide paths, bends in the glide path shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point "A"	0.035

ILS Point “A” to ILS Point “B”	0.035 at ILS Point “A” decreasing at a linear rate to 0.023 at ILS Point “B”
ILS Point “B” to the ILS reference datum	0.023

Note 1.— The amplitudes referred to in 3.1.5.4.1 and 3.1.5.4.2 are the DDMs due to bends as realized on the mean ILS glide path correctly adjusted.

Note 2.— In regions of the approach where ILS glide path curvature is significant, bend amplitudes are calculated from the mean curved path, and not the downward extended straight line.

Note 3.— Guidance material relevant to the ILS glide path course structure is given in 2.1.4 of Attachment C.

3.1.5.5 Carrier modulation

3.1.5.5.1 The nominal depth of modulation of the radio frequency carrier due to each of the 90 Hz and 150 Hz tones shall be 40 per cent along the ILS glide path. The depth of modulation shall not deviate outside the limits of 37.5 per cent to 42.5 per cent.

3.1.5.5.2 The following tolerances shall be applied to the frequencies of the modulating tones:

a) the modulating tones shall be 90 Hz and 150 Hz within 2.5 per cent for Facility Performance Category I —ILS;

b) the modulating tones shall be 90 Hz and 150 Hz within 1.5 per cent for Facility Performance Category II —ILS;

c) the modulating tones shall be 90 Hz and 150 Hz within 1 per cent for Facility Performance Category III —ILS;

d) the total harmonic content of the 90 Hz tone shall not exceed 10 per cent: additionally, for Facility Performance Category III equipment, the second harmonic of the 90 Hz tone shall not exceed 5 per cent;

e) the total harmonic content of the 150 Hz tone shall not exceed 10 per cent.

3.1.5.5.2.1 **Reserved**.

3.1.5.5.2.2 For Facility Performance Category III glide path equipment, the depth of amplitude modulation of the radio frequency carrier at the power supply frequency or harmonics, or at other noise frequencies, shall not exceed 1 per cent.

3.1.5.5.3 The modulation shall be phase-locked so that within the ILS half glide path sector, the demodulated 90 Hz and 150 Hz wave forms pass through zero in the same direction within:

a) for Facility Performance Categories I and II — ILS glide paths: 20 degrees;

b) for Facility Performance Category III — ILS glide paths: 10 degrees,

of phase relative to the 150 Hz component, every half cycle of the combined 90 Hz and 150 Hz wave form.

Note 1.— The definition of phase relationship in this manner is not intended to imply a requirement for measurement of phase within the ILS half glide path sector.

Note 2.— Guidance material relating to such measures is given at Figure C-6 of Attachment C.

3.1.5.5.3.1 With two-frequency glide path systems, 3.1.5.5.3 shall apply to each carrier. In addition, the 90 Hz modulating tone of one carrier shall be phase-locked to the 90 Hz modulating tone of the other carrier so that the demodulated wave forms pass through zero in the same direction within:

a) for Categories I and II — ILS glide paths: 20 degrees;

b) for Category III — ILS glide paths: 10 degrees,

of phase relative to 90 Hz. Similarly, the 150 Hz tones of the two carriers shall be phase-locked so that the demodulated wave forms pass through zero in the same direction, within:

1) for Categories I and II — ILS glide paths: 20 degrees;

2) for Category III — ILS glide paths: 10 degrees,

of phase relative to 150 Hz.

3.1.5.5.3.2 Alternative two-frequency glide path systems that employ audio phasing different from the normal in-phase condition described in 3.1.5.5.3.1 shall be permitted. In these alternative systems, the 90 Hz to 90 Hz phasing and the 150 Hz to 150 Hz phasing shall be adjusted to their nominal values to within limits equivalent to those stated in 3.1.5.5.3.1.

Note.— This is to ensure correct airborne receiver operation within the glide path sector where the two carrier signal strengths are approximately equal.

3.1.5.5.4 Reserved.

Note.— Relevant guidance material is given in 2.15 of Attachment C.

3.1.5.6 Displacement sensitivity

3.1.5.6.1 For Facility Performance Category I — ILS glide paths, the nominal angular displacement sensitivity shall correspond to a DDM of 0.0875 at angular displacements above and below the glide path between 0.07 θ and 0.14 θ.

Note.— The above is not intended to preclude glide path systems which inherently have asymmetrical upper and lower sectors.

3.1.5.6.2 **Reserved**.

3.1.5.6.3 For Facility Performance Category II — ILS glide paths, the angular displacement sensitivity shall be as symmetrical as practicable. The nominal angular displacement sensitivity shall correspond to a DDM of 0.0875 at an angular displacement of:

a) 0.12 θ below path with a tolerance of plus or minus 0.02 θ;

b) 0.12 θ above path with a tolerance of plus 0.02 θ and minus 0.05 θ

3.1.5.6.4 For Facility Performance Category III — ILS glide paths, the nominal angular displacement sensitivity shall correspond to a DDM of 0.0875 at angular displacements above and below the glide path of 0.12 θ with a tolerance of plus or minus 0.02 θ.

3.1.5.6.5 The DDM below the ILS glide path shall increase smoothly for decreasing angle until a value of 0.22 DDM is reached. This value shall be achieved at an angle not less than 0.30 θ above the horizontal. However, if it is achieved at an angle above 0.45 θ, the DDM value shall not be less than 0.22 at least down to 0.45 θ or to such lower angle, down to 0.30 θ, as required to safeguard the promulgated glide path intercept procedure.

Note.— The limits of glide path equipment adjustment are pictorially represented in Figure C-11 of Attachment C.

3.1.5.6.6 For Facility Performance Category I — ILS glide paths, the angular displacement sensitivity shall be adjusted and maintained within plus or minus 25 per cent of the nominal value selected.

3.1.5.6.7 For Facility Performance Category II — ILS glide paths, the angular displacement sensitivity shall be adjusted and maintained within plus or minus 20 per cent of the nominal value selected.

3.1.5.6.8 For Facility Performance Category III — ILS glide paths, the angular displacement sensitivity shall be adjusted and maintained within plus or minus 15 per cent of the nominal value selected.

3.1.5.7 Monitoring

3.1.5.7.1 The automatic monitor system shall provide a warning to the designated control points and cause radiation to cease within the periods specified in 3.1.5.7.3.1 if any of the following conditions persist:

a) shift of the mean ILS glide path angle equivalent to more than minus 0.075 θ to plus 0.10 θ from θ;

b) in the case of ILS glide paths in which the basic functions are provided by the use of a single-frequency system, a reduction of power output to less than 50 per cent of normal, provided the glide path continues to meet the requirements of 3.1.5.3, 3.1.5.4 and 3.1.5.5;

c) in the case of ILS glide paths in which the basic functions are provided by the use of two-frequency systems, a reduction of power output for either carrier to less than 80 per cent of normal, except that a greater reduction to between 80 per cent and 50 per cent of normal may be permitted, provided the glide path continues to meet the requirements of 3.1.5.3, 3.1.5.4 and 3.1.5.5;

Note.— It is important to recognize that a frequency change resulting in a loss of the frequency difference specified in 3.1.5.2.1 may produce a hazardous condition. This problem is of greater operational significance for Categories II and III installations. As necessary, this problem can be dealt with through special monitoring provisions or highly reliable circuitry.

d) for Facility Performance Category I — ILS glide paths, a change of the angle between the glide path and the line below the glide path (150 Hz predominating) at which a DDM of 0.0875 is realized by more than the greater of:

   i) plus or minus 0.0375 θ; or

   ii) an angle equivalent to a change of displacement sensitivity to a value differing by 25 per cent from the nominal value;

e) for Facility Performance Categories II and III — ILS glide paths, a change of displacement sensitivity to a value differing by more than 25 per cent from the nominal value;

f) lowering of the line beneath the ILS glide path at which a DDM of 0.0875 is realized to less than 0.7475 θ from horizontal;

g) a reduction of DDM to less than 0.175 within the specified coverage below the glide path sector.

Note 1.— The value of 0.7475 θ from horizontal is intended to ensure adequate obstacle clearance. This value was derived from other parameters of the glide path and monitor specification. Since the measuring accuracy to four significant figures is not intended, the value of 0.75 θ may be used as a monitor limit for this purpose. Guidance on obstacle clearance criteria is given in the Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS) *(Doc 8168).*

Note 2.— Subparagraphs f) and g) are not intended to establish a requirement for a separate monitor to protect against deviation of the lower limits of the half-sector below 0.7475 θ from horizontal.

Note 3.— At glide path facilities where the selected nominal angular displacement sensitivity corresponds to an angle below the ILS glide path which is close to or at the maximum limits specified in 3.1.5.6, it may be necessary to adjust the monitor operating limits to protect against sector deviations below 0.7475 θ from horizontal.

Note 4.— Guidance material relating to the condition described in g) appears in Attachment C, 2.4.11.

3.1.5.7.2 **Reserved.**

3.1.5.7.3 The total period of radiation, including period(s) of zero radiation, outside the performance limits specified in 3.1.5.7.1 shall be as short as practicable, consistent with the need for avoiding interruptions of the navigation service provided by the ILS glide path.

3.1.5.7.3.1 The total period referred to under 3.1.5.7.3 shall not exceed under any circumstances:

6 seconds for Category I — ILS glide paths;

2 seconds for Categories II and III — ILS glide paths.

Note 1.— The total time periods specified are never-to-be-exceeded limits and are intended to protect aircraft in the final stages of approach against prolonged or repeated periods of ILS glide path guidance outside the monitor limits. For this reason, they include not only the initial period of outside tolerance operation but also the total of any or all periods of outside tolerance radiation, including periods of zero radiation, which might occur during action to restore service, for example, in the course of consecutive monitor functioning and consequent changeovers to glide path equipments or elements thereof.

Note 2.— From an operational point of view, the intention is that no guidance outside the monitor limits be radiated after the time periods given, and that no further attempts be made to restore service until a period in the order of 20 seconds has elapsed.

3.1.5.7.3.2 **Reserved.**

3.1.5.7.4 Design and operation of the monitor system shall be consistent with the requirement that radiation shall cease and a warning shall be provided at the designated remote control points in the event of failure of the monitor system itself.

Note.— Guidance material on the design and operation of monitor systems is given in 2.1.7 of Attachment C.

3.1.5.8 Integrity and continuity of service requirements

3.1.5.8.1 The probability of not radiating false guidance signals shall not be less than $1 – 0.5 \times 10^{–9}$ in any one landing for Facility Performance Categories II and III glide paths.

3.1.5.8.2 The probability of not radiating false guidance signals shall not be less than $1 – 1.0 \times 10^{–7}$ in any one landing for Facility Performance Category I glide paths.

3.1.5.8.3 The probability of not losing the radiated guidance signal shall be greater than $1 – 2 \times 10^{–6}$ in any period of 15 seconds for Facility Performance Categories II and III glide paths (equivalent to 2 000 hours mean time between outages).

3.1.5.8.4 The probability of not losing the radiated guidance signal shall exceed $1 – 4 \times 10^{–6}$ in any period of 15 seconds for Facility Performance Category I glide paths (equivalent to 1 000 hours mean time between outages).

Note.— Guidance material on integrity and continuity of service is given in 2.8 of Attachment C.

3.1.6 Localizer and glide path frequency pairing

3.1.6.1 The pairing of the runway localizer and glide path transmitter frequencies of an instrument landing system shall be taken from the following list in accordance with the provisions of Annex 10, Volume V, Chapter 4, 4.2:

Localizer (MHz)	*Glide path (MHz)*	*Localizer (MHz)*	*Glide path (MHz)*
108.1	334.7	110.1	334.4
108.15	334.55	110.15	334.25
108.3	334.1	110.3	335.0
108.35	333.95	110.35	334.85
108.5	329.9	110.5	329.6
108.55	329.75	110.55	329.45
108.7	330.5	110.7	330.2
108.75	330.35	110.75	330.05
108.9	329.3	110.9	330.8
108.95	329.15	110.95	330.65
109.1	331.4	111.1	331.7
109.15	331.25	111.15	331.55
109.3	332.0	111.3	332.3
109.35	331.85	111.35	332.15
109.5	332.6	111.5	332.9
109.55	332.45	111.55	332.75
109.7	333.2	111.7	333.5
109.75	333.05	111.75	333.35
109.9	333.8	111.9	331.1
109.95	333.65	111.95	330.95

3.1.6.1.1 In those regions where the requirements for runway localizer and glide path transmitter frequencies of an instrument landing system do not justify more than 20 pairs, they shall be selected sequentially, as required, from the following list:

Sequence number	*Localizer (MHz)*	*Glide path (MHz)*
1	110.3	335.0
2	109.9	333.8
3	109.5	332.6
4	110.1	334.4
5	109.7	333.2
6	109.3	332.0
7	109.1	331.4
8	110.9	330.8
9	110.7	330.2
10	110.5	329.6
11	108.1	334.7
12	108.3	334.1
13	108.5	329.9
14	108.7	330.5
15	108.9	329.3
16	111.1	331.7
17	111.3	332.3
18	111.5	332.9
19	111.7	333.5
20	111.9	331.1

3.1.6.2 Where existing ILS localizers meeting national requirements are operating on frequencies ending in even tenths of a megahertz, they shall be reassigned frequencies, conforming with 3.1.6.1 or 3.1.6.1.1 as soon as practicable and may continue operating on their present assignments only until this reassignment can be effected.

3.1.6.3 Existing ILS localizers in the international service operating on frequencies ending in odd tenths of a megahertz shall not be assigned new frequencies ending in odd tenths plus one twentieth of a megahertz except where, by regional agreement, general use may be made of any of the channels listed in 3.1.6.1 (see Annex10 Volume V, Chapter 4, 4.2).

3.1.7 VHF marker beacons

Note.— Requirements relating to marker beacons apply only when one or more marker beacons are installed.

3.1.7.1 General

a) There shall be two marker beacons in each installation except where, the Civil Aviation Authority of Nepal considers a single marker beacon to be sufficient. A third marker beacon may be added whenever, Civil Aviation Authority of Nepal considers an additional beacon is required because of operational procedures at a particular site.

b) A marker beacon shall conform to the requirements prescribed in 3.1.7. When the installation comprises only two marker beacons, the requirements applicable to the middle marker and to the outer marker shall be complied with.

When the installation comprises only one marker beacon, the requirements applicable to either the middle or the outer marker shall be complied with. If marker beacons are replaced by DME, the requirements of 3.1.7.6.5 shall apply.

c) The marker beacons shall produce radiation patterns to indicate predetermined distance from the threshold along the ILS glide path.

3.1.7.1.1 When a marker beacon is used in conjunction with the back course of a localizer, it shall conform with the marker beacon characteristics specified in 3.1.7.

3.1.7.1.2 Identification signals of marker beacons used in conjunction with the back course of a localizer shall be clearly distinguishable from the inner, middle and outer marker beacon identifications, as prescribed in 3.1.7.5.1.

3.1.7.2 Radio frequency

3.1.7.2.1 The marker beacons shall operate at 75 MHz with a frequency tolerance of plus or minus 0.005 per cent and shall utilize horizontal polarization.

3.1.7.3 Coverage

3.1.7.3.1 The marker beacon system shall be adjusted to provide coverage over the following distances, measured on the ILS glide path and localizer course line:

a) *inner marker:* 150 m plus or minus 50 m (500 ft plus or minus 160 ft);

b) *middle marker:* 300 m plus or minus 100 m (1 000 ft plus or minus 325 ft);

c) *outer marker:* 600 m plus or minus 200 m (2 000 ft plus or minus 650 ft).

3.1.7.3.2 The field strength at the limits of coverage specified in 3.1.7.3.1 shall be 1.5 millivolts per metre (minus 82 dBW/m^2). In addition, the field strength within the coverage area shall rise to at least 3.0 millivolts per metre (minus 76 dBW/m^2).

Note 1.— In the design of the ground antenna, it is advisable to ensure that an adequate rate of change of field strength is provided at the edges of coverage. It is also advisable to ensure that aircraft within the localizer course sector will receive visual indication.

Note 2.— Satisfactory operation of a typical airborne marker installation will be obtained if the sensitivity is so adjusted that visual indication will be obtained when the field strength is 1.5 millivolts per metre (minus 82 dBW/m^2*).*

3.1.7.4 Modulation

3.1.7.4.1 The modulation frequencies shall be as follows:

a) *inner marker:* 3 000 Hz;

b) *middle marker:* 1 300 Hz;

c) *outer marker:* 400 Hz.

The frequency tolerance of the above frequencies shall be plus or minus 2.5 per cent, and the total harmonic content of each of the frequencies shall not exceed 15 per cent.

3.1.7.4.2 The depth of modulation of the markers shall be 95 per cent plus or minus 4 per cent.

3.1.7.5 Identification

3.1.7.5.1 The carrier energy shall not be interrupted. The audio frequency modulation shall be keyed as follows:

a) *inner marker:* 6 dots per second continuously;

b) *middle marker:* a continuous series of alternate dots and dashes, the dashes keyed at the rate of 2 dashes per second, and the dots at the rate of 6 dots per second;

c) *outer marker:* 2 dashes per second continuously.

These keying rates shall be maintained to within plus or minus 15 per cent.

3.1.7.6 Siting

3.1.7.6.1 The inner marker shall be located so as to indicate in low visibility conditions the imminence of arrival at the runway threshold.

3.1.7.6.1.1 If the radiation pattern is vertical, the inner marker shall be located between 75 m (250 ft) and 450 m (1 500 ft) from the threshold and at not more than 30 m (100 ft) from the extended centre line of the runway.

Note 1.— It is intended that the inner marker pattern should intercept the downward extended straight portion of the nominal ILS glide path at the lowest decision height applicable in Category II operations.

Note 2.— Care must be exercised in siting the inner marker to avoid interference between the inner and middle markers. Details regarding the siting of inner markers are contained in Attachment C, 2.10.

3.1.7.6.1.2 If the radiation pattern is other than vertical, the equipment shall be located so as to produce a field within the course sector and ILS glide path sector that is substantially similar to that produced by an antenna radiating a vertical pattern and located as prescribed in 3.1.7.6.1.1.

3.1.7.6.2 The middle marker shall be located so as to indicate the imminence, in low visibility conditions, of visual approach guidance.

3.1.7.6.2.1 If the radiation pattern is vertical, the middle marker shall be located 1 050 m (3 500 ft) plus or minus 150 m (500 ft), from the landing threshold at the approach end of the runway and at not more than 75 m (250 ft) from the extended centre line of the runway.

Note.— See Attachment C, 2.10, regarding the siting of inner and middle marker beacons.

3.1.7.6.2.2 If the radiation pattern is other than vertical, the equipment shall be located so as to produce a field within the course sector and ILS glide path sector that is substantially similar to that produced by an antenna radiating a vertical pattern and located as prescribed in 3.1.7.6.2.1.

3.1.7.6.3 The outer marker shall be located so as to provide height, distance and equipment functioning checks to aircraft on intermediate and final approach.

3.1.7.6.3.1 The outer marker shall be located 7.2 km (3.9 NM) from the threshold except that, where for topographical or operational reasons this distance is not practicable, the outer marker may be located between 6.5 and 11.1 km (3.5 and 6 NM) from the threshold.

3.1.7.6.4 If the radiation pattern is vertical, the outer marker shall be not more than 75 m (250 ft) from the extended centre line of the runway. If the radiation pattern is other than vertical, the equipment should be located so as to produce a field within the course sector and ILS glide path sector that is substantially similar to that produced by an antenna radiating a vertical pattern.

3.1.7.6.5 The positions of marker beacons, or where applicable, the equivalent distance(s) indicated by the DME when used as an alternative to part or all of the marker beacon component of the ILS, shall be published in accordance with the provisions of Annex 15.

3.1.7.6.5.1 When so used, the DME shall provide distance information operationally equivalent to that furnished by marker beacon(s).

3.1.7.6.5.2 When used as an alternative for the middle marker, the DME shall be frequency paired with the ILS localizer and sited so as to minimize the error in distance information.

3.1.7.6.5.3 The DME in 3.1.7.6.5 shall conform to the specification in 3.5.

3.1.7.7 Monitoring

3.1.7.7.1 Suitable equipment shall provide signals for the operation of an automatic monitor. The monitor shall transmit a warning to a control point if either of the following conditions arise:

a) failure of the modulation or keying;

b) reduction of power output to less than 50 per cent of normal.

3.1.7.7.2 For each marker beacon, suitable monitoring equipment shall be provided which will indicate at the appropriate location a decrease of the modulation depth below 50 per cent.

3.2 Reserved

3.3 Specification for VHF omnidirectional radio range (VOR)

3.3.1 General

3.3.1.1 The VOR shall be constructed and adjusted so that similar instrumental indications in aircraft represent equal clockwise angular deviations (bearings), degree for degree from magnetic North as measured from the location of the VOR.

3.3.1.2 The VOR shall radiate a radio frequency carrier with which are associated two separate 30 Hz modulations. One of these modulations shall be such that its phase is independent of the azimuth of the point of observation (reference phase). The other modulation (variable phase) shall be such that its phase at the point of observation differs from that of the reference phase by an angle equal to the bearing of the point of observation with respect to the VOR.

3.3.1.3 The reference and variable phase modulations shall be in phase along the reference magnetic meridian through the station.

Note.— The reference and variable phase modulations are in phase when the maximum value of the sum of the radio frequency carrier and the sideband energy due to the variable phase modulation occurs at the same time as the highest instantaneous frequency of the reference phase modulation.

3.3.2 Radio frequency

3.3.2.1 The VOR shall operate in the band 111.975 MHz to 117.975 MHz except that frequencies in the band 108 MHz to 111.975 MHz may be used when, in accordance with the provisions of Annex-10, Volume V, Chapter 4, 4.2.1 and 4.2.3.1, the use of such frequencies is acceptable. The highest assignable frequency shall be 117.950 MHz. The channel separation shall be in increments of 50 kHz referred to the highest assignable frequency. In areas where 100 kHz or 200 kHz channel spacing is in general use, the frequency tolerance of the radio frequency carrier shall be plus or minus 0.005 per cent.

3.3.2.2 The frequency tolerance of the radio frequency carrier of all new installations implemented after 23 May 1974 in areas where 50 kHz channel spacing is in use shall be plus or minus 0.002 per cent.

3.3.2.3 In areas where new VOR installations are implemented and are assigned frequencies spaced at 50 kHz from existing VORs in the same area, priority shall be given to ensuring that the frequency tolerance of the radio frequency carrier of the existing VORs is reduced to plus or minus 0.002 per cent.

3.3.3 Polarization and pattern accuracy

3.3.3.1 The emission from the VOR shall be horizontally polarized. The vertically polarized component of the radiation shall be as small as possible.

Note.— It is not possible at present to state quantitatively the maximum permissible magnitude of the vertically polarized component of the radiation from the VOR. (Information is provided in the Manual on Testing of Radio Navigation Aids *(Doc 8071) as to flight checks that can be carried out to determine the effects of vertical polarization on the bearing accuracy.)*

3.3.3.2 The ground station contribution to the error in the bearing information conveyed by the horizontally polarized radiation from the VOR for all elevation angles between 0 and 40 degrees, measured from the centre of the VOR antenna system, shall be within plus or minus 2 degrees.

3.3.4 Coverage

3.3.4.1 The VOR shall provide signals such as to permit satisfactory operation of a typical aircraft installation at the levels and distances required for operational reasons, and up to an elevation angle of 40 degrees.

3.3.4.2 The field strength or power density in space of VOR signals required to permit satisfactory operation of a typical aircraft installation at the minimum service level at the maximum specified service radius shall be 90 microvolts per metre or minus 107 dBW/m^2.

Note.— Typical equivalent isotropically radiated powers (EIRPs) to achieve specified ranges are contained in 3.1 of Attachment C. The definition of EIRP is contained in 3.5.1.

3.3.5 Modulations of navigation signals

3.3.5.1 The radio frequency carrier as observed at any point in space shall be amplitude modulated by two signals as follows:

a) a subcarrier of 9 960 Hz of constant amplitude, frequency modulated at 30 Hz:

  1) for the conventional VOR, the 30 Hz component of this FM subcarrier is fixed without respect to azimuth and is termed the “reference phase” and shall have a deviation ratio of 16 plus or minus 1 (i.e. 15 to 17);

  2) for the Doppler VOR, the phase of the 30 Hz component varies with azimuth and is termed the “variable phase” and shall have a deviation ratio of 16 plus or minus 1 (i.e. 15 to 17) when observed at any angle of elevation up to 5 degrees, with a minimum deviation ratio of 11 when observed at any angle of elevation above 5 degrees and up to 40 degrees;

b) a 30 Hz amplitude modulation component:

  1) for the conventional VOR, this component results from a rotating field pattern, the phase of which varies with azimuth, and is termed the “variable phase”;

  2) for the Doppler VOR, this component, of constant phase with relation to azimuth and constant amplitude, is radiated omnidirectionally and is termed the “reference phase”.

3.3.5.2 The nominal depth of modulation of the radio frequency carrier due to the 30 Hz signal or the subcarrier of 9 960 Hz shall be within the limits of 28 per cent and 32 per cent.

Note.— This requirement applies to the transmitted signal observed in the absence of multipath.

3.3.5.3 The depth of modulation of the radio frequency carrier due to the 30 Hz signal, as observed at any angle of elevation up to 5 degrees, shall be within the limits of 25 to 35 per cent. The depth of modulation of the radio frequency carrier due to the 9 960 Hz signal, as observed at any angle of elevation up to 5 degrees, shall be within the limits of 20 to 55 per cent on facilities without voice modulation, and within the limits of 20 to 35 per cent on facilities with voice modulation.

Note.— When modulation is measured during flight testing under strong dynamic multipath conditions, variations in the received modulation percentages are to be expected. Short-term variations beyond these values may be acceptable. The Manual on Testing of Radio Navigation Aids *(Doc 8071) contains additional information on the application of airborne modulation tolerances.*

3.3.5.4 The variable and reference phase modulation frequencies shall be 30 Hz within plus or minus 1 per cent.

3.3.5.5 The subcarrier modulation mid-frequency shall be 9 960 Hz within plus or minus 1 per cent.
3.3.5.6

a) Reserved.

b) For the Doppler VOR, the percentage of amplitude modulation of the 9 960 Hz subcarrier shall not exceed 40 per cent when measured at a point at least 300 m (1 000 ft) from the VOR.

3.3.5.7 Where 50 kHz VOR channel spacing is implemented, the sideband level of the harmonics of the 9 960 Hz component in the radiated signal shall not exceed the following levels referred to the level of the 9 960 Hz sideband:

Subcarrier	*Level*
9 960 Hz	0 dB reference
2nd harmonic	–30 dB
3rd harmonic	–50 dB
4th harmonic and above	–60 dB

3.3.6 Voice and identification

3.3.6.1 If the VOR provides a simultaneous communication channel ground-to-air, it shall be on the same radio frequency carrier as used for the navigational function. The radiation on this channel shall be horizontally polarized.

3.3.6.2 The peak modulation depth of the carrier on the communication channel shall not be greater than 30 per cent.

3.3.6.3 The audio frequency characteristics of the speech channel shall be within 3 dB relative to the level at 1 000 Hz over the range 300 Hz to 3 000 Hz.

3.3.6.4 The VOR shall provide for the simultaneous transmission of a signal of identification on the same radio frequency carrier as that used for the navigational function. The identification signal radiation shall be horizontally polarized.

3.3.6.5 The identification signal shall employ the International Morse Code and consist of two or three letters. It shall be sent at a speed corresponding to approximately 7 words per minute. The signal shall be repeated at least once every 30 seconds and the modulation tone shall be 1 020 Hz within plus or minus 50 Hz.

3.3.6.5.1 **Reserved**

Note.— Where a VOR and DME are associated in accordance with 3.5.2.5, the identification provisions of 3.5.3.6.4 influence the VOR identification.

3.3.6.6 The depth to which the radio frequency carrier is modulated by the code identification signal shall be close to, but not in excess of 10 per cent except that, where a communication channel is not provided, it shall be permissible to increase the modulation by the code identification signal to a value not exceeding 20 per cent.

3.3.6.6.1 If the VOR provides a simultaneous communication channel ground-to-air, the modulation depth of the code identification signal shall be 5 plus or minus 1 per cent in order to provide a satisfactory voice quality.

3.3.6.7 The transmission of speech shall not interfere in any way with the basic navigational function. When speech is being radiated, the code identification shall not be suppressed.

3.3.6.8 The VOR receiving function shall permit positive identification of the wanted signal under the signal conditions encountered within the specified coverage limits, and with the modulation parameters specified at 3.3.6.5, 3.3.6.6 and 3.3.6.7.

3.3.7 Monitoring

3.3.7.1 Suitable equipment located in the radiation field shall provide signals for the operation of an automatic monitor. The monitor shall transmit a warning to a control point, and either remove the identification and navigation components from the carrier or cause radiation to cease if any one or a combination of the following deviations from established conditions arises:

a) a change in excess of 1 degree at the monitor site of the bearing information transmitted by the VOR;

b) a reduction of 15 per cent in the modulation components of the radio frequency signals voltage level at the monitor of either the subcarrier, or 30 Hz amplitude modulation signals, or both.

3.3.7.2 Failure of the monitor itself shall transmit a warning to a control point and either:

a) remove the identification and navigation components from the carrier; or

b) cause radiation to cease.

Note.— Guidance material on VOR appears in Attachment C, 3, and Attachment E.

3.3.8 Interference immunity performance for VOR receiving systems

3.3.8.1 The VOR receiving system shall provide adequate immunity to interference from two signal, third-order intermodulation products caused by VHF FM broadcast signals having levels in accordance with the following:

$$2N_1 + N_2 + 72 \leq 0$$

for VHF FM sound broadcasting signals in the range 107.7 – 108.0 MHz and

$$2N_1 + N_2 + 3\left(24 - 20\log\frac{\Delta f}{0{,}4}\right) \leq 0$$

for VHF FM sound broadcasting signals below 107.7 MHz,

where the frequencies of the two VHF FM sound broadcasting signals produce, within the receiver, a two-signal, third-order intermodulation product on the desired VOR frequency.

N_1 and N_2 are the levels (dBm) of the two VHF FM sound broadcasting signals at the VOR receiver input. Neither level shall exceed the desensitization criteria set forth in 3.3.8.2.

$\Delta f = 108.1 - f_1$, where f_1 is the frequency of N_1, the VHF FM sound broadcasting signal closer to 108.1 MHz.

3.3.8.2 The VOR receiving system shall not be desensitized in the presence of VHF FM broadcast signals having levels in accordance with the following table:

Frequency (MHz)	*Maximum level of unwanted signal at receiver input (dBm)*
88-102	+15
104	+10
106	+ 5
107.9	–10

Note 1.— The relationship is linear between adjacent points designated by the above frequencies.

Note 2.— Guidance material on immunity criteria to be used for the performance quoted in 3.3.8.1 and 3.3.8.2 is contained in Attachment C, 3.6.5.

3.4 Specification for non-directional radio beacon (NDB)

3.4.1 Definitions

Note.— In Attachment C, guidance is given on the meaning and application of rated coverage and effective coverage and on coverage of NDBs.

Average radius of rated coverage. The radius of a circle having the same area as the rated coverage.

Effective coverage. The area surrounding an NDB within which bearings can be obtained with an accuracy sufficient for the nature of the operation concerned.

Locator. An LF/MF NDB used as an aid to final approach.

Note.— A locator usually has an average radius of rated coverage of between 18.5 and 46.3 km (10 and 25 NM).

Rated coverage. The area surrounding an NDB within which the strength of the vertical field of the ground wave exceeds the minimum value specified for the geographical area in which the radio beacon is situated.

Note.— The above definition is intended to establish a method of rating radio beacons on the normal coverage to be expected in the absence of sky wave transmission and/or anomalous propagation from the radio beacon concerned or interference from other LF/MF facilities, but taking into account the atmospheric noise in the geographical area concerned.

3.4.2 Coverage

3.4.2.1 The minimum value of field strength in the rated coverage of an NDB shall be 70°microvolts per metre.

Note 1.— Guidance on the field strengths required particularly in the latitudes between 30°N and 30°S is given in 6.1 of Attachment C, and the relevant ITU provisions are given in Chapter VIII, Article 35, Section IV, Part B of the Radio Regulations.

Note 2.— The selection of locations and times at which the field strength is measured is important in order to avoid abnormal results for the locality concerned; locations on air routes in the area around the beacon are operationally most significant.

3.4.2.2 All notifications or promulgations of NDBs shall be based upon the average radius of the rated coverage.

Note 1.— In classifying radio beacons in areas where substantial variations in rated coverage may occur diurnally and seasonally, such variations should be taken into account.

Note 2.— Beacons having an average radius of rated coverage of between 46.3 and 278 km (25 and 150 NM) may be designated by the nearest multiple of 46.3 km (25 NM) to the average radius of rated coverage, and beacons of rated coverage over 278 km (150 NM) to the nearest multiple of 92.7 km (50 NM).

3.4.2.3 Where the rated coverage of an NDB is materially different in various operationally significant sectors, its classification shall be expressed in terms of the average radius of rated coverage and the angular limits of each sector as follows:

Radius of coverage of sector/angular limits of sector expressed as magnetic bearing clockwise from the beacon.

Where it is desirable to classify an NDB in such a manner, the number of sectors should be kept to a minimum and preferably should not exceed two.

Note.— The average radius of a given sector of the rated coverage is equal to the radius of the corresponding circle-sector of the same area. Example:

150/210° – 30°
100/30° – 210°.

3.4.3 Limitations in radiated power

The power radiated from an NDB shall not exceed by more than 2 dB that necessary to achieve its agreed rated coverage, except that this power may be increased if coordinated regionally or if no harmful interference to other facilities will result.

3.4.4 Radio frequencies

3.4.4.1 The radio frequencies assigned to NDBs shall be selected from those available in that portion of the spectrum between 190 kHz and 1 750 kHz.

3.4.4.2 The frequency tolerance applicable to NDBs shall be 0.01 per cent except that, for NDBs of antenna power above 200 W using frequencies of 1 606.5 kHz and above, the tolerance shall be 0.005 per cent.

3.4.4.3 **Reserved**

3.4.4.4 Where locators associated with ILS facilities serving opposite ends of a single runway are assigned a common frequency, provision shall be made to ensure that the facility not in operational use cannot radiate.

Note.— Additional guidance on the operation of locator beacons on common frequency channels is contained in Volume V, Chapter 3, 3.2.2.

3.4.5 Identification

3.4.5.1 Each NDB shall be individually identified by a two- or three-letter International Morse Code group transmitted at a rate corresponding to approximately 7 words per minute.

3.4.5.2 The complete identification shall be transmitted at least once every 30 seconds, except where the beacon identification is effected by on/off keying of the carrier. In this latter case, the identification shall be at approximately 1-minute intervals, except that a shorter interval may be used at particular NDB stations where this is found to be operationally desirable.

3.4.5.2.1 **Reserved**

3.4.5.3 For NDBs with an average radius of rated coverage of 92.7 km (50 NM) or less that are primarily approach and holding aids in the vicinity of an aerodrome, the identification shall be transmitted at least three times each 30 seconds, spaced equally within that time period.

3.4.5.4 The frequency of the modulating tone used for identification shall be 1 020 Hz plus or minus 50 Hz or 400 Hz plus or minus 25 Hz.

Note.— Determination of the figure to be used would be made regionally, in the light of the considerations contained in Attachment C, 6.5.

3.4.6 Characteristics of emissions

Note.— The following specifications are not intended to preclude employment of modulations or types of modulations that may be utilized in NDBs in addition to those specified for identification, including simultaneous identification and voice modulation, provided that these additional modulations do not materially affect the operational performance of the NDBs in conjunction with currently used airborne direction finders, and provided their use does not cause harmful interference to other NDB services.

3.4.6.1 Except as provided in 3.4.6.1.1, all NDBs shall radiate an uninterrupted carrier and be identified by on/off keying of an amplitude modulating tone (NON/A2A).

3.4.6.1.1 NDBs other than those wholly or partly serving as holding, approach and landing aids, or those having an average radius of rated coverage of less than 92.7 km (50 NM), may be identified by on/off keying of the unmodulated carrier (NON/A1A) if they are in areas of high beacon density and/or where the required rated coverage is not practicable of achievement because of:

a) radio interference from radio stations;

b) high atmospheric noise;

c) local conditions.

Note.— In selecting the types of emission, the possibility of confusion, arising from an aircraft tuning from a NON/A2A facility to a NON/A1A facility without changing the radio compass from "MCW" to "CW" operation, will need to be kept in mind.

3.4.6.2 For each NDB identified by on/off keying of an audio modulating tone, the depth of modulation shall be maintained as near to 95 per cent as practicable.

3.4.6.3 For each NDB identified by on/off keying of an audio modulating tone, the characteristics of emission during identification shall be such as to ensure satisfactory identification at the limit of its rated coverage.

Note 1.— The foregoing requirement necessitates as high a percentage modulation as practicable, together with maintenance of an adequate radiated carrier power during identification.

Note 2.— With a direction-finder pass band of plus or minus 3 kHz about the carrier, a signal to noise ratio of 6 dB at the limit of rated coverage will, in general, meet the foregoing requirement.

Note 3.— Some considerations with respect to modulation depth are contained in Attachment C, 6.4.

3.4.6.4 **Reserved**

3.4.6.5 Unwanted audio frequency modulations shall total less than 5 per cent of the amplitude of the carrier.

Note.— Reliable performance of airborne automatic direction-finding equipment (ADF) may be seriously prejudiced if the beacon emission contains modulation by an audio frequency equal or close to the loop switching frequency or its second harmonic. The loop switching frequencies in currently used equipment lie between 30 Hz and 120 Hz.

3.4.6.6 The bandwidth of emissions and the level of spurious emissions shall be kept at the lowest value that the state of technique and the nature of the service permit.

Note.— Article S3 of the ITU Radio Regulations contains the general provisions with respect to technical characteristics of equipment and emissions. The Radio Regulations contain specific provisions relating to necessary bandwidth, frequency tolerance, spurious emissions and classification of emissions (see Appendices APS1, APS2 and APS3).

3.4.7 Siting of locators

3.4.7.1 Where locators are used as a supplement to the ILS, they shall be located at the sites of the outer and middle marker beacons. Where only one locator is used as a supplement to the ILS, preference shall be given to location at the site of the outer marker beacon. Where locators are employed as an aid to final approach in the absence of an ILS, equivalent locations to those applying when an ILS is installed shall be selected, taking into account the relevant obstacle clearance provisions of the PANS-OPS (Doc 8168).

3.4.7.2 Where locators are installed at both the middle and outer marker positions, they shall be located, where practicable, on the same side of the extended centre line of the runway in order to provide a track between the locators which will be more nearly parallel to the centre line of the runway.

3.4.8 Monitoring

3.4.8.1 For each NDB, suitable means shall be provided to enable detection of any of the following conditions at an appropriate location:

a) a decrease in radiated carrier power of more than 50 per cent below that required for the rated coverage;

b) failure to transmit the identification signal;

c) malfunctioning or failure of the means of monitoring itself.

3.4.8.2 **Reserved**

3.4.8.3 During the hours of service of a locator, the means of monitoring shall provide for a continuous check on the functioning of the locator as prescribed in 3.4.8.1 a), b) and c).

3.4.8.4 During the hours of service of an NDB other than a locator, the means of monitoring shall provide for a continuous check on the functioning of the NDB as prescribed in 3.4.8.1 a), b) and c).

Note.— Guidance material on the testing of NDBs is contained in 6.6 of Attachment C.

3.5 Specification for UHF distance measuring equipment (DME)

Note.— In the following section, provision is made for two types of DME facility: DME/N for general application, and DME/P as outlined in 3.11.3.

3.5.1 Definitions

Control motion noise (CMN). That portion of the guidance signal error which causes control surface, wheel and column motion and could affect aircraft attitude angle during coupled flight, but does not cause aircraft displacement from the desired course and/or glide path. (See 3.11.)

DME dead time. A period immediately following the decoding of a valid interrogation during which a received interrogation will not cause a reply to be generated.

Note.— Dead time is intended to prevent the transponder from replying to echoes resulting from multipath effects.

DME/N. Distance measuring equipment, primarily serving operational needs of en-route or TMA navigation, where the “N” stands for narrow spectrum characteristics.

DME/P. The distance measuring element of the MLS, where the “P” stands for precise distance measurement. The spectrum characteristics are those of DME/N.

Equivalent isotropically radiated power (EIRP). The product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain).

Final approach (FA) mode. The condition of DME/P operation which supports flight operations in the final approach and runway regions.

Initial approach (IA) mode. The condition of DME/P operation which supports those flight operations outside the final approach region and which is interoperable with DME/N.

Key down time. The time during which a dot or dash of a Morse character is being transmitted.

MLS approach reference datum. A point on the minimum glide path at a specified height above the threshold. (See 3.11.)

MLS datum point. The point on the runway centre line closest to the phase centre of the approach elevation antenna. (See 3.11.)

Mode W, X, Y, Z. *A method of coding the DME transmissions by time spacing pulses of a pulse pair, so that each frequency can be used more than once.*

Partial rise time. The time as measured between the 5 and 30 per cent amplitude points on the leading edge of the pulse envelope, i.e. between points h and i on Figures 3-1 and 3-2.

Path following error (PFE). That portion of the guidance signal error which could cause aircraft displacement from the desired course and/or glide path. (See 3.11.)

Pulse amplitude. The maximum voltage of the pulse envelope, i.e. A in Figure 3-1.

Pulse decay time. The time as measured between the 90 and 10 per cent amplitude points on the trailing edge of the pulse envelope, i.e. between points e and g on Figure 3-1.

Pulse code. The method of differentiating between W, X, Y and Z modes and between FA and IA modes.

Pulse duration. The time interval between the 50 per cent amplitude point on leading and trailing edges of the pulse envelope, i.e. between points b and f on Figure 3-1.

Pulse rise time. The time as measured between the 10 and 90 per cent amplitude points on the leading edge of the pulse envelope, i.e. between points a and c on Figure 3-1.

Reply efficiency. The ratio of replies transmitted by the transponder to the total of received valid interrogations.

Search. The condition which exists when the DME interrogator is attempting to acquire and lock onto the response to its own interrogations from the selected transponder.

System efficiency. The ratio of valid replies processed by the interrogator to the total of its own interrogations.

Track. The condition which exists when the DME interrogator has locked onto replies in response to its own interrogations, and is continuously providing a distance measurement.

Transmission rate. The average number of pulse pairs transmitted from the transponder per second.

Virtual origin. The point at which the straight line through the 30 per cent and 5 per cent amplitude points on the pulse leading edge intersects the 0 per cent amplitude axis (see Figure 3-2).

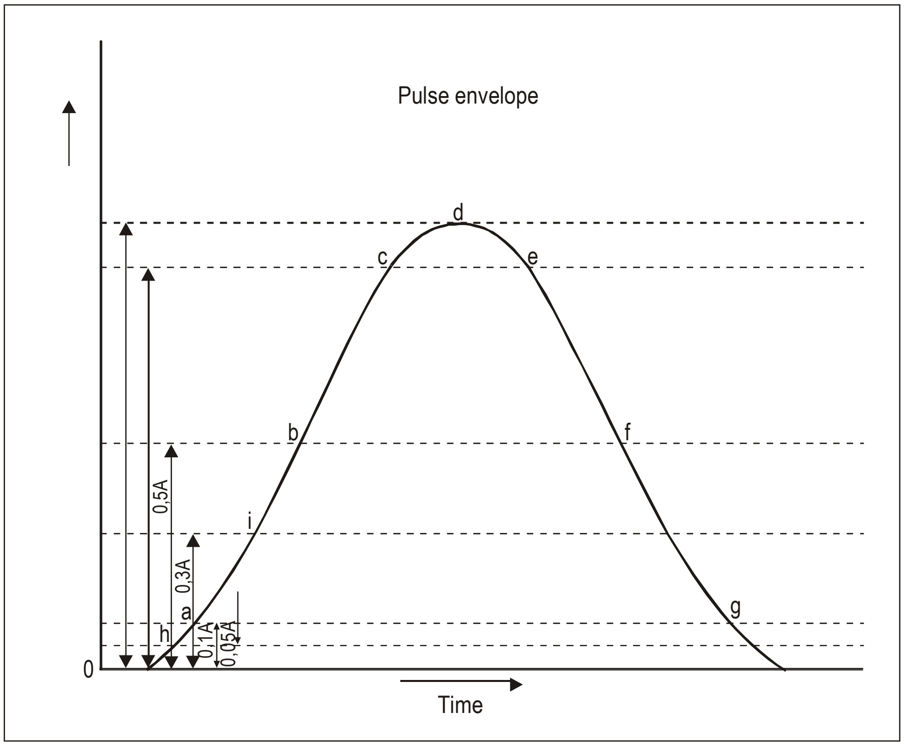

Figure 3-1

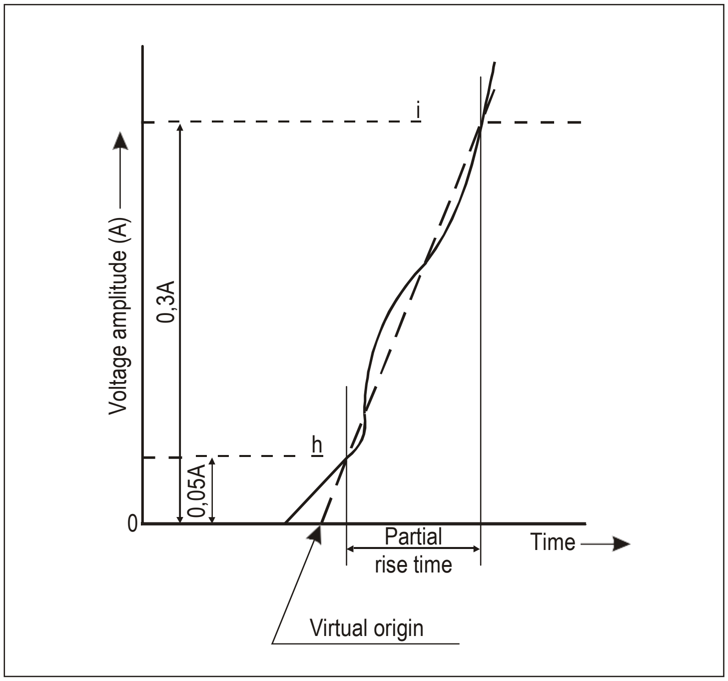

Figure 3-2

3.5.2 General

3.5.2.1 The DME system shall provide for continuous and accurate indication in the cockpit of the slant range distance of an equipped aircraft from an equipped ground reference point.

3.5.2.2 The system shall comprise two basic components, one fitted in the aircraft, the other installed on the ground. The aircraft component shall be referred to as the interrogator and the ground component as the transponder.

3.5.2.3 In operation, interrogators shall interrogate transponders which shall, in turn, transmit to the interrogator replies synchronized with the interrogations, thus providing means for accurate measurement of distance.

3.5.2.4 **Reserved.**

3.5.2.5 When a DME is associated with an ILS,or VOR for the purpose of constituting a single facility, they shall:

a) be operated on a standard frequency pairing in accordance with 3.5.3.3.4;

b) be collocated within the limits prescribed for associated facilities in 3.5.2.6; and

c) comply with the identification provisions of 3.5.3.6.4.

3.5.2.6 Collocation limits for a DME facility associated with an ILS or VOR facility

3.5.2.6.1 Associated VOR and DME facilities shall be collocated in accordance with the following:

a) for those facilities used in terminal areas for approach purposes or other procedures where the highest position fixing accuracy of system capability is required, the separation of the VOR and DME antennas does not exceed 80 m (260 ft);

b) for purposes other than those indicated in a), the separation of the VOR and DME antennas does not exceed 600 m (2 000 ft).

3.5.2.6.2 Association of DME with ILS

Note.— Attachment C, 2.11 gives guidance on the association of DME with ILS.

3.5.2.6.3 Association of DME with MLS

3.5.2.6.3.1 **Reserved.**

3.5.2.7 The Standards in 3.5.3, 3.5.4 and 3.5.5 denoted by ‡ shall apply only to DME equipment first installed after 1 January 1989.

3.5.3 System characteristics

3.5.3.1 Performance

3.5.3.1.1 *Range.* The system shall provide a means of measurement of slant range distance from an aircraft to a selected transponder to the limit of coverage prescribed by the operational requirements for the selected transponder.

3.5.3.1.2 Coverage

3.5.3.1.2.1 When associated with a VOR, DME/N coverage shall be at least that of the VOR to the extent practicable.

3.5.3.1.2.2 When associated with either an ILS or an MLS, DME/N coverage shall be at least that of the respective ILS or of the MLS azimuth angle guidance coverage sectors.

3.5.3.1.2.3 **Reserved.**

Note.— This is not intended to specify the operational range and coverage to which the system may be used; spacing of facilities already installed may limit the range in certain areas.

3.5.3.1.3 Accuracy

3.5.3.1.3.1 *System accuracy.* The accuracy standards specified in 3.5.3.1.4, 3.5.4.5 and 3.5.5.4 shall be met on a 95 per cent probability basis.

3.5.3.1.4 Reserved.

3.5.3.2 *Radio frequencies and polarization.* The system shall operate with vertical polarization in the frequency band 960 MHz to 1 215 MHz. The interrogation and reply frequencies shall be assigned with 1MHz spacing between channels.

3.5.3.3 Channelling

3.5.3.3.1 DME operating channels shall be formed by pairing interrogation and reply frequencies and by pulse coding on the paired frequencies.

3.5.3.3.2 Reserved

3.5.3.3.3 DME operating channels shall be chosen from Table A (located at the end of this chapter), of 352 channels in which the channel numbers, frequencies, and pulse codes are assigned.

3.5.3.3.4 *Channel pairing.* When a DME transponder is intended to operate in association with a single VHF navigation facility in the 108 MHz to 117.95 MHz frequency band and/or an MLS angle facility in the 5 031.0 MHz to 5 090.7 MHz frequency band, the DME operating channel shall be paired with the VHF channel and/or MLS angle frequency as given in Table A.

Note.— There may be instances when a DME channel will be paired with both the ILS frequency and an MLS channel (see Volume V, Chapter 4, 4.3).

3.5.3.4 Interrogation pulse repetition frequency

Note.— If the interrogator operates on more than one channel in one second, the following specifications apply to the sum of interrogations on all channels.

3.5.3.4.1 *DME/N.* The interrogator average pulse repetition frequency (PRF) shall not exceed 30 pairs of pulses per second, based on the assumption that at least 95 per cent of the time is occupied for tracking.

3.5.3.4.2 *DME/N.* If it is desired to decrease the time of search, the PRF may be increased during search but shall not exceed 150 pairs of pulses per second.

3.5.3.4.3 DME/N. After 15 000 pairs of pulses have been transmitted without acquiring indication of distance, the PRF shall not exceed 60 pairs of pulses per second thereafter, until a change in operating channel is made or successful search is completed.

‡3.5.3.4.4 *DME/N.* When, after a time period of 30 seconds, tracking has not been established, the pulse pair repetition frequency shall not exceed 30 pulse pairs per second thereafter.

3.5.3.4.5 Reserved.

3.5.3.5 Aircraft handling capacity of the system

3.5.3.5.1 The aircraft handling capacity of transponders in an area shall be adequate for the peak traffic of the area or 100 aircraft, whichever is the lesser.

3.5.3.5.2 Reserved.

Note.— Guidance material on aircraft handling capacity will be found in Attachment C, 7.1.5.

3.5.3.6 Transponder identification

3.5.3.6.1 All transponders shall transmit an identification signal in one of the following forms as required by 3.5.3.6.5:

a) an “independent” identification consisting of coded (International Morse Code) identity pulses which can be used with all transponders;

b) an “associated” signal which can be used for transponders specifically associated with a VHF navigation angle guidance facility which itself transmits an identification signal.

Note.— Reserved

The systems of identification shall use signals, which shall consist of the transmission for an appropriate period of a series of paired pulses transmitted at a repetition rate of 1 350 pulse pairs per second, and shall temporarily replace all reply pulses that would normally occur at that time except as in 3.5.3.6.2.2. These pulses shall have similar characteristics to the other pulses of the reply signals.

‡ 3.5.3.6.2.1 *DME/N.* Reply pulses shall be transmitted between key down times.

3.5.3.6.2.2 **Reserved.**

3.5.3.6.2.3 *Reserved*

3.5.3.6.2.4 *Reserved*

3.5.3.6.2.5 *Reserved*

3.5.3.6.3 The characteristics of the "independent" identification signal shall be as follows:

a) the identity signal shall consist of the transmission of the beacon code in the form of dots and dashes (International Morse Code) of identity pulses at least once every 40 seconds, at a rate of at least 6 words per minute; and

b) the identification code characteristic and letter rate for the DME transponder shall conform to the following to ensure that the maximum total key down time does not exceed 5 seconds per identification code group. The dots shall be a time duration of 0.1 second to 0.160 second. The dashes shall be typically 3 times the duration of the dots. The duration between dots and/or dashes shall be equal to that of one dot plus or minus 10 per cent. The time duration between letters or numerals shall not be less than three dots. The total period for transmission of an identification code group shall not exceed 10 seconds.

Note.— The tone identification signal is transmitted at a repetition rate of 1 350 pps. This frequency may be used directly in the airborne equipment as an aural output for the pilot, or other frequencies may be generated at the option of the interrogator designer (see 3.5.3.6.2).

3.5.3.6.4 The characteristics of the "associated" signal shall be as follows:

a) when associated with a VHF angle facility, the identification shall be transmitted in the form of dots and dashes (International Morse Code) as in 3.5.3.6.3 and shall be synchronized with the VHF facility identification code;

b) each 40-second interval shall be divided into four or more equal periods, with the transponder identification transmitted during one period only and the associated VHF angle facility identification, where these are provided, transmitted during the remaining periods;

c) Reserved.

3.5.3.6.5 Identification implementation

3.5.3.6.5.1 The "independent" identification code shall be employed wherever a transponder is not specifically associated with a VHF navigational facility.

3.5.3.6.5.2 Wherever a transponder is specifically associated with a VHF navigational facility, identification shall be provided by the "associated" code.

3.5.3.6.5.3 When voice communications are being radiated on an associated VHF navigational facility, an "associated" signal from the transponder shall not be suppressed.

3.5.3.7 ***Reserved.***

3.5.3.8 **Reserved.**

3.5.4 Detailed technical characteristics of transponder and associated monitor

3.5.4.1 Transmitter

3.5.4.1.1 *Frequency of operation.* The transponder shall transmit on the reply frequency appropriate to the assigned DME channel (see 3.5.3.3.3).

3.5.4.1.2 *Frequency stability.* The radio frequency of operation shall not vary more than plus or minus 0.002 per cent from the assigned frequency.

3.5.4.1.3 *Pulse shape and spectrum.* The following shall apply to all radiated pulses:

a) *Pulse rise time.*

   1) *DME/N.* Pulse rise time shall not exceed 3 microseconds.

   2) Reserved.

   3) **Reserved.**

b) Pulse duration shall be 3.5 microseconds plus or minus 0.5 microsecond.

c) Pulse decay time shall nominally be 2.5 microseconds but shall not exceed 3.5 microseconds.

d) The instantaneous amplitude of the pulse shall not, at any instant between the point of the leading edge which is 95 per cent of maximum amplitude and the point of the trailing edge which is 95 per cent of the maximum amplitude, fall below a value which is 95 per cent of the maximum voltage amplitude of the pulse.

e) For DME/N: the spectrum of the pulse modulated signal shall be such that during the pulse the EIRP contained in a 0.5 MHz band centred on frequencies 0.8 MHz above and 0.8 MHz below the nominal channel frequency in each case shall not exceed 200 mW, and the EIRP contained in a 0.5 MHz band centred on frequencies 2 MHz above and 2 MHz below the nominal channel frequency in each case shall not exceed 2 mW. The EIRP contained within any 0.5 MHz band shall decrease monotonically as the band centre frequency moves away from the nominal channel frequency.

   Note.— Guidance material relating to the pulse spectrum measurement is provided in Document EUROCAE ED-57 (including Amendment No. 1).

f) To ensure proper operation of the thresholding techniques, the instantaneous magnitude of any pulse turn-on transients which occur in time prior to the virtual origin shall be less than one per cent of the pulse peak amplitude. Initiation of the turn-on process shall not commence sooner than 1 microsecond prior to the virtual origin.

Note 1.— The time "during the pulse" encompasses the total interval from the beginning of pulse transmission to its end. For practical reasons, this interval may be measured between the 5 per cent points on the leading and trailing edges of the pulse envelope.

Note 2.— The power contained in the frequency bands specified in 3.5.4.1.3 e) is the average power during the pulse. Average power in a given frequency band is the energy contained in this frequency band divided by the time of pulse transmission according to Note 1.

3.5.4.1.4 Pulse spacing

3.5.4.1.4.1 The spacing of the constituent pulses of transmitted pulse pairs shall be as given in the table in 3.5.4.4.1.

3.5.4.1.4.2 *DME/N.* The tolerance on the pulse spacing shall be plus or minus 0.25 microsecond.

3.5.4.1.4.3 **Reserved.**

3.5.4.1.4.4 *Reserved*

3.5.4.1.4.5 The pulse spacings shall be measured between the half voltage points on the leading edges of the pulses.

3.5.4.1.5 Peak power output

3.5.4.1.5.1 **Reserved**.

‡3.5.4.1.5.2 *DME/N.* The peak equivalent isotropically radiated power shall not be less than that required to ensure a peak pulse power density of minus 89 dBW/m^2 under all operational weather conditions at any point within coverage specified in 3.5.3.1.2.

Note.— Although the Standard in 3.5.4.1.5.2 implies an improved interrogator receiver sensitivity, it is intended that the power density specified in 3.5.4.1.5.1 be available at the maximum specified service range and level.

3.5.4.1.5.3 Reserved.

3.5.4.1.5.4 The peak power of the constituent pulses of any pair of pulses shall not differ by more than 1 dB.

3.5.4.1.5.5 The reply capability of the transmitter shall be such that the transponder shall be capable of continuous operation at a transmission rate of 2 700 plus or minus 90 pulse pairs per second (if 100 aircraft are to be served).

Note.— Guidance on the relationship between number of aircraft and transmission rate is given in Attachment C, 7.1.5.

3.5.4.1.5.6 The transmitter shall operate at a transmission rate, including randomly distributed pulse pairs and distance reply pulse pairs, of not less than 700 pulse pairs per second except during identity. The minimum transmission rate shall be as close as practicable to 700 pulse pairs per second.

Note.— Operating DME transponders with quiescent transmission rates close to 700 pulse pairs per second will minimize the effects of pulse interference, particularly to other aviation services such as GNSS.

3.5.4.1.6 *Spurious radiation.* During intervals between transmission of individual pulses, the spurious power received and measured in a receiver having the same characteristics as a transponder receiver, but tuned to any DME interrogation or reply frequency, shall be more than 50 dB below the peak pulse power received and measured in the same receiver tuned to the reply frequency in use during the transmission of the required pulses. This provision refers to all spurious transmissions, including modulator and electrical interference.

‡3.5.4.1.6.1 *DME/N.* The spurious power level specified in 3.5.4.1.6 shall be more than 80 dB below the peak pulse power level.

3.5.4.1.6.2 Reserved.

3.5.4.1.6.3 *Out-of-band spurious radiation.* At all frequencies from 10 to 1 800 MHz, but excluding the band of frequencies from 960 to 1 215 MHz, the spurious output of the DME transponder transmitter shall not exceed minus 40 dBm in any one kHz of receiver bandwidth.

3.5.4.1.6.4 The equivalent isotropically radiated power of any CW harmonic of the carrier frequency on any DME operating channel shall not exceed minus 10 dBm.

3.5.4.2 Receiver

3.5.4.2.1 *Frequency of operation.* The receiver centre frequency shall be the interrogation frequency appropriate to the assigned DME operating channel (see 3.5.3.3.3).

3.5.4.2.2 *Frequency stability.* The centre frequency of the receiver shall not vary more than plus or minus 0.002 per cent from the assigned frequency.

3.5.4.2.3 Transponder sensitivity

3.5.4.2.3.1 In the absence of all interrogation pulse pairs, with the exception of those necessary to perform the sensitivity measurement, interrogation pulse pairs with the correct spacing and nominal frequency shall trigger the transponder if the peak power density at the transponder antenna is at least:

a) minus 103 dBW/m^2 for DME/N with coverage range greater than 56 km (30 NM);

b) minus 93 dBW/m^2 for DME/N with coverage range not greater than 56 km (30 NM);

c) reserved

d) reserved.

3.5.4.2.3.2 The minimum power densities specified in 3.5.4.2.3.1 shall cause the transponder to reply with an efficiency of at least:

a) 70 per cent for DME/N;

b) Reserved.

c) Reserved.

‡3.5.4.2.3.3 *DME/N dynamic range.* The performance of the transponder shall be maintained when the power density of the interrogation signal at the transponder antenna has any value between the minimum specified in 3.5.4.2.3.1 up to a maximum of minus 22 dBW/m^2 when installed with ILS or MLS and minus 35 dBW/m^2 when installed for other applications.

3.5.4.2.3.4 *Reserved.*

3.5.4.2.3.5 The transponder sensitivity level shall not vary by more than 1 dB for transponder loadings between 0 and 90 per cent of its maximum transmission rate.

‡3.5.4.2.3.6 *DME/N.* When the spacing of an interrogator pulse pair varies from the nominal value by up to plus or minus 1 microsecond, the receiver sensitivity shall not be reduced by more than 1 dB.

3.5.4.2.3.7 *Reserved*

3.5.4.2.4 Load limiting

3.5.4.2.4.1 *DME/N.* When transponder loading exceeds 90 per cent of the maximum transmission rate, the receiver sensitivity shall be automatically reduced in order to limit the transponder replies, so as to ensure that the maximum permissible transmission rate is not exceeded. (The available range of sensitivity reduction shall be at least 50 dB.)

3.5.4.2.4.2 *Reserved.*

3.5.4.2.5 *Noise.* When the receiver is interrogated at the power densities specified in 3.5.4.2.3.1 to produce a transmission rate equal to 90 per cent of the maximum, the noise generated pulse pairs shall not exceed 5 per cent of the maximum transmission rate.

3.5.4.2.6 Bandwidth

3.5.4.2.6.1 The minimum permissible bandwidth of the receiver shall be such that the transponder sensitivity level shall not deteriorate by more than 3 dB when the total receiver drift is added to an incoming interrogation frequency drift of plus or minus 100 kHz.

3.5.4.2.6.2 *DME/N.* The receiver bandwidth shall be sufficient to allow compliance with 3.5.3.1.3 when the input signals are those specified in 3.5.5.1.3.

3.5.4.2.6.3 *Reserved*

3.5.4.2.6.4 *Reserved.*

3.5.4.2.6.5 Signals greater than 900 kHz removed from the desired channel nominal frequency and having power densities up to the values specified in 3.5.4.2.3.3 for DME/N. Signals arriving at the intermediate frequency shall be suppressed at least 80 dB. All other spurious response or signals within the 960 MHz to 1 215 MHz band and image frequencies shall be suppressed at least 75 dB.

3.5.4.2.7 *Recovery time.* Within 8 microseconds of the reception of a signal between 0 dB and 60 dB above minimum sensitivity level, the minimum sensitivity level of the transponder to a desired signal shall be within 3 dB of the value obtained in the absence of signals. This requirement shall be met with echo suppression circuits, if any, rendered inoperative. The 8 microseconds are to be measured between the half voltage points on the leading edges of the two signals, both of which conform in shape, with the specifications in 3.5.5.1.3.

3.5.4.2.8 *Spurious radiations.* Radiation from any part of the receiver or allied circuits shall meet the requirements stated in 3.5.4.1.6.

3.5.4.2.9 CW and echo suppression-

CW and echo suppression shall be adequate for the sites at which the transponders will be used.

Note.— In this connection, echoes mean undesired signals caused by multipath transmission (reflections, etc.).

3.5.4.2.10 Protection against interference

Protection against interference outside the DME frequency band shall be adequate for the sites at which the transponders will be used.

3.5.4.3 Decoding

3.5.4.3.1 The transponder shall include a decoding circuit such that the transponder can be triggered only by pairs of received pulses having pulse duration and pulse spacings appropriate to interrogator signals as described in 3.5.5.1.3 and 3.5.5.1.4.

3.5.4.3.2 The decoding circuit performance shall not be affected by signals arriving before, between, or after, the constituent pulses of a pair of the correct spacing.

‡3.5.4.3.3 *DME/N — Decoder rejection.* An interrogation pulse pair with a spacing of plus or minus 2 microseconds, or more, from the nominal value and with any signal level up to the value specified in 3.5.4.2.3.3 shall be rejected such that the transmission rate does not exceed the value obtained when interrogations are absent.

3.5.4.3.4 Reserved.

3.5.4.4 Time delay

3.5.4.4.1 When a DME is associated only with a VHF facility, the time delay shall be the interval from the half voltage point on the leading edge of the second constituent pulse of the interrogation pair and the half voltage point on the leading edge of the second constituent pulse of the reply transmission. This delay shall be consistent with the following table, when it is desired that aircraft interrogators are to indicate distance from the transponder site.

		Pulse pair spacing (µs)		*Time delay (µs)*	
Channel suffix	*Operating mode*	*Interrogation*	*Reply*	*1st pulse timing*	*2nd pulse timing*
X	DME/N	12	12	50	50
Y	DME/N	36	30	56	50

3.5.4.4.2 Reserved.

3.5.4.4.2.1 Reserved.

3.5.4.4.3 For the DME/N the transponder time delay shall be capable of being set to an appropriate value between the nominal value of the time delay minus 15 microseconds and the nominal value of the time delay, to permit aircraft interrogators to indicate zero distance at a specific point remote from the transponder site.

Note.— Modes not allowing for the full 15 microseconds range of adjustment in transponder time delay may only be adjustable to the limits given by the transponder circuit delay and recovery time.

‡3.5.4.4.3.1 *DME/N.* The time delay shall be the interval from the half voltage point on the leading edge of the first constituent pulse of the interrogation pair and the half voltage point on the leading edge of the first constituent pulse of the reply transmission.

3.5.4.4.3.2 Reserved.

3.5.4.4.3.3 *Reserved*

3.5.4.4.4 *DME/N.* Transponders shall be sited as near to the point at which zero indication is required as is practicable.

Note 1.— It is desirable that the radius of the sphere at the surface of which zero indication is given be kept as small as possible in order to keep the zone of ambiguity to a minimum.

Note 2.— reserved

3.5.4.5 Accuracy

3.5.4.5.1 *DME/N.* The transponder shall not contribute more than plus or minus 1 microsecond (150 m (500 ft)) to the overall system error.

3.5.4.5.1.1 Reserved.

Note.—

‡3.5.4.5.1.2 *DME/N.* The combination of the transponder errors, transponder location coordinate errors, propagation effects and random pulse interference effects shall not contribute more than plus or minus 185 m (0.1 NM) to the overall system error.

Note.— This error contribution limit includes errors from all causes except the airborne equipment, and assumes that the airborne equipment measures time delay based on the first constituent pulse of a pulse pair.

‡3.5.4.5.2 *DME/N.* A transponder associated with a landing aid shall not contribute more than plus or minus 0.5 microsecond (75 m (250 ft)) to the overall system error.

3.5.4.5.3 Reserved.

3.5.4.5.4 *Reserved.*

3.5.4.5.5 **Reserved.**

3.5.4.6 Efficiency

3.5.4.6.1 The transponder reply efficiency shall be at least 70 per cent for DME/N at all values of transponder loading up to the loading corresponding to 3.5.3.5 and at the minimum sensitivity level specified in 3.5.4.2.3.1 and 3.5.4.2.3.5.

Note.— When considering the transponder reply efficiency value, account is to be taken of the DME dead time and of the loading introduced by the monitoring function.

3.5.4.6.2 *Transponder dead time.* The transponder shall be rendered inoperative for a period normally not to exceed 60 microseconds after a valid interrogation decode has occurred. In extreme cases when the geographical site of the transponder is such as to produce undesirable reflection problems, the dead time may be increased but only by the minimum amount necessary to allow the suppression of echoes for DME/N.

3.5.4.6.2.1 Reserved.

3.5.4.7 Monitoring and control

3.5.4.7.1 Means shall be provided at each transponder site for the automatic monitoring and control of the transponder in use.

3.5.4.7.2 DME/N monitoring action

3.5.4.7.2.1 In the event that any of the conditions specified in 3.5.4.7.2.2 occur, the monitor shall cause the following action to take place:

a) a suitable indication shall be given at a control point;

b) the operating transponder shall be automatically switched off; and

c) the standby transponder, if provided, shall be automatically placed in operation.

3.5.4.7.2.2 The monitor shall cause the actions specified in 3.5.4.7.2.1 if:

a) the transponder delay differs from the assigned value by 1 microsecond (150 m (500 ft)) or more;

‡b) in the case of a DME/N associated with a landing aid, the transponder delay differs from the assigned value by 0.5 microsecond (75 m (250 ft)) or more.

3.5.4.7.2.3 The monitor shall cause the actions specified in 3.5.4.7.2.1 if the spacing between the first and second pulse of the transponder pulse pair differs from the nominal value specified in the table following 3.5.4.4.1 by 1 microsecond or more.

3.5.4.7.2.4 The monitor shall also cause a suitable indication to be given at a control point if any of the following conditions arise:

a) a fall of 3 dB or more in transponder transmitted power output;

b) a fall of 6 dB or more in the minimum transponder receiver sensitivity (provided that this is not due to the action of the receiver automatic gain reduction circuits);

c) the spacing between the first and second pulse of the transponder reply pulse pair differs from the normal value specified in 3.5.4.1.4 by 1 microsecond or more;

d) variation of the transponder receiver and transmitter frequencies beyond the control range of the reference circuits (if the operating frequencies are not directly crystal controlled).

3.5.4.7.2.5 Means shall be provided so that any of the conditions and malfunctioning enumerated in 3.5.4.7.2.2, 3.5.4.7.2.3 and 3.5.4.7.2.4 which are monitored can persist for a certain period before the monitor takes action. This period shall be as low as practicable, but shall not exceed 10 seconds, consistent with the need for avoiding interruption, due to transient effects, of the service provided by the transponder.

3.5.4.7.2.6 The transponder shall not be triggered more than 120 times per second for either monitoring or automatic frequency control purposes, or both.

3.5.4.7.3 Reserved.

3.5.4.7.3.1 Reserved.

3.5.4.7.3.2 **Reserved.**

3.5.4.7.3.3 Reserved.

3.5.4.7.3.4 Reserved.

3.5.4.7.3.5 *DME/N monitor failure.* Failure of any part of the monitor itself shall automatically produce the same results as the malfunctioning of the element being monitored.

3.5.5 Technical characteristics of interrogator

Note.— The following subparagraphs specify only those interrogator parameters which must be defined to ensure that the interrogator:

a) does not jeopardize the effective operation of the DME system, e.g. by increasing transponder loading abnormally; and

b) is capable of giving accurate distance readings.

3.5.5.1 Transmitter

3.5.5.1.1 *Frequency of operation.* The interrogator shall transmit on the interrogation frequency appropriate to the assigned DME channel (see 3.5.3.3.3).

Note.— This specification does not preclude the use of airborne interrogators having less than the total number of operating channels.

3.5.5.1.2 *Frequency stability.* The radio frequency of operation shall not vary more than plus or minus 100 kHz from the assigned value.

3.5.5.1.3 *Pulse shape and spectrum.* The following shall apply to all radiated pulses:

a) *Pulse rise time.*

   1) *DME/N.* Pulse rise time shall not exceed 3 microseconds.

   2) Reserved.

   *3) R***eserved**

b) Pulse duration shall be 3.5 microseconds plus or minus 0.5 microsecond.

c) Pulse decay time shall nominally be 2.5 microseconds, but shall not exceed 3.5 microseconds.

d) The instantaneous amplitude of the pulse shall not, at any instant between the point of the leading edge which is 95 per cent of maximum amplitude and the point of the trailing edge which is 95 per cent of the maximum amplitude, fall below a value which is 95 per cent of the maximum voltage amplitude of the pulse.

e) The spectrum of the pulse modulated signal shall be such that at least 90 per cent of the energy in each pulse shall be within 0.5 MHz in a band centred on the nominal channel frequency.

f) To ensure proper operation of the thresholding techniques, the instantaneous magnitude of any pulse turn-on transients which occur in time prior to the virtual origin shall be less than one per cent of the pulse peak amplitude. Initiation of the turn-on process shall not commence sooner than 1 microsecond prior to the virtual origin.

Note 1.— The lower limit of pulse rise time (see 3.5. 5.1.3 a)) and decay time (see 3.5.5.1.3 c)) are governed by the spectrum requirements in 3.5.5.1.3 e).

Note 2.— While 3.5.5.1.3 e) calls for a practically attainable spectrum, it is desirable to strive for the following spectrum control characteristics: the spectrum of the pulse modulated signal is such that the power contained in a 0.5 MHz band centred on frequencies 0.8 MHz above and 0.8 MHz below the nominal channel frequency is, in each case, at least 23 dB below the power contained in a 0.5 MHz band centred on the nominal channel frequency. The power contained in a 0.5 MHz band centred on frequencies 2 MHz above and 2 MHz below the nominal channel frequency is, in each case, at least 38 dB below the power contained in a 0.5 MHz band centred on the nominal channel frequency. Any additional lobe of the spectrum is of less amplitude than the adjacent lobe nearer the nominal channel frequency.

3.5.5.1.4 Pulse spacing

3.5.5.1.4.1 The spacing of the constituent pulses of transmitted pulse pairs shall be as given in the table in 3.5.4.4.1.

3.5.5.1.4.2 *DME/N.* The tolerance on the pulse spacing shall be plus or minus 0.5 microsecond.

3.5.5.1.4.3 Reserved.

3.5.5.1.4.4 *Reserved.*

3.5.5.1.4.5 The pulse spacing shall be measured between the half voltage points on the leading edges of the pulses.

3.5.5.1.5 Pulse repetition frequency

3.5.5.1.5.1 The pulse repetition frequency shall be as specified in 3.5.3.4.

3.5.5.1.5.2 The variation in time between successive pairs of interrogation pulses shall be sufficient to prevent false lock-on.

3.5.5.1.5.3 *Reserved.*

3.5.5.1.6 *Spurious radiation.* During intervals between transmission of individual pulses, the spurious pulse power received and measured in a receiver having the same characteristics of a DME transponder receiver, but tuned to any DME interrogation or reply frequency, shall be more than 50 dB below the peak pulse power received and measured in the same receiver tuned to the interrogation frequency in use during the transmission of the required pulses. This provision shall apply to all spurious pulse transmissions. The spurious CW power radiated from the interrogator on any DME interrogation or reply frequency shall not exceed 20 microwatts (minus 47 dBW).

Note.— Although spurious CW radiation between pulses is limited to levels not exceeding minus 47 dBW, where DME interrogators and secondary surveillance radar transponders are employed in the same aircraft, it may be necessary to provide protection to airborne SSR in the band 1 015 MHz to 1 045 MHz. This protection may be provided by limiting conducted and radiated CW to a level of the order of minus 77 dBW. Where this level cannot be achieved, the required degree of protection may be provided in planning the relative location of the SSR and DME aircraft antennas. It is to be noted that only a few of these frequencies are utilized in the VHF/DME pairing plan.

3.5.5.1.7 The spurious pulse power received and measured under the conditions stated in 3.5.5.1.6 shall be 80 dB below the required peak pulse power received.

Note.— Reference 3.5.5.1.6 and 3.5.5.1.7 — although limitation of spurious CW radiation between pulses to levels not exceeding 80 dB below the peak pulse power received, where DME interrogators and secondary surveillance radar transponders are employed in the same aircraft, it may be necessary to limit direct and radiated CW to not more than 0.02 microwatt in the frequency band 1 015 MHz to 1 045 MHz. It is to be noted that only a few of these frequencies are utilized in the VHF/DME pairing plan.

3.5.5.1.8 R*eserved.*

3.5.5.2 Time delay

3.5.5.2.1 The time delay shall be consistent with the table in 3.5.4.4.1.

3.5.5.2.2 *DME/N.* The time delay shall be the interval between the time of the half voltage point on the leading edge of the second constituent interrogation pulse and the time at which the distance circuits reach the condition corresponding to zero distance indication.

‡3.5.5.2.3 *DME/N.* The time delay shall be the interval between the time of the half voltage point on the leading edge of the first constituent interrogation pulse and the time at which the distance circuits reach the condition corresponding to zero distance indication.

3.5.5.2.4 *Reserved.*

3.5.5.2.5 *Reserved.*

3.5.5.3 Receiver

3.5.5.3.1 *Frequency of operation.* The receiver centre frequency shall be the transponder frequency appropriate to the assigned DME operating channel (see 3.5.3.3.3).

3.5.5.3.2 Receiver sensitivity

‡3.5.5.3.2.1 *DME/N.* The airborne equipment sensitivity shall be sufficient to acquire and provide distance information to the accuracy specified in 3.5.5.4 for the signal power density specified in 3.5.4.1.5.2.

Note.— Although the Standard in 3.5.5.3.2.1 is for DME/N interrogators, the receiver sensitivity is better than that necessary in order to operate with the power density of DME/N transponders given in 3.5.4.1.5.1 in order to assure interoperability with the IA mode of DME/P transponders.

3.5.5.3.2.2 *Reserved.*

‡3.5.5.3.2.3 *DME/N.* The performance of the interrogator shall be maintained when the power density of the transponder signal at the interrogator antenna is between the minimum values given in 3.5.4.1.5 and a maximum of minus 18 dBW/m^2.

3.5.5.3.2.4 *Reserved.*

3.5.5.3.3 Bandwidth

3.5.5.3.3.1 *DME/N.* The receiver bandwidth shall be sufficient to allow compliance with 3.5.3.1.3, when the input signals are those specified in 3.5.4.1.3.

3.5.5.3.3.2 *Reserved.*

3.5.5.3.3.3 *Reserved.*

3.5.5.3.4 Interference rejection

3.5.5.3.4.1 When there is a ratio of desired to undesired co-channel DME signals of at least 8 dB at the input terminals of the airborne receiver, the interrogator shall display distance information and provide unambiguous identification from the stronger signal.

Note.— Co-channel refers to those reply signals that utilize the same frequency and the same pulse pair spacing.

‡3.5.5.3.4.2 *DME/N.* DME signals greater than 900 kHz removed from the desired channel nominal frequency and having amplitudes up to 42 dB above the threshold sensitivity shall be rejected.

3.5.5.3.4.3 *Reserved.*

3.5.5.3.5 Decoding

3.5.5.3.5.1 The interrogator shall include a decoding circuit such that the receiver can be triggered only by pairs of received pulses having pulse duration and pulse spacings appropriate to transponder signals as described in 3.5.4.1.4.

‡3.5.5.3.5.2 *DME/N — Decoder rejection.* A reply pulse pair with a spacing of plus or minus 2 microseconds, or more, from the nominal value and with any signal level up to 42 dB above the receiver sensitivity shall be rejected.

3.5.5.3.5.3 R*eserved.*

3.5.5.4 Accuracy

‡3.5.5.4.1 *DME/N.* The interrogator shall not contribute more than plus or minus 315 m (plus or minus 0.17 NM) or 0.25 per cent of indicated range, whichever is greater, to the overall system error.

3.5.5.4.2 *Reserved.*

3.5.5.4.3 Reserved.

3.5.5.4.4 *Reserved.*

Note.— Guidance material on system efficiency is given in Attachment C, 7.1.1.

3.6 Specification for en-route VHF marker beacons (75 MHz)

3.6.1 Equipment

3.6.1.1 *Frequencies.* The emissions of an en-route VHF marker beacon shall have a radio frequency of 75 MHz plus or minus 0.005 per cent.

3.6.1.2 Characteristics of emissions

3.6.1.2.1 Radio marker beacons shall radiate an uninterrupted carrier modulated to a depth of not less than 95 per cent or more than 100 per cent. The total harmonic content of the modulation shall not exceed 15 per cent.

3.6.1.2.2 The frequency of the modulating tone shall be 3 000 Hz plus or minus 75 Hz.

3.6.1.2.3 The radiation shall be horizontally polarized.

3.6.1.2.4 *Identification.* If a coded identification is required at a radio marker beacon, the modulating tone shall be keyed so as to transmit dots or dashes or both in an appropriate sequence. The mode of keying shall be such as to provide a dot-and-dash duration together with spacing intervals corresponding to transmission at a rate equivalent to approximately six to ten words per minute. The carrier shall not be interrupted during identification.

3.6.1.2.5 Coverage and radiation pattern

Note.— The coverage and radiation pattern of marker beacons will ordinarily be established by Contracting States on the basis of operational requirements, taking into account recommendations of regional meetings.

The most desirable radiation pattern would be one that:

a) in the case of fan marker beacons, results in lamp operation only when the aircraft is within a rectangular parallelepiped, symmetrical about the vertical line through the marker beacon and with the major and minor axes adjusted in accordance with the flight path served;

b) in the case of a Z marker beacon, results in lamp operation only when the aircraft is within a cylinder, the axis of which is the vertical line through the marker beacons.

In practice, the production of such patterns is impracticable and a compromise radiation pattern is necessary. In Attachment C, antenna systems currently in use and which have proved generally satisfactory are described for guidance. Such designs and any new designs providing a closer approximation to the most desirable radiation pattern outlined above will normally meet operational requirements.

3.6.1.2.6 *Determination of coverage.* The limits of coverage of marker beacons shall be determined on the basis of the field strength specified in 3.1.7.3.2.

3.6.1.2.7 Radiation pattern- The radiation pattern of a marker beacon normally shall be such that the polar axis is vertical, and the field strength in the pattern is symmetrical about the polar axis in the plane or planes containing the flight paths for which the marker beacon is intended.

Note.— Difficulty in siting certain marker beacons may make it necessary to accept a polar axis that is not vertical.

3.6.1.3 *Monitoring.***—** For each marker beacon, suitable monitoring equipment shall be provided which will show at an appropriate location:

a) a decrease in radiated carrier power below 50 per cent of normal;

b) a decrease of modulation depth below 70 per cent;

c) a failure of keying.

3.7 Requirements for the Global Navigation Satellite System (GNSS)

3.7.1 Definitions

Aircraft-based augmentation system (ABAS). An augmentation system that augments and/or integrates the information obtained from the other GNSS elements with information available on board the aircraft.

Alert. An indication provided to other aircraft systems or annunciation to the pilot to identify that an operating parameter of a navigation system is out of tolerance.

Alert limit. For a given parameter measurement, the error tolerance not to be exceeded without issuing an alert.

Antenna port. A point where the received signal power is specified. For an active antenna, the antenna port is a fictitious point between the antenna elements and the antenna pre-amplifier. For a passive antenna, the antenna port is the output of the antenna itself.

Axial ratio. The ratio, expressed in decibels, between the maximum output power and the minimum output power of an antenna to an incident linearly polarized wave as the polarization orientation is varied over all directions perpendicular to the direction of propagation.

Channel of standard accuracy (CSA). The specified level of positioning, velocity and timing accuracy that is available to any GLONASS user on a continuous, worldwide basis.

Core satellite constellation(s). The core satellite constellations are GPS and GLONASS.

Global navigation satellite system (GNSS). A worldwide position and time determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation.

Global navigation satellite system (GLONASS). The satellite navigation system operated by the Russian Federation.

Global positioning system (GPS). The satellite navigation system operated by the United States.

GNSS position error. The difference between the true position and the position determined by the GNSS receiver.

Ground-based augmentation system (GBAS). An augmentation system in which the user receives augmentation information directly from a ground-based transmitter.

Ground-based regional augmentation system (GRAS). An augmentation system in which the user receives augmentation information directly from one of a group of ground-based transmitters covering a region.

Integrity. A measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts).

Pseudo-range. The difference between the time of transmission by a satellite and reception by a GNSS receiver multiplied by the speed of light in a vacuum, including bias due to the difference between a GNSS receiver and satellite time reference.

Satellite-based augmentation system (SBAS). A wide coverage augmentation system in which the user receives augmentation information from a satellite-based transmitter.

Standard positioning service (SPS). The specified level of positioning, velocity and timing accuracy that is available to any global positioning system (GPS) user on a continuous, worldwide basis.

Time-to-alert. The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert.

3.7.2 General

3.7.2.1 Functions

3.7.2.1.1 The GNSS shall provide position and time data to the aircraft.

Note.— These data are derived from pseudo-range measurements between an aircraft equipped with a GNSS receiver and various signal sources on satellites or on the ground.

3.7.2.2 GNSS elements

3.7.2.2.1 The GNSS navigation service shall be provided using various combinations of the following elements installed on the ground, on satellites and/or on board the aircraft:

a) Global Positioning System (GPS) that provides the Standard Positioning Service (SPS) as defined in 3.7.3.1;

b) Reserved.

c) aircraft-based augmentation system (ABAS) as defined in 3.7.3.3;

d) satellite-based augmentation system (SBAS) as defined in 3.7.3.4;

e) ground-based augmentation system (GBAS) as defined in 3.7.3.5;

f) ground-based regional augmentation system (GRAS) as defined in 3.7.3.5; and

g) aircraft GNSS receiver as defined in 3.7.3.6.

3.7.2.3 Space and time reference

3.7.2.3.1 *Space reference*. The position information provided by the GNSS to the user shall be expressed in terms of the World Geodetic System — 1984 (WGS-84) geodetic reference datum.

Note 1.— SARPs for WGS-84 are contained in Annex 4, Chapter 2; CAR 11, Chapter 2; Annex 14, Volumes I and II, Chapter 1 and CAR 15, Chapter 1.

Note 2.— If GNSS elements using other than WGS-84 coordinates are employed, appropriate conversion parameters are to be applied.

3.7.2.3.2 *Time reference*. The time data provided by the GNSS to the user shall be expressed in a time scale that takes the Universal Time Coordinated (UTC) as reference.

3.7.2.4 Signal-in-space performance

3.7.2.4.1 The combination of GNSS elements and a fault-free GNSS user receiver shall meet the signal-in-space requirements defined in Table 3.7.2.4-1 (located at the end of section 3.7).

Note 1.— The concept of a fault-free user receiver is applied only as a means of defining the performance of combinations of different GNSS elements. The fault-free receiver is assumed to be a receiver with nominal accuracy and time-to-alert performance. Such a receiver is assumed to have no failures that affect the integrity, availability and continuity performance.

Note 2. --- for GBAS approach service (as defined in Attachment D, 7.1.2.1) intended to support approach and landing operations using category III minima, performance requirement are defined that applied in addition to the signal in space requirements defined in table 3.7.2.4-1.

3.7.3 GNSS elements specifications

3.7.3.1 *GPS Standard Positioning Service (SPS) (L1)*

3.7.3.1.1 *Space and control segment accuracy*

Note.— The following accuracy standards do not include atmospheric or receiver errors as described in Attachment D, 4.1.2. They apply under the conditions specified in Appendix B, 3.1.3.1.1.

3.7.3.1.1.1 *Positioning accuracy*. The GPS SPS position errors shall not exceed the following limits:

	Global average 95% of the time	Worst site 95% of the time
Horizontal position error	9 m (30 ft)	17 m (56 ft)
Vertical position error	15 m (49 ft)	37 m (121 ft)

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3.7.3.1.1.2 *Time transfer accuracy*. The GPS SPS time transfer errors shall not exceed 40 nanoseconds 95 per cent of the time.

3.7.3.1.1.3 *Range domain accuracy*. The range domain error shall not exceed the following limits:

a) range error of any satellite — 30 m (100 ft) with reliability specified in 3.7.3.1.3;

b) 95th percentile range rate error of any satellite — 0.006 m (0.02 ft) per second (global average);

c) 95th percentile range acceleration error of any satellite — 0.002 m (0.006 ft) per second-squared (global average); and

d) 95th percentile range error for any satellite over all time differences between time of data generation and time of use of data — 7.8 m (26 ft) (global average).

3.7.3.1.2 *Availability*. The GPS SPS availability shall be as follows:

≥99 per cent horizontal service availability, average location (17 m 95 per cent threshold)

≥99 per cent vertical service availability, average location (37 m 95 per cent threshold)

≥90 per cent horizontal service availability, worst-case location (17 m 95 per cent threshold)

≥90 per cent vertical service availability, worst-case location (37 m 95 per cent threshold)

3.7.3.1.3 *Reliability*. The GPS SPS reliability shall be within the following limits:

a) reliability — at least 99.94 per cent (global average); and

b) reliability — at least 99.79 per cent (worst single point average).

3.7.3.1.4 *Probability of major service failure.* The probability that the user range error (URE) of any satellite will exceed 4.42 times the upper bound on the user range accuracy (URA) broadcast by that satellite without an alert received at the user receiver antenna within 10 seconds shall not exceed 1×10^{-5} per hour.

Note.— The different alert indications are described in the United States Department of Defense, Global Positioning System – Standard Positioning Service – Performance Standard, *4th Edition, September 2008, Section 2.3.4.*

3.7.3.1.5 *Continuity.* The probability of losing GPS SPS signal-in-space (SIS) availability from a slot of the nominal 24-slot constellation due to unscheduled interruption shall not exceed 2×10^{-4} per hour.

3.7.3.1.6 *Coverage.* The GPS SPS shall cover the surface of the earth up to an altitude of 3 000 kilometres.

Note.— Guidance material on GPS accuracy, availability, reliability and coverage is given in Attachment D, 4.1.

3.7.3.1.7 Radio frequency (RF) characteristics

Note.— Detailed RF characteristics are specified in Appendix B, 3.1.1.1.

3.7.3.1.7.1 *Carrier frequency*. Each GPS satellite shall broadcast an SPS signal at the carrier frequency of 1 575.42 MHz (GPS L1) using code division multiple access (CDMA).

Note.— A new civil frequency will be added to the GPS satellites and will be offered by the United States for critical safety-of-life applications. SARPs for this signal may be developed at a later date.

3.7.3.1.7.2 *Signal spectrum*. The GPS SPS signal power shall be contained within a ±12 MHz band (1 563.42 – 1 587.42 MHz) centred on the L1 frequency.

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3.7.3.1.7.3 *Polarization*. The transmitted RF signal shall be right-hand (clockwise) circularly polarized.

3.7.3.1.7.4 *Signal power level*. Each GPS satellite shall broadcast SPS navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the antenna port of a 3 dBi linearly-polarized antenna is within the range of –158.5 dBW to –153 dBW for all antenna orientations orthogonal to the direction of propagation.

3.7.3.1.7.5 *Modulation*. The SPS L1 signal shall be bipolar phase shift key (BPSK) modulated with a pseudo random noise (PRN) 1.023 MHz coarse/acquisition (C/A) code. The C/A code sequence shall be repeated each millisecond. The transmitted PRN code sequence shall be the Modulo-2 addition of a 50 bits per second navigation message and the C/A code.

3.7.3.1.8 *GPS time*. GPS time shall be referenced to UTC (as maintained by the U.S. Naval Observatory).

3.7.3.1.9 *Coordinate system*. The GPS coordinate system shall be WGS-84.

3.7.3.1.10 *Navigation information*. The navigation data transmitted by the satellites shall include the necessary information to determine:

a) satellite time of transmission;

b) satellite position;

c) satellite health;

d) satellite clock correction;

e) propagation delay effects;

f) time transfer to UTC; and

g) constellation status.

Note.— Structure and contents of data are specified in Appendix B, 3.1.1.2 and 3.1.1.3, respectively.

3.7.3.2 Reserved.

3.7.3.3 Aircraft-based augmentation system (ABAS)

3.7.3.3.1 *Performance*. The ABAS function combined with one or more of the other GNSS elements and both a fault-free GNSS receiver and fault-free aircraft system used for the ABAS function shall meet the requirements for accuracy, integrity, continuity and availability as stated in 3.7.2.4.

3.7.3.4 Satellite-based augmentation system (SBAS)

3.7.3.4.1 *Performance*. SBAS combined with one or more of the other GNSS elements and a fault-free receiver shall meet the requirements for system accuracy, integrity, continuity and availability for the intended operation as stated in 3.7.2.4, through out the corresponding service area (see 3.7.3.4.3).

Note.— SBAS complements the core satellite constellation(s) by increasing accuracy, integrity, continuity and availability of navigation provided within a service area, typically including multiple aerodromes.

3.7.3.4.1.1 SBAS combined with one or more of the other GNSS element and of fault-free receiver shall meet the requirement for signal in space integrity has stated in 3.7.2.4, through out the SBAS coverage area.

Note…. Message types 27 or 28 can be used to comply with the integrity requirements in the coverage area.

Additional guidance on the rationale and interpretation of this requirement provided in attachment D, 3.3.

3.7.3.4.2 *Functions.* SBAS shall perform one or more of the following functions:

a) ranging: provide an additional pseudo-range signal with an accuracy indicator from an SBAS satellite (3.7.3.4.2.1 and Appendix B, 3.5.7.2);

b) GNSS satellite status: determine and transmit the GNSS satellite health status (Appendix B, 3.5.7.3);

c) basic differential correction: provide GNSS satellite ephemeris and clock corrections (fast and long-term) to be applied to the pseudo-range measurements from satellites (Appendix B, 3.5.7.4); and

d) precise differential correction: determine and transmit the ionospheric corrections (Appendix B, 3.5.7.5).

Note.— If all the functions are provided, SBAS in combination with core satellite constellation(s) can support departure, en-route, terminal and approach operations including Category I precision approach. The level of performance that can be achieved depends upon the infrastructure incorporated into SBAS and the ionospheric conditions in the geographic area of interest.

3.7.3.4.2.1 Ranging

3.7.3.4.2.1.1 Excluding atmospheric effects, the range error for the ranging signal from SBAS satellites shall not exceed 25 m (82 ft) (95 per cent).

3.7.3.4.2.1.2 The probability that the range error exceeds 150 m (490 ft) in any hour shall not exceed 10^{-5}.

3.7.3.4.2.1.3 The probability of unscheduled outages of the ranging function from an SBAS satellite in any hour shall not exceed 10^{-3}.

3.7.3.4.2.1.4 The range rate error shall not exceed 2 m (6.6 ft) per second.

3.7.3.4.2.1.5 The range acceleration error shall not exceed 0.019 m (0.06 ft) per second-squared.

3.7.3.4.3 *Service area*. An SBAS service area for any approved type of operation shall be a declared area within the SBAS coverage area where SBAS meets the corresponding requirements of 3.7.2.4.

Note 1.— An SBAS system

Note 2.— The coverage area is that area within which the SBAS broadcast can be received (e.g. the geostationary satellite footprints).

Note 3.— SBAS coverage and service areas are discussed in Attachment D, 6.2.

3.7.3.4.4 RF characteristics

Note.— Detailed RF characteristics are specified in Appendix B, 3.5.2.

3.7.3.4.4.1 *Carrier frequency*. The carrier frequency shall be 1 575.42 MHz.

Note.— Reserved..

3.7.3.4.4.2 *Signal spectrum*. At least 95 per cent of the broadcast power shall be contained within a ±12 MHz band centred on the L1 frequency. The bandwidth of the signal transmitted by an SBAS satellite shall be at least 2.2 MHz.

3.7.3.4.4.3 SBAS satellite signal power level

3.7.3.4.4.3.1 Each SBAS satellite placed in orbit before 1 January 2014 shall broadcast navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the antenna port of a 3 dBi linearly polarized antenna is within the range of –161 dBW to –153 dBW for all antenna orientations orthogonal to the direction of propagation.

3.7.3.4.4.3.2 Each SBAS satellite placed in orbit after 31 December 2013 shall comply with the following requirements:

a) The satellite shall broadcast navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at or above the minimum elevation angle for which a trackable GEO signal needs to be provided, the level of the received RF signal at the antenna port of the antenna specified in Appendix B, Table B-88, is at least –164.0 dBW.

b) The minimum elevation angle used to determine GEO coverage shall not be less than 5 degrees for a user near the ground.

c) The level of a received SBAS RF signal at the antenna port of a 0 dBic antenna located near the ground shall not exceed –152.5 dBW.

d) The ellipticity of the broadcast signal shall be no worse than 2 dB for the angular range of ±9.1° from boresight.

3.7.3.4.4.4 *Polarization*. The broadcast signal shall be right-hand circularly polarized.

3.7.3.4.4.5 *Modulation.* The transmitted sequence shall be the Modulo-2 addition of the navigation message at a rate of 500 symbols per second and the 1 023 bit pseudo-random noise code. It shall then be BPSK-modulated onto the carrier at a rate of 1.023 megachips per second.

3.7.3.4.5 *SBAS network time (SNT)*. The difference between SNT and GPS time shall not exceed 50 nanoseconds.

3.7.3.4.6 *Navigation information*. The navigation data transmitted by the satellites shall include the necessary information to determine:

a) SBAS satellite time of transmission;

b) SBAS satellite position;

c) corrected satellite time for all satellites;

d) corrected satellite position for all satellites;

e) ionospheric propagation delay effects;

f) user position integrity;

g) time transfer to UTC; and

h) service level status.

Note.— Structure and contents of data are specified in Appendix B, 3.5.3 and 3.5.4, respectively.

3.7.3.5 Ground-based augmentation system (GBAS) and ground-based regional augmentation system (GRAS)

Note .— Except where specifically annotated, GBAS Standards and Recommended Practices apply to GBAS and GRAS.

3.7.3.5.1 *Performance*. GBAS combined with one or more of the other GNSS elements and a fault-free GNSS receiver shall meet the requirements for system accuracy, continuity, availability and integrity for the intended operation as stated in 3.7.2.4 within the service volume for the service used to support the operation as defined in 3.7.3.5.3.

Note.— GBAS is intended to support all types of approach, landing, guided take-off, departure and surface operations and may support en-route and terminal operations. GRAS is intended to support en-route, terminal, non-precision approach, departure, and approach with vertical guidance. The following SARPs are developed to support all Categories precision approach, approach with vertical guidance, and a GBAS positioning service.

3.7.3.5.2 *Functions*. GBAS shall perform the following functions:

a) provide locally relevant pseudo-range corrections;

b) provide GBAS-related data;

c) provide final approach segment data when supporting precision approach;

d) provide predicted ranging source availability data; and

e) provide integrity monitoring for GNSS ranging sources.

3.7.3.5.3 Service Volume

3.7.3.5.3.1 *General requirement for approach services.* The minimum GBAS approach service volume shall be as follows, except where topographical features dictate and operational requirements permit:

a) laterally, beginning at 140 m (450 ft) each side of the landing threshold point/fictitious threshold point (LTP/FTP) and projecting out ±35 degrees either side of the final approach path to 28 km (15 NM) and ±10 degrees either side of the final approach path to 37 km (20 NM); and

b) vertically, within the lateral region, up to the greater of 7 degrees or 1.75 promulgated glide path angle (GPA) above the horizontal with an origin at the glide path interception point (GPIP) to an upper bound of 3 000 m (10 000 ft) height above threshold (HAT) and 0.45 GPA above the horizontal or to such lower angle, down to 0.30 GPA, as required, to safeguard the promulgated glide path intercept procedure. The lower bound is half the lowest decision height supported or 3 ,.7 m (12 ft), whichever is larger.

Note 1.— LTP/FTP and GPIP are defined in Appendix B, 3.6.4.5.1.

3.7.3.5.3.1.1 Reserved.

3.7.3.5.3.1.2 Reserved.

Note 2.— Guidance material concerning the approach service volume is provided in Attachment D, 7.3.

3.7.3.5.3.2 *Approach services supporting auto land and guided take-off.* The minimum additional GBAS service volume to support approach operations that include automatic landing and rollout, including during guided take-off, shall be as follows, except where operational requirements permit:

a) Horizontally within a sector spanning the width of the runway beginning at the stop end of the runway and extending parallel with the runway centre line towards the LTP to join the minimum service volume as described in 3.7.3.5.3.1.

b) Vertically, between two horizontal surfaces one at 3.7 m (12 ft) and the other at 30 m (100 ft) above the runway centreline to join the minimum service volume as described in 3.7.3.5.3.1.

Note.— Guidance material concerning the approach service volume is provided in Attachment D, 7.3.

3.7.3.5.3.3 *GBAS positioning service.* The *service volume for the* GBAS positioning service shall be where the data broadcast can be received and the positioning service meets the requirements of 3.7.2.4 and supports the corresponding approved operations.

Note. Guidance material concerning the positioning service volume is provided in Attachment D, 7.3.

3.7.3.5.4 Data broadcast characteristics

Note.— RF characteristics are specified in Appendix B, 3.6.2.

3.7.3.5.4.1 *Carrier frequency*. The data broadcast radio frequencies used shall be selected from the radio frequencies in the band 108 to 117.975 MHz. The lowest assignable frequency shall be 108.025 MHz and the highest assignable frequency shall be 117.950 MHz. The separation between assignable frequencies (channel spacing) shall be 25 kHz.

Note 1.— Guidance material on VOR/GBAS frequency assignments and geographical separation criteria is given in Attachment D, 7.2.1.

Note 2.— ILS/GBAS geographical separation criteria and geographical separation criteria for GBAS and VHF communication services operating in the 118 – 137 MHz band are under development. Until these criteria are defined and included in SARPs, it is intended that frequencies in the band 112.050 – 117.900 MHz will be used.

3.7.3.5.4.2 *Access technique*. A time division multiple access (TDMA) technique shall be used with a fixed frame structure. The data broadcast shall be assigned one to eight slots.

Note.— Two slots is the nominal assignment. Some GBAS facilities that use multiple VHF data broadcast (VDB) transmit antennas to improve VDB coverage may require assignment of more than two time slots. Guidance on the use of multiple antennas is given in Attachment D, 7.12.4; some GBAS broadcast stations in a GRAS may use one time slot.

3.7.3.5.4.3 *Modulation*. GBAS data shall be transmitted as 3-bit symbols, modulating the data broadcast carrier by D8PSK, at a rate of 10 500 symbols per second.

3.7.3.5.4.4 Data broadcast RF field strength and polarization

Note 1.— GBAS can provide a VHF data broadcast with either horizontal (GBAS/H) or elliptical (GBAS/E) polarization that employs both horizontal polarization (HPOL) and vertical polarization (VPOL) components. Aircraft using a VPOL component will not be able to conduct operations with GBAS/H equipment. Relevant guidance material is provided in Attachment D, 7.1.

Note 2.— The minimum and maximum field strengths are consistent with a minimum distance of 80 m (263 ft) from the transmitter antenna for a range of 43 km (23 NM).

Note 3.— When supporting approach services at airports with challenging VDB transmitter siting constraints, it is acceptable to adjust the service volume when operational requirements permit (as stated in the service volume definition sections 3.7.3.5.3.1 and 3.7.3.5.3.2). Such adjustments of the service volume may be operationally acceptable when they have no impact on the GBAS service outside a radius of 80 m from the VDB antenna, assuming a nominal effective isotropic radiated power of 47dBm (Attachment D, Table D-3).

3.7.3.5.4.4.1 GBAS/H

3.7.3.5.4.4.1.1 A horizontally polarized signal shall be broadcast.

3.7.3.5.4.4.1.2 The effective isotropically radiated power (EIRP) shall provide for a horizontally polarized signal with a minimum field strength of 215 microvolts per metre (-99 dBW/m_2) and a maximum field strength of 0.879 volts per metre (–27 dBW/m_2) within the GBAS service volume as specified in 3.7.3.5.3.1. The field strength shall be measured as an average over the period of the synchronization and ambiguity resolution field of the burst. Within the additional GBAS service volume as specified in 3.7.3.5.3.2, the effective isotropic radiated power (EIRP) shall provide for a horizontally polarized signal with a minimum field strength of 215 microvolts per metre (–99 dBW/m_2) below 36 ft and down to 12 ft above the runway surface and 650 microvolts per metre (–89.5 dBW/m_2) at 36 ft or more above the runway surface.

Note.— Guidance material concerning the approach service volume is provided in Attachment D, 7.3.

3.7.3.5.4.4.2 *GBAS/E*

3.7.3.5.4.4.2.1 **Reserved**

3.7.3.5.4.4.2.2 When an elliptically polarized signal is broadcast, the horizontally polarized component shall meet the requirements in 3.7.3.5.4.4.1.2, and the effective isotropically radiated power (EIRP) shall provide for a vertically polarized signal with a minimum field strength of 136 microvolts per metre (–103 dBW/m^2) and a maximum field strength of 0.555 volts per metre (–31 dBW/m^2) within the GBAS service volume. The field strength shall be measured as an average over the period of the synchronization and ambiguity resolution field of the burst.

3.7.3.5.4.5 *Power transmitted in adjacent channel*s. The amount of power during transmission under all operating conditions when measured over a 25 kHz bandwidth centred on the i^{th} adjacent channel shall not exceed the values shown in Table 3.7.3.5-1 (located at the end of section 3.7).

3.7.3.5.4.6 *Unwanted emissions.* Unwanted emissions, including spurious and out-of-band emissions, shall be compliant with the levels shown in Table 3.7.3.5-2 (located at the end of section 3.7). The total power in any VDB harmonic or discrete signal shall not be greater than –53 dBm.

3.7.3.5.5 *Navigation information*. The navigation data transmitted by GBAS shall include the following information:

a) pseudo-range corrections, reference time and integrity data;

b) GBAS-related data;

c) final approach segment data when supporting precision approach; and

d) predicted ranging source availability data.

Note.— Structure and contents of data are specified in Appendix B, 3.6.3.

3.7.3.6 Aircraft GNSS receiver

3.7.3.6.1 The aircraft GNSS receiver shall process the signals of those GNSS elements that it intends to use as specified in Appendix B, 3.1 (for GPS), Appendix B, 3.5 (for SBAS) and Appendix B, 3.6 (for GBAS and GRAS).

3.7.4 Resistance to interference

3.7.4.1 GNSS shall comply with performance requirements defined in 3.7.2.4 and Appendix B, 3.7 in the presence of the interference environment defined in Appendix B, 3.7.

Note.— GPS operating in the frequency band 1 559 – 1 610 MHz are classified by the ITU as providing a radio navigation satellite service (RNSS) and aeronautical radio navigation service (ARNS) and are afforded special spectrum protection status for RNSS. In order to achieve the performance objectives for precision approach guidance to be supported by the GNSS and its augmentations, RNSS/ARNS is intended to remain the only global allocation in the 1 559 – 1 610 MHz band and emissions from systems in this and adjacent frequency bands are intended to be tightly controlled by national and/or international regulation.

3.7.5 Database

Note.— SARPs applicable to aeronautical data are provided in Annex 4, CAR 11, Annex 14 and CAR 15.

3.7.5.1 Aircraft GNSS equipment that uses a database shall provide a means to:

a) update the electronic navigation database; and

b) determine the Aeronautical Information Regulation and Control (AIRAC) effective dates of the aeronautical database.

Note.— Guidance material on the need for a current navigation database in aircraft GNSS equipment is provided in Attachment D, 11.

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Table 3.7.2.4-1 Signal-in-space performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1 - 2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

NOTES.—

1. The 95th percentile values for GNSS position errors are those required for the intended operation at the lowest height above threshold (HAT), if applicable. Detailed requirements are specified in Appendix B and guidance material is given in Attachment D, 3.2.
2. The definition of the integrity requirement includes an alert limit against which the requirement can be assessed. For Category I precision approach, a vertical alert limit (VAL) greater than 10 m for a specific system design may only be used if a system-specific safety analysis has been completed. Further guidance on the alert limits is provided in Attachment D, 3.3.6 to 3.3.10. These alert limits are:

Typical operation	Horizontal alert limit	Vertical alert limit
En-route (oceanic/continental low density)	7.4 km (4 NM)	N/A
En-route (continental)	3.7 km (2 NM)	N/A
En-route, Terminal	1.85 km (1 NM)	N/A
NPA	556 m (0.3 NM)	N/A
APV-I	40 m (130 ft)	50 m (164 ft)
APV- II	40 m (130 ft)	20.0 m (66 ft)
Category I precision approach	40 m (130 ft)	35.0 m to 10.0 m (115 ft to 33 ft)

3. The accuracy and time-to-alert requirements include the nominal performance of a fault-free receiver.
4. Ranges of values are given for the continuity requirement for en-route, terminal, initial approach, NPA and departure operations, as this requirement is dependent upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigation aids. The lower value given is the minimum requirement for areas with low traffic density and airspace complexity. The higher value given is appropriate for areas with high traffic density and airspace complexity (see Attachment D, 3.4.2). Continuity requirements for APV and Category I operations apply to the average risk (over time) of loss of service, normalized to a 15-second exposure time (see Attachment D, 3.4.3).

5. A range of values is given for the availability requirements as these requirements are dependent upon the operational need which is based upon several factors including the frequency of operations, weather environments, the size and duration of the outages, availability of alternate navigation aids, radar coverage, traffic density and reversionary operational procedures. The lower values given are the minimum availabilities for which a system is considered to be practical but are not adequate to replace non-GNSS navigation aids. For en-route navigation, the higher values given are adequate for GNSS to be the only navigation aid provided in an area. For approach and departure, the higher values given are based upon the availability requirements at airports with a large amount of traffic assuming that operations to or from multiple runways are affected but reversionary operational procedures ensure the safety of the operation (see Attachment D, 3.5).
6. A range of values is specified for Category I precision approach. The 4.0 m (13 feet) requirement is based upon ILS specifications and represents a conservative derivation from these specifications (see Attachment D, 3.2.7).
7. GNSS performance requirements intended to support Category II and III precision approach operations necessitate lower level requirements in the technical appendix (Appendix B section 3.6) to be applied in addition to these signal in space requirements(See Attachment D, 7.5.1)
8. The terms APV-I and APV-II refer to two levels of GNSS approach and landing operations with vertical guidance (APV) and these terms are not necessarily intended to be used operationally.

Table 3.7.3.5-1. GBAS broadcast power transmitted in adjacent channels

Channel	Relative power	Maximum power
1st adjacent	–40 dBc	12 dBm
2nd adjacent	–65 dBc	–13 dBm
4th adjacent	–74 dBc	–22 dBm
8th adjacent	–88.5 dBc	–36.5 dBm
16th adjacent	–101.5 dBc	–49.5 dBm
32nd adjacent	–105 dBc	–53 dBm
64th adjacent	–113 dBc	–61 dBm
76th adjacent and beyond	–115 dBc	–63 dBm

NOTES.—

1. The maximum power applies if the authorized transmitter power exceeds 150 W.
2. The relationship is linear between single adjacent points designated by the adjacent channels identified above.

Table 3.7.3.5-2. GBAS broadcast unwanted emissions

Frequency	Relative unwanted emission level (Note 2)	Maximum unwanted emission level (Note 1)
9 kHz to 150 kHz	–93 dBc (Note 3)	–55 dBm/1 kHz (Note 3)
150 kHz to 30 MHz	–103 dBc (Note 3)	–55 dBm/10 kHz (Note 3)
30 MHz to 106.125 MHz	–115 dBc	–57 dBm/100 kHz
106.425 MHz	–113 dBc	–55 dBm/100 kHz
107.225 MHz	–105 dBc	–47 dBm/100 kHz
107.625 MHz	–101.5 dBc	–53.5 dBm/10 kHz
107.825 MHz	–88.5 dBc	–40.5 dBm/10 kHz
107.925 MHz	–74 dBc	–36 dBm/1 kHz
107.9625 MHz	–71 dBc	–33 dBm/1 kHz
107.975 MHz	–65 dBc	–27 dBm/1 kHz
118.000 MHz	–65 dBc	–27 dBm/1 kHz
118.0125 MHz	–71 dBc	–33 dBm/1 kHz
118.050 MHz	–74 dBc	–36 dBm/1 kHz
118.150 MHz	–88.5 dBc	–40.5 dBm/10 kHz
118.350 MHz	–101.5 dBc	–53.5 dBm/10 kHz
118.750 MHz	–105 dBc	–47 dBm/100 kHz
119.550 MHz	–113 dBc	–55 dBm/100 kHz
119.850 MHz to 1 GHz	–115 dBc	–57 dBm/100 kHz
1 GHz to 1.7 GHz	–115 dBc	–47 dBm/1 MHz

NOTES.—

1. The maximum unwanted emission level (absolute power) applies if the authorized transmitter power exceeds 150 W.
2. The relative unwanted emission level is to be computed using the same bandwidth for desired and unwanted signals. This may require conversion of the measurement for unwanted signals done using the bandwidth indicated in the maximum unwanted emission level column of this table.
3. This value is driven by measurement limitations. Actual performance is expected to be better.
4. The relationship is linear between single adjacent points designated by the adjacent channels identified above.

3.8 Reserved

3.9 System characteristics of airborne ADF receiving systems

3.9.1 Accuracy of bearing indication

3.9.1.1 The bearing given by the ADF system shall not be in error by more than plus or minus 5 degrees with a radio signal from any direction having a field strength of 70 microvolts per meter or more radiated from an LF/MF NDB or locator operating within the tolerances permitted by this CAR and in the presence also of an unwanted signal from a direction 90 degrees from the wanted signal and:

a) on the same frequency and 15 dB weaker; or

b) plus or minus 2 kHz away and 4 dB weaker; or

c) plus or minus 6 kHz or more away and 55 dB stronger.

Note.— The above bearing error is exclusive of aircraft magnetic compass error.

3.10 Reserved

3.11 Reserved

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APPENDIX A. Reserved

APPENDIX B. TECHNICAL SPECIFICATIONS FOR THE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

1. DEFINITIONS

GBAS/E. A ground-based augmentation system transmitting an elliptically-polarized VHF data broadcast.

GBAS/H. A ground-based augmentation system transmitting a horizontally-polarized VHF data broadcast.

Receiver. A subsystem that receives GNSS signals and includes one or more sensors.

Reserved (bits/words/fields). Bits/words/fields that are not allocated, but which are reserved for a particular GNSS application.

Spare (bits/words/fields). Bits/words/fields that are not allocated or reserved, and which are available for future allocation.

Note.— All spare bits are set to zero.

2. GENERAL

Note.— The following technical specifications supplement the provisions of Chapter 3, 3.7.

3. GNSS ELEMENTS

3.1 Global Positioning System (GPS) Standard Positioning Service (SPS) (L1)

3.1.1 NON-AIRCRAFT ELEMENTS

3.1.1.1 *RADIO FREQUENCY (RF) CHARACTERISTICS*

3.1.1.1.1 *Carrier phase noise*. The carrier phase noise spectral density of the unmodulated carrier shall be such that a phase locked loop of 10 Hz one-sided noise bandwidth is able to track the carrier to an accuracy of 0.1 radian (1 sigma).

3.1.1.1.2 *Spurious emissions.* In-band spurious emissions shall be at least 40 dB below the unmodulated L1 carrier over the allocated channel bandwidth.

3.1.1.1.3 *Correlation loss.* The loss in the recovered signal power due to imperfections in the signal modulation and waveform distortion shall not exceed 1 dB.

Note.— The loss in signal power is the difference between the broadcast power in a 2.046 MHz bandwidth and the signal power recovered by a noise-free, loss-free receiver with 1-chip correlator spacing and a 2.046 MHz bandwidth.

3.1.1.1.4 *Coarse/acquisition (C/A) code generation and timing.* Each C/A code pattern $G_i(t)$ shall be formed by the Modulo-2 sum of two 1 023-bit linear patterns, G1 and $G2_i$. The $G2_i$ sequence shall be formed by effectively delaying the G2 sequence by an integer number of chips to produce one of 36 unique $G_i(t)$ patterns defined in Table B-1. The G1 and G2 sequences shall be generated by 10-stage shift registers having the following polynomials as referred to in the shift register input:

a) G1: $X^{10} + X^3 + 1$; and

b) G2: $X^{10} + X^9 + X^8 + X^6 + X^3 + X^2 + 1$.

The initialization vector for the G1 and G2 sequences shall be "1111111111". The code phase assignments shall be as shown in Table B-1. The G1 and G2 registers shall be clocked at a 1.023 MHz rate. Timing relationships related to the C/A code shall be as shown in Figure B-1.[*]

3.1.1.2 *Data structure.* The navigation message shall be formatted as shown in Figure B-2. Each page, as shown in Figure B-6, shall utilize a basic format of a 1 500-bit-long frame with up to 5 subframes, each of 300 bits in length. All words shall be transmitted most significant bit (MSB) first.

3.1.1.2.1 *Subframe structure.* Each subframe and/or page of a subframe shall start with a telemetry (TLM) word followed by a handover word (HOW). The HOW shall be followed by 8 data words. Each word in each frame shall contain 6 parity bits. The TLM word and HOW formats shall be as shown in Figures B-3 and B-4, respectively.

3.1.1.2.2 *End/start of week.* At the end/start of week:

a) the cyclic paging of subframes 1 through 5 shall restart with subframe 1 regardless of which subframe was last transmitted prior to the end/start of week; and

b) the cycling of 25 pages of subframes 4 and 5 shall restart with page 1 of each of the subframes, regardless of which page was transmitted prior to the end/start of week. All upload and page cutovers shall occur on frame boundaries (i.e. Modulo 30 seconds relative to the end/start of week).

Note.— New data in subframes 4 and 5 may start to be transmitted with any of the 25 pages of these subframes.

3.1.1.2.3 *Data parity.* Words 1 through 10 of subframes 1 through 5 shall each contain 6 parity bits as their least significant bits (LSBs). In addition, two non-information bearing bits shall be provided as bits 23 and 24 of words 2 and 10 for parity computation purposes.

3.1.1.2.4 *Telemetry (TLM) word.* Each TLM word shall be 30 bits long, occur every 6 seconds in the data frame and be the first word in each subframe. The TLM format shall be as shown in Figure B-3. Each TLM word shall begin with a preamble, followed by 16 reserved bits and 6 parity bits.

3.1.1.2.5 *Handover word (HOW).* The HOW shall be 30 bits long and shall be the second word in each subframe/page, immediately following the TLM word. A HOW shall occur every 6 seconds in the data frame. The HOW format and content shall be as shown in Figure B-4. The full time-of-week (TOW) count shall consist of the 19 LSBs of the 29-bit Z-count (3.1.1.2.6). The HOW shall begin with the 17 MSBs of the TOW count. These 17 bits shall correspond to the TOW count at the 1.5-second epoch that occurs at the start (leading edge) of the next following subframe.

3.1.1.2.5.1 *Bit 18*. On satellites designed by configuration code 001, bit 18 shall be an “alert” flag. When this flag is raised (bit 18 is a “1”), it shall indicate to the user that the satellite user range accuracy (URA) may be worse than indicated in subframe 1 and that use of the satellite is at the user’s risk.

* All figures are located at the end of the appendix.

Table B-1. Code phase assignments

Satellite ID number	GPS PRN signal	G2 delay (chips)	First 10 chips octal*
1	1	5	1440
2	2	6	1620
3	3	7	1710
4	4	8	1744
5	5	17	1133
6	6	18	1455
7	7	139	1131
8	8	140	1454
9	9	141	1626
10	10	251	1504
11	11	252	1642
12	12	254	1750
13	13	255	1764
14	14	256	1772
15	15	257	1775
16	16	258	1776
17	17	469	1156
18	18	470	1467
19	19	471	1633
20	20	472	1715
21	21	473	1746
22	22	474	1763
23	23	509	1063
24	24	512	1706
25	25	513	1743
26	26	514	1761
27	27	515	1770
28	28	516	1774
29	29	859	1127
30	30	860	1453
31	31	861	1625
32	32	862	1712
***	33	863	1745
***	34**	950	1713
***	35	947	1134
***	36	948	1456
***	37**	950	1713

* In the octal notation for the first 10 chips of the C/A code as shown in this column, the first digit represents a "1" for the first chip and the last three digits are the conventional octal representation of the remaining 9 chips (e.g. the first 10 chips of the C/A code for pseudo-random noise (PRN) signal assembly 1 are: 1100100000).

** C/A codes 34 and 37 are common.

*** PRN signal assemblies 33 through 37 are reserved for other uses (e.g. ground transmitters).

3.1.1.2.5.2 *Bit 19.* Bit 19 shall be reserved.

3.1.1.2.5.3 *Bits 20, 21 and 22*. Bits 20, 21 and 22 of the HOW shall provide the identification (ID) of the subframe in which that particular HOW is the second word. The ID code shall be as defined below:

ID	Code
1	001
2	010
3	011
4	100
5	101

3.1.1.2.6 *Satellite Z-count.* Each satellite shall internally derive a 1.5-second epoch that shall contain a convenient unit for precisely counting and communicating time. Time stated in this manner shall be referred to as a Z-count. The Z-count shall be provided to the user as a 29-bit binary number consisting of two parts as follows.

3.1.1.2.6.1 *Time-of-week (TOW) count.* The binary number represented by the 19 LSBs of the Z-count shall be referred to as the TOW count and is defined as being equal to the number of 1.5-second epochs that have occurred since the transition from the previous week. The count shall be short-cycled such that the range of the TOW count is from 0 to 403 199 1.5-second epochs (equalling one week) and shall be reset to zero at the end of each week. The TOW count's zero state shall be the 1.5-second epoch that is coincident with the start of the present week. A truncated version of the TOW count, consisting of its 17 MSBs, shall be contained in the HOW of the L1 downlink data stream. The relationship between the actual TOW count and its truncated HOW version shall be as indicated in Figure B-5.

Note.— The above-mentioned epoch occurs at (approximately) midnight Saturday night/Sunday morning, where midnight is defined as 0000 hours on the UTC scale which is nominally referenced to the Greenwich Meridian.

3.1.1.2.6.2 *Week count*. The 10 MSBs of the Z-count shall be a binary representation of the sequential number assigned to the present GPS week (Modulo 1024). The range of this count shall be from 0 to 1 023. Its zero state shall be that week which starts with the 1.5-second epoch occurring at (approximately) the UTC zero time point (3.1.4). At the expiration of GPS week number 1 023, the GPS week number shall roll over to zero. The previous 1 024 weeks in conversions from GPS time to a calendar date shall be accounted for by the user.

3.1.1.3 *DATA CONTENT*

3.1.1.3.1 *Subframe 1 — satellite clock and health data*. The content of words 3 through 10 of subframe 1 shall contain the clock parameters and other data as indicated in Table B-2. The parameters in a data set shall be valid during the interval of time in which they are transmitted and shall remain valid for an additional period of time after transmission of the next data set has started.

3.1.1.3.1.1 *Week number.* The 10 MSBs of word 3 shall contain the 10 MSBs of the 29-bit Z-count and shall represent the number of the current GPS week at the start of the data set transmission interval with all zeros indicating week "zero." The GPS week number shall increment at each end/start of week epoch.

3.1.1.3.1.2 *User range accuracy (URA).* Bits 13 through 16 of word 3 shall provide the predicted satellite URA as shown in Table B-3.

Note 1.— The URA does not include error estimates due to inaccuracies of the single-frequency ionospheric delay model.

Note 2.— The URA is a statistical indicator of the contribution of the apparent clock and ephemeris prediction accuracies to the ranging accuracies obtainable with a specific satellite based on historical data.

Table B-2. Subframe 1 parameters

Parameter	Number of bits**	Scale factor (LSB)	Effective range***	Units
Week number	10	1		weeks
Satellite accuracy	4			
Satellite health	6	1		discretes
T_{GD}	8*	2^{-31}		seconds
IODC	10			
t_{oc}	16	2^4	604 784	seconds
a_{f2}	8*	2^{-55}		seconds/second^2
a_{f1}	16*	2^{-43}		seconds/second
a_{f0}	22*	2^{-31}		seconds

* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.
** See Figure B-6 for complete bit allocation.
*** Unless otherwise indicated in this column, effective range is the maximum range.

Table B-3. User range accuracy

URA	Accuracy
0	2 m
1	2.8 m
2	4 m
3	5.7 m
4	8 m
5	11.3 m
6	16 m
7	32 m
8	64 m
9	128 m
10	256 m
11	512 m

12	1 024 m
13	2 048 m
14	4 096 m
15	Do not use

3.1.1.3.1.3 *Health.* The transmitting satellite 6-bit health indication shall be provided by bits 17 through 22 of word 3. The MSB shall indicate a summary of the health of the navigation data, where:

a) 0 = all navigation data are valid; and

b) 1 = some of the navigation data are not valid.

The 5 LSBs shall indicate the health of the signal components in accordance with 3.1.1.3.3.4. The health indication shall be provided relative to the capabilities of each satellite as designated by the configuration code in 3.1.1.3.3.5. Any satellite that does not have a certain capability shall be indicated as "healthy" if the lack of this capability is inherent in its design or it has been configured into a mode which is normal from a receiver standpoint and does not require that capability. Additional health data shall be given in subframes 4 and 5.

Note.— The data given in subframe 1 may differ from that shown in subframes 4 and/or 5 of other satellites since the latter may be updated at a different time.

3.1.1.3.1.4 *Issue of data, clock (IODC).* Bits 23 and 24 of word 3 in subframe 1 shall be the 2 MSBs of the 10-bit IODC term. Bits 1 through 8 of word 8 in subframe 1 shall contain the 8 LSBs of the IODC. The IODC shall indicate the issue number of data set. The transmitted IODC shall be different from any value transmitted by the satellite during the preceding 7 days.

Note.— The relationship between the IODC and the Issue of Data, Ephemeris (IODE) terms is defined in 3.1.1.3.2.2.

3.1.1.3.1.5 *Estimated group delay differential.* Bits 17 through 24 of word 7 shall contain the correction term, T_{GD}, to account for the effect of satellite group delay differential.

Note.— T_{GD} *does not include any C/A to P(Y) code relative group delay error.*

3.1.1.3.1.6 *Satellite clock correction parameters.* Bits 9 through 24 of word 8, bits 1 through 24 of word 9, and bits 1 through 22 of word 10 shall contain the parameters needed by the users for apparent satellite clock correction (t_{oc}, $a_{f2,}$ a_{f1} and a_{f0}).

3.1.1.3.1.7 *Reserved data fields*. Reserved data fields shall be as indicated in Table B-4. All reserved data fields shall support valid parity within their respective words.

3.1.1.3.2 *Subframes 2 and 3 — satellite ephemeris data.* Subframes 2 and 3 shall contain the ephemeris representation of the transmitting satellite.

3.1.1.3.2.1 *Ephemeris parameters.* The ephemeris parameters shall be as indicated in Table B-5. For each parameter in subframe 2 and 3, the number of bits, the scale factor of the LSB, the range, and the units shall be as specified in Table B-6.

3.1.1.3.2.2 *Issue of data, ephemeris (IODE).* The IODE shall be an 8-bit number equal to the 8 LSBs of the 10-bit IODC of the same data set. The IODE shall be provided in both subframes 2 and 3 for the purpose of comparison with the 8 LSBs of the IODC term in subframe 1. Whenever these three terms do not match, as a result of a data set cutover, new data shall be collected. The transmitted IODE shall be different from any value transmitted by the satellite during the preceding six hours (*Note 1*). Any change in the subframe 2 and 3 data shall be accomplished in concert with a change in both IODE words.

Change to new data sets shall occur only on hour boundaries except for the first data set of a new upload. Additionally, the t_{oe} value, for at least the first data set transmitted by a satellite after an upload, shall be different from that transmitted prior to the change (*Note 2*).

Table B-4. Subframe 1 reserved data fields

Word	Bit
3	11 – 12
4	1 – 24
5	1 – 24
6	1 – 24
7	1 – 16

Table B-5. Ephemeris data

M_0 Mean anomaly at reference time
Δn Mean motion difference from computed value e
Eccentricity
$\sqrt{A}$ Square root of the semi-major axis
$OMEGA_0$ Longitude of ascending node of orbit plane at weekly
epoch i_0 Inclination angle at reference time
ω Argument of perigee
OMEGADOT Rate of right ascension
iDOT Rate of inclination angle
C_{uc} Amplitude of the cosine harmonic correction term to the argument of latitude
C_{us} Amplitude of the sine harmonic correction term to the argument of latitude
C_{rc} Amplitude of the cosine harmonic correction term to the orbit radius
C_{rs} Amplitude of the sine harmonic correction term to the orbit radius
C_{ic} Amplitude of the cosine harmonic correction term to the angle of inclination
C_{is} Amplitude of the sine harmonic correction term to the angle of
inclination t_{oe} Reference time, ephemeris IODE Issue of data, ephemeris

Table B-6. Ephemeris parameters

Parameter	Number of bits**	Scale factor (LSB)	Effective range***	Units
IODE	8			
C_{rs}	16*	2_{-5}		metres
Δn	16*	2_{-43}		semi-circles/second
M_0	32*	2_{-31}		semi-circles
C_{uc}	16*	2_{-29}		radians
e	32	2_{-33}	0.03	dimensionless
$C_{\underline{us}}$	16*	2_{-29}		radians
$\sqrt{A}$	32	2_{-19}		$metres^{1/2}$
t_{oe}	16	2^4	604 784	seconds

C_{ic}	16*	2^{-29}	radians
$OMEGA_0$	32*	2^{-31}	semi-circles
C_{is}	16*	2^{-29}	radians
i_0	32*	2^{-31}	semi-circles
C_{rc}	16*	2^{-5}	metres
ω	32*	2^{-31}	semi-circles
OMEGADOT	24*	2^{-43}	semi-circles/second
iDOT	14*	2^{-43}	semi-circles/second

* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.

** See Figure B-6 for complete bit allocation in subframe.

*** Unless otherwise indicated in this column, effective range is the maximum range attainable with the indicated bit allocation and scale factor.

Note 1.— The IODE/IODC terms provide the receiver with a means for detecting any changes in the ephemeris/clock representation parameters.

Note 2.— The first data set may change (3.1.1.2.2) at any time during the hour and therefore may be transmitted by the satellite for less than 1 hour.

3.1.1.3.2.3 *Reserved data fields.* Within word 10, subframe 2, bits 17 through 22 shall be reserved. Reserved data fields shall support the valid parity within their respective words.

3.1.1.3.3 *Subframes 4 and 5 — support data.* Both subframes 4 and 5 shall be subcommutated 25 times each. With the possible exception of "reserved" pages and explicit repeats, each page shall contain different data in words 3 through 10. The pages of subframe 4 shall use 6 different formats, and the pages of subframe 5 shall use two different formats as indicated in Figure B-6.

Pages of subframe 4 shall be as follows:

a) Pages 2, 3, 4, 5, 7, 8, 9 and 10: almanac data for satellites 25 through 32 respectively. If the 6-bit health status word of page 25 is set to 6 "ones" (3.1.1.3.3.4) then the satellite ID of the page shall not have a value in the range of 25 through 32;

Note.— These pages may be designed for other functions. The format and content for each page is defined by the satellite ID of that page.

b) Page 17: special messages;

c) Page 18: ionospheric and UTC data;

d) Page 25: satellite configurations for 32 satellites; and

e) Pages 1, 6, 11, 12, 13, 14, 15, 16, 19, 20, 21, 22, 23 and 24: reserved.

Pages of subframe 5 shall be as follows:

a) Pages 1 through 24: almanac data for satellite 1 through 24; and

b) Page 25: satellite health data for satellite 1 through 24, the almanac reference time and the almanac reference week number.

3.1.1.3.3.1 *Data ID.* The two MSBs of word 3 in each page shall contain the data ID that defines the applicable GPS navigation data structure. The data ID shall be as indicated in Table B-7 in accordance with the following:

a) for those pages which are assigned to contain the almanac data of one specific satellite, the data ID shall define the data structure utilized by that satellite whose almanac data are contained in that page;

b) for all other pages, the data ID shall denote the data structure of the transmitting satellite; and

c) data ID "1" (denoted by binary state 00) shall not be used.

3.1.1.3.3.2 *Satellite ID.* The satellite ID shall be provided by bits 3 through 8 of word 3 in each page. The satellite IDs shall be utilized two ways:

a) for those pages which contain the almanac data of a given satellite, the satellite ID shall be the same number that is assigned the PRN code phase of that satellite in accordance with Table B-1; and

b) for all other pages the satellite ID assigned in accordance with Table B-7 shall serve as the "page ID". IDs 1 through 32 shall be assigned to those pages which contain the almanac data of specific satellites (pages 1 through 24 of subframe 5 and pages 2 through 5, and 7 through 10 of subframe 4). The "0" ID (binary all zeros) shall be assigned to indicate a dummy satellite, while IDs 51 through 63 shall be utilized for pages containing other than almanac data for a specific satellite (Notes 1 and 2).

Note 1.— Specific IDs are reserved for each page of subframes 4 and 5; however, the satellite ID of pages 2, 3, 4, 5, 7, 8, 9 and 10 of subframe 4 may change for each page to reflect the alternate contents for that page.

Note 2.— The remaining IDs (33 through 50) are unassigned.

Table B-7. Data IDs and satellite IDs in subframes 4 and 5

	Subframe 4		Subframe 5	
Page	Data ID	Satellite ID*	Data ID	Satellite ID*
1	***	57	**	1
2****	**	25	**	2
3****	**	26	**	3
4****	**	27	**	4
5****	**	28	**	5
6	***	57	**	6
7****	**	29	**	7
8****	**	30	**	8
9****	**	31	**	9
10****	**	32	**	10
11	***	57	**	11
12	***	62	**	12
13	***	52	**	13
14	***	53	**	14
15	***	54	**	15
16	***	57	**	16
17	***	55	**	17

18	***	56	**	18
19	***	58*****	**	19
20	***	59*****	**	20
21	***	57	**	21
22	***	60*****	**	22
23	***	61*****	**	23
24	***	62	**	24
25	***	63	***	51

* “0” indicates “dummy” satellite. When using “0” to indicate a dummy satellite, the data ID of the transmitting satellite is used.

** Data ID of that satellite whose satellite ID appears in that page.

*** Data ID of transmitting satellite.

**** Pages 2, 3, 4, 5, 7, 8, 9 and 10 of subframe 4 may contain almanac data for satellites 25 through 32, respectively, or data for other functions as identified by a different satellite ID from the value shown.

***** Satellite ID may vary.

3.1.1.3.3.3 *Almanac.* Pages 1 through 24 of subframe 5, as well as pages 2 through 5 and 7 through 10 of subframe 4 shall contain the almanac data and a satellite health status word (3.1.1.3.3.4) for up to 32 satellites. The almanac data shall be a reduced-precision subset of the clock and ephemeris parameters. The data shall occupy all bits of words 3 through 10 of each page except the 8 MSBs of word 3 (data ID and satellite ID), bits 17 through 24 of word 5 (satellite health), and the 50 bits devoted to parity. The number of bits, the scale factor (LSB), the range and the units of the almanac parameters shall be as indicated in Table B-8. The almanac message for any dummy satellite shall contain alternating “ones” and “zeros” with a valid parity.

3.1.1.3.3.3.1 *Almanac reference time.* The almanac reference time, t_{oa}, shall be a multiple of 2^{12} seconds occurring approximately 70 hours after the first valid transmission time for this almanac data set. The almanac shall be updated often enough to ensure that GPS time, t, will differ from t_{oa} by less than 3.5 days during the transmission period. The almanac parameters shall be updated at least once every 6 days during normal operations.

3.1.1.3.3.3.2 *Almanac time parameters.* The almanac time parameters shall consist of an 11-bit constant term (a_{f0}) and an 11-bit first order term (a_{f1}).

3.1.1.3.3.3.3 *Almanac reference week.* Bits 17 through 24 of word 3 in page 25 of subframe 5 shall indicate the number of the week (WN_a) to which the almanac reference time (t_{oa}) is referenced. The WN_a term shall consist of the 8 LSBs of the full week number. Bits 9 through 16 of word 3 in page 25 of subframe 5 shall contain the value of t_{oa} that is referenced to this WN_a.

3.1.1.3.3.4 *Health summary.* Subframes 4 and 5 shall contain two types of satellite health data:

a) each of the 32 pages that contain the clock/ephemeris related almanac data shall provide an 8-bit satellite health status word regarding the satellite whose almanac data they carry; and

b) the 25th pages of subframes 4 and 5 jointly shall contain 6-bit health data for up to 32 satellites.

3.1.1.3.3.4.1 The 8-bit health status words shall occupy bits 17 through 24 of word 5 in those 32 pages that contain the almanac data for individual satellites. The 6-bit health status words shall occupy the 24 MSBs of words 4 through 9 in page 25 of subframe 5, and bits 19 through 24 of word 8, the 24 MSBs of word 9, and the 18 MSBs of word 10 in page 25 of subframe 4.

Table B-8. Almanac parameters

Parameter	Number of bits**	Scale factor (LSB)	Effective range***	Units
e	16	2_{-21}		dimensionless
t_{oa}	8	2_{12}	602 112	seconds
δi****	16*	2_{-19}		semi-circles
OMEGADOT	16*	2_{-38}		semi-circles/second
$\sqrt{A}$	24*	2_{-11}		$\text{metres}^{1/2}$
$OMEGA_0$	24*	2_{-23}		semi-circles
ω	24*	2_{-23}		semi-circles
M_0	24*	2_{-23}		semi-circles
a_{f0}	11*	2_{-20}		seconds
a_{f1}	11*	2^{-38}		seconds/second

* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.

** See Figure B-6 for complete bit allocation in subframe.

*** Unless otherwise indicated in this column, effective range is the maximum range attainable with the indicated bit allocation and scale factor.

**** Relative to i_0 = 0.30 semi-circles.

3.1.1.3.3.4.2 The 3 MSBs of the 8-bit health status words shall indicate health of the navigation data in accordance with the code given in Table B-9. The 6-bit words shall provide a 1-bit summary of the navigation data's health status in the MSB position in accordance with 3.1.1.3.1.3. The 5 LSBs of both the 8-bit and the 6-bit health status words shall provide the health status of the satellite's signal components in accordance with the code given in Table B-10.

Table B-9. Navigation data health indication

Bit position in page			
137	138	139	Indication
0	0	0	ALL DATA OK
0	0	1	PARITY FAILURE — some or all parity bad
0	1	0	TLM/HOW FORMAT PROBLEM — any departure from standard format (e.g. preamble misplaced and/or incorrect), except for incorrect Z-count, as reported in HOW
0	1	1	Z-COUNT in HOW BAD — any problem with Z-count value not reflecting actual code phase

1	0	0	SUBFRAMES 1, 2, 3 — one or more elements in words 3 through 10 of one or more subframes are bad
1	0	1	SUBFRAMES 4, 5 — one or more elements in words 3 through 10 of one or more subframes are bad
1	1	0	ALL UPLOADED DATA BAD — one or more elements in words 3 through 10 of any one (or more) subframes are bad
1	1	1	ALL DATA BAD — TLM word and/or HOW and one or more elements in any one (or more) subframes are bad

Table B-10. Codes for health of satellite signal components

MSB				LSB	Indication
0	0	0	0	0	ALL SIGNALS OK
1	1	1	0	0	SATELLITE IS TEMPORARILY OUT — do not use this satellite during current pass ___
1	1	1	0	1	SATELLITE WILL BE TEMPORARILY OUT — use with caution __
1	1	1	1	0	SPARE
1	1	1	1	1	MORE THAN ONE COMBINATION WOULD BE REQUIRED TO DESCRIBE ANOMALIES, EXCEPT THOSE MARKED BY ___
All other combinations					SATELLITE EXPERIENCING CODE MODULATION AND/OR SIGNAL POWER LEVEL TRANSMISSION PROBLEMS. The user may experience intermittent tracking problems if satellite is acquired.

3.1.1.3.3.4.3 A special meaning shall be assigned, to the 6 “ones” combination of the 6-bit health status words in the 25th pages of subframes 4 and 5; it shall indicate that “the satellite which has that ID is not available and there may be no data regarding that satellite in the page of subframe 4 or 5 that is assigned to normally contain the almanac data of that satellite”.

Note.— This special meaning applies to the 25th pages of subframes 4 and 5 only. There may be data regarding another satellite in the almanac page referred to above as defined in 3.1.1.3.3.3.

3.1.1.3.3.4.4 The health indication shall be provided relative to the capabilities of each satellite as designated by the configuration code in 3.1.1.3.3.5. Accordingly, any satellite that does not have a certain capability shall be indicated as “healthy” if the lack of this capability is inherent in its design or it has been configured into a mode which is normal from a receiver standpoint and does not require that capability. The predicted health data shall be updated at the time of upload.

Note 1.— The transmitted health data may not correspond to the actual health of the transmitting satellite or other satellites in the constellation.

Note 2.— The data given in subframes 1, 4 and 5 of the other satellites may differ from that shown in subframes 4 and/or 5 since the latter may be updated at a different time.

3.1.1.3.3.5 *Satellite configuration summary.* Page 25 of subframe 4 shall contain a 4-bit-long term for each of up to 32 satellites to indicate the configuration code of each satellite. These 4-bit terms shall occupy bits 9 through 24 of words 3, the 24 MSBs of words 4 through 7, and the 16 MSBs of word 8, all in page 25 of subframe 4. The MSB of each 4-bit term shall indicate whether anti-spoofing is activated (MSB = 1) or not activated (MSB = 0). The 3 LSBs shall indicate the configuration of each satellite using the following code:

Code	Satellite configuration
001	Block II/IIA/IIR satellite
010	Block IIR-M satellite
011	Block IIF satellite

3.1.1.3.3.6 *UTC parameters.* Page 18 of subframe 4 shall include:

a) the parameters needed to relate GPS time to UTC time; and

b) notice to the user regarding the scheduled future or past (relative to navigation message upload) value of the delta time due to leap seconds (t_{LSF}), together with the week number (WN_{LSF}) and the day number (DN) at the end of which the leap second becomes effective. "Day one" shall be the first day relative to the end/start of week and the WN_{LSF} value consists of the 8 LSBs of the full week number. The absolute value of the difference between the untruncated WN and WN_{LSF} values shall not exceed 127.

Note.— The user is expected to account for the truncated nature of this parameter as well as truncation of WN, WN_t and WN_{LSF} due to rollover of the full week number (3.1.1.2.6.2).

3.1.1.3.3.6.1 The 24 MSBs of words 6 through 9, and the 8 MSBs of word 10 in page 18 of subframe 4 shall contain the parameters related to correlating UTC time with GPS time. The bit length, scale factors, ranges, and units of these parameters shall be as specified in Table B-11.

3.1.1.3.3.7 *Ionospheric parameters*. The ionospheric parameters that allow the GPS SPS user to utilize the ionospheric model for computation of the ionospheric delay shall be contained in page 18 of subframe 4 as specified in Table B-12.

3.1.1.3.3.8 *Special message.* Page 17 of subframe 4 shall be reserved for special messages.

Table B-11. UTC parameters

Parameter	Number of bits**	Scale factor (LSB)	Effective range***	Units
A_o	32*	2^{-30}		seconds
A_1	24*	2^{-50}		seconds/second
Δt_{LS}	8*	1		seconds
t_{ot}	8	2^{12}	602 112	seconds
WN_t	8	1		weeks
WN_{LSF}	8	1		weeks
DN	8****	1	7	days
Δt_{LSF}	8*	1		seconds

* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB.
** See Figure B-6 for complete bit allocation in subframe.
*** Unless otherwise indicated in this column, effective range is the maximum range attainable with the indicated bit allocation and scale factor.
**** Right justified.

Table B-12. Ionospheric parameters

Parameter	Number of bits[**]	Scale factor (LSB)	Effective range[***]	Units
α_0	8[*]	2_{-30}		seconds
α_1	8[*]	2_{-27}		seconds/semi-circle
α_2	8[*]	2_{-24}		seconds/semi-circle^2
α_3	8[*]	2_{-24}		seconds/semi-circle^3
β_0	8[*]	2_{11}		seconds
β_1	8[*]	2_{14}		seconds/semi-circle
β_2	8[*]	2_{16}		seconds/semi-circle^2
β_3	8[*]	2^{16}		seconds/semi-circle^3

* Parameters so indicated are two's complement, with the sign bit (+ or –) occupying the MSB. See
** Figure B-6 for complete bit allocation in subframe.
*** Unless otherwise indicated in this column, effective range is the maximum range attainable with the indicated bit allocation and scale factor.

3.1.1.3.3.9 *Reserved data fields.* All bits of words 3 through 10, except the 58 bits used for data ID, satellite (page) ID, parity (six LSBs of each word) and parity computation (bits 23 and 24 of word 10) of pages 1, 6, 11, 12, 13, 14, 15, 16, 19, 20, 21, 22, 23 and 24 of subframe 4, and those almanac pages assigned satellite ID of zero shall be designated as reserved. Other reserved bits in subframes 4 and 5 shall be as shown in Table B-13. Reserved bit positions of each word shall contain a pattern of alternating ones and zeros with a valid word parity.

3.1.2 DEFINITIONS OF PROTOCOLS FOR DATA APPLICATION

Note.— This section defines the inter-relationships of the data broadcast message parameters. It provides definitions of parameters that are not transmitted, but are used by either or both non-aircraft and aircraft elements, and that define terms applied to determine the navigation solution and its integrity.

Table B-13. Reserved bits in subframes 4 and 5

Subframe	Pages	Words	Reserved bit position in word
4	17	10	17 – 22
4	18	10	9 – 22
4	25	8	17 – 18
4	25	10	19 – 22
5	25	10	4 – 22

Table B-14. Parity encoding algorithms

$D_1 = d_1 \oplus D^{*}_{30}$
$D_2 = d_2 \oplus D^{*}_{30}$
$D_3 = d_3 \oplus D^{*}_{30}$
• •
• •
• •
• •
$D_{24} = d_{24} \oplus D^{*}_{30}$
$D_{25} = D^{*}_{29} \oplus d_1 \oplus d_2 \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_{10} \oplus d_{11} \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{17} \oplus d_{18} \oplus d_{20} \oplus d_{23}$
$D_{26} = D^{*}_{30} \oplus d_2 \oplus d_3 \oplus d_4 \oplus d_6 \oplus d_7 \oplus d_{11} \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{18} \oplus d_{19} \oplus d_{21} \oplus d_{24}$
$D_{27} = D^{*}_{29} \oplus d_1 \oplus d_3 \oplus d_4 \oplus d_5 \oplus d_7 \oplus d_8 \oplus d_{12} \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{19} \oplus d_{20} \oplus d_{22}$
$D_{28} = D^{*}_{30} \oplus d_2 \oplus d_4 \oplus d_5 \oplus d_6 \oplus d_8 \oplus d_9 \oplus d_{13} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17} \oplus d_{20} \oplus d_{21} \oplus d_{23}$
$D_{29} = D^{*}_{30} \oplus d_1 \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_7 \oplus d_9 \oplus d_{10} \oplus d_{14} \oplus d_{15} \oplus d_{16} \oplus d_{17} \oplus d_{18} \oplus d_{21} \oplus d_{22} \oplus d_{24}$
$D_{30} = D^{*}_{29} \oplus d_3 \oplus d_5 \oplus d_6 \oplus d_8 \oplus d_9 \oplus d_{10} \oplus d_{11} \oplus d_{13} \oplus d_{15} \oplus d_{19} \oplus d_{22} \oplus d_{23} \oplus d_{24}$

where:

$D_1, D_2, D_3, \ldots D_{29}, D_{30}$ are the bits transmitted by the satellite;
$D_{25}, \ldots D_{30}$ are the computed parity bits;
$d_1, d_2, \ldots d_{24}$ are the source data bits;
$\oplus$ is the Modulo-2 or “Exclusive-Or” operation; and
* is used to identify the last two bits of the previous word of the subframe.

3.1.2.1 *Parity algorithm*. GPS parity algorithms are defined as indicated in Table B-14.

3.1.2.2 *Satellite clock correction parameters.* GPS system time *t* is defined as:

$$t = t_{sv} - (\Delta t_{sv})_{L1}$$

where

t = GPS system time (corrected for beginning and end-of-week crossovers);
t_{sv} = satellite time at transmission of the message;
$(\Delta t_{sv})_{L1}$ = the satellite PRN code phase offset;
$(\Delta t_{sv})_{L} = a_{f0} + a_{f1}(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_r - T_{GD}$

where

a_{f0}, a_{f1} and a_{f2} and t_{oc}, are contained in subframe1; and
Δt_r = the relativistic correction term (seconds)

$$\Delta t_r = F e \sqrt{A} \sin E_k$$

where

e and A are contained in subframes 2 and 3;
E_k is defined in Table B-15; and

$$F = \frac{-2\,(\mu)^{1/2}}{c^2} = -4.442807633(10)^{-10}\ \text{s/m}^{1/2}$$

where

μ = WGS-84 universal gravitational parameter ($3.986005 \times 10^{14}\ \text{m}^3/\text{s}^2$)
c = the speed of light in a vacuum (2.99792458×10^{8} m/s)

Note.— The value of t is intended to account for the beginning or end-of-week crossovers. That is, if the quantity $t\text{-}t_{oc}$ *is greater than 302 400 seconds, subtract 604 800 seconds from t. If the quantity* $t\text{-}t_{oc}$ *is less than –302 400 seconds, add 604 800 seconds to t.*

3.1.2.3 *Satellite position.* The current satellite position (X_k, Y_k, Z_k) is defined as shown in Table B-15.

3.1.2.4 *Ionospheric correction.* The ionospheric correction (T_{iono}) is defined as:

$$T_{iono} = \left\{ \begin{array}{ll} F \times \left[5.0 \times 10^{-9} + AMP \left(1 - \frac{x^2}{2} + \frac{x^4}{24} \right) \right], & |x| < 1.57 \\ F \times \left(5.0 \times 10^{-9} \right) & |x| \geq 1.57 \end{array} \right\} \text{(seconds)}$$

where

$$AMP = \left\{ \begin{array}{l} \sum_{n=0}^{3} \alpha_n \phi_{m,}^{n}, \quad AMP \geq 0 \\ \text{if } AMP < 0,\ AMP = 0 \end{array} \right\} \text{(seconds)}$$

$$x = \frac{2\pi(t\text{-}50\ 400)}{PER}, \text{(radians)}$$

$$PER = \left\{ \begin{array}{l} \sum_{n=0}^{3} \beta_n \phi_{m,}^{n}, \qquad PER \geq 72\ 000 \\ \text{if } PER < 72\ 000,\ PER = 72\ 000 \end{array} \right\} \text{(seconds)}$$

$$F = 1.0 + 16.0[0.53 - E]^3$$

α_n and β_n are the satellite transmitted data words with n = 0, 1, 2 and 3

$$\phi_m = \phi_i + 0.064 \cos(\lambda_i - 1.617) \text{ (semi-circles)}$$

$$\lambda_i = \lambda_u + \frac{\psi \sin A}{\cos\phi_i} \text{ (semi-circles)}$$

$$\bar{\phi}_i = \phi_u + \psi \cos A \text{ (semi-circles)}$$

$$\phi_i = \begin{Bmatrix} \phi_i = \bar{\phi}_i \text{ if } |\bar{\phi}_i| \leq 0.416 \\ \phi_i = +0.416 \text{ if } \bar{\phi}_i > 0.416, \\ \phi_i = -0.416 \text{ if } \bar{\phi}_i < -0.416 \end{Bmatrix} \text{ (semi-circles)}$$

$$\psi = \frac{0.0137}{E+0.11} - 0.022 \text{ (semi-circles)}$$

t = $4.32 \times 10^4 \lambda_i$ + GPS time (seconds) where $0 \leq t < 86\,400$,
therefore: if $t \geq 86\,400$ seconds, subtract 86 400 seconds; and
if $t < 0$ seconds, add 86 400 seconds

E = satellite elevation angle

3.1.2.4.1 The terms used in computation of ionospheric delay are as follows:

a) Satellite transmitted terms

α_n = the coefficients of a cubic equation representing the amplitude of the vertical delay (4 coefficients = 8 bits each)
β_n = the coefficients of a cubic equation representing the period of the model (4 coefficients = 8 bits each)

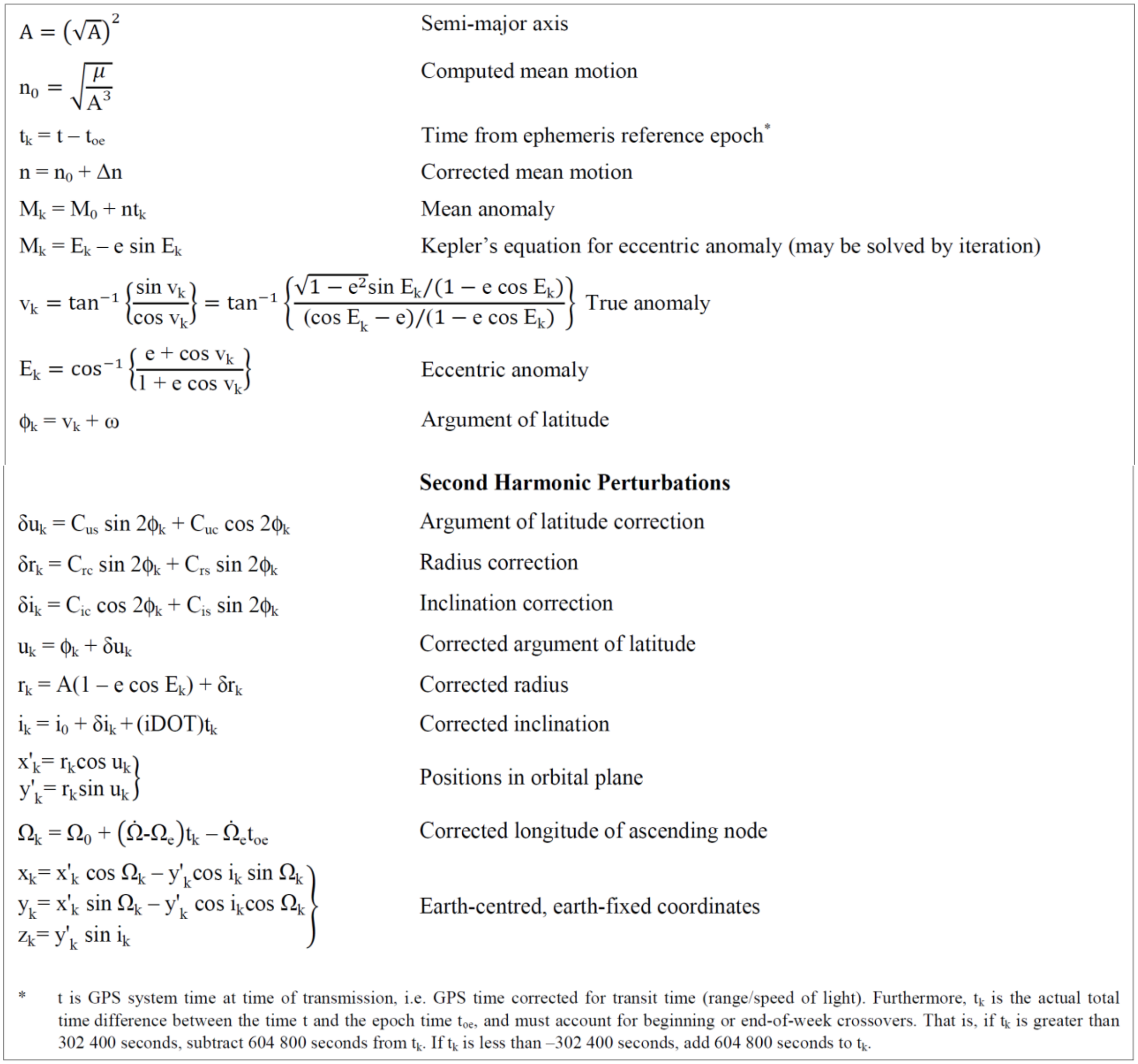
b) Receiver generated terms

E = elevation angle between the user and satellite (semi-circles)
A = azimuth angle between the user and satellite, measured clockwise positive from the true North (semi-circles)
φ_u = user geodetic latitude (semi-circles) WGS-84
λ_u = user geodetic longitude (semi-circles) WGS-84
GPS time = receiver computed system time

c) Computed terms

x = phase (radians)
F = obliquity factor (dimensionless)
t = local time (seconds)
φ_m = geomagnetic latitude of the earth projection of the ionospheric intersection point (mean ionospheric height assumed 350 km) (semi-circles)
λ_i = geomagnetic longitude of the earth projection of the ionospheric intersection point (semi-circles)
φ_i = geomagnetic latitude of the earth projection of the ionospheric intersection point (semi-circles)
ψ = earth's central angle between user position and earth projection of ionospheric intersection point (semi-circles)

Table B-15. Elements of coordinate systems



$A = \left(\sqrt{A}\right)^2$	Semi-major axis
$n_0 = \sqrt{\frac{\mu}{A^3}}$	Computed mean motion
$t_k = t - t_{oe}$	Time from ephemeris reference epoch*
$n = n_0 + \Delta n$	Corrected mean motion
$M_k = M_0 + nt_k$	Mean anomaly
$M_k = E_k - e \sin E_k$	Kepler's equation for eccentric anomaly (may be solved by iteration)
$v_k = \tan^{-1}\left\{\frac{\sin v_k}{\cos v_k}\right\} = \tan^{-1}\left\{\frac{\sqrt{1-e^2}\sin E_k/(1-e\cos E_k)}{(\cos E_k - e)/(1-e\cos E_k)}\right\}$	True anomaly
$E_k = \cos^{-1}\left\{\frac{e+\cos v_k}{1+e\cos v_k}\right\}$	Eccentric anomaly
$\phi_k = v_k + \omega$	Argument of latitude
	Second Harmonic Perturbations
$\delta u_k = C_{us}\sin 2\phi_k + C_{uc}\cos 2\phi_k$	Argument of latitude correction
$\delta r_k = C_{rc}\sin 2\phi_k + C_{rs}\sin 2\phi_k$	Radius correction
$\delta i_k = C_{ic}\cos 2\phi_k + C_{is}\sin 2\phi_k$	Inclination correction
$u_k = \phi_k + \delta u_k$	Corrected argument of latitude
$r_k = A(1 - e\cos E_k) + \delta r_k$	Corrected radius
$i_k = i_0 + \delta i_k + (iDOT)t_k$	Corrected inclination
$\left.\begin{matrix} x'_k = r_k\cos u_k \\ y'_k = r_k\sin u_k \end{matrix}\right\}$	Positions in orbital plane
$\Omega_k = \Omega_0 + \left(\dot{\Omega}-\Omega_e\right)t_k - \dot{\Omega}_e t_{oe}$	Corrected longitude of ascending node
$\left.\begin{matrix} x_k = x'_k\cos\Omega_k - y'_k\cos i_k\sin\Omega_k \\ y_k = x'_k\sin\Omega_k - y'_k\cos i_k\cos\Omega_k \\ z_k = y'_k\sin i_k \end{matrix}\right\}$	Earth-centred, earth-fixed coordinates

* t is GPS system time at time of transmission, i.e. GPS time corrected for transit time (range/speed of light). Furthermore, t_k is the actual total time difference between the time t and the epoch time t_{oe}, and must account for beginning or end-of-week crossovers. That is, if t_k is greater than 302 400 seconds, subtract 604 800 seconds from t_k. If t_k is less than –302 400 seconds, add 604 800 seconds to t_k.

3.1.3 AIRCRAFT ELEMENTS

3.1.3.1 *GNSS (GPS) RECEIVER*

3.1.3.1.1 *Satellite exclusion*. The receiver shall exclude any marginal or unhealthy satellite.

Note.— Conditions indicating that a satellite is "healthy", "marginal" or "unhealthy" can be found in the United States Department of Defense, Global Positioning System – Standard Positioning Service – Performance Standard*, 4th Edition, September 2008, Section 2.3.2.*

3.1.3.1.2 *Satellite tracking*. The receiver shall provide the capability to continuously track a minimum of four satellites and generate a position solution based upon those measurements.

3.1.3.1.3 *Doppler shift*. The receiver shall be able to compensate for dynamic Doppler shift effects on nominal SPS signal carrier phase and C/A code measurements. The receiver shall compensate for the Doppler shift that is unique to the anticipated application.

3.1.3.1.4 *Resistance to interference*. The receiver shall meet the requirements for resistance to interference as specified in Chapter 3, 3.7.

3.1.3.1.5 *Application of clock and ephemeris data*. The receiver shall ensure that it is using the correct ephemeris and clock data before providing any position solution. The receiver shall monitor the IODC and IODE values, and to update ephemeris and clock databased upon a detected change in one or both of these values. The SPS receiver shall use clock and ephemeris data with corresponding IODC and IODE values for a given satellite.

3.1.4 TIME

GPS time shall be referenced to a UTC (as maintained by the U.S. Naval Observatory) zero time-point defined as midnight on the night of 5 January 1980/morning of 6 January 1980. The largest unit used in stating GPS time shall be 1 week, defined as 604 800 seconds. The GPS time scale shall be maintained to be within 1 microsecond of UTC (Modulo 1 second) after correction for the integer number of leap seconds difference. The navigation data shall contain the requisite data for relating GPS time to UTC.

3.2 Reserved

3.3 Reserved

3.4 Aircraft-based augmentation system (ABAS)

Note.— Guidance on ABAS is given in Attachment D, section 5.

3.5 Satellite-based augmentation system (SBAS)

3.5.1 GENERAL

Note.— Parameters in this section are defined in WGS-84.

3.5.2 RF CHARACTERISTICS

3.5.2.1 *Carrier frequency stability*. The short-term stability of the carrier frequency (square root of the Allan Variance) at the output of the satellite transmit antenna shall be better than 5×10^{-11} over 1 to 10 seconds.

3.5.2.2 *Carrier phase noise*. The phase noise spectral density of the unmodulated carrier shall be such that a phase locked loop of 10 Hz one-sided noise bandwidth is able to track the carrier to an accuracy of 0.1 radian (1 sigma).

3.5.2.3 *Spurious emissions*. Spurious emissions shall be at least 40 dB below the unmodulated carrier power over all frequencies.

3.5.2.4 *Code/carrier frequency coherence*. The short-term (less than 10 seconds) fractional frequency difference between the code phase rate and the carrier frequency shall be less than 5×10^{-11} (standard deviation). Over the long term (less than 100 seconds), the difference between the change in the broadcast code phase, converted to carrier cycles by multiplying the number of code chips by 1 540, and the change in the broadcast carrier phase, in cycles, shall be within one carrier cycle (standard deviation).

Note.— This applies to the output of the satellite transmit antenna and does not include code/carrier divergence due to ionospheric refraction in the downlink propagation path.

3.5.2.5 *Correlation loss*. The loss in the recovered signal power due to imperfections in the signal modulation and waveform distortion shall not exceed 1 dB.

Note.— The loss in signal power is the difference between the broadcast power in a 2.046 MHz bandwidth and the signal power recovered by a noise-free, loss-free receiver with 1-chip correlator spacing and a 2.046 MHz bandwidth.

3.5.2.6 *Maximum code phase deviation*. The maximum uncorrected code phase of the broadcast signal shall not deviate from the equivalent SBAS network time (SNT) by more than $\pm 2^{-20}$ seconds.

3.5.2.7 *Code/data coherence*. Each 2-millisecond symbol shall be synchronous with every other code epoch.

3.5.2.8 *Message synchronization*. The leading edge of the first symbol that depends on the first bit of the current message shall be broadcast from the SBAS satellite synchronous with a 1-second epoch of SNT.

3.5.2.9 *Convolutional encoding*. A 250-bit-per-second data stream shall be encoded at a rate of 2 symbols per bit using a convolutional code with a constraint length of 7 to yield 500 symbols per second. The convolutional encoder logic arrangement shall be as illustrated in Figure B-11 with the G3 output selected for the first half of each 4-millisecond data bit period.

3.5.2.10 *Pseudo-random noise (PRN) codes*. Each PRN code shall be a 1 023-bit Gold code which is itself the Modulo-2 addition of two 1 023-bit linear patterns, G1 and $G2_i$. The $G2_i$ sequence shall be formed by delaying the G2 sequence by the associated integer number of chips as illustrated in Table B-23. Each of the G1 and G2 sequences shall be defined as the output of stage 10 of a 10-stage shift register, where the input to the shift register is the Modulo-2 addition of the following stages of the shift register:

a) G1: stages 3 and 10; and

b) G2: stages 2, 3, 6, 8, 9 and 10.

The initial state for the G1 and G2 shift registers shall be “1111111111”.

Table B-23. SBAS PRN codes

PRN code number	G2 delay (chips)	First 10 SBAS chips (Leftmost bit represents first transmitted chip, binary)
120	145	0110111001
121	175	0101011110
122	52	1101001000
123	21	1101100101
124	237	0001110000
125	235	0111000001
126	886	0000001011
127	657	1000110000
128	634	0010100101
129	762	0101010111
130	355	1100011110
131	1 012	1010010110
132	176	1010101111
133	603	0000100110
134	130	1000111001
135	359	0101110001
136	595	1000011111
137	68	0111111000
138	386	1011010111
139	797	1100111010
140	456	0001010100
141	499	0011110110
142	883	0001011011
143	307	0100110101
144	127	0111001111
145	211	0010001111
146	121	1111100010
147	118	1100010010
148	163	1100100010
149	628	0101010011
150	853	0111011110
151	484	1110011101
152	289	0001011110
153	811	0010111011
154	202	1000010110
155	1021	0000000011
156	463	1110111000
157	568	0110010100
158	904	0010011101

3.5.3 DATA STRUCTURE

3.5.3.1 *Format summary*. All messages shall consist of a message type identifier, a preamble, a data field and a cyclic redundancy check as illustrated in Figure B-12.

3.5.3.2 *Preamble.* The preamble shall consist of the sequence of bits “01010011 10011010 11000110”, distributed over three successive blocks. The start of every other 24-bit preamble shall be synchronous with a 6-second GPS subframe epoch.

3.5.3.3 *Message type identifier*. The message type identifier shall be a 6-bit value identifying the message type (Types 0 to 63) as defined in Table B-24. The message type identifier shall be transmitted MSB first.

3.5.3.4 *Data field*. The data field shall be 212 bits as defined in 3.5.6. Each data field parameter shall be transmitted MSB first.

3.5.3.5 *Cyclic redundancy check (CRC).* The SBAS message CRC code shall be calculated in accordance with 3.9.

3.5.3.5.1 The length of the CRC code shall be k = 24 bits.

3.5.3.5.2 The CRC generator polynomial shall be:

$$G(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^{7} + x^{6} + x^{5} + x^{4} + x^{3} + x + 1$$

Table B-24. Broadcast message types

Message type	Contents
0	“Do Not Use” (SBAS test mode)
1	PRN mask
2 to 5	Fast corrections
6	Integrity information
7	Fast correction degradation factor
8	Spare
9	GEO ranging function parameters
10	Degradation parameters
11	Spare
12	SBAS network time/UTC offset parameters
13 to 16	Spare
17	GEO satellite almanacs
18	Ionospheric grid point masks
19 to 23	Spare
24	Mixed fast/long-term satellite error corrections
25	Long-term satellite error corrections
26	Ionospheric delay corrections
27	SBAS service message
28	Clock-ephemeris covariance matrix
29 to 61	Spare
62	Reserved
63	Null message

3.5.3.5.3 The CRC information field, M(x), shall be:

$$M(x)=\sum_{i=1}^{226} m_i x^{226-i} = m_1 x^{225} + m_2 x^{224} + \cdots + m_{226} x^0$$

3.5.3.5.4 M(x) shall be formed from the 8-bit SBAS message preamble, 6-bit message type identifier, and 212-bit data field. Bits shall be arranged in the order transmitted from the SBAS satellite, such that m_1 corresponds to the first transmitted bit of the preamble, and m_{226} corresponds to bit 212 of the data field.

3.5.3.5.5 The CRC code r-bits shall be ordered such that r_1 is the first bit transmitted and r_{24} is the last bit transmitted.

3.5.4 DATA CONTENT

3.5.4.1 *PRN mask parameters*. PRN mask parameters shall be as follows:

PRN code number: a number that uniquely identifies the satellite PRN code and related assignments as shown in Table B-25.

PRN mask: 210 PRN mask values that correspond to satellite PRN code numbers. The mask shall set up to 51 of the 210 PRN mask values.

Note.— The first transmitted bit of the PRN mask corresponds to PRN code number 1.

Table B-25. PRN code number assignments

PRN code number	Assignment
1 – 37	GPS
38 – 61	GLONASS slot number plus 37
62 – 119	Spare
120 – 158	SBAS
159 – 210	Spare

PRN mask value: a bit in the PRN mask indicating whether data are provided for the associated satellite PRN code number (1 to 210).

Coding: 0 = data not provided
1 = data provided

PRN mask number: the sequence number (1 to 51) of the mask values set in the PRN mask.

Note.— The PRN mask number is "1" for the lowest satellite PRN number for which the PRN mask value is "1".

Issue of data — PRN (IODP): an indicator that associates the correction data with a PRN mask.

Note.— Parameters are broadcast in the following messages:

a) *PRN mask (consisting of 210 PRN mask values) in Type 1 message;*

b) *PRN mask number in Type 24, 25 and 28 messages;*

c) *PRN code number in Type 17 message; and*

d) *IODP in Type 1 to 5, 7, 24, 25 and 28 messages.*

3.5.4.2 *Geostationary orbit (GEO) ranging function parameters.* GEO ranging function parameters shall be as follows:

$t_{0,GEO}$: the reference time for the GEO ranging function data, expressed as the time after midnight of the current day.

$[X_G\ Y_G\ Z_G]$: the position of the GEO at time $t_{0,GEO}$.

$[\dot{X}_G\ \dot{Y}_G\ \dot{Z}_G]$: the velocity of the GEO at time $t_{0,GEO}$.

$[\ddot{X}_G \ddot{Y}_G \ddot{Z}_G]$: the acceleration of the GEO at time $t_{0,GEO}$.

a_{Gf0}: the time offset of the GEO clock with respect to SNT, defined at $t_{0,GEO}$.

a_{Gf1}: the drift rate of the GEO clock with respect to SNT.

User range accuracy (URA): an indicator of the root-mean-square ranging error, excluding atmospheric effects, as described in Table B-26.

Note.— All parameters are broadcast in Type 9 message.

Table B-26. User range accuracy

URA	Accuracy (rms)
0	2 m
1	2.8 m
2	4 m
3	5.7 m
4	8 m
5	11.3 m
6	16 m
7	32 m
8	64 m
9	128 m
10	256 m
11	512 m
12	1 024 m
13	2 048 m
14	4 096 m
15	“Do Not Use”

Note.— URA values 0 to 14 are not used in the protocols for data application (3.5.5). Airborne receivers will not use the GEO ranging function if URA indicates “Do Not Use”(3.5.8.3).

3.5.4.3 *GEO almanac parameters.* GEO almanac parameters shall be as follows:

PRN code number: see 3.5.4.1.

Health and status: an indication of the functions provided by the SBAS. The service provider identifiers are shown in Table B-27.

Coding:	Bit 0 (LSB)	Ranging	On (0)	Off (1)
	Bit 1	Precision corrections	On (0)	Off (1)
	Bit 2	Satellite status and basic corrections	On (0)	Off (1)
	Bits 3	Spare		
	Bits 4 to 7	Service provider identifier		

Note.— A service provider ID of 14 is used for GBAS and is not applicable to SBAS.

$[X_{G,A}\ Y_{G,A}\ Z_{G,A}]$*:* the position of the GEO at time $t_{almanac}$.

$[\dot{X}_{G,A}\ \dot{Y}_{G,A}\ \dot{Z}_{G,A}]$ *:* the velocity of the GEO at time $t_{almanac}$.

$t_{almanac}$*:* the reference time for the GEO almanac data, expressed as the time after midnight of the current day.

Note.— All parameters are broadcast in Type 17 message.

3.5.4.4 SATELLITE CORRECTION BROADCAST PARAMETERS

3.5.4.4.1 Long-term correction parameters shall be as follows:

Issue of data (IOD_i): an indicator that associates the long-term corrections for the ith satellite with the ephemeris data broadcast by that satellite.

Note 1.— For GPS, the IOD_i matches the IODE and 8 LSBs of the IODC (3.1.1.3.1.4 and 3.1.1.3.2.2).

Note 2.— reserved.

δx_i*:* for satellite i, the ephemeris correction for the x axis.

δy_i*:* for satellite i, the ephemeris correction for the y axis.

δz_i*:* for satellite i, the ephemeris correction for the z axis.

$\delta a_{i,f0}$*:* for satellite i, the ephemeris time correction.

$\delta \dot{x}_i$*:* for satellite i, ephemeris velocity correction for x axis.

$\delta \dot{y}_i$*:* for satellite i, ephemeris velocity correction for y axis.

$\delta \dot{z}_i$*:* for satellite i, ephemeris velocity correction for z axis.

$\delta a_{i,f1}$: for satellite i, rate of change of the ephemeris time correction.

$t_{i,LT}$: the time of applicability of the parameters δx_i, δy_i, δz_i, $\delta a_{i,f0}$, $\delta \dot{x}_i$, $\delta \dot{y}_i$, $\delta \dot{z}_i$ and $\delta a_{i,f1}$, expressed in seconds after midnight of the current day.

Velocity code: an indicator of the message format broadcast (Table B-48 and Table B-49).

Coding: 0 = $\delta \dot{x}_i$, $\delta \dot{y}_i$, $\delta \dot{z}_i$ and $\delta a_{i,f1}$ are not broadcast.

1 = $\delta \dot{x}_i$, $\delta \dot{y}_i$, $\delta \dot{z}_i$ and $\delta a_{i,f1}$ are broadcast.

Note.— All parameters are broadcast in Type 24 and 25 messages.

Table B-27. SBAS service provider identifiers

Identifier	Service provider
0	WAAS
1	EGNOS
2	MSAS
3	GAGAN
4	SDCM
5 to 13	Spare
14, 15	Reserved

Table B-28. reserved.

3.5.4.4.2 Fast correction parameters shall be as follows:

Fast correction (FC_i): for satellite *i*, the pseudo-range correction for rapidly varying errors, other than tropospheric or ionospheric errors, to be added to the pseudo-range after application of the long-term correction.

Note.— The user receiver applies separate tropospheric corrections (3.5.8.4.2 and 3.5.8.4.3).

Fast correction type identifier: an indicator (0, 1, 2, 3) of whether the Type 24 message contains the fast correction and integrity data associated with the PRN mask numbers from Type 2, Type 3, Type 4 or Type 5 messages, respectively.

Issue of data-fast correction ($IODF_j$): an indicator that associates $UDREI_i$s with fast corrections. The index *j* shall denote the message type (j = 2 to 5) to which $IODF_j$ applies (the fast correction type identifier +2).

Note.— The fast correction type identifier is broadcast in Type 24 messages. The FC_i are broadcast in Type 2 to 5, and Type 24 messages. The $IODF_j$ are broadcast in Type 2 to 6, and Type 24 messages.

3.5.4.5 *Fast and long-term correction integrity parameters*. Fast and long-term correction integrity parameters shall be as follows:

$UDREI_i$: an indicator that defines the $\sigma^2_{i,UDRE}$ for satellite *i* as described in Table B-29.

Model variance of residual clock and ephemeris errors ($\sigma^2_{i,UDRE}$): the variance of a normal distribution associated with the user differential range errors for satellite *i* after application of fast and long-term corrections, excluding atmospheric effects and used in horizontal protection level/vertical protection level computations (3.5.5.6).

Note.— All parameters are broadcast in Type 2 to 6, and Type 24 messages.

3.5.4.6 *Ionospheric correction parameters.* Ionospheric correction parameters shall be as follows:

IGP mask: a set of 11 ionospheric grid point (IGP) band masks defined in Table B-30.

IGP band mask: a set of IGP mask values which correspond to all IGP locations in one of the 11 IGP bands defined in Table B-30.

Table B-29. Evaluation of $UDREI_i$

$UDREI_i$	$\sigma^2_{i,UDRE}$
0	0.0520 m^2
1	0.0924 m^2
2	0.1444 m^2
3	0.2830 m^2
4	0.4678 m^2
5	0.8315 m^2
6	1.2992 m^2
7	1.8709 m^2
8	2.5465 m^2
9	3.3260 m^2
10	5.1968 m^2
11	20.7870 m^2
12	230.9661 m^2
13	2 078.695 m^2
14	“Not Monitored”
15	“Do Not Use”

IGP mask value: a bit indicating whether data are provided within that IGP band for the associated IGP.

Coding: 0 = data are not provided
1 = data are provided

Number of IGP bands: the number of IGP band masks being broadcast.

IGP band identifier: the number identifying the ionospheric band as defined in Table B-30.

IGP block identifier: the identifier of the IGP block. The IGP blocks are defined by dividing into groups of 15 IGPs the sequence of IGPs within an IGP band mask which have IGP mask values of “1”. The IGP blocks are numbered in an order of IGP mask value transmission, starting with “0”.

$IODI_k$: an indication of when the kth IGP band mask changes.

IGP vertical delay estimate: an estimate of the delay induced for a signal at 1 575.42 MHz if it traversed the ionosphere vertically at the IGP.

Coding: The bit pattern “111111111” indicates “Do Not Use”.

GIVEI$_i$: an indicator that defines the $\sigma^2_{i,GIVE}$ as described in Table B-33.

Model variance of residual ionospheric errors ($\sigma^2_{i,GIVE}$): the variance of a normal distribution associated with the residual ionospheric vertical error at the IGP for an L1 signal.

Note.— All parameters are broadcast in Type 18 and Type 26 messages.

Table B-30. IGP locations and band numbers

IGP location		Transmission order in IGP band mask
Band 0		
180 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	1 – 28
175 W	55S, 50S, 45S, ..., 45N, 50N, 55N	29 – 51
170 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	52 – 78
165 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 – 101
160 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 – 128
155 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 – 151
150 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 – 178
145 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 1		
140 W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 28
135 W	55S, 50S, 45S, ..., 45N, 50N, 55N	29 – 51
130 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	52 – 78
125 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 – 101
120 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 – 128
115 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 – 151
110 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 – 178
105 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 2		
100 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
95 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50

IGP location		Transmission order in IGP band mask
90 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	51 – 78
85 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 – 101
80 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 – 128
75 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 – 151
70 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 – 178
65 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 3		
60 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
55 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50
50 W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 – 78
45 W	55S, 50S, 45S, ..., 45N, 50N, 55N	79 – 101
40 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102 – 128
35 W	55S, 50S, 45S, ..., 45N, 50N, 55N	129 – 151
30 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 – 178
25 W	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 4		
20 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
15 W	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50
10 W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 – 77
5 W	55S, 50S, 45S, ..., 45N, 50N, 55N	78 – 100
0	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	101 – 128
5 E	55S, 50S, 45S, ..., 45N, 50N, 55N	129 – 151
10 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 – 178
15 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 5		
20 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
25 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50
30 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 – 77
35 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 – 100
40 E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 – 128
45 E	55S, 50S, 45S, ..., 45N, 50N, 55N	129 – 151

50 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152 – 178
55 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 6		
60 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
65 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50
70 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 – 77
IGP location		Transmission order in IGP band mask
75 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 – 100
80 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 – 127
85 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 – 150
90 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	151 – 178
95 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 7		
100 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
105 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50
110 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 – 77
115 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 – 100
120 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 – 127
125 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 – 150
130 E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	151 – 178
135 E	55S, 50S, 45S, ..., 45N, 50N, 55N	179 – 201
Band 8		
140 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1 – 27
145 E	55S, 50S, 45S, ..., 45N, 50N, 55N	28 – 50
150 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51 – 77
155 E	55S, 50S, 45S, ..., 45N, 50N, 55N	78 – 100
160 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101 – 127
165 E	55S, 50S, 45S, ..., 45N, 50N, 55N	128 – 150
170 E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	151 – 177
175 E	55S, 50S, 45S, ..., 45N, 50N, 55N	178 – 200
Band 9		
60 N	180W, 175W, 170W, …, 165E, 170E, 175E	1 – 72

65 N	180W, 170W, 160W, …, 150E, 160E, 170E	73 – 108
70 N	180W, 170W, 160W, …, 150E, 160E, 170E	109 – 144
75 N	180W, 170W, 160W, …, 150E, 160E, 170E	145 – 180
85 N	180W, 150W, 120W, …, 90E, 120E, 150E	181 – 192
Band 10		
60 S	180W, 175W, 170W, …, 165E, 170E, 175E	1 – 72
65 S	180W, 170W, 160W, …, 150E, 160E, 170E	73 – 108
70 S	180W, 170W, 160W, …, 150E, 160E, 170E	109 – 144
75 S	180W, 170W, 160W, …, 150E, 160E, 170E	145 – 180
85 S	170W, 140W, 110W, …, 100E, 130E, 160E	181 – 192

Table B-31. Validity interval

Data	Bits used	Range of values	Resolution
Validity interval (V)	5	30 s to 960 s	30 s

Table B-32. Reserved

Table B-33. Evaluation of $GIVEI_i$

$GIVEI_i$	$\sigma^2_{i,GIVE}$
0	0.0084 m^2
1	0.0333 m^2
2	0.0749 m^2
3	0.1331 m^2
4	0.2079 m^2
5	0.2994 m^2
6	0.4075 m^2
7	0.5322 m^2
8	0.6735 m^2
9	0.8315 m^2
10	1.1974 m^2
11	1.8709 m^2
12	3.3260 m^2
13	20.787 m^2
14	187.0826 m^2
15	“Not Monitored”

3.5.4.7 *Degradation parameters.* Degradation parameters, whenever used, shall be as follows:

Fast correction degradation factor indicator (ai_i): an indicator of the fast correction degradation factor (a_i) for the i^th^ satellite as described in Table B-34.

Note.— The ai_i is also used to define the time-out interval for fast corrections, as described in 3.5.8.1.2.

System latency time (t_{lat}): the time interval between the origin of the fast correction degradation and the user differential range estimate indicator (UDREI) reference time.

B_{rrc}: a parameter that bounds the noise and round-off errors when computing the range rate correction degradation as in 3.5.5.6.2.2.

C_{ltc_lsb}: the maximum round-off error due to the resolution of the orbit and clock information.

C_{ltc_v1}: the velocity error bound on the maximum range rate difference of missed messages due to clock and orbit rate differences.
I_{ltc_v1}: the update interval for long-term corrections if velocity code = 1 (3.5.4.4.1).

C_{ltc_v0}: a parameter that bounds the difference between two consecutive long-term corrections for satellites with a velocity code = 0.

I_{ltc_v0}: the minimum update interval for long-term messages if velocity code = 0 (3.5.4.4.1).

C_{GEO_lsb}: the maximum round-off error due to the resolution of the orbit and clock information.

C_{GEO_v}: the velocity error bound on the maximum range rate difference of missed messages due to clock and orbit rate differences.

I_{GEO}: the update interval for GEO ranging function messages.

Table B-34. Fast correction degradation factor

Fast correction degradation factor indicator (ai_i)	Fast correction degradation factor (a_i)
0	0.0 mm/s^2
1	0.05 mm/s^2
2	0.09 mm/s^2
3	0.12 mm/s^2
4	0.15 mm/s^2
5	0.20 mm/s^2
6	0.30 mm/s^2
7	0.45 mm/s^2
8	0.60 mm/s^2
9	0.90 mm/s^2
10	1.50 mm/s^2
11	2.10 mm/s^2
12	2.70 mm/s^2
13	3.30 mm/s^2
14	4.60 mm/s^2

15	5.80 mm/s^2

C_{er}: the bound on the residual error associated with using data beyond the precision approach/approach with vertical guidance time-out.

C_{iono_step}: the bound on the difference between successive ionospheric grid delay values.

I_{iono}: the minimum update interval for ionospheric correction messages.

$C_{iono\ ramp}$: the rate of change of the ionospheric corrections.

RSS_{UDRE}: the root-sum-square flag for fast and long-term correction residuals.

Coding: 0 = correction residuals are linearly summed
1 = correction residuals are root-sum-squared

RSS_{iono}: the root-sum-square flag for ionospheric residuals.

Coding: 0 = correction residuals are linearly summed
1 = correction residuals are root-sum-squared

$C_{covariance}$: the term which is used to compensate for quantization effects when using the Type 28 message.

Note 1.— The parameters a_i *and* t_{lat} *are broadcast in Type 7 message. All other parameters are broadcast in Type 10 message.*
Note 2.— If message Type 28 is not broadcast, $C_{covariance}$ *is not applicable.*

3.5.4.8 *Time parameters.* Time parameters, whenever used, shall be as follows:

UTC standard identifier: an indication of the UTC reference source as defined in Table B-35.

GPS time-of-week count: the number of seconds that have passed since the transition from the previous GPS week (similar to the GPS parameter in 3.1.1.2.6.1 but with a 1-second resolution).

Table B-35. UTC standard identifier

UTC standard identifier	UTC standard
0	UTC as operated by the Communications Research Laboratory, Tokyo, Japan
1	UTC as operated by the U.S. National Institute of Standards and Technology
2	UTC as operated by the U.S. Naval Observatory
3	UTC as operated by the International Bureau of Weights and Measures
4	Reserved for UTC as operated by a European laboratory

5 to 6	Spare
7	UTC not provided

GPS week number (week count): see 3.1.1.2.6.2.

UTC parameters: A_{1SNT}, A_{0SNT}, t_{0t}, WN_t, Δt_{LS}, WN_{LSF}, DN and Δt_{LSF} are as described in 3.1.1.3.3.6, with the exception that the SBAS parameters relate SNT to UTC time, rather than GPS time.

Note.— All parameters are broadcast in Type 12 message.

3.5.4.9 *Service region parameters.* Service region parameters shall be as follows:

Issue of data, service (IODS): an indication of a change of the service provided in the region.

Number of service messages: the number of different Type 27 SBAS service messages being broadcast. (Value is coded with an offset of 1.)

Service message number: a sequential number identifying the message within the currently broadcast set of Type 27 messages (from 1 to number of service messages, coded with an offset of 1).

Number of regions: the number of service regions for which coordinates are broadcast in the message.

Priority code: an indication of a message precedence if two messages define overlapping regions. The message with a higher value of priority code takes precedence. If priority codes are equal, the message with the lower δUDRE takes precedence.

δ*UDRE indicator-inside:* an indication of regional UDRE degradation factor (δUDRE) applicable at locations inside any region defined in the message, in accordance with Table B-36.

δ*UDRE indicator-outside:* an indication of regional UDRE degradation factor (δUDRE) applicable at locations outside all regions defined in all current Type 27 messages, in accordance with Table B-36.

Coordinate latitude: the latitude of one corner of a region.

Coordinate longitude: the longitude of one corner of a region.

Region shape: an indication of whether a region is a triangle or quadrangle.

Coding: 0 = triangle
1 = quadrangle

Note 1.— Coordinate 3 has Coordinate 1 latitude and Coordinate 2 longitude. If region is a quadrangle, Coordinate 4 has Coordinate 2 latitude and Coordinate 1 longitude. Region boundary is formed by joining coordinates in the sequence 1-2-3-1 (triangle) or 1-3-2-4-1 (quadrangle). Boundary segments have either constant latitude, constant longitude, or constant slope in degrees of latitude per degree of longitude. The change in latitude or longitude along any boundary segment between two coordinates is less than ±180 degrees.

Note 2.— All parameters are broadcast in Type 27 message.

Table B-36. δUDRE indicator evaluation

δUDRE indicator	δUDRE

0	1
1	1.1
2	1.25
3	1.5
4	2
5	3
6	4
7	5
8	6
9	8
10	10
11	20
12	30
13	40
14	50
15	100

3.5.4.10 *Clock-ephemeris covariance matrix parameters*. Clock-ephemeris covariance matrix parameters shall be as follows:

PRN mask number: see 3.5.4.1.

Scale exponent: A term to compute the scale factor used to code the Cholesky factorization elements.

Cholesky factorization elements ($E_{i,j}$): Elements of an upper triangle matrix which compresses the information in the clock and ephemeris covariance matrix. These elements are used to compute the user differential range estimate (UDRE) degradation factor (δUDRE) as a function of user position.

3.5.5 DEFINITIONS OF PROTOCOLS FOR DATA APPLICATION

Note.— This section provides definitions of parameters used by the non-aircraft or aircraft elements that are not transmitted. These parameters, necessary to ensure interoperability of SBAS, are used to determine the navigation solution and its integrity (protection levels).

3.5.5.1 *GEO POSITION AND CLOCK*

3.5.5.1.1 *GEO position estimate*. The estimated position of a GEO at any time t_k is:

$$\begin{bmatrix}\hat{X}_G\\ \hat{Y}_G\\ \hat{Z}_G\end{bmatrix}=\begin{bmatrix}X_G\\ Y_G\\ Z_G\end{bmatrix}+\begin{bmatrix}\dot{X}_G\\ \dot{Y}_G\\ \dot{Z}_G\end{bmatrix}(t-t_{0,GEO})+\frac{1}{2}\begin{bmatrix}\ddot{X}_G\\ \ddot{Y}_G\\ \ddot{Z}_G\end{bmatrix}(t-t_{0,GEO})^2$$

3.5.5.1.2 *GEO clock correction*. The clock correction for a SBAS GEO satellite *i* is applied in accordance with the following equation:

$$t = t_G - \Delta t_G$$

where

t = SBAS network time;
t_G = GEO code phase time at transmission of message;
and Δt_G = GEO code phase offset.

3.5.5.1.2.1 GEO code phase offset (Δt_G) at any time t is:

$$\Delta t_G = a_{Gf0} + a_{Gf1}\,(t - t_{0,GEO})$$

where $(t - t_{0,GEO})$ is corrected for end-of-day crossover.

3.5.5.2 *LONG-TERM CORRECTIONS*

3.5.5.2.1 *GPS clock correction*. The clock correction for a GPS satellite i is applied in accordance with the following equation:

$$t = t_{SV,i} - [(\Delta t_{SV,i})_{L1} + \delta\Delta t_{SV,i}]$$

where

t = SBAS network time;
$t_{SV,i}$ = the GPS satellite time at transmission of message;
$(\Delta t_{SV,i})_L$ = the satellite PRN code phase offset as defined in 3.1.2.2; and
$\delta\Delta t_{SV,I}$ = the code phase offset correction.

3.5.5.2.1.1 The code phase offset correction ($\delta\Delta t_{SV,i}$) for a GPS or SBAS satellite i at any time of day t_k is:

$$\delta\Delta t_{SV,i} = \delta a_{i,f0} + \delta a_{i,f1}\,(t_k - t_{i,LT})$$

3.5.5.2.2 *Reserved.*

3.5.5.2.3 *Satellite position correction*. The SBAS-corrected vector for a core satellite constellation(s) or SBAS satellite i at time t is:

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}_{\text{corrected}} = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} + \begin{bmatrix} \delta x_i \\ \delta y_i \\ \delta z_i \end{bmatrix} + \begin{bmatrix} \delta \dot{x}_i \\ \delta \dot{y}_i \\ \delta \dot{z}_i \end{bmatrix} (t - t_{i,LT})$$

where

$(t - t_{i,LT})$ is corrected for end-of-day crossover; and
$[x_i\ y_i\ z_i]^T$ = the core satellite constellation(s) or SBAS satellite position vector as defined in 3.1.2.3, 3.2.2.3 and 3.5.5.1.1.

If the velocity code = 0, then $[\delta\dot{x}_i\ \delta\dot{y}_i\ \delta\dot{z}_i]^T = [0\ 0\ 0]^T$.

3.5.5.3 *Pseudo-range corrections*. The corrected pseudo-range at time t for satellite i is:

$$PR_{i,corrected} = PR_i + FC_i + RRC_i\,(t - t_{i,0f}) + IC_i + TC_i$$

where

PR_i = the measured pseudo-range after application of the satellite clock correction;
FC_i = the fast correction;
RRC_i = the range rate correction;
IC_i = the ionospheric correction;
TC_i = the tropospheric correction (negative value representing the troposphere delay); and
$t_{i,0f}$ = the time of applicability of the most recent fast corrections, which is the start of the epoch of the SNT second that is coincident with the transmission at the SBAS satellite of the first symbol of the message block.

3.5.5.4 *Range rate corrections (RRC)*. The range rate correction for satellite *i* is:

$$RRC_i = \begin{cases} \dfrac{FC_{i,current} - FC_{i,previous}}{t_{i,0f} - t_{i,0f\_previous}}, if\ a_i \neq 0 \\ 0, if\ a_i = 0 \end{cases}$$

where

$FC_{i,current}$ = the most recent fast correction;
$FC_{i,previos}$ = a previous fast correction;
$t_{i,0f}$ = the time of applicability of $FC_{i,current}$;
$t_{i,0f\_previs}$ = the time of applicability of $FC_{i,previous}$; and
a_i = fast correction degradation factor (see Table B-34).

3.5.5.5 BROADCAST IONOSPHERIC CORRECTIONS

3.5.5.5.1 *Location of ionospheric pierce point (IPP)*. The location of an IPP is defined to be the intersection of the line segment from the receiver to the satellite and an ellipsoid with constant height of 350 km above the WGS-84 ellipsoid. This location is defined in WGS-84 latitude (φ_{pp}) and longitude (λ_{pp}).

3.5.5.5.2 *Ionospheric corrections*. The ionospheric correction for satellite *i* is:

$$IC_i = -F_{pp}\,\tau_{vpp}$$

where

F_{pp} = obliquity factor $= \left[1 - \left(\frac{R_e \cos\theta_i}{R_e + h_1}\right)^2\right]^{-\frac{1}{2}}$;
τ_{vpp} = interpolated vertical ionospheric delay estimate (3.5.5.5.3);
R_e = 6 378.1363 km;
θ_i = elevation angle of satellite *i*; and
h_I = 350 km.

3.5.5.5.3 *Interpolated vertical ionospheric delay estimate.* When four points are used for interpolation, the interpolated vertical ionospheric delay estimate at latitude φ_{pp} and longitude λ_{pp} is:

$$\tau_{vpp} = \sum_{k=1}^{4} W_k \tau_{vk}$$

where

τ_{vk}: the broadcast grid point vertical delay values at the k^{th} corner of the IGP grid, as shown in Figure B-13.

$W_1 = x_{pp} y_{pp};$
$W_2 = (1 - x_{pp}) y_{pp};$
$W_3 = (1 - x_{pp}) (1 - y_{pp});$ and
$W_4 = x_{pp} (1 - y_{pp}).$

3.5.5.5.3.1 For IPPs between N85° and S85°:

$$x_{pp} = \frac{\lambda_{pp} - \lambda_1}{\lambda_2 - \lambda_1}$$

$$y_{pp} = \frac{\phi_{pp} - \phi_1}{\phi_2 - \phi_1}$$

where

λ_1 = longitude of IGPs west of IPP;
λ_2 = longitude of IGPs east of IPP;
φ_1 = latitude of IGPs south of IPP; and
φ_2 = latitude of IGPs north of IPP.

Note.— If λ_1 and λ_2 cross 180 degrees of longitude, the calculation of x_{pp} must account for the discontinuity in longitude values.

3.5.5.5.3.2 For IPPs north of N85° or south of S85°:

$$y_{pp} = \frac{|\phi_{pp}| - 85°}{10°}$$

$$x_{pp} = \frac{\lambda_{pp} - \lambda_3}{90°} \times (1 - 2\, y_{pp}) + y_{pp}$$

where

λ_1 = longitude of the second IGP to the east of the IPP;
λ_2 = longitude of the second IGP to the west of the IPP;
λ_3 = longitude of the closest IGP to the west of the IPP; and
λ_4 = longitude of the closest IGP to the east of the IPP.

When three points are used for interpolation, the interpolated vertical ionospheric delay estimated is:

3.5.5.5.3.3 For points between S75° and N75°:

$$\tau_{vpp} = \sum_{k=1}^{3} W_k \tau_{vk}$$

where

$W_1 = y_{pp}$;
$W_2 = 1 - x_{pp} - y_{pp}$; and
$W_3 = x_{pp}$.

3.5.5.5.3.4 x_{pp} and y_{pp} are calculated as for four-point interpolation, except that λ_1 and φ_1 are always the longitude and latitude of IGP2, and λ_2 and φ_2 are the other longitude and latitude. IGP2 is always the vertex opposite the hypotenuse of the triangle defined by the three points, IGP1 has the same longitude as IGP2, and IGP3 has the same latitude as IGP2 (an example is shown in Figure B-14).

3.5.5.5.3.5 For points north of N75° and south of S75°, three-point interpolation is not supported.

3.5.5.5.4 *Selection of ionospheric grid points (IGPs).* The protocol for the selection of IGPs is:

a) For an IPP between N60° and S60°:

1) if four IGPs that define a 5-degree-by-5-degree cell around the IPP are set to “1” in the IGP mask, they are selected; else,

2) if any three IGPs that define a 5-degree-by-5-degree triangle that circumscribes the IPP are set to “1” in the IGP mask, they are selected; else,

3) if any four IGPs that define a 10-degree-by-10-degree cell around the IPP are set to “1” in the IGP mask, they are selected; else,

4) if any three IGPs that define a 10-degree-by-10-degree triangle that circumscribes the IPP are set to “1” in the IGP mask, they are selected; else,
5) an ionospheric correction is not available.

b) For an IPP between N60° and N75° or between S60° and S75°:

1) if four IGPs that define a 5-degree-latitude-by-10-degree longitude cell around the IPP are set to “1” in the IGP mask, they are selected; else,

2) if any three IGPs that define a 5-degree-latitude-by-10-degree longitude triangle that circumscribes the IPP are set to “1” in the IGP mask, they are selected; else,

3) if any four IGPs that define a 10-degree-by-10-degree cell around the IPP are set to “1” in the IGP mask, they are selected; else,

4) if any three IGPs that define a 10-degree-by-10-degree triangle that circumscribes the IPP are set to “1” in the IGP mask, they are selected; else,

5) an ionospheric correction is not available.

c) For an IPP between N75° and N85° or between S75° and S85°:

1) if the two nearest IGPs at 75° and the two nearest IGPs at 85° (separated by 30° longitude if Band 9 or 10 is used, separated by 90° otherwise) are set to “1” in the IGP mask, a 10-degree-by-10-degree cell is created by linearly interpolating between the IGPs at 85° to obtain virtual IGPs at longitudes equal to the longitudes of the IGPs at 75°; else,

2) an ionospheric correction is not available.

d) For an IPP north of N85°:

1) if the four IGPs at N85° latitude and longitudes of W180°, W90°, 0° and E90° are set to “1” in the IGP mask, they are selected; else,

2) an ionospheric correction is not available.

e) For an IPP south of S85°:

1) if the four IGPs at S85° latitude and longitudes of W140°, W50°, E40° and E130° are set to “1” in the IGP mask, they are selected; else,

2) an ionospheric correction is not available.

Note.— This selection is based only on the information provided in the mask, without regard to whether the selected IGPs are monitored, “Not Monitored”, or “Do Not Use”. If any of the selected IGPs is identified as “Do Not Use”, an ionospheric correction is not available. If four IGPs are selected, and one of the four is identified as “Not Monitored”, then three-point interpolation is used if the IPP is within the triangular region covered by the three corrections that are provided.

3.5.5.6 *Protection levels*. The horizontal protection level (HPL) and the vertical protection level (VPL) are:

$$\mathrm{HPL}_{\mathrm{SBAS}}=\begin{cases} K_{H,NPA}\times d_{major} & \text{for en-route through non-precision approach (NPA) modes} \\ K_{H,PA}\times d_{major} & \text{for precision approach (PA) and approach with vertical guidance (APV) modes} \end{cases}$$

$$\mathrm{VPL}_{\mathrm{SBAS}} = K_{V,PA} \times d_V$$

where

$d^2_V = \sum^N_{i=1} s_{v,i}^2\,\sigma^2_i$ = variance of model distribution that overbounds the true error distribution in the vertical axis;

$$d_{major}=\sqrt{\frac{d_x^2+d_y^2}{2}+\sqrt{\left(\frac{d_x^2-d_y^2}{2}\right)^2+d_{xy}^2}}$$

where

$d_x^2=\sum_{i=1}^N s_{x,i}^2\sigma_i^2$ = variance of model distribution that overbounds the true error distribution in the x axis;

$d_y^2=\sum_{i=1}^N s_{y,i}^2\sigma_i^2$ = variance of model distribution that overbounds the true error distribution in the y axis;

$d_{xy}=\sum^N_{i=1} s_{x,i}\,s_{y,i}\,\sigma^2_i$ = covariance of model distribution in the x and y axis;

where

$s_{x,i}$ = the partial derivative of position error in the x-direction with respect to pseudo-range error on the i^{th} satellite;

$s_{y,i}$ = the partial derivative of position error in the y-direction with respect to pseudo-range error on the i^{th} satellite;

$s_{V,i}$ = the partial derivative of position error in the vertical direction with respect to pseudo-range error on the i^{th} satellite; and

$\sigma_{2i} = \sigma_{2i,flt} + \sigma_{2i,UIRE} + \sigma_{2i,air} + \sigma_{2i,tropo}$.

The variances ($\sigma^2_{i,flt}$ and $\sigma^2_{i,UIRE}$) are defined in 3.5.5.6.2 and 3.5.5.6.3.1. The parameters ($\sigma^2_{i,air}$ and $\sigma^2_{i,tropo}$) are determined by the aircraft element (3.5.8.4.2 and 3.5.8.4.3).

The x and y axes are defined to be in the local horizontal plane, and the v axis represents local vertical.

For a general least-squares position solution, the projection matrix S is:

$$S \equiv \begin{bmatrix} S_{x,1} & S_{x,2} & \cdots & S_{x,N} \\ S_{y,1} & S_{y,2} & \cdots & S_{y,N} \\ S_{v,1} & S_{v,2} & \cdots & S_{v,N} \\ S_{t,1} & S_{t,2} & \cdots & S_{t,N} \end{bmatrix} = (G^T \times W \times G)^{-1} \times G^T \times W$$

where

$G_i = [-\cos El_i \cos Az_i \; -\cos El_i \sin Az_i \; -\sin El_i \; 1] = i^{th}$ row of G;

$$W^{-1} = \begin{bmatrix} w_1 & 0 & \cdots & 0 \\ 0 & w_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & & \cdots & w_i \end{bmatrix};$$

El_i = the elevation angle of the i^{th} ranging source (in degrees);
Az_i = the azimuth of the i^{th} ranging source taken counter-clockwise from the x axis in degrees; and
w_i = the inverse weight associated with satellite $i = \sigma^2_i$.

Note 1.— To improve readability, the subscript i *was omitted from the protection matrix's equation.*

Note 2.— For an unweighted least-squares solution, the weighting matrix is an identity matrix ($w_i = 1$).

3.5.5.6.1 *Definition of K values.* The K values are:

$K_{H,NPA} = 6.18$;

$K_{H,PA} = 6.0$; and

$K_{V,PA} = 5.33$.

3.5.5.6.2 *Definition of fast and long-term correction error model*. If fast corrections and long-term correction/GEO ranging parameters are applied, and degradation parameters are applied:

$$\sigma^2_{i,\text{flt}} = \begin{cases} \left[(\sigma_{i,\text{UDRE}})(\delta_{\text{UDRE}}) + \varepsilon_{\text{fc}} + \varepsilon_{\text{rrc}} + \varepsilon_{\text{ltc}} + \varepsilon_{\text{er}}\right]^2, & \text{if } \text{RSS}_{\text{UDRE}} = 0 \text{ (message Type 10)} \\ \left[(\sigma_{i,\text{UDRE}})(\delta_{\text{UDRE}})\right]^2 + \varepsilon^2{}_{\text{fc}} + \varepsilon^2{}_{\text{rrc}} + \varepsilon^2{}_{\text{ltc}} + \varepsilon^2{}_{\text{er}}, & \text{if } \text{RSS}_{\text{UDRE}} = 1 \text{ (message Type10)} \end{cases}$$

where

if using message Type 27, δ_{UDRE} is a region-specific term as defined in section 3.5.4.9,
if using message Type 28, δ_{UDRE} is a satellite-specific term as defined in section 3.5.5.6.2.5,
if using neither message, $\delta_{\text{UDRE}} = 1$.

If fast corrections and long-term corrections/GEO ranging parameters are applied, but degradation parameters are not applied:

$$\sigma^2_{i,\text{flt}} = [(\sigma_{i,\text{UDRE}})\ (\delta_{\text{UDRE}}) + 8\text{m}]^2$$

3.5.5.6.2.1 *Fast correction degradation.* The degradation parameter for fast correction data is:

$$\varepsilon_{\text{fc}} = \frac{a(t - t_u + t_{\text{lat}})^2}{2}$$

where

t = the current time;

t_u = (UDREI_i reference time): if $\text{IODF}_j \neq 3$, the start time of the SNT 1-second epoch that is coincident with the start of the transmission of the message block that contains the most recent UDREI_i data (Type 2 to 6, or Type 24 messages) that matches the IODF_j of the fast correction being used. If $\text{IODF}_j = 3$, the start time of the epoch of the SNT 1-second epoch that is coincident with the start of transmission of the message that contains the fast correction for the i^{th} satellite; and

t_{lat} = (as defined in 3.5.4.7).

Note.— For UDREs broadcast in Type 2 to 5, and Type 24 messages, t_u equals the time of applicability of the fast corrections since they are in the same message. For UDREs broadcast in Type 6 message and if the IODF = 3, t_u also equals the time of applicability of the fast corrections (t_{0f}). For UDREs broadcast in Type 6 message and IODF ≠ 3, t_u is defined to be the time of transmission of the first bit of Type 6 message at the GEO.

3.5.5.6.2.2 *Range rate correction degradation*

3.5.5.6.2.2.1 If the RRC = 0, then $\varepsilon_{\text{rrc}} = 0$.

3.5.5.6.2.2.2 If the RRC ≠ 0 and IODF ≠ 3, the degradation parameter for fast correction data is:

$$\varepsilon_{\text{rrc}} = \begin{cases} 0, & \text{if } (\text{IODF}_{\text{current}} - \text{IODF}_{\text{previous}})\text{MOD}3 = 1 \\ \left(\dfrac{aI_{\text{fc}}}{4} + \dfrac{B_{\text{rrc}}}{\Delta t}\right)(t - t_{0f}), & \text{if } (\text{IODF}_{\text{current}} - \text{IODF}_{\text{previous}})\text{MOD}3 \neq 1 \end{cases}$$

3.5.5.6.2.2.3 If RRC ≠ 0 and IODF = 3, the degradation parameter for range rate data is:

$$\varepsilon_{\text{rrc}} = \begin{cases} 0, & \text{if } \left|\Delta t - \dfrac{I_{\text{fc}}}{2}\right| = 0 \\ \left(\dfrac{a\left|\Delta t - \dfrac{I_{\text{fc}}}{2}\right|}{2} + \dfrac{B_{\text{rrc}}}{\Delta t}\right)(t - t_{0f}), & \text{if } \left|\Delta t - \dfrac{I_{\text{fc}}}{2}\right| \neq 0 \end{cases}$$

Where

t = the current time;

$IODF_{current}$ = IODF associated with most recent fast correction;
$IODF_{previous}$ = IODF associated with previous fast correction;
$\Delta t = t_{i,0f} - t_{i,0f\_previous}$; and
I_{fc} = the user time-out interval for fast corrections.

3.5.5.6.2.3 *Long-term correction degradation*

3.5.5.6.2.3.1 *Core satellite constellation(s)*

3.5.5.6.2.3.1.1 For velocity code = 1, the degradation parameter for long-term corrections of satellite *i* is:

$$\varepsilon_{ltc} = \begin{cases} 0, & \text{if } t_{i,LT} < t < t_{i,LT} + I_{ltc\_v1} \\ C_{ltc\_lsb} + C_{ltc\_v1} \max\left(0, t_{i,LT} - t, t - t_{i,LT} - I_{ltc\_v1}\right), & \text{otherwise} \end{cases}$$

3.5.5.6.2.3.1.2 For velocity code = 0, the degradation parameter for long-term corrections is:

$$\varepsilon_{ltc} = C_{ltc\_v0} \frac{t - t_{ltc}}{I_{lt\text{-}v0}}$$

where

t = the current time;
t_{ltc} = the time of transmission of the first bit of the long-term correction message at the GEO; and
[*x*] = the greatest integer less than *x*.

3.5.5.6.2.3.2 *GEO satellites.* The degradation parameter for long-term corrections is:

$$\varepsilon_{ltc} = \begin{cases} 0, & \text{if } t_{0,GEO} < t < t_{0,GEO} + I_{GEO} \\ C_{geo\_lsb} + C_{geo\_v} \max\left(0, t_{0,GEO} - t, t - t_{0,GEO} - I_{geo}\right), & \text{otherwise} \end{cases}$$

where t = the current time.

Note.— When long-term corrections are applied to a GEO satellite, the long-term correction degradation is applied and the GEO navigation message degradation is not applied.

3.5.5.6.2.4 *Degradation for en-route through non-precision approach*

$$\varepsilon_{er} = \begin{cases} 0, & \text{if neither fast nor long-term corrections have timed out for precision approach/approach with vertical guidance} \\ C_{er}, & \text{if fast or long-term corrections have timed out for precision approach/approach with vertical guidance} \end{cases}$$

3.5.5.6.2.5 *UDRE degradation factor calculated with message Type 28 data*. The δUDRE is:

$$\delta_{UDRE} = \sqrt{I^T \cdot C \cdot I} + \varepsilon_c$$

where

$$\mathrm{I} = \begin{bmatrix} \mathrm{i_x} \\ \mathrm{i_y} \\ \mathrm{i_z} \\ 1 \end{bmatrix},$$

$\begin{bmatrix} \mathrm{i_x} \\ \mathrm{i_y} \\ \mathrm{i_z} \end{bmatrix}$ = the unit vector from the user to the satellite in the WGS-84 ECEF coordinate frame

$\mathrm{C} = \mathrm{R^T} \cdot \mathrm{R}$

$\varepsilon_{\mathrm{C}} = \mathrm{C_{covariance}} \cdot \mathrm{SF}$

$\mathrm{SF} = 2^{\text{scale exponent}-5}$

$\mathrm{R} = \mathrm{E} \cdot \mathrm{SF}$

$$\mathrm{E} = \begin{bmatrix} \mathrm{E_{1,1}} & \mathrm{E_{1,2}} & \mathrm{E_{1,3}} & \mathrm{E_{1,4}} \\ 0 & \mathrm{E_{2,2}} & \mathrm{E_{2,3}} & \mathrm{E_{2,4}} \\ 0 & 0 & \mathrm{E_{3,3}} & \mathrm{E_{3,4}} \\ 0 & 0 & 0 & \mathrm{E_{4,4}} \end{bmatrix}$$

3.5.5.6.3 *Definition of ionospheric correction error model*

3.5.5.6.3.1 *Broadcast ionospheric corrections.* If SBAS-based ionospheric corrections are applied, σ^2_{UIRE} is:

$$\sigma^2_{\mathrm{UIRE}} = \mathrm{F}^2_{\mathrm{pp}} \times \sigma^2_{\mathrm{UIVE}}$$

where

$\mathrm{F_{pp}}$ = (as defined in 3.5.5.5.2);

$$\sigma^2_{\mathrm{UIVE}} = \sum_{n=1}^{4} W_n \cdot \sigma^2_{\mathrm{n,ionogrid}} \text{ or } \sigma^2_{\mathrm{UIVE}} = \sum_{n=1}^{3} W_n \cdot \sigma^2_{\mathrm{n,ionogrid}}$$

using the same ionospheric pierce point weights ($\mathrm{W_n}$) and grid points selected for the ionospheric correction (3.5.5.5).

If degradation parameters are used, for each grid point:

$$\sigma^2_{\mathrm{n,ionogrid}} = \begin{cases} \left(\sigma_{\mathrm{n,GIVE}} + \varepsilon_{\mathrm{iono}}\right)^2, & \text{if } \mathrm{RSS_{iono}} = 0 \text{ (Type 10 message)} \\ \sigma^2_{\mathrm{n,GIVE}} + \varepsilon^2_{\mathrm{iono}}, & \text{if } \mathrm{RSS_{iono}} = 1 \text{ (Type 10 message)} \end{cases}$$

where

$\varepsilon_{\mathrm{iono}} = \mathrm{C_{iono\_step}} \left[\frac{\mathrm{t} - \mathrm{t_{iono}}}{\mathrm{I_{iono}}}\right] + \mathrm{C_{iono\_ramp}} (\mathrm{t} - \mathrm{t_{iono}});$

t = the current time;

$\mathrm{t_{iono}}$ = the time of transmission of the first bit of the ionospheric correction message at the GEO; and

[*x*] = the greatest integer less than *x*.

If degradation parameters are not used, for each grid point:

$$\sigma_{n,ionogrid} = \sigma_{n,GIVE}$$

3.5.5.6.3.2 *Ionospheric corrections.* If SBAS-based ionospheric corrections are not applied, σ^2_{UIRE} is:

$$\sigma_{UIRE}^2 = MAX\left\{\left(\frac{T_{iono}}{5}\right)^2, \left(F_{pp}\cdot\tau_{vert}\right)^2\right\}$$

where

T_{iono} = the ionospheric delay estimated by the chosen model (GPS correction or other model);
F_{pp} = (as defined in 3.5.5.5.2);
$$\tau_{vert} = \begin{cases} 9\text{ m}, & 0 \le |\phi_{pp}| \le 20 \\ 4.5\text{ m}, & 20 < |\phi_{pp}| \le 55\text{; and} \\ 6\text{ m}, & 55 < |\phi_{pp}| \end{cases}$$
ϕ_{pp} = latitude of the ionospheric pierce point.

3.5.6 MESSAGE TABLES

Each SBAS message shall be coded in accordance with the corresponding message format defined in Tables B-37 through B-53. All signed parameters in these tables shall be represented in two's complement, with the sign bit occupying the MSB.

Note.— The range for the signed parameters is smaller than indicated, as the maximum positive value is constrained to be one value less (the indicated value minus the resolution).

Table B-37. Type 0 "Do Not Use" message

Data content	Bits used	Range of values	Resolution
Spare	212	—	—

Table B-38. Type 1 PRN mask message

Data content	Bits used	Range of values	Resolution
For each of 210 PRN code numbers			
Mask value	1	0 or 1	1
IODP	2	0 to 3	1

Note.— All parameters are defined in 3.5.4.1.

Table B-39. Types 2 to 5 fast correction message

Data content	Bits used	Range of values	Resolution
$IODF_j$	2	0 to 3	1
IODP	2	0 to 3	1
For 13 slots			
Fast correction (FC_i)	12	±256.000 m	0.125 m
For 13 slots			
$UDREI_i$	4	(see Table B-29)	(see Table B-29)

Notes.—

1. *The parameters $IODF_j$ and FC_i are defined in 3.5.4.4.2.*
2. *The parameter IODP is defined in 3.5.4.1.*
3. *The parameter $UDREI_i$ is defined in 3.5.4.5.*

Table B-40. Type 6 integrity message

Data content	Bits used	Range of values	Resolution
$IODF_2$	2	0 to 3	1
$IODF_3$	2	0 to 3	1
$IODF_4$	2	0 to 3	1
$IODF_5$	2	0 to 3	1
For 51 satellites (ordered by PRN mask number)			
$UDREI_i$	4	(see Table B-29)	(see Table B -29)

Notes.—

1. *The parameters $IODF_j$ are defined in 3.5.4.4.2.*
2. *The parameter $UDREI_i$ is defined in 3.5.4.5.*

Table B-41. Type 7 fast correction degradation factor message

Data content	Bits used	Range of values	Resolution
System latency (t_{lat})	4	0 to 15 s	1 s
IODP	2	0 to 3	1
Spare	2	----	—
For 51 satellites (ordered by PRN mask number)			
Degradation factor indicator (ai_i)	4	(see Table B-34)	(see Table B-34)

Notes.—

1. *The parameters t_{lat} and ai_i are defined in 3.5.4.7.*
2. *The parameter IODP is defined in 3.5.4.1.*

Table B-42. Type 9 ranging function message

Data content	Bits used	Range of values	Resolution
Reserved	8	—	—
$t_{0,GEO}$	13	0 to 86 384 s	16 s
URA	4	(see Table B-26)	(see Table B-26)
X_G	30	±42 949 673 m	0.08 m
Y_G	30	±42 949 673 m	0.08 m
Z_G	25	±6 710 886.4 m	0.4 m
$\dot{X}$	17	±40.96 m/s	0.000625 m/s
$\dot{Y}$	17	±40.96 m/s	0.000625 m/s
$\dot{Z}$	18	±524.288 m/s	0.004 m/s
$\ddot{X}$	10	± 0.0064 m/s^2	0.0000125 m/s^2
$\ddot{Y}$	10	± 0.0064 m/s^2	0.0000125 m/s^2
$\ddot{Z}_G$	10	± 0.032 m/s^2	0.0000625 m/s^2
a_{Gf0}	12	$\pm 0.9537 \times 10^{-6}$ s	2^{-31} s
a_{Gf1}	8	$\pm 1.1642 \times 10^{-10}$ s/s	2^{-40} s/s

Note.— All parameters are defined in 3.5.4.2.

Table B-43. Type 10 degradation parameter message

Data content	Bits used	Range of values	Resolution
B_{rrc}	10	0 to 2.046 m	0.002 m
$C_{ltc\ lsb}$	10	0 to 2.046 m	0.002 m
$C_{ltc\ v1}$	10	0 to 0.05115 m/s	0.00005 m/s
$I_{ltc\ v1}$	9	0 to 511 s	1 s
$C_{ltc\ v0}$	10	0 to 2.046 m	0.002 m
$I_{ltc\ v0}$	9	0 to 511 s	1 s
$C_{geo\ lsb}$	10	0 to 0.5115 m	0.0005 m
$C_{geo\ v}$	10	0 to 0.05115 m/s	0.00005 m/s
I_{geo}	9	0 to 511 s	1 s
C_{er}	6	0 to 31.5 m	0.5 m
$C_{iono\ step}$	10	0 to 1.023 m	0.001 m
I_{iono}	9	0 to 511 s	1 s
$C_{iono\ ramp}$	10	0 to 0.005115 m/s	0.000005 m/s
RSS_{UDRE}	1	0 or 1	1
RSS_{iono}	1	0 or 1	1
$C_{covariance}$	7	0 to 12.7	0.1
Spare	81	—	—

Note.— All parameters are defined in 3.5.4.7.

Table B-44. Type 12 SBAS network time/UTC message

Data content	Bits used	Range of values	Resolution
A_{1SNT}	24	$\pm 7.45 \times 10^{-9}$ s/s	2^{-50} s/s
A_{0SNT}	32	±1 s	2^{-30} s
t_{0t}	8	0 to 602 112 s	4 096 s
WN_t	8	0 to 255 weeks	1 week
Δt_{LS}	8	±128 s	1 s
WN_{LSF}	8	0 to 255 weeks	1 week
DN	8	1 to 7 days	1 day
Δt_{LSF}	8	±128 s	1 s
UTC standard identifier	3	(see Table B-35)	(see Table B-35)
GPS time-of-week (TOW)	20	0 to 604 799 s	1 s
GPS week number (WN)	10	0 to 1 023 weeks	1 week
Spare	50	—	—

Notes.—
1. All parameters are defined in 3.5.4.8.

Table B-45. Type 17 GEO almanac message

Data content	Bits used	Range of values	Resolution
For each of 3 satellites			
Reserved	2	0	—
PRN code number	8	0 to 210	1
Health and status	8	—	—
$X_{G,A}$	15	±42 598 400 m	2 600 m
$Y_{G,A}$	15	±42 598 400 m	2 600 m
$Z_{G,A}$	9	±6 656 000 m	26 000 m
$\dot{X}_{G,A}$	3	±40 m/s	10 m/s
$\dot{Y}_{G,A}$	3	±40 m/s	10 m/s
$\dot{Z}_{G,A}$	4	±480 m/s	60 m/s
$t_{almanac}$ (applies to all three satellites)	11	0 to 86 336 s	64 s

Note.— All parameters are defined in 3.5.4.3.

Table B-46. Type 18 IGP mask message

Data content	Bits used	Range of values	Resolution
Number of IGP bands	4	0 to 11	1
IGP band identifier	4	0 to 10	1
Issue of data — ionosphere ($IODI_k$)	2	0 to 3	1
For 201 IGPs			
IGP mask value	1	0 or 1	1
Spare	1	—	—

Note.— All parameters are defined in 3.5.4.6.

Table B-47. Type 24 mixed fast/long-term satellite error correction message

Data content	Bits used	Range of values	Resolution
For 6 slots			
Fast correction (FC_i)	12	±256.000 m	0.125 m
For 6 slots			
$UDREI_i$	4	(see Table B-31)	(see Table B-31)
IODP	2	0 to 3	1
Fast correction type identifier	2	0 to 3	1
$IODF_j$	2	0 to 3	1
Spare	4	—	—
Type 25 half-message	106	—	—

Notes.—

1. *The parameters fast correction type identifier, $IODF_j$, and FC_i are defined in 3.5.4.4.2.*
2. *The parameter IODP is defined in 3.5.4.1.*
3. *The parameter $UDREI_i$ is defined in 3.5.4.5.*
4. *The long-term satellite error correction message is divided into two half-messages. The half message for a velocity code = 0 is defined in Table B-48. The half message for a velocity code = 1 is defined in Table B-49.*

Table B-48. Type 25 long-term satellite error correction half message (VELOCITY CODE = 0)

Data content	Bits used	Range of values	Resolution
Velocity Code = 0	1	0	1
For 2 Satellites			
PRN mask number	6	0 to 51	1
Issue of data (IOD_i)	8	0 to 255	1
δx_i	9	±32 m	0.125 m
δy_i	9	±32 m	0.125 m
δz_i	9	±32 m	0.125 m
$\delta a_{i,f0}$	10	$\pm 2^{-22}$ s	2^{-31} s
IODP	2	0 to 3	1
Spare	1	—	—

Notes.—

1. *The parameters PRN mask number and IODP are defined in 3.5.4.1.*
2. *All other parameters are defined in 3.5.4.4.1.*

Table B-49. Type 25 long-term satellite error correction half message (VELOCITY CODE = 1)

Data content	Bits used	Range of values	Resolution
For 1 Satellite			
Velocity Code = 1	1	1	1
PRN mask number	6	0 to 51	1
Issue of data (IOD_i)	8	0 to 255	1
δx_i	11	±128 m	0.125 m
δy_i	11	±128 m	0.125 m
δz_i	11	±128 m	0.125 m
$\delta a_{i,f0}$	11	$\pm 2^{-21}$ s	2^{-31} s
$\delta \dot{x}_i$	8	±0.0625 m/s	2^{-11} m/s
$\delta \dot{y}_i$	8	±0.0625 m/s	2^{-11} m/s
$\delta \dot{z}_i$	8	±0.0625 m/s	2^{-11} m/s
$\delta a_{i,f1}$	8	$\pm 2^{-32}$ s/s	2^{-39} s/s
Time-of-applicability ($t_{i,LT}$)	13	0 to 86 384 s	16 s
IODP	2	0 to 3	1

Notes.—

1. *The parameters PRN mask number and IODP are defined in 3.5.4.1.*
2. *All other parameters are defined in 3.5.4.4.1.*

Table B-50. Type 26 ionospheric delay message

Data content	Bits used	Range of values	Resolution
IGP band identifier	4	0 to 10	1
IGP block identifier	4	0 to 13	1
For each of 15 grid points			
IGP vertical delay estimate	9	0 to 63.875 m	0.125 m
Grid ionospheric vertical error indicator ($GIVEI_i$)	4	(see Table B-33)	(see Table B-33)
$IODI_k$	2	0 to 3	1
Spare	7	—	—

Note.— All parameters are defined in 3.5.4.6.

Table B-51. Type 27 SBAS service message

Data content	Bits used	Range of values	Resolution
Issue of data, service (IODS)	3	0 to 7	1
Number of service messages	3	1 to 8	1
Service message number	3	1 to 8	1
Number of regions	3	0 to 5	1
Priority code	2	0 to 3	1
δUDRE indicator-inside	4	0 to 15	1
δUDRE indicator-outside	4	0 to 15	1
For each of 5 regions			
Coordinate 1 latitude	8	±90°	1°
Coordinate 1 longitude	9	±180°	1°
Coordinate 2 latitude	8	±90°	1°
Coordinate 2 longitude	9	±180°	1°
Region shape	1	—	—
Spare	15	—	—

Note.— All parameters are defined in 3.5.4.9.

Table B-52. Type 63 null message

Data content	Bits used	Range of values	Resolution
Spare	212	—	—

Table B-53. Type 28 clock-ephemeris covariance matrix

Data content	Bits used	Range of values	Resolution
IODP	2	0 to 3	1
For two satellites			
PRN mask number	6	0 to 51	1
Scale exponent	3	0 to 7	1
$E_{1,1}$	9	0 to 511	1
$E_{2,2}$	9	0 to 511	1
$E_{3,3}$	9	0 to 511	1
$E_{4,4}$	9	0 to 511	1
$E_{1,2}$	10	±512	1
$E_{1,3}$	10	±512	1
$E_{1,4}$	10	±512	1
$E_{2,3}$	10	±512	1
$E_{2,4}$	10	±512	1

$E_{3,4}$	10	±512	1

Notes.—

1. *The parameters PRN mask number and IODP are defined in 3.5.4.1.*
2. *All other parameters are defined in 3.5.4.10.*

3.5.7 NON-AIRCRAFT ELEMENTS

Note 1.— Depending on the level of service offered by a particular SBAS, different functions can be implemented as described in Chapter 3, 3.7.3.4.2.

Note 2.— The parameters that are referred to in this section are defined in 3.5.4.

3.5.7.1 *GENERAL*

3.5.7.1.1 *Required data and broadcast intervals*. SBAS shall broadcast the data required for the supported functions as shown in Table B-54. If the SBAS broadcasts data that are not required for a particular function, the requirements for that data supporting other functions shall apply. The maximum interval between broadcasts for all data of each data type provided shall be as defined in Table B-54.

3.5.7.1.2 *SBAS radio frequency monitoring.* The SBAS shall monitor the SBAS satellite parameters shown in Table B-55 and take the indicated action.

Note.— SBAS may broadcast null messages (Type 63 messages) in each time slot for which no other data are broadcast.

3.5.7.1.3 *"Do Not Use".* SBAS shall broadcast a "Do Not Use" message (Type 0 message) when necessary to inform users not to use the SBAS satellite ranging function and its broadcast data.

3.5.7.1.4 The Doppler shift in the GEO satellite signal seen at any fixed location within the GEO footprint for any GEO shall not exceed ±450 Hz.

Note.— This maximum Doppler shift corresponds approximately to the maximum GEO satellite orbit inclination that can be supported by the coding ranges for Type 9 and Type 17 messages.

3.5.7.1.5 *Geostationary orbit (GEO) ranging function parameters.* Each SBAS satellite shall broadcast geostationary orbit (GEO) ranging function parameters (defined in 3.5.4.2).

Note.— It is necessary to broadcast geostationary orbit ranging function parameters even when a ranging function is not provided, so that airborne receivers may implement a positive identification of the broadcasting SBAS satellite. When ranging is not provided, the accuracy of the Type 17 data (and Type 9 data) only needs to support the acquisition of the satellite.

3.5.7.1.5.1 The error in the Doppler shift of a GEO satellite derived from any Type 9 message that has not timed out, with respect to the true GEO Doppler shift seen at any fixed location within the GEO footprint, shall not exceed ±210 Hz.

3.5.7.1.6 *Almanac data.* Each SBAS satellite shall broadcast almanac data (defined in 3.5.4.3) for all SBAS satellites of the same service provider.

3.5.7.1.6.1 The error in the estimated position of the satellite derived from any Type 17 message broadcast within the previous 15 minutes, with respect to the true satellite position, shall not exceed 3 000 km.

3.5.7.1.6.2 The separation distance between the estimated position of the satellite derived from any Type 17 message broadcast within the previous 15 minutes and the position of the satellite derived from the GEO ranging parameters in any Type 9 message that has not timed out shall not exceed 200 km.

3.5.7.1.6.3 The error in the Doppler shift of a GEO satellite derived from any Type 17 message broadcast within the previous 15 minutes, with respect to the true GEO Doppler shift seen at any fixed location within the GEO footprint, shall not exceed ±210 Hz.

3.5.7.1.6.4 SBAS shall not broadcast almanac data for any SBAS satellite from a different service provider for which the position estimated from the almanac data broadcast within the previous 15 minutes would be within 200 km of the position of any of its own GEOs as derived from the GEO ranging parameters from any Type 9 message that has not timed out.

3.5.7.1.6.5 Where the estimated position of a GEO satellite providing a ranging function, derived from the Type 17 message broadcast within the previous 15 minutes, is within 200 km of the position of another GEO satellite of the same service provider, derived from a Type 9 message for this GEO that has not timed out, the GEO UDRE value shall be set sufficiently large to account for the possibility that a user could misidentify the PRN of the GEO providing the ranging function.

3.5.7.1.6.6 The health and status parameter shall indicate the satellite status and the service provider identifier, as defined in 3.5.4.3.

3.5.7.1.6.7 Unused almanac slots in Type 17 messages shall be coded with a PRN code number of “0”.

3.5.7.1.6.8 The service provider shall ensure the correctness of the service provider ID broadcast in any almanac.

3.5.7.2 *Ranging function*. If an SBAS provides a ranging function, it shall comply with the requirements contained in this section in addition to the requirements of 3.5.7.1.

3.5.7.2.1 *Performance requirements*

Note.— See Chapter 3, 3.7.3.4.2.1.

3.5.7.2.2 *Ranging function data*. SBAS shall broadcast ranging function data such that the SBAS satellite position error projected on the line-of-sight to any user in the satellite footprint is less than 256 metres. Each SBAS satellite shall broadcast a URA representing an estimate of the standard deviation of the ranging errors referenced to SNT.

3.5.7.3 *GNSS satellite status function*. If an SBAS provides a satellite status function, it shall also comply with the requirements contained in this section.

Note.— An SBAS may be able to provide integrity on some GPS satellites that are designated either marginal or unhealthy.

3.5.7.3.1 *Performance of satellite status functions*. Given any valid combination of active data, the probability of a horizontal error exceeding the HPL_{SBAS} (as defined in 3.5.5.6) for longer than 8 consecutive seconds shall be less than 10^{-7} in any hour, assuming a user with zero latency.

Note.— Active data is defined to be data that have not timed out per 3.5.8.1.2. This requirement includes core satellite constellation(s) and SBAS failures.

3.5.7.3.2 *PRN mask and Issue of data — PRN (IODP)*. SBAS shall broadcast a PRN mask and IODP (Type 1 message). The PRN mask values shall indicate whether or not data are being provided for each GNSS satellite. The IODP shall change when there is a change in the PRN mask. The change of IODP in Type 1 messages shall occur before the IODP changes in any other message. The IODP in Type 2 to 5, 7, 24, 25 and 28 messages shall equal the IODP broadcast in the PRN mask message (Type 1 message) used to designate the satellites for which data are provided in that message.

Table B-54. Data broadcast intervals and supported functions

Data type	Maximum broadcast interval	Ranging	GNSS satellite status	Basic differential correction	Precise differential correction	Associated message types
Clock-Ephemeris covariance matrix	120 s					28
SBAS in test mode	6 s					0
PRN mask	120 s		R	R	R	1
UDREI	6 s		R*	R	R	2 to 6, 24
Fast corrections	$I_{fc}/2$ (see *Note 4*)		R*	R	R	2 to 5, 24
Long-term corrections	120 s		R*	R	R	24, 25
GEO ranging function data	120 s	R	R	R	R	9
Fast correction degradation	120 s		R*	R	R	7
Degradation parameters	120 s				R	10
Ionospheric grid mask	300 s				R	18
Ionospheric corrections, GIVEI	300 s				R	26
Almanac data	300 s	R	R	R	R	17
Service level	300 s					27

Notes.—

1. *"R" indicates that the data must be broadcast to support the function.*
2. *"R*" indicates special coding as described in 3.5.7.3.3.*
3. *Reserved.*
4. *I_{fc} refers to the PA/APV time-out interval for fast corrections, as defined in Table B-57.*

Table B-55. SBAS radio frequency monitoring

Parameter	Reference	Alarm limit	Required action
Signal power level	Chapter 3, 3.7.3.4.4.3	minimum specified power maximum specified power *(Note 2)*	Cease ranging function (*Note 1*). Cease broadcast.
Modulation	Chapter 3, 3.7.3.4.4.5	Monitor for waveform distortion	Cease ranging function (*Note 1*).
SNT-to-GPS time	Chapter 3, 3.7.3.4.5	N/A (*Note 3*)	Cease ranging function unless σ_{UDRE} reflects error.
Carrier frequency stability	3.5.2.1	N/A (*Note 3*)	Cease ranging function unless σ_{UDRE} reflects error.
Code/frequency coherence	3.5.2.4	N/A (*Note 3*)	Cease ranging function unless σ_{UDRE} reflects error.
Maximum code phase deviation	3.5.2.6	N/A (*Notes 2* and *3*)	Cease ranging function unless σ_{UDRE} reflects error.
Convolutional encoding	3.5.2.9	all transmit messages are erroneous	Cease broadcast.

Notes.—

1. *Ceasing the ranging function is accomplished by broadcasting a URA and σ^2_{UDRE} of "Do Not Use" for that SBAS satellite.*
2. *These parameters can be monitored by their impact on the received signal quality (C/N_0 impact), since that is the impact on the user.*
3. *Alarm limits are not specified because the induced error is acceptable, provided it is represented in the σ^2_{UDRE} and URA parameters. If the error cannot be represented, the ranging function must cease.*

3.5.7.3.2.1 When the PRN mask is changed, SBAS shall repeat the Type 1 message several times before referencing it in other messages to ensure that users receive the new mask.

3.5.7.3.3 *Integrity data*. If SBAS does not provide the basic differential correction function, it shall transmit fast corrections, long-term corrections and fast correction degradation parameters coded to zero for all visible satellites indicated in the PRN mask.

3.5.7.3.3.1 If SBAS does not provide the basic differential correction function, SBAS shall indicate that the satellite is unhealthy ("Do Not Use") if the pseudo-range error exceeds 150 metres.

3.5.7.3.3.2 If SBAS does not provide the basic differential correction function, SBAS shall indicate that the satellite is “Not Monitored” if the pseudo-range error cannot be determined.

3.5.7.3.3.3 If SBAS does not provide the basic differential correction function, SBAS shall transmit a $UDREI_i$ of 13 if the satellite is not “Do Not Use” or “Not Monitored”.

3.5.7.3.3.4 The $IODF_j$ parameter in Type 2 to 5, 6 or 24 messages shall be equal to 3.

3.5.7.4 *Basic differential correction function*. If an SBAS provides a basic differential correction function, it shall comply with the requirements contained in this section in addition to the GNSS satellite status function requirements defined in 3.5.7.3.

3.5.7.4.1 *Performance of basic differential correction function*. Given any valid combination of active data, the probability of a horizontal error exceeding the HPL_{SBAS} (as defined in 3.5.5.6) for longer than 8 consecutive seconds shall be less than 10^{-7} in any hour, assuming a user with zero latency.

Note.— Active data is defined to be data that has not timed out per 3.5.8.1.2. This requirement includes core satellite constellation(s) and SBAS failures.

3.5.7.4.2 *Long-term corrections*. Except for SBAS satellites from the same service provider, SBAS shall determine and broadcast long-term corrections for each visible GNSS satellite (see *Note*) indicated in the PRN mask (PRN mask value equal to “1”). The long-term corrections shall be such that the core satellite constellation(s) satellite position error projected on the line-of-sight to any user in the satellite footprint after application of these long-term corrections is less than 256 metres. For each GPS satellite, the broadcast IOD shall match both the GPS IODE and 8 LSBs of IODC associated with the clock and ephemeris data used to compute the corrections (3.1.1.3.1.4 and 3.1.1.3.2.2). Upon transmission of a new ephemeris by a GPS satellite, SBAS shall continue to use the old ephemeris to determine the fast and long-term error corrections for at least 2 minutes and not more than 4 minutes.

Note.— The criteria for satellite visibility include the locations of reference stations and the achieved mask angle at those locations.

3.5.7.4.2.1 **Reserved.**

3.5.7.4.3 *Fast corrections.* SBAS shall determine fast corrections for each visible GNSS satellite indicated in the PRN mask (PRN mask value equal to “1”). Unless the IODF = 3, each time any fast correction data in Type j (j = 2, 3, 4 or 5) message changes, the $IODF_j$ shall sequence “0, 1, 2, 0, ...”.

Note.— If there is an alarm condition, the $IODF_j$ may equal 3 (see 3.5.7.4.5).

3.5.7.4.4 *Reserved.*

3.5.7.4.5 *Integrity data*. For each satellite for which corrections are provided, SBAS shall broadcast integrity data ($UDREI_i$ and, optionally, Type 27 or 28 message data to calculate δUDRE) such that the integrity requirement in 3.5.7.4.1 is met. If the fast corrections or long-term corrections exceed their coding range, SBAS shall indicate that the satellite is unhealthy (“Do Not Use”). If $\sigma^2_{i,UDRE}$ cannot be determined, SBAS shall indicate that the satellite is “Not Monitored”.

If Type 6 message is used to broadcast $\sigma^2_{i,UDRE}$, then:

a) the $IODF_j$ shall match the $IODF_j$ for the fast corrections received in Type j message to which the $\sigma^2_{i,UDRE}$ apply; or

b) the $IODF_j$ shall equal 3 if the $\sigma^2_{i,UDRE}$ apply to all valid fast corrections received in Type j message which have not timed out.

3.5.7.4.6 *Degradation data*. SBAS shall broadcast degradation parameters (Type 7 message) to indicate the applicable time out interval for fast corrections and ensure that the integrity requirement in 3.5.7.4.1 is met.

3.5.7.5 *Precise differential correction function*. If SBAS provides a precise differential correction function, it shall comply with the requirements contained in this section in addition to the basic differential correction function requirements in 3.5.7.4.

3.5.7.5.1 *Performance of precise differential correction function*. Given any valid combination of active data, the probability of an out-of-tolerance condition for longer than the relevant time-to-alert shall be less than 2×10^{-7} during any approach, assuming a user with zero latency. The time-to-alert shall be 5.2 seconds for an SBAS that supports precision approach operations, and 8 seconds for an SBAS that supports APV or NPA operations. An out-of-tolerance condition shall be defined as a horizontal error exceeding the HPL_{SBAS} or a vertical error exceeding the VPL_{SBAS} (as defined in 3.5.5.6). When an out-of-tolerance condition is detected, the resulting alert message (broadcast in a Type 2 to 5 and 6, 24, 26 or 27 messages) shall be repeated three times after the initial notification of the alert condition for a total of four times in 4 seconds.

Note 1.— Active data is defined to be data that has not timed out per 3.5.8.1.2. This requirement includes core satellite constellation(s) and SBAS failures.

Note 2.— Subsequent messages can be transmitted at the normal update rate.

3.5.7.5.2 *Ionospheric grid point (IGP) mask*. SBAS shall broadcast an IGP mask and $IODI_k$ (up to 11 Type 18 messages, corresponding to the 11 IGP bands). The IGP mask values shall indicate whether or not data are being provided for each IGP. If IGP Band 9 is used, then the IGP mask values for IGPs north of 55°N in Bands 0 through 8 shall be set to “0”. If IGP Band 10 is used, then the IGP mask values for IGPs south of 55°S in Bands 0 through 8 shall be set to “0”. The $IODI_k$ shall change when there is a change of IGP mask values in the k^{th} band. The new IGP mask shall be broadcast in a Type 18 message before it is referenced in a related Type 26 message. The $IODI_k$ in Type 26 message shall equal the $IODI_k$ broadcast in the IGP mask message (Type 18 message) used to designate the IGPs for which data are provided in that message.

3.5.7.5.2.1 Reserved.

3.5.7.5.3 *Ionospheric corrections*. SBAS shall broadcast ionospheric corrections for the IGPs designated in the IGP mask (IGP mask values equal to “1”).

3.5.7.5.4 *Ionospheric integrity data*. For each IGP for which corrections are provided, SBAS shall broadcast GIVEI data such that the integrity requirement in 3.5.7.5.1 is met. If the ionospheric correction or $\sigma^2_{i,GIVE}$ exceed their coding range, SBAS shall indicate the status “Do Not Use” (designated in the correction data, 3.5.4.6) for the IGP. If $\sigma^2_{i,GIVE}$ cannot be determined, SBAS shall indicate that the IGP is “Not Monitored” (designated in the GIVEI coding).

3.5.7.5.5 *Degradation data*. SBAS shall broadcast degradation parameters (Type 10 message) such that the integrity requirement in 3.5.7.5.1 is met.

3.5.7.6 *OPTIONAL FUNCTIONS*

3.5.7.6.1 *Timing data*. If UTC time parameters are broadcast, they shall be as defined in 3.5.4.8 (Type 12 message).

3.5.7.6.2 *Service indication*. If service indication data are broadcast, they shall be as defined in 3.5.4.9 (Type 27 message) and Type 28 messages shall not be broadcast. The IODS in all Type 27 messages shall increment when there is a change in any Type 27 message data.

3.5.7.6.3 *Clock-ephemeris covariance matrix*. If clock-ephemeris covariance matrix data are broadcast, they shall be broadcast for all monitored satellites as defined in 3.5.4.10 (Type 28 message) and Type 27 messages shall not be broadcast.

3.5.7.7 *MONITORING*

3.5.7.7.1 *SBAS radio frequency monitoring.* The SBAS shall monitor the SBAS satellite parameters shown in Table B-55 and take the indicated action.

Note.— In addition to the radio frequency monitoring requirements in this section, it will be necessary to make special provisions to monitor pseudo-range acceleration specified in Chapter 3, 3.7.3.4.2.1.5, and carrier phase noise specified in 3.5.2.2 and correlation loss in 3.5.2.5, unless analysis and testing shows that these parameters cannot exceed the stated limits.

3.5.7.7.2 *Data monitoring.* SBAS shall monitor the satellite signals to detect conditions that will result in improper operation of differential processing for airborne receivers with the tracking performance defined in Attachment D, 8.11.

3.5.7.7.2.1 The ground subsystem shall use the strongest correlation peak in all receivers used to generate the pseudorange corrections.

3.5.7.7.2.2 The ground subsystem shall also detect conditions that cause more than one zero crossing for airborne receivers that use the Early-Late discriminator function as defined in Attachment D, 8.11.

3.5.7.7.2.3 The monitor action shall be to set UDRE to “Do Not Use” for the satellite.

3.5.7.7.2.4 SBAS shall monitor all active data that can be used by any user within the service area.

3.5.7.7.2.5 SBAS shall raise an alarm within 5.2 seconds if any combination of active data and GNSS signals-in-space results in an out-of-tolerance condition for precision approach (3.5.7.5.1).

3.5.7.7.2.6 SBAS shall raise an alarm within 8 seconds if any combination of active data and GNSS signals-in-space results in an out-of-tolerance condition for en-route through APV I (3.5.7.4.1).

Note.— The monitoring applies to all failure conditions, including failures in core satellite constellation(s) or SBAS satellites. This monitoring assumes that the aircraft element complies with the requirements of RTCA/DO-229D with Change 1, except as superseded by 3.5.8 and Attachment D, 8.11.

3.5.7.8 *Robustness to core satellite constellation(s) failures*. Upon occurrence of a core satellite constellation(s) satellite anomaly, SBAS shall continue to operate normally using the available healthy satellite signals that can be tracked.

3.5.8 AIRCRAFT ELEMENTS

Note 1.— The parameters that are referred to in this section are defined in 3.5.4.

Note 2.— Some of the requirements of this section may not apply to equipment that integrates additional navigation sensors, such as equipment that integrates SBAS with inertial navigation sensors.

3.5.8.1 *SBAS-capable GNSS receiver*. Except as specifically noted, the SBAS-capable GNSS receiver shall process the signals of the SBAS and meet the requirements specified in 3.1.3.1 (GPS receiver). Pseudo-range measurements for each satellite shall be smoothed using carrier measurements and a smoothing filter which deviates less than 0.25 metre within 200 seconds after initialization, relative to the steady-state response of the filter defined in 3.6.5.1 in the presence of drift between the code phase and integrated carrier phase of up to 0.018 metre per second.

3.5.8.1.1 *GEO satellite acquisition*. The receiver shall be able to acquire and track GEO satellites for which a stationary receiver at the user receiver location would experience a Doppler shift as large as ±450 Hz.

3.5.8.1.2 *Conditions for use of data*. The receiver shall use data from an SBAS message only if the CRC of this message has been verified. Reception of a Type 0 message from an SBAS satellite shall result in deselection of that satellite for at least one minute and all data from that satellite shall be discarded, except that there is no requirement to discard data from Type 12 and Type 17 messages. For GPS satellites, the receiver shall apply long-term corrections only if the IOD matches both the IODE and 8 least significant bits of the IODC.

Note 1.— For SBAS satellites, there is no mechanism that links GEO ranging function data (Type 9 message) and longterm corrections.

Note 2.— This requirement does not imply that the receiver has to stop tracking the SBAS satellite.

3.5.8.1.2.1 *SBAS satellite identification.* Upon acquisition or re-acquisition of an SBAS satellite, the receiver shall not use SBAS satellite data unless the calculated separation between the satellite position derived from its GEO ranging function parameters and the satellite position derived from the almanac message most recently received from the same service provider within the last 15 minutes is less than 200 km.

Note.— This check ensures that a receiver will not mistake one SBAS satellite for another due to cross-correlation during acquisition or re-acquisition.

3.5.8.1.2.2 The receiver shall use integrity or correction data only if the IODP associated with that data matches the IODP associated with the PRN mask.

3.5.8.1.2.3 The receiver shall use SBAS-provided ionospheric data (IGP vertical delay estimate and GIVEI_i) only if the IODI_k associated with that data in a Type 26 message matches the IODI_k associated with the relevant IGP band mask transmitted in a Type 18 message.

3.5.8.1.2.4 The receiver shall use the most recently received integrity data for which the IODF_j equals 3 or the IODF_j matches the IODF_j associated with the fast correction data being applied (if corrections are provided).

3.5.8.1.2.5 The receiver shall apply any regional degradation to the $\sigma^2_{i,\text{UDRE}}$ as defined by a Type 27 service message. If a Type 27 message with a new IODS indicates a higher δ_{UDRE} for the user location, the higher δ_{UDRE} shall be applied immediately. A lower δ_{UDRE} in a new Type 27 message shall not be applied until the complete set of messages with the new IODS has been received.

3.5.8.1.2.6 The receiver shall apply satellite-specific degradation to the $\sigma^2_{i,\text{UDRE}}$ as defined by a Type 28 clockephemeris covariance matrix message. The δ_{UDRE} derived from a Type 28 message with an IODP matching that of the PRN mask shall be applied immediately.

3.5.8.1.2.7 In the event of a loss of four successive SBAS messages during an SBAS-based approach operation with a HAL of 40 m or a VAL of 50 m or less, the receiver shall invalidate all UDREI data from that SBAS satellite.

3.5.8.1.2.8 The receiver shall not use a broadcast data parameter after it has timed out as defined in Table B-56.

3.5.8.1.2.9 The receiver shall not use a fast correction if Δt for the associated RRC exceeds the time-out interval for fast corrections, or if the age of the RRC exceeds $8\Delta t$.

3.5.8.1.2.10 The calculation of the RRC shall be reinitialized if a “Do Not Use” or “Not Monitored” indication is received for that satellite.

3.5.8.1.2.11 For SBAS-based precision approach or APV operations, the receiver shall only use satellites with elevation angles at or above 5 degrees.

3.5.8.1.2.12 The receiver shall no longer support SBAS-based precision approach or APV operation using a particular satellite if the $UDREI_i$ received is greater than or equal to 12.

Table B-56. Data time-out intervals

Data	Associated message types	En-route, terminal, NPA time-out	Precision approach, APV time-out
Clock-ephemeris covariance matrix	28	360	240
SBAS in test mode	0	N/A	N/A
PRN mask	1	600 s	600 s
UDREI	2 to 6, 24	18 s	12 s
Fast corrections	2 to 5, 24	(see Table B-57)	(see Table B-57)
Long-term corrections	24, 25	360 s	240 s
GEO ranging function data	9	360 s	240 s
Fast correction degradation	7	360 s	240 s
Degradation parameters	10	360 s	240 s
Ionospheric grid mask	18	1 200 s	1 200 s
Ionospheric corrections, GIVEI	26	600 s	600 s
Timing data	12	86 400 s	86 400 s
Almanac data	17	None	None
Service level	27	86 400 s	86 400 s

Note.— The time-out intervals are defined from the end of the reception of a message.

Table B-57. Fast correction time-out interval evaluation

Fast correction degradation factor indicator (ai_i)	NPA time-out interval for fast corrections (I_{fc})	PA/APV time-out interval for fast corrections (I_{fc})
0	180 s	120 s
1	180 s	120 s
2	153 s	102 s
3	135 s	90 s
4	135 s	90 s
5	117 s	78 s
6	99 s	66 s
7	81 s	54 s
8	63 s	42 s
9	45 s	30 s
10	45 s	30 s
11	27 s	18 s
12	27 s	18 s
13	27 s	18 s
14	18 s	12 s

15	18 s	12 s

3.5.8.2 *Ranging function*

3.5.8.2.1 *Precision approach and APV operations*. The root-mean-square (1 sigma) of the total airborne error contribution to the error in a corrected pseudo-range for an SBAS satellite at the minimum received signal power level (Chapter 3, 3.7.3.4.4.3) under the worst interference environment as defined in 3.7 shall be less than or equal to 1.8 metres, excluding multipath effects, tropospheric and ionospheric residual errors.

Note.— The aircraft element will bound the errors caused by multipath and troposphere (3.5.8.4.1). For the purpose of predicting service, the multipath error is assumed to be less than 0.6 metres (1 sigma).

3.5.8.2.2 *Departure, en-route, terminal, and non-precision approach operations*. The root-mean-square (1 sigma) of the total airborne contribution to the error in a corrected pseudo-range for an SBAS satellite at the minimum received signal power level (Chapter 3, 3.7.3.4.4.3) under the worst interference environment as defined in 3.7 shall be less than or equal to 5 metres, excluding multipath, tropospheric and ionospheric errors.

3.5.8.2.3 *SBAS satellite position*

3.5.8.2.3.1 *Position computation*. The receiver shall decode Type 9 message and determine the code phase offset and position (X_G, Y_G, Z_G) of the SBAS satellite.

3.5.8.2.3.2 *SBAS satellite identification*. The receiver shall discriminate between SBAS satellites.

Note.— This requirement applies to false acquisition of a satellite due to cross-correlation.

3.5.8.2.4 *Almanac data*

3.5.8.2.4.1 The almanac data provided by the SBAS shall be used for acquisition.

Note.— Health and status information provided in the GEO almanac data does not override or invalidate data provided in other SBAS messages. The use of bits 0 to 2 by airborne equipment is optional; there are no requirements covering their usage.

3.5.8.3 *GNSS satellite status function*. The receiver shall exclude satellites from the position solution if they are identified as "Do Not Use" by SBAS. If SBAS-provided integrity is used, the receiver shall not be required to exclude GPS satellites based on the GPS-provided ephemeris health flag as required in 3.1.3.1.1.

Note 1.— In the case of a satellite designated marginal or unhealthy by the core satellite constellation(s) health flag, SBAS may be able to broadcast ephemeris and clock corrections that will allow the user to continue using the satellite.

Note 2.— If satellites identified as "Not Monitored" by SBAS are used in the position solution, integrity is not provided by SBAS. ABAS or GBAS may be used to provide integrity, if available.

3.5.8.4 *BASIC AND PRECISE DIFFERENTIAL FUNCTIONS*

3.5.8.4.1 *Core satellite constellation(s) ranging accuracy.* The root-mean-square (1 sigma) of the total airborne contribution to the error in a corrected pseudo-range for a GPS satellite at the minimum and maximum received signal power level (Chapter 3, 3.7.3.1.7.4) under the worst interference environment as defined in 3.7 shall be less than or equal to 0.36 metres for minimum signal level and 0.15 metres for maximum signal level, excluding multipath effects, tropospheric and ionospheric residual errors.

3.5.8.4.2 *Precision approach and APV operations*

3.5.8.4.2.1 The receiver shall obtain correction and integrity data for all satellites in the position solution from the same SBAS signal (PRN code).

3.5.8.4.2.2 The receiver shall compute and apply long-term corrections, fast corrections, range rate corrections and the broadcast ionospheric corrections.

3.5.8.4.2.3 The receiver shall use a weighted-least-squares position solution.

3.5.8.4.2.4 The receiver shall apply a tropospheric model such that residual pseudo-range errors have a mean value (μ) less than 0.15 metres and a 1 sigma deviation less than 0.07 metres.

Note.— A model was developed that meets this requirement. Guidance is provided in Attachment D, 6.5.4.

3.5.8.4.2.5 The receiver shall compute and apply horizontal and vertical protection levels defined in 3.5.5.6. In this computation, $\sigma_{i,tropo}$ shall be:

$$\frac{1.001}{\sqrt{0.002001 + \sin^2(\theta_i)}} \times 0.12\ \mathrm{m}$$

where θ_i is the elevation angle of the i^{th} satellite.

In addition, $\sigma_{i,air}$ shall satisfy the condition that a normal distribution with zero mean and a standard deviation equal to $\sigma_{i,air}$ bounds the error distribution for residual aircraft pseudo-range errors as follows:

$$\int_{y}^{\infty} f_n(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \geq 0 \text{ and}$$

$$\int_{-\infty}^{-y} f_n(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \geq 0$$

where

$f_i(x)$ = probability density function of the residual aircraft pseudo-range error and

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{t^2}{2}} dt$$

Note.— The standard allowance for airborne multipath defined in 3.6.5.5.1 may be used to bound the multipath errors.

3.5.8.4.2.6 The parameters that define the approach path for a single precision approach or APV shall be contained in the FAS data block.

Note 1.— The FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). The local level plane for the approach is a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). Local vertical for the approach is normal to the WGS-84 ellipsoid at the LTP/FTP. The glide path intercept point (GPIP) is where the final approach path intercepts the local level plane.

Note 2.— For SBAS, FAS data blocks are stored in airborne databases. The format of the data for validation of a cyclic redundancy check is shown in Attachment D, 6.6. It differs from the GBAS FAS data block in 3.6.4.5.

3.5.8.4.2.6.1 FAS data block parameters shall be as follows (see Table B-57A):

Operation type: straight-in approach procedure or other operation types.

Coding: 0 = straight-in approach procedure
1 to 15 = spare

SBAS service provider ID: indicates the service provider associated with this FAS data block.

Coding: See Table B-27.
14 = FAS data block is to be used with GBAS only.
15 = FAS data block can be used with any SBAS service provider.

Airport ID: the three- or four-letter designator used to designate an airport.

Coding: Each character is coded using the lower 6 bits of its IA-5 representation. For each character, b_1 is transmitted first, and 2 zero bits are appended after b_6, so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 “space” are used. The rightmost character is transmitted first. For a threecharacter airport ID, the rightmost (first transmitted) character shall be IA-5 “space”.

Runway number: the runway orientation, point-in-space final approach course, or SBAS circling only procedure course rounded to the nearest 10 degrees and truncated to two characters.

Coding: 01 to 36 = runway number

Note.— For heliport operations, the runway number value is the integer nearest to one tenth of the final approach course, except when that integer is zero, in which case the runway number is 36.

Runway letter: the one-letter designator used, as necessary, to differentiate between parallel runways.

Coding: 0 = no letter
1 = R (right)
2 = C (centre)
3 = L (left)

Approach performance designator: this field is not used by SBAS.

Table B-57A. Final approach segment (FAS) data block

Data content	Bits used	Range of values	Resolution
Operation type	4	0 to 15	1
SBAS service provider ID	4	0 to 15	1
Airport ID	32	—	—
Runway number	6	01 to 36	1
Runway letter	2	—	—
Approach performance designator	3	0 to 7	1
Route indicator	5	—	—
Reference path data selector	8	0 to 48	1
Reference path identifier	32	—	—
LTP/FTP latitude	32	±90.0°	0.0005 arcsec
LTP/FTP longitude	32	±180.0°	0.0005 arcsec
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m
ΔFPAP latitude	24	±1.0°	0.0005 arcsec
ΔFPAP longitude	24	±1.0°	0.0005 arcsec
Approach TCH (*Note 1*)	15	0 to 1 638.35 m or 0 to 3 276.7 ft	0.05 m or 0.1 ft
Approach TCH units selector	1	—	—
Glide path angle (GPA)	16	0 to 90.0°	0.01°
Course width	8	80 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2 032 m	8 m
Horizontal alert limit (HAL)	8	0 to 51.0 m	0.2 m
Vertical alert limit (VAL) (*Note 2*)	8	0 to 51.0 m	0.2 m
Final approach segment CRC	32		—

Note 1.— Information can be provided in either feet or metres as indicated by the approach TCH unit selector.

Note 2.— A VAL of 0 indicates that the vertical deviations cannot be used (i.e., a lateral only approach). This does not preclude providing advisory vertical guidance on such approaches, refer to FAA AC 20-138.

Route indicator: a “blank” or the one-letter identifier used to differentiate between multiple procedures to the same runway end.

Note.— Procedures are considered to be different even if they only differ by the missed approach segment.

Coding: The letter is coded using bits b_1 through b_5 of its IA-5 representation. Bit b_1 is transmitted first. Only upper case letters, excluding “I” and “O”, or IA-5 “space” (blank) are used. Blank indicates that there is only one procedure to the runway end. For multiple procedures to the same runway end, the route indicator is coded using a letter starting from Z and moving backward in the alphabet for additional procedures.

Reference path data selector (RPDS): this field is not used by SBAS.

Reference path identifier (RPI): four characters used to uniquely designate the reference path. The four characters consist of three alphanumeric characters plus a blank or four alphanumeric characters.

Note.— The best industry practice matches the 2nd and 3rd character encoding to the encoded runway number. The last character is a letter starting from A or a “blank.”

Coding: Each character is coded using bits b_1 through b_6 of its IA-5 representation. For each character, b_1 is transmitted first, and 2 zero bits are appended after b_6 so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 “space” are used. The rightmost character is transmitted first. For a threecharacter reference path identifier, the rightmost (first transmitted) character shall be IA-5 “space”.

Note.— The LTP/FTP is a point over which the FAS path passes at a height above the LTP/FTP height specified by the TCH.

LTP/FTP latitude: the latitude of the LTP/FTP point in arc seconds.

Coding: positive value denotes north latitude.
negative value denotes south latitude.

LTP/FTP longitude: the longitude of the LTP/FTP point in arc seconds.

Coding: positive value denotes east longitude.
negative value denotes west longitude.

LTP/FTP height: the height of the LTP/FTP above the WGS-84 ellipsoid.

Coding: This field is coded as an unsigned fixed-point number with an offset of –512 metres. A value of zero in this field places the LTP/FTP 512 metres below the earth ellipsoid.

Note.— The FPAP is a point at the same height as the LTP/FTP that is used to define the alignment of the approach. The origin of angular deviations in the lateral direction is defined to be 305 metres (1 000 ft) beyond the FPAP along the lateral FAS path. For an approach aligned with the runway, the FPAP is at or beyond the stop end of the runway.

ΔFPAP latitude: the difference of latitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value denotes the FPAP latitude north of LTP/FTP latitude.
Negative value denotes the FPAP latitude south of the LTP/FTP latitude.

ΔFPAP longitude: the difference of longitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value indicates the FPAP longitude east of LTP/FTP longitude.

Negative value indicates the FPAP longitude west of LTP/FTP longitude.

Approach TCH: the height of the FAS path above the LTP/FTP defined in either feet or metres as indicated by the TCH units selector.

Approach TCH units selector: the units used to describe the TCH.

Coding: 0 = feet
1 = metres

Glide path angle (GPA): the angle of the FAS path with respect to the horizontal plane tangent to the WGS-84 ellipsoid at the LTP/FTP.

Course width: the lateral displacement from the path defined by the FAS at the LTP/FTP at which full-scale deflection of a course deviation indicator is attained.

Coding: This field is coded as an unsigned fixed-point number with an offset of 80 metres. A value of zero in this field indicates a course width of 80 metres at the LTP/FTP.

ΔLength offset: the distance from the stop end of the runway to the FPAP.

Coding: 1111 1111 = not provided

HAL: Horizontal alert limit to be used during the approach in metres.

VAL: Vertical alert limit to be used during the approach in metres.

Final approach segment CRC: the 32-bit CRC appended to the end of each FAS data block in order to ensure approach data integrity. The 32-bit final approach segment CRC shall be calculated in accordance with 3.9. The length of the CRC code shall be k = 32 bits.

The CRC generator polynomial shall be:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^{8} + x^{7} + x^{5} + x^{3} + x + 1$$

The CRC information field, M(x), shall be:

$$M(x)=\sum_{i=1}^{288} m_i\, x^{288-i} = m_1 x^{287} + m_2 x^{286} + \ldots + m_{288} x^0$$

M(x) shall be formed from all bits of the associated FAS data block, excluding the CRC. Bits shall be arranged in the order transmitted, such that m_1 corresponds to the LSB of the operation type field, and m_{288} corresponds to the MSB of the Vertical Alert Limit (VAL) field. The CRC shall be ordered such that r_1 is the LSB and r_{32} is the MSB.

3.5.8.4.2.6.2 For precision approach and APV operations, the service provider ID broadcast Type 17 message shall be identical to the service provider ID in the FAS data block, except if ID equals 15 in the FAS data block.

Note.— If the service provider ID in the FAS data block equals 15, then any service provider can be used. If the service provider ID in the FAS data block equals 14, then SBAS precise differential corrections cannot be used for the approach.

3.5.8.4.2.6.3 *SBAS FAS data points accuracy.* The survey error of all the FAS data points, relative to WGS-84, shall be less than 0.25 metres vertical and 1 metre horizontal.

3.5.8.4.3 *Departure, en-route, terminal, and non-precision approach operations*

3.5.8.4.3.1 The receiver shall compute and apply long-term corrections, fast corrections and range rate corrections.

3.5.8.4.3.2 The receiver shall compute and apply ionospheric corrections.

Note.— Two methods of computing ionospheric corrections are provided in 3.1.2.4 and 3.5.5.5.2.

3.5.8.4.3.3 The receiver shall apply a tropospheric model such that residual pseudo-range errors have a mean value (μ) less than 0.15 metres and a standard deviation less than 0.07 metres.

Note.— A model was developed that meets this requirement. Guidance is provided in Attachment D, 6.5.4.

3.5.8.4.3.4 The receiver shall compute and apply horizontal and vertical protection levels as defined in 3.5.5.6. In this computation, σ_{tropo} shall be obtained either from the formula in 3.5.8.4.2.5, which can be used for elevation angles not less than 4 degrees, or from the alternate formula below, which can be used for elevation angles not less than 2 degrees:

$$\frac{1.001}{\sqrt{0.002001+\sin^2(\theta_i)}} \times (1 + 0.015 \times (\max(0, 4-\theta_i))^2) \times 0.12 \text{ m}$$

where θ_i is the elevation angle of the i^{th} satellite.

In addition, $\sigma_{i,air}$ shall satisfy the condition that a normal distribution with zero mean and standard deviation equal to $\sigma_{i,air}$ bounds the error distribution for residual aircraft pseudo-range errors as follows:

$$\int_y^\infty f_i(x)dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0 \text{ and}$$

$$\int_{-\infty}^{-y} f_i(x)dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0$$

where

$f_i(x)$ = probability density function of the residual aircraft pseudo-range error and

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^\infty e^{-\frac{t^2}{2}}dt$$

Note.— The standard allowance for airborne multipath defined in 3.6.5.5.1 may be used to bound the multipath errors.

3.5.8.4.4 For departure, en-route, terminal, and non-precision approach operations, the receiver shall use the broadcast ionospheric corrections, when available, and a tropospheric model with performance equal to that specified in 3.5.8.4.3.

3.5.9 INTERFACE BETWEEN SBAS

Note.— Guidance material on the interface between different SBAS service providers is given in Attachment D, 6.3.

3.6 Ground-based augmentation system (GBAS) and ground-based regional augmentation system (GRAS)

3.6.1 GENERAL

The GBAS shall consist of a ground subsystem and an aircraft subsystem. The GBAS ground subsystem shall provide data and corrections for the GNSS ranging signals over a digital VHF data broadcast to the aircraft subsystem. The GRAS ground subsystem shall consist of one or more GBAS ground subsystems.

Note.— Guidance material is provided in Attachment D, 7.1.

3.6.1.1 *GBAS service types*. A GBAS ground subsystem shall support either the positioning service, approach service or both types of service.

Note 1.— Service types refers to a matched set of ground and airborne functional and performance requirements that ensure that quantifiable navigation performance is achieved by the airborne equipment. Guidance material concerning service types is given in Attachment D, 7.1.

Note 2.— GBAS ground facilities are characterized by a GBAS facility classification (GFC). Many GBAS performance and functional requirements depend on the GFC. These SARPs are organized according to which requirements apply for a given facility classification element (i.e. the facility approach service type (FAST) letter, the facility polarization, etc.). Guidance material concerning facility classifications is given in Attachment D, 7.1.4.1.

3.6.1.2 All GBAS ground subsystems shall comply with the requirements of 3.6.1, 3.6.2, 3.6.3, 3.6.4, 3.6.6 and 3.6.7, unless otherwise stated. A FAST D ground subsystem shall comply with all FAST C requirements in addition to the specific FAST D requirements.

3.6.2 RF CHARACTERISTICS

3.6.2.1 *Carrier frequency stability*. The carrier frequency of the data broadcast shall be maintained within ±0.0002 per cent of the assigned frequency.

3.6.2.2 *Bit-to-phase-change encoding*. GBAS messages shall be assembled into symbols, each consisting of 3 consecutive message bits. The end of the message shall be padded by 1 or 2 fill bits if necessary to form the last 3-bit symbol of the message. Symbols shall be converted to D8PSK carrier phase shifts ($\Delta\varphi_k$) in accordance with Table B-58.

Note.— The carrier phase for the k^{th} *symbol* (φ_k) *is given by:* $\varphi_k = \varphi_{k-1} + \Delta\varphi_k$. *The D8PSK signal may be produced as shown in Figure B-19 by combining two quadrature RF signals which are independently suppressed-carrier amplitudemodulated by base band filtered impulses. A positive increase in* $\Delta\varphi_k$ *represents a counterclockwise rotation in the complex I-Q plane of Figure B-19.*

3.6.2.3 *Modulation wave form and pulse shaping filters*. The output of differential phase encoder shall be filtered by a pulse shaping filter whose output, s(t), is described as follows:

$$s(t) = \sum_{k=-\infty}^{k=\infty} e^{j\phi_k} h\,(t - kT)$$

where

h = the impulse response of the raised cosine filter; φ_k = (as defined in 3.6.2.2);
t = time; and
T = the duration of each symbol = 1/10 500 second.

This pulse shaping filter shall have a nominal complex frequency response of a raised-cosine filter with α = 0.6. The time response, h(t), and frequency response, H(f), of the base band filters shall be as follows:

$$h(t)=\frac{\sin\left(\frac{\pi t}{T}\right)\cos\left(\frac{\pi\alpha t}{T}\right)}{\frac{\pi t}{T}\left[1-\left(\frac{2\alpha t}{T}\right)^{2}\right]}$$

$$H(f)=\begin{cases} 1 & \text{for} \quad 0 \le f < \frac{1-\alpha}{2T} \\ \frac{1-\sin\left(\frac{\pi}{2\alpha}(2fT-1)\right)}{2} & \text{for} \quad \frac{1-\alpha}{2T} \le f \le \frac{1+\alpha}{2T} \\ 0 & \text{for} \quad f > \frac{1+\alpha}{2T} \end{cases}$$

The output s(t) of the pulse shaping filter shall modulate the carrier.

3.6.2.4 *Error vector magnitude.* The error vector magnitude of the transmitted signal shall be less than 6.5 per cent root-mean-square (1 sigma).

3.6.2.5 *RF data rate*. The symbol rate shall be 10 500 symbols per second ±0.005 per cent, resulting in a nominal bit rate of 31 500 bits per second.

Table B-58. Data encoding

Message bits			Symbol phase shift
I_{3k-2}	I_{3k-1}	I_{3k}	$\Delta\varphi_k$
0	0	0	$0\pi/4$
0	0	1	$1\pi/4$
0	1	1	$2\pi/4$
0	1	0	$3\pi/4$
1	1	0	$4\pi/4$
1	1	1	$5\pi/4$
1	0	1	$6\pi/4$
1	0	0	$7\pi/4$

Note.— I_j is the j^{th} bit of the burst to be transmitted, where I_1 is the first bit of the training sequence.

3.6.2.6 *Emissions in unassigned time slots*. Under all operating conditions, the maximum power over a 25 kHz channel bandwidth, centred on the assigned frequency, when measured over any unassigned time slot, shall not exceed –105 dBc referenced to the authorized transmitter power.

Note.— The –105 dBc may not protect reception of emissions in a slot assigned to another desired transmitter for receivers within 80 metres from the undesired transmitting antenna.

3.6.3 DATA STRUCTURE

3.6.3.1 TRANSMITTER TIMING

3.6.3.1.1 *Data broadcast timing structure*. The time division multiple access (TDMA) timing structure shall be based on frames and time slots. Each frame shall be 500 milliseconds in duration. There shall be 2 such frames contained in each 1-second UTC epoch. The first of these frames shall start at the beginning of the UTC epoch and the second frame shall start 0.5 seconds after the beginning of the UTC epoch. The frame shall be time division multiplexed such that it shall consist of 8 individual time slots (A to H) of 62.5-millisecond duration.

3.6.3.1.2 *Bursts*. Each assigned time slot shall contain at most 1 burst. To initiate the use of a time slot, the GBAS shall broadcast a burst in that time slot in each of 5 consecutive frames. For each time slot in use, the ground subsystem shall broadcast a burst in at least 1 frame of every 5 consecutive frames.

Note 1.— Bursts contain one or more messages and may be of variable length up to the maximum allowed within the slot as required by 3.6.3.2.

Note 2.— During time slot initiation, the airborne receiver may not receive the first 4 bursts.

3.6.3.1.3 *Timing budget for bursts*

3.6.3.1.3.1 Each burst shall be contained in a 62.5-millisecond time slot.

3.6.3.1.3.2 The beginning of the burst shall occur 95.2 microseconds after the beginning of the time slot with a tolerance of ±95.2 microseconds.

3.6.3.1.3.3 For GBAS/E equipment, the start of the synchronization and ambiguity resolution portion of the burst, transmitted with horizontal polarization (HPOL), shall occur within 10 microseconds of the start of the burst transmitted with vertical polarization (VPOL).

Note.— Table B-59 illustrates the burst timing.

3.6.3.1.4 *Ramp-up and transmitter power stabilization*. The transmitter shall ramp up to 90 per cent of the steady-state power level within 190.5 microseconds after the beginning of the burst (2 symbols). The transmitter shall stabilize at the steady-state power within 476.2 microseconds after the beginning of the burst (5 symbols).

Note.— The transmitter power stabilization period may be used by the aircraft receiver to settle its automatic gain control.

3.6.3.1.5 *Ramp-down*. After the final information symbol is transmitted in an assigned time slot, the transmitter output power level shall decrease to at least 30 dB below the steady-state power within 285.7 microseconds (3 symbols).

3.6.3.2 *Burst organization and coding*. Each burst shall consist of the data elements shown in Table B-60. Encoding of the messages shall follow the sequence: application data formatting, training sequence forward error correction (FEC) generation, application FEC generation and bit scrambling.

3.6.3.2.1 *Synchronization and ambiguity resolution*. The synchronization and ambiguity resolution field shall consist of the 48-bit sequence shown below, with the rightmost bit transmitted first:

010 001 111 101 111 110 001 100 011 101 100 000 011 110 010 000

Table B-59. Burst timing

Event	Nominal event duration	Nominal percentage of steady-state power
Ramp-up	190.5 µs	0% to 90%
Transmitter power stabilization	285.7 µs	90% to 100%
Synchronization and ambiguity resolution	1 523.8 µs	100%
Transmission of scrambled data	58 761.9 µs	100%
Ramp-down	285.7 µs (*Note 1*)	100% to 0%

Notes.—

1. *Event duration indicated for transmission of scrambled data is for maximum application data length of 1 776 bits, 2 fill bits and nominal symbol duration.*

2. *These timing requirements provide a propagation guard time of 1 259 microseconds, allowing for a one-way propagation range o f approximately 370 km (200 NM).*

3. *Where bursts from a GBAS broadcast antenna can be received at a range more than 370 km (200 NM) greater than the range from another broadcast antenna using the next adjacent slot, a longer guard time is required to avoid loss of both bursts. To provide a long er guard time, it is necessary to limit the application data length of the first burst to 1 744 bits. This allows a difference in propagation ranges of up to 692 km (372 NM) without conflict.*

Table B-60. Burst data content

Element	Data content	Number of bits
Beginning of burst Power stabilization	all zeros	15
Synchronization and ambiguity resolution	3.6.3.2.1	48
Scrambled data:	3.6.3.3	
station slot identifier (SSID)	3.6.3.3.1	3
transmission length	3.6.3.3.2	17
training sequence FEC	3.6.3.3.3	5
application data	3.6.3.3.4	up to 1 776
application FEC	3.6.3.3.5	48
fill bits (Note)	3.6.2.2	0 to 2

Note.— Data scrambling of the fill bits is optional (3.6.3.3.6).

3.6.3.3 SCRAMBLED DATA CONTENT

3.6.3.3.1 *Station slot identifier (SSID).* The SSID shall be a numeric value corresponding to the letter designation A to H of the first time slot assigned to the GBAS ground subsystem, where slot A is represented by 0, B by 1, C by 2, … and H by 7. The identifier is transmitted LSB first.

3.6.3.3.2 *Transmission length*. The transmission length shall indicate the total number of bits in both application data and application FEC. The transmission length is transmitted LSB first.

3.6.3.3.3 *Training sequence FEC*. The training sequence FEC shall be computed over the SSID and transmission length fields, using a (25, 20) block code, in accordance with the following equation:

$$[P_1, ..., P_5] = [SSID_1, \ldots, SSID_3, TL_1, \ldots, TL_{17}]\, H^T$$

where

P_n = the nth bit of the training sequence FEC (P_1 shall be transmitted first);
SSI_n = the nth bit of the station slot identifier ($SSID_1$ = LSB);
TL_n = the nth bit in the transmission length (TL_1 = LSB); and
H^T = the transpose of the parity matrix, defined below:

$$H^T = \begin{bmatrix} 0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1&1&1&1&1 \\ 0&0&1&1&1&1&1&1&0&0&0&0&1&1&1&1&1&1&1&1 \\ 1&1&0&0&0&1&1&1&0&0&1&1&0&0&0&0&1&1&1&1 \\ 1&1&0&1&1&0&1&1&0&1&0&1&0&0&1&1&0&0&1&1 \\ 0&1&1&0&1&0&0&1&1&1&1&0&0&1&0&1&0&1&0&1 \end{bmatrix}^T$$

Note.— This code is capable of correcting all single bit errors and detecting 75 of 300 possible double bit errors.

3.6.3.3.4 *Application data*. The application data shall consist of one or more message blocks, as defined in 3.6.3.4. The message blocks shall be mapped directly into the application data with no additional overhead of intervening layers.

3.6.3.3.5 *Application FEC*. The application FEC shall be calculated using the application data by means of a systematic, fixed-length, Reed-Solomon (R-S) (255, 249) code.

3.6.3.3.5.1 The field-defining primitive, p(x), of the R-S code shall be:
$p(x) = x^8 + x^7 + x^2 + x + 1$

3.6.3.3.5.2 The generator polynomial of the R-S code, g(x), shall be:

$$g(x)=\prod_{i=120}^{125}(x-\alpha^i)= x^6 + \alpha^{176}x^5 + \alpha^{186}x^4 + \alpha^{244}x^3 + \alpha^{176}x^2 + \alpha^{156}x + \alpha^{225}$$

where α is a root of p(x) used for construction of the Galois Field of size 2^8, GF(256), and α^i is the ith primitive element in GF(256).

3.6.3.3.5.3 In generating the application FEC, the data to be encoded, m(x), shall be grouped into 8-bit R-S symbols. All data fields in the message blocks that define the application data shall be ordered such as specified in Tables B-61 and B-62, and in the message tables in 3.6.6. However, since the R-S code is a block code, application data blocks shorter than 249 bytes (1 992 bits) shall be extended to 249 bytes by virtual fill bits set to zero and appended to the application data. These virtual fill bits shall not be transferred to the bit scrambler. The data to be encoded, m(x), shall be defined by:

$$m(x) = a_{248}x_{248} + a_{247}x_{247} + ... + a_{248\text{-length}+1}\, x_{248\text{-length}+1} + a_{248\text{-length}}\, x_{248\text{-length}} + ... + a_1x+a_0$$

where

length represents the number of 8-bit bytes in the application data block;

a_{248} represents the message block identifier, with the rightmost bit defined as the LSB and the first bit of the application data sent to the bit scrambler;

$a_{248\text{-length}+1}$ represents the last byte of the message block CRC, with the leftmost bit defined as the MSB and the last bit of the application data sent to the bit scrambler; and

$a_{248\text{-length}}, ..., a_1, a_0$ are the virtual fill bits (if any).

3.6.3.3.5.4 The 6 R-S check symbols (b_i) shall be defined as the coefficients of the remainder resulting from dividing the message polynomial $x^6m(x)$ by the generator polynomial g(x):

$$b(x)=\sum_{i=0}^{5} b_i x^i + b_5x^5+b_4x^4+b_3x^3+b_2x^2+b_1x^1+b_0 = [x^6m(x)] \bmod g(x)$$

3.6.3.3.5.5 The 8-bit R-S check symbols shall be appended to the application data. Each 8-bit R-S check symbol shall be transmitted MSB first from b_0 to b_5, i.e. the first application FEC bit transferred to the bit scrambler shall be the MSB of b_0 and the last application FEC bit transferred to the bit scrambler shall be the LSB of b_5.

Note 1.— This R-S code is capable of correcting up to 3 symbol errors.

Note 2.— The order of the transmitted 8-bit R-S check symbols of the appended application FEC differs from the VHF data link (VDL) Mode 2. Moreover, for VDL Mode 2 each R-S check symbol is transmitted LSB first.

Note 3.— Example results of application FEC encoding are given in Attachment D, 7.15.

Table B-61. Format of a GBAS message block

Message block	Bits
Message block header	48
Message	up to 1 696
CRC	32

Table B-62. Format of message block header

Data field	Bits
Message block identifier	8
GBAS ID	24
Message type identifier	8
Message length	8

3.6.3.3.6 *Bit scrambling*

3.6.3.3.6.1 The output of a pseudo-noise scrambler with a 15-stage generator register shall be exclusive OR'ed with the burst data starting with the SSID and ending with the application FEC. Bit scrambling of the fill bits is optional and the set value of the fill bits is optional.

Note.— The fill bits are not used by the aircraft receiver and their values have no impact on the system.

3.6.3.3.6.2 The polynomial for the register taps of the scrambler shall be $1 + x + x^{15}$. The register content shall be rotated at the rate of one shift per bit. The initial status of the register, prior to the first SSID bit of each burst, shall be "1101 0010 1011 001", with the leftmost bit in the first stage of the register. The first output bit of the scrambler shall be sampled prior to the first register shift.

Note.— A diagram of the bit scrambler is given in Attachment D, 7.4.

3.6.3.4 *Message block format*. The message blocks shall consist of a message block header, a message and a 32-bit CRC. Table B-61 shows the construction of the message block. All signed parameters shall be two's complement numbers and all unsigned parameters shall be unsigned fixed point numbers. The scaling of the data shall be as shown in the message tables in 3.6.6. All data fields in the message block shall be transmitted in the order specified in the message tables, with the LSB of each field transmitted first.

Note.— All binary representations reading left to right are MSB to LSB.

3.6.3.4.1 *Message block header*. The message block header shall consist of a message block identifier, a GBAS identifier (ID), a message type identifier and a message length, as shown in Table B-62.

Message block identifier: the 8-bit identifier for the operating mode of the GBAS message block.

Coding: 1010 1010 = normal GBAS message
1111 1111 = test GBAS message
All other values are reserved.

GBAS ID: The four-character GBAS identification to differentiate between GBAS ground subsystems.

Coding: Each character is coded using bits b_1 through b_6 of its International Alphabet No. 5 (IA-5) representation. For each character, bit b_1 is transmitted first and six bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 "space" are used. The rightmost character is transmitted first. For a three-character GBAS ID, the rightmost (first transmitted) character shall be IA-5 "space".

Note.— The GBAS ID is normally identical to the location indicator at the nearest airport. Assignment of GBAS IDs will be coordinated as appropriate to avoid conflicts.

Message type identifier: the numeric label identifying the content of the message (Table B-63).

Message length: the length of the message in 8-bit bytes including the 6-byte message block header, the message and the 4-byte message CRC code.

3.6.3.4.2 *Cyclic redundancy check (CRC).* The GBAS message CRC shall be calculated in accordance with 3.9.

3.6.3.4.2.1 The length of the CRC code shall be k = 32 bits.

3.6.3.4.2.2 The CRC generator polynomial shall be:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^{8} + x^{7} + x^{5} + x^{3} + x + 1$$

3.6.3.4.2.3 The CRC information field, M(x), shall be:

$$M(x)=\sum_{i=1}^{n} m_i x^{n-i} + m_1 x^{n-1} + m_2 x^{n-2} + \ldots + m_n x^0$$

3.6.3.4.2.4 M(x) shall be formed from the 48-bit GBAS message block header and all bits of the variable-length message, excluding the CRC. Bits shall be arranged in the order transmitted, such that m_1 corresponds to the first transmitted bit of the message block header, and m_n corresponds to the last transmitted bit of the (n-48) message bits.

3.6.3.4.2.5 The CRC shall be ordered such that r_1 is the first bit transmitted and r_{32} is the last bit transmitted.

3.6.4 DATA CONTENT

3.6.4.1 *Message types*. The message types that can be transmitted by GBAS shall be as in Table B-63.

3.6.4.2 *TYPE 1 MESSAGE — PSEUDO-RANGE CORRECTIONS*

3.6.4.2.1 The Type 1 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70). The message shall contain three sections:

a) message information (time of validity, additional message flag, number of measurements and the measurement type);

b) low-frequency information (ephemeris decorrelation parameter, satellite ephemeris CRC and satellite availability information); and

c) satellite data measurement blocks.

Note 1.— Transmission of the low-frequency data for SBAS ranging sources is optional.

Note 2.— All parameters in this message type apply to 100-second carrier-smoothed pseudo-ranges.

3.6.4.2.2 Each Type 1 message shall include ephemeris decorrelation parameter, ephemeris CRC and source availability duration parameters for one satellite ranging source. The ephemeris decorrelation parameter, ephemeris CRC and source availability duration shall apply to the first ranging source in the message.

3.6.4.2.3 Pseudo-range correction parameters shall be as follows:

Modified Z-count: the indication of the time of applicability for all the parameters in the message.

Coding: the modified Z-count resets on the hour (xx:00), 20 minutes past the hour (xx:20) and 40 minutes past the hour (xx:40) referenced to GPS time.

Additional message flag: an identification of whether the set of measurement blocks in a single frame for a particular measurement type is contained in a single Type 1 message or a linked pair of messages.

Coding: 0 = All measurement blocks for a particular measurement type are contained in one Type 1 message.
1 = This is the first transmitted message of a linked pair of Type 1 messages that together contain the set of all measurement blocks for a particular measurement type.

2 = Spare
3 = This is the second transmitted message of a linked pair of Type 1 messages that together contain the set of all measurement blocks for a particular measurement type.

Note.— When a linked pair of Type 1 messages is used for a particular measurement type, the number of measurements and low-frequency data are computed separately for each of the two individual messages.

Number of measurements: the number of measurement blocks in the message.

Measurement type: the type of ranging signal from which the corrections have been computed.

Table B-63. GBAS VHF data broadcast messages

Message type identifier	Message name
0	Spare
1	Pseudo-range corrections
2	GBAS-related data
3	Null message
4	Final approach segment (FAS) data
5	Predicted ranging source availability
6	Reserved
7	Reserved for national applications
8	Reserved for test applications
9 to 10	Spare
11	Pseudo-range corrections – 30-second smoothed pseudo-ranges
12 to 100	Spare
101	GRAS pseudo-range corrections
102 to 255	Spare

Note.— See 3.6.6 for message formats.

Coding: 0 = C/A or CSA code L1
1 = reserved
2 = reserved
3 = reserved
4 to 7 = spare

Ephemeris decorrelation parameter (P): a parameter that characterizes the impact of residual ephemeris errors due to decorrelation for the first measurement block in the message.

For a SBAS geostationary satellite, the ephemeris decorrelation parameter, if transmitted, shall be coded as all zeros.

For GBAS ground subsystems that do not broadcast the additional data block 1 in the Type 2 message, the ephemeris decorrelation parameter shall be coded as all zeros.

Ephemeris CRC: the CRC computed with the ephemeris data used to determine corrections for the first measurement block in the message. The ephemeris CRC for core satellite constellation(s) ranging sources shall be calculated in accordance with 3.9. The length of the CRC code shall be k = 16 bits. The CRC generator polynomial shall be:

$$G(x) = x^{16} + x^{12} + x^{5} + 1$$

The CRC information field, M(x), for a given satellite shall be:

$$M(x)=\sum_{i=1}^{n} m_i x^{n-i} = m_1 x^{n-1} + m_2 x^{n-2} + \ldots + m_n x^0$$

For a GPS satellite, M(x) shall be of length n = 576 bits. M(x) for a GPS satellite shall be calculated using the first 24 bits from each of words 3 to S10 of subframes 1, 2 and 3 of the data transmission from that satellite, ANDed with the GPS satellite ephemeris mask of Table B-64. M(x) shall be arranged in the order that bytes are transmitted by the GPS satellite, but with each byte ordered LSB first, such that m_1 corresponds to bit 68 of subframe 1, and m_{576} corresponds to bit 287 of subframe 3.

Note.— M(x) for a GPS satellite does not include word 1 (TLM) or word 2 (HOW), which start each subframe, or the 6 parity bits at the end of each word.

For a SBAS geostationary satellite, the ephemeris CRC, if transmitted shall be coded as all zeros.

The CRC shall be transmitted in the order r_9, r_{10}, r_{11}...., r_{16}, r_1, r_2, r_3...r_8, where r_i is the i^{th} coefficient of the remainder R(x) as defined in 3.9**.**

Source availability duration: the predicted duration for which corrections for the ranging source are expected to remain available, relative to the modified Z-count for the first measurement block.

Coding: 1111 1110 = The duration is greater than or equal to 2 540 seconds.
1111 1111 = Prediction of source availability duration is not provided by this ground subsystem.

3.6.4.2.4 The measurement block parameters shall be as follows:
Ranging source ID: the identity of the ranging source to which subsequent measurement block data are applicable.

Table B-64. GPS satellite ephemeris mask

Subframe 1:	Byte 1	Byte 2	Byte 3		Byte 1	Byte 2	Byte 3
Word 3	0000 0000	0000 0000	0000 0011	Word 4	0000 0000	0000 0000	0000 0000
Word 5	0000 0000	0000 0000	0000 0000	Word 6	0000 0000	0000 0000	0000 0000
Word 7	0000 0000	0000 0000	1111 1111	Word 8	1111 1111	1111 1111	1111 1111
Word 9	1111 1111	1111 1111	1111 1111	Word 10	1111 1111	1111 1111	1111 1100
Subframe 2:	Byte 1	Byte 2	Byte 3		Byte 1	Byte 2	Byte 3
Word 3	1111 1111	1111 1111	1111 1111	Word 4	1111 1111	1111 1111	1111 1111
Word 5	1111 1111	1111 1111	1111 1111	Word 6	1111 1111	1111 1111	1111 1111
Word 7	1111 1111	1111 1111	1111 1111	Word 8	1111 1111	1111 1111	1111 1111
Word 9	1111 1111	1111 1111	1111 1111	Word 10	1111 1111	1111 1111	0000 0000
Subframe 3:	Byte 1	Byte 2	Byte 3		Byte 1	Byte 2	Byte 3
Word 3	1111 1111	1111 1111	1111 1111	Word 4	1111 1111	1111 1111	1111 1111
Word 5	1111 1111	1111 1111	1111 1111	Word 6	1111 1111	1111 1111	1111 1111
Word 7	1111 1111	1111 1111	1111 1111	Word 8	1111 1111	1111 1111	1111 1111

Word 9	1111 1111	1111 1111	1111 1111	Word 10	1111 1111	1111 1111	1111 1100

Table B-65. Reserved

Coding: 1 to 36 = GPS satellite IDs (PRN)
37 = reserved
38 to 61 = reserved
62 to 119 = spare
120 to 158 = SBAS satellite IDs (PRN)
159 to 255 = spare

Issue of data (IOD): The issue of data associated with the ephemeris data used to determine pseudo-range and range rate corrections.

Coding: for GPS, IOD = GPS IODE parameter (3.1.1.3.2.2)
for SBAS, IOD = 1111 1111

Pseudo-range correction (PRC): the correction to the ranging source pseudo-range.

Range rate correction (RRC): the rate of change of the pseudo-range correction.

σ_{pr_gnd}: the standard deviation of a normal distribution associated with the signal-in-space contribution of the pseudo-range error at the GBAS reference point (3.6.5.5.1, 3.6.5.5.2 and 3.6.7.2.2.4).

Coding: 1111 1111 = Ranging source correction invalid.

B_1 through B_4: are the integrity parameters associated with the pseudo-range corrections provided in the same measurement block. For the ith ranging source these parameters correspond to $B_{i,1}$ through $B_{i,4}$ (3.6.5.5.1.2, 3.6.5.5.2.2 and 3.6.7.2.2.4). During continuous operation, the indices “1-4” correspond to the same physical reference receiver for every epoch transmitted from a given ground subsystem with the following exception: the physical reference receiver tied to any of the indices 1 to 4 can be replaced by any other physical reference receiver (including a previously removed one) that has not been used for transmissions during the last 5 minutes.

Coding: 1000 0000 = Reference receiver was not used to compute the pseudo-range correction.

Note 1.— A physical reference receiver is a receiver with an antenna at a fixed location.

Note 2. — Some airborne inertial integrations may expect a largely static correspondence of the reference receivers to the indices. Refer to RTCA/DO-253D, Appendix L.

3.6.4.3 *Type 2 message — GBAS-related data.* Type 2 message shall identify the location of the GBAS reference point at which the corrections provided by the GBAS apply and shall give other GBAS-related data (Table B-71). GBAS-related data parameters shall be as follows:

Note.— Additional data blocks may be included in the Type 2 message. Additional data block 1 and additional data block 2 are defined. In the future, other additional data blocks may be defined. Data blocks 2 through 255 are variable length and may be appended to the message after additional data block 1 in any order.

GBAS reference receivers: the number of GNSS reference receivers installed in this GBAS ground subsystem.

Coding: 0 = GBAS installed with 2 reference receivers
1 = GBAS installed with 3 reference receivers
2 = GBAS installed with 4 reference receivers
3 = The number of GNSS reference receivers installed in this GBAS ground subsystem is not applicable

Ground accuracy designator letter: the letter designator indicating the minimum signal-in-space accuracy performance provided by GBAS (3.6.7.1.1).

Coding: 0 = accuracy designation A
1 = accuracy designation B
2 = accuracy designation C
3 = spare

GBAS continuity/integrity designator (GCID): numeric designator indicating the operational status of the GBAS.

Coding: 0 = spare
1 = GCID 1
2 = GCID 2
3 = GCID 3
4 = GCID 4
5 = spare
6 = spare
7 = unhealthy

Note 1.— The values of GCID 2, 3 and 4 are specified in order to ensure compatibility of equipment with future GBAS.

Note 2.— The value of GCID 7 indicates that all approach services supported by the ground facility are unavailable.

Local magnetic variation: the published magnetic variation at the GBAS reference point.

Coding: Positive value denotes east variation (clockwise from true north), Negative value denotes west variation (counterclockwise from true north)
100 0000 0000 = Precision approach procedures supported by this GBAS are published based on true bearing.

Note.— Local magnetic variation is chosen to be consistent with procedure design and is updated during magnetic epoch years.

$\sigma_{vert\_iono\_gradient}$: the standard deviation of a normal distribution associated with the residual ionospheric uncertainty due to spatial decorrelation (3.6.5.4).

Refractivity index (N_r): the nominal tropospheric refractivity index used to calibrate the tropospheric correction associated with the GBAS ground subsystem (3.6.5.3).

Coding: This field is coded as two's complement number with an offset of +400. A value of zero in this field indicates a refractivity index of 400.

Scale height (h_0): a scale factor used to calibrate the tropospheric correction and residual tropospheric uncertainty associated with the GBAS ground subsystem (3.6.5.3).

Refractivity uncertainty (σ_n): the standard deviation of a normal distribution associated with the residual tropospheric uncertainty (3.6.5.3).

Latitude: the latitude of the GBAS reference point defined in arc seconds.

Coding: Positive value denotes north latitude.
Negative value denotes south latitude.

Longitude: the longitude of the GBAS reference point defined in arc seconds.

Coding: Positive value denotes east longitude.
Negative value denotes west longitude.

Reference point height: the height of the GBAS reference point above the WGS-84 ellipsoid.

3.6.4.3.1 *Additional data block 1 parameters*. Additional data block 1 parameters shall be as follows:

REFERENCE STATION DATA SELECTOR (RSDS): the numerical identifier that is used to select the GBAS ground subsystem.

Note.— The RSDS is different from every other RSDS and every reference path data selector (RPDS) broadcast on the same frequency by every GBAS ground subsystem within the broadcast region.

Coding: 1111 1111 = GBAS positioning service is not provided

MAXIMUM USE DISTANCE (D_{max}): the maximum distance (slant range) from the GBAS reference point within which pseudo-range corrections are applied by the aircraft element.

Note.— This parameter does not indicate a distance within which VHF data broadcast field strength requirements are met.

Coding: 0 = distance limitation

GPS EPHEMERIS MISSED DETECTION PARAMETER, GBAS Positioning Service ($K_{md\_e\_POS,GPS}$): the multiplier for computation of the ephemeris error position bound for the GBAS positioning service derived from the probability of missed detection given that there is an ephemeris error in a GPS satellite.

For GBAS ground subsystems that do not broadcast corrections for GPS ranging sources or that do not provide the GBAS positioning service, this parameter shall be coded as all zeros.

GPS EPHEMERIS MISSED DETECTION PARAMETER, GBAS approach service types A, B or C ($K_{md\_e,GPS}$): the multiplier for computation of the ephemeris error position bound for GBAS approach service types A, B and C derived from the probability of missed detection given that there is an ephemeris error in a GPS satellite.

For GBAS ground subsystems that do not broadcast corrections for GPS ranging sources, this parameter shall be coded as all zeros.

3.6.4.3.2 *Additional data blocks*. For additional data blocks other than additional data block 1, the parameters for each data block shall be as follows:

ADDITIONAL DATA BLOCK LENGTH: the number of bytes in the additional data block, including the additional data block length and additional data block number fields.

ADDITIONAL DATA BLOCK NUMBER: the numerical identifier of the type of additional data block.

Coding: 0 to 1 = reserved
2 = additional data block 2, GRAS broadcast stations
3 = additional data block 3, GAST D parameters
4 = additional data block 4, VDB authentication parameters
5 to 255 = spare

ADDITIONAL DATA PARAMETERS: the set of data defined in accordance with the additional data block number.

3.6.4.3.2.1 *GRAS broadcast stations*

Parameters for additional data block 2 shall include data for one or more broadcast stations as follows (Table B-65A):

CHANNEL NUMBER: the channel number, as defined in 3.6.5.7, associated with a GBAS broadcast station.

Note.— The channel number in this field refers to a frequency and an RSDS.

Δ*LATITUDE*: the difference of latitude of a GBAS broadcast station, measured from the latitude provided in the latitude parameter of Type 2 message.

Coding: Positive value denotes that the GBAS broadcast station is north of the GBAS reference point.
Negative value denotes that the GBAS broadcast station is south of the GBAS reference point.

Δ*LONGITUDE*: the difference of longitude of a GBAS broadcast station, measured from the longitude provided in the longitude parameter of Type 2 message.

Coding: Positive value denotes that the GBAS broadcast station is east of the GBAS reference point.
Negative value denotes that the GBAS broadcast station is west of the GBAS reference point.

Note.— Guidance material concerning additional data block 2 is provided in Attachment D, 7.17.

3.6.4.3.2.2 *GAST D parameters*

Parameters for additional data block 3 shall include parameters (Table B-65B) to be used when the active service type is GAST D as follows:

Kmd_e_D,GPS ($K_{md\_e\_D,GPS}$)*:* is the multiplier for computation of the ephemeris error position bound for GAST D derived from the probability of missed detection given that there is an ephemeris error in a GPS satellite. For GBAS ground subsystems that do not broadcast corrections for GPS ranging sources, this parameter is coded as all zeros.

Note.— This parameter, Kmd_e_D,GPS, may be different than the ephemeris decorrelation parameter Kmd_e_GPS provided in additional data block 1 of the Type 2 message. Additional information regarding the difference in these parameters is given in Attachment D, 7.5.6.1.2 and 7.5.6.1.3.

Sigma_vert_iono_gradient_D ($\sigma_{vert\_iono\_gradient\_D}$): is the standard deviation of a normal distribution associated with the residual ionospheric uncertainty due to spatial decorrelation. This parameter is used by airborne equipment when its active approach service type is D.

Note.— This parameter, Sigma_vert_iono_gradient_D, may be different than the ionospheric decorrelation parameter Sigma_vert_iono_gradient provided in the Type 2 message. Additional information regarding the difference in these parameters is given in Attachment D, 7.5.6.1.2 and 7.5.6.1.3.

Y_{EIG}: is the maximum value of E_{IG} at zero distance from the GBAS reference point. This parameter is used by airborne equipment when its active approach service type is D.

M_{EIG}: is the slope of maximum E_{IG} versus distance from the GBAS reference point. This parameter is used by airborne equipment when its active approach service type is D.

Table B-65A. GRAS broadcast station data

Data content	Bits used	Range of values	Resolution
Channel number	16	20001 to 39999	1
ΔLatitude	8	±25.4°	0.2°
ΔLongitude	8	±25.4°	0.2°

Table B-65B. Additional data block 3 GAST D parameters

Data content	Bits used	Range of values	Resolution
$K_{md\ e\ D,GPS}$	8	0 to 12.75	0.05
$\sigma_{vert\ iono\ gradient\ D}$	8	0 to 25.5 × 10^{-6} m/m	0.1 × 10^{-6} m/m
Y_{EIG}	5	0 to 3.0 m	0.1
M_{EIG}	3	0 to 0.7 m/km	0.1

3.6.4.3.2.3 *VDB authentication parameters*

Additional data block 4 includes information needed to support VDB authentication protocols (Table B-65C).

Slot group definition: This 8-bit field indicates which of the 8 slots (A-H) are assigned for use by the ground station. The field is transmitted LSB first. The LSB corresponds to slot A, the next bit to slot B, and so on. A “1” in the bit position indicates the slot is assigned to the ground station. A “0” indicates the slot is not assigned to the ground station.

Table B-65C. VDB authentication parameters

Data content	Bits used	Range of values	Resolution
Slot group definition	8	—	—

3.6.4.4 *TYPE 3 MESSAGE — NULL MESSAGE*

3.6.4.4.1 The Type 3 message is a variable length “null message” which is intended to be used by ground subsystems that support the authentication protocols (see section 3.6.7.4).

3.6.4.4.2 The parameters for the Type 3 message shall be as follows:

Filler: a sequence of bits alternating between “1” and “0” with a length in bytes that is 10 less than the value in the message length field in the message header.

3.6.4.5 *Type 4 message — Final approach segment (FAS).* Type 4 message shall contain one or more sets of FAS data, each defining a single precision approach (Table B-72). Each Type 4 message data set shall include the following:

Data set length: the number of bytes in the data set. The data set includes the data set length field and the associated FAS data block, FAS vertical alert limit (FASVAL)/approach status and FAS lateral alert limit (FASLAL)/approach status fields.

FAS data block: the set of parameters to identify an approach and define its associated approach path.

Coding: See 3.6.4.5.1 and Table B-66.

Note.— Guidance material for FAS path definition is contained in Attachment D, 7.11.

FASVAL/approach status: the value of the parameter FASVAL as used in 3.6.5.6.

Coding: 1111 1111 = Do not use vertical deviations.

Note.— The range and resolution of values for FASVAL depend upon the approach performance designator in the associated FAS data block.

FASLAL/approach status: the value of the parameter FASLAL as used in 3.6.5.6.

Coding: 1111 1111 = Do not use approach.

Note.— The Procedures for Air Navigation Services — Aircraft Operations *(PANS-OPS) (Doc 8168), Volume II, specifies conventions to be used by procedure designers when applying the FAS data block definitions and codings below to encode procedures.*

3.6.4.5.1 *FAS data block.* The FAS data block shall contain the parameters that define a single GAST A, B, C or D approach. The FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). The local level plane for the approach is a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). Local vertical for the approach is normal to the WGS-84 ellipsoid at the LTP/FTP. The glide path intercept point (GPIP) is where the final approach path intercepts the local level plane. FAS data block parameters shall be as follows:

Operation type: straight-in approach procedure or other operation types.

Coding: 0 = straight-in approach procedure
1 to 15 = spare

Note.— Offset procedures are straight-in procedures and coded as “0”.

Table B-66. Final approach segment (FAS) data block

Data content	Bits used	Range of values	Resolution
Operation type	4	0 to 15	1

SBAS provider ID	4	0 to 15	1
Airport ID	32	—	—
Runway number	6	1 to 36	1
Runway letter	2	—	—
Approach performance designator	3	0 to 7	1
Route indicator	5	—	—
Reference path data selector	8	0 to 48	1
Reference path identifier	32	—	—
LTP/FTP latitude	32	±90.0°	0.0005 arcsec
LTP/FTP longitude	32	±180.0°	0.0005 arcsec
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m
ΔFPAP latitude	24	±1.0°	0.0005 arcsec
ΔFPAP longitude	24	±1.0°	0.0005 arcsec
Approach TCH (Note)	15	0 to 1 638.35 m or 0 to 3 276.7 ft	0.05 m or 0.1 ft
Approach TCH units selector	1	—	—
GPA	16	0 to 90.0°	0.01°
Course width	8	80 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2 032 m	8 m
Final approach segment CRC	32	—	—

Note.— Information can be provided in either feet or metres as indicated by the approach TCH unit selector.

SBAS service provider ID: indicates the service provider associated with this FAS data block.

Coding: See Table B-27.
14 = FAS data block is to be used with GBAS only.
15 = FAS data block can be used with any SBAS service provider.

Note.— This parameter is not used for approaches conducted using GBAS or GRAS pseudo-range corrections.

Airport ID: the three- or four-letter designator used to designate an airport.

Coding: Each character is coded using the lower 6 bits of its IA-5 representation. For each character, b_i is transmitted first, and 2 zero bits are appended after b_6, so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 “space” are used. The rightmost character is transmitted first. For a threecharacter airport ID, the rightmost (first transmitted) character shall be IA-5 “space”.

Runway number: the approach runway number.

Coding: 1 to 36 = runway number

Note.— For heliport and point-in-space operations, the runway number value is the integer nearest to one tenth of the final approach course, except when that integer is zero, in which case the runway number is 36.

Runway letter: the one-letter designator used, as necessary, to differentiate between parallel runways.
Coding: 0 = no letter

1 = R (right)
2 = C (centre)
3 = L (left)

Approach performance designator: the general information about the approach design.

Coding:
0 = GAST A or B
1 = GAST C
2 = GAST C and GAST D
3 = GAST C, GAST D and an additional approach service type to be defined in the future
4 = GAST C, GAST D and two additional approach service types to be defined in the future
5 to 7 = spare

Note.— Some airborne equipment designed for Category I performance is insensitive to the value of the APD. It is intended that airborne equipment designed for Category I performance accepts APD values of at least 1-4 as valid to accommodate future extensions to higher performance types using the same FAS data block.

Route indicator: the one-letter identifier used to differentiate between multiple approaches to the same runway end.

Coding: The letter is coded using bits b_1 through b_5 of its IA-5 representation. Bit b_1 is transmitted first. Only upper case letters, excluding "I" and "O", or IA-5 "space" are used.

Reference path data selector (RPDS): the numeric identifier that is used to select the FAS data block (desired approach).

Note.— The RPDS for a given FAS data block is different from every other RPDS and every reference station data selector (RSDS) broadcast on the same frequency by every GBAS within the broadcast region.

Reference path identifier (RPI): the three or four alphanumeric characters used to uniquely designate the reference path.

Coding: Each character is coded using bits b_1 through b_6 of its IA-5 representation. For each character, b_1 is transmitted first, and 2 zero bits are appended after b_6 so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 "space" are used. The rightmost character is transmitted first. For a threecharacter reference path identifier, the rightmost (first transmitted) character shall be IA-5 "space".

Note.— The LTP/FTP is a point over which the FAS path passes at a relative height specified by the TCH. LTP is normally located at the intersection of the runway centre line and the threshold.

LTP/FTP latitude: the latitude of the LTP/FTP point in arc seconds.

Coding: Positive value denotes north latitude.
Negative value denotes south latitude.

LTP/FTP longitude: the longitude of the LTP/FTP point in arc seconds.

Coding: Positive value denotes east longitude.
Negative value denotes west longitude.

LTP/FTP height: the height of the LTP/FTP above the WGS-84 ellipsoid.

Coding: This field is coded as an unsigned fixed-point number with an offset of –512 metres. A value of zero in this field places the LTP/FTP 512 metres below the earth ellipsoid.

Note.— The FPAP is a point at the same height as the LTP/FTP that is used to define the alignment of the approach. The origin of angular deviations in the lateral direction is defined to be 305 metres (1 000 ft) beyond the FPAP along the lateral FAS path. For an approach aligned with the runway, the FPAP is at or beyond the stop end of the runway.

ΔFPAP latitude: the difference of latitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value denotes the FPAP latitude north of LTP/FTP latitude.
Negative value denotes the FPAP latitude south of the LTP/FTP latitude.

ΔFPAP longitude: the difference of longitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value indicates the FPAP longitude east of LTP/FTP longitude.
Negative value indicates the FPAP longitude west of LTP/FTP longitude.

Approach TCH: the height of the FAS path above the LTP/FTP defined in either feet or metres as indicated by the TCH units selector.

Approach TCH units selector: the units used to describe the TCH.

Coding: 0 = feet
1 = metres

Glide path angle (GPA): the angle of the FAS path with respect to the horizontal plane tangent to the WGS-84 ellipsoid at the LTP/FTP.

Course width: the lateral displacement from the path defined by the FAS at the LTP/FTP at which full-scale deflection of a course deviation indicator is attained.

Coding: This field is coded as an unsigned fixed-point number with an offset of 80 metres. A value of zero in this field indicates a course width of 80 metres at the LTP/FTP.

ΔLength offset: the distance from the stop end of the runway to the FPAP.

Coding: 1111 1111 = not provided

Final approach segment CRC: the 32-bit CRC appended to the end of each FAS data block in order to ensure approach data integrity. The 32-bit final approach segment CRC shall be calculated in accordance with 3.9. The length of the CRC code shall be k = 32 bits.

The CRC generator polynomial shall be:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^{8} + x^{7} + x^{5} + x^{3} + x + 1$$

The CRC information field, M(x), shall be:

$$M(x)=\sum_{i=1}^{272} m_i x^{272-i} = m_1x^{271} + m_2x^{270} + \ldots + m_{272}x^0$$

M(x) shall be formed from all bits of the associated FAS data block, excluding the CRC. Bits shall be arranged in the order transmitted, such that m_1 corresponds to the LSB of the operation type field, and m_{272} corresponds to the MSB of the Δlength offset field. The CRC shall be ordered such that r_1 is the LSB and r_{32} is the MSB.

3.6.4.6 *Type 5 message — predicted ranging source availability.* When used, the Type 5 message shall contain rising and setting information for the currently visible or soon to be visible ranging sources. Predicted ranging source availability parameters shall be as follows:

Modified Z-count: indicates the time of applicability of the parameters in this message.

Coding: Same as modified Z-count field in Type 1 message (3.6.4.2).

Number of impacted sources: the number of sources for which duration information applicable to all approaches is provided.

Coding: 0 = Only specified obstructed approaches have limitations.
1 to 31 = The number of ranging sources impacted.

Ranging source ID: as for Type 1 message (3.6.4.2).

Source availability sense: indicates whether the ranging source will become available or cease to be available.

Coding: 0 = Differential corrections will soon cease to be provided for the associated ranging source.
1 = Differential corrections will soon start to be provided for the associated ranging source.

Source availability duration: the predicted minimum ranging source availability duration relative to the modified Z-count.

Coding: 111 1111 = The duration is greater than or equal to 1 270 seconds.

Number of obstructed approaches: the number of approaches for which the corrections will be reduced due to approach unique constellation masking.

Reference path data selector: an indication of the FAS data block to which the source availability data applies (3.6.4.5.1).

Number of impacted sources for this approach: the number of sources for which duration information applicable only to this approach is provided.

3.6.4.7 *TYPE 6 MESSAGE*

Note.— Type 6 message is reserved for future use to provide the information required for Category II/III precision approaches.

3.6.4.8 *TYPE 7 MESSAGE*

Note.— Type 7 message is reserved for national applications.

3.6.4.9 *TYPE 8 MESSAGE*

Note.— Type 8 message is reserved for local and regional test applications.

3.6.4.10 *TYPE 101 MESSAGE — GRAS PSEUDO-RANGE CORRECTIONS*

3.6.4.10.1 The Type 101 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70A). The message shall contain three sections:

a) message information (time of validity, additional message flag, number of measurements and the measurement type);

b) low-frequency information (ephemeris decorrelation parameter, satellite ephemeris CRC and satellite availability information); and

c) satellite data measurement blocks.

Note.— All parameters in this message type apply to 100-second carrier-smoothed pseudo-ranges.

3.6.4.10.2 Each Type 101 message shall include ephemeris decorrelation parameter, ephemeris CRC and source availability duration parameters for one satellite ranging source. The ephemeris decorrelation parameter, ephemeris CRC and source availability duration shall apply to the first ranging source in the message.

3.6.4.10.3 Pseudo-range correction parameters shall be as follows:

Modified Z-count: as defined in 3.6.4.2.3.

Additional message flag: as defined in 3.6.4.2.3 except applicable to Type 101 messages.

Number of measurements: as defined in 3.6.4.2.3.

Measurement type: as defined in 3.6.4.2.3.

Ephemeris decorrelation parameter (P): as defined in 3.6.4.2.3.

Ephemeris CRC: as defined in 3.6.4.2.3.

Source availability duration: as defined in 3.6.4.2.3.

Number of B parameters: an indication of whether the B parameters are included in the measurement block for each ranging source.

Coding: 0 = B parameters are not included
1 = 4 B parameters per measurement block

3.6.4.10.4 The measurement block parameters shall be as follows:

Ranging source ID: as defined in 3.6.4.2.4.

Issue of data (IOD): as defined in 3.6.4.2.4.

Pseudo-range correction (PRC): as defined in 3.6.4.2.4.

Range rate correction (RRC): as defined in 3.6.4.2.4.

σ_{pr_gnd}: as defined in 3.6.4.2.4, with the exception of the range of values and resolution.

B1 through B4: as defined in 3.6.4.2.4.

Note.— Inclusion of the B parameters in the measurement block is optional for Type 101 messages.

3.6.4.11 *TYPE 11 MESSAGE — PSEUDO-RANGE CORRECTIONS — 30-SECOND SMOOTHED PSEUDO-RANGES*

3.6.4.11.1 The Type 11 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70B) with 30-second carrier-smoothing applied. The message shall contain three sections:

a) message information (time of validity, additional message flag, number of measurements and the measurement type);

b) low-frequency information (ephemeris decorrelation parameter); and

c) satellite data measurement blocks.

Note.— Transmission of the low-frequency data for SBAS ranging sources is optional.

3.6.4.11.2 Each Type 11 message shall include the ephemeris decorrelation parameter for one satellite ranging source. The ephemeris decorrelation parameter shall apply to the first ranging source in the message.

Note.— The ephemeris CRC and source availability duration parameters are not included in the Type 11 message because they are provided in the Type 1 message.

3.6.4.11.3 Pseudo-range correction parameters for the Type 11 message shall be as follows:

Modified Z-count: as defined in 3.6.4.2.3.

Additional message flag: an identification of whether the set of measurement blocks in a single frame for a particular measurement type is contained in a single Type 11 message or a linked pair of messages.

Coding: 0 = All measurement blocks for a particular measurement type are contained in one Type 11 message.
1 = This is the first transmitted message of a linked pair of Type 11 messages that together contain the set of all measurement blocks for a particular measurement type.
2 = Spare
3 = This is the second transmitted message of a linked pair of Type 11 messages that together contain the set of all measurement blocks for a particular measurement type.

Number of measurements: the number of measurement blocks in the message.

Measurement type: as defined in 3.6.4.2.3.

Ephemeris decorrelation parameter D (P_D): a parameter that characterizes the impact of residual ephemeris errors due to decorrelation for the first measurement block in the message.

Note.— This parameter, P_D, may be different than the ephemeris decorrelation parameter P provided in the Type 1 message. Additional information regarding the difference in these parameters is given in Attachment D, 7.5.6.1.3 and 7.5.6.1.4.

For an SBAS geostationary satellite, the ephemeris decorrelation parameter, if transmitted, shall be coded as all zeros.

3.6.4.11.4 The measurement block parameters shall be as follows:

Ranging source ID: as defined in 3.6.4.2.3.

Pseudo-range correction (PRC_{30}): the correction to the ranging source pseudo-range based on 30-second carrier-smoothing.

Range rate correction (RRC_{30}): the rate of change of the pseudo-range correction based on 30-second carrier-smoothing.

Sigma_PR_gnd_D ($\sigma_{pr\_gnd\_D}$): the standard deviation of a normal distribution associated with the signal in-space contribution of the pseudo-range error in the 100-second smoothed correction in the Type 1 message at the GBAS reference point (3.6.5.5.1 and 3.6.7.2.2.4).

Note.— The parameter $\sigma_{pr\_gnd\_D}$ differs from σ_{pr_gnd} for the corresponding measurement in the Type 1 message in that $\sigma_{pr\_gnd\_D}$ should include no inflation to address overbounding of decorrelated ionospheric errors.

Coding: 1111 1111 = Ranging source correction invalid.

Sigma_PR_gnd_30 ($\sigma_{pr\_gnd\_30}$): the standard deviation of a normal distribution that describes the nominal accuracy of corrected pseudo-range smoothed with a time constant of 30 seconds at the GBAS reference point.

Note.— The normal distribution $N(0, \sigma_{pr\_gnd\_30})$ is intended to be an appropriate description of the errors to be used in optimizing the weighting used in a weighted least-squares-position solution. The distribution need not bound the errors as described in 3.6.5.5.1 and 3.6.7.2.2.4.

Coding: 1111 1111 = Ranging source correction invalid.

3.6.5 DEFINITIONS OF PROTOCOLS FOR DATA APPLICATION

Note.— This section defines the inter-relationships of the data broadcast message parameters. It provides definitions of parameters that are not transmitted, but are used by either or both non-aircraft and aircraft elements, and that define terms applied to determine the navigation solution and its integrity.

3.6.5.1 *Measured and carrier smoothed pseudo-range.* The broadcast correction is applicable to carrier smoothed code pseudo-range measurements that have not had the satellite broadcast troposphere and ionosphere corrections applied to them. The carrier smoothing is defined by the following filter:

$$P_{CSCn} = \alpha P + (1 - \alpha)\left(P_{CSC_{n-1}} + \frac{\lambda}{2\pi}(\phi_n - \phi_{n-1})\right)$$

where

P_{CSCn} = the smoothed pseudo-range;
P_{CSCn-1} = the previous smoothed pseudo-range;
P = the raw pseudo-range measurement where the raw pseudo-range measurements are obtained from a carrier driven code loop, first order or higher and with a one-sided noise bandwidth greater than or equal to 0.125 Hz;
λ = the L1 wavelength;
φ_n = the carrier phase;
φ_{n-1} = the previous carrier phase; and
α = the filter weighting function equal to the sample interval divided by the smoothing time constant. For GBAS pseudo-range corrections in message Type 1 and message Type 101, the smoothing time constant is 100 seconds, except as specified in 3.6.8.3.5.1 for airborne equipment. For GBAS pseudo-range corrections in message Type 11, the smoothing time constant is 30 seconds.

3.6.5.2 *Corrected pseudo-range.* The corrected pseudo-range for a given satellite at time *t* is:

$$PR_{corrected} = P_{CSC} + PRC + RRC \times (t - tz\text{-}count) + TC + c \times (\Delta t_{sv})_{L1}$$

where

P_{CSC} = the smoothed pseudo-range (defined in 3.6.5.1);
PRC = the pseudo-range correction from the appropriate message:
a) for 100-second smoothed pseudo-ranges, PRC is taken from message Type 1 or Type 101 defined in 3.6.4.2; and
b) for 30-second smoothed pseudo-ranges, PRC is PRC_{30} taken from message Type 11 defined in 3.6.4.11;
RRC = the pseudo-range correction rate from the appropriate message:
a) for 100-second smoothed pseudo-ranges, RRC is taken from message Type 1 or Type 101 defined in 3.6.4.2; and
b) for 30-second smoothed pseudo-ranges, RRC is RRC30 taken from message Type 11 defined in 3.6.4.11;
t = the current time;
tz-count = the time of applicability derived from the modified Z-count of the message containing PRC and RRC;
TC = the tropospheric correction (defined in 3.6.5.3); and
c and $(\Delta t_{sv})_{L1}$ are as defined in 3.1.2.2 for GPS satellites.

3.6.5.3 *TROPOSPHERIC DELAY*

3.6.5.3.1 The tropospheric correction for a given satellite is:

$$TC = N_r h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(El_i)}} (1 - e^{-\Delta h / h_0})$$

where

N_r = refractivity index from the Type 2 message (3.6.4.3);
Δh = height of the aircraft above the GBAS reference point;
El_i = elevation angle of the i^th^ satellite; and
h_0 = troposphere scale height from the Type 2 message.

3.6.5.3.2 The residual tropospheric uncertainty is:

$$\sigma_{tropo} = \sigma_n h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(El_i)}} (1 - e^{-\Delta h / h_0})$$

where σ_n = the refractivity uncertainty from the Type 2 message (3.6.4.3).

3.6.5.4 *Residual ionospheric uncertainty.* The residual ionospheric uncertainty for a given satellite is:

$$\sigma_{iono} = F_{pp} \times \sigma_{vig} \times (x_{air} + 2 \times \tau \times v_{air})$$

where

F_{pp} = the vertical-to-slant obliquity factor for a given satellite (3.5.5.5.2);

σ_{vig} = is dependent on the active GAST.
For GAST A, B or C, $\sigma_{vig} = \sigma_{vert\_iono\_gradient}$ (as defined in 3.6.4.3);
For GAST D, $\sigma_{vig} = \sigma_{vert\ iono\ gradient\ D}$ (as defined in 3.6.4.3.2.2);

x_{air} = the distance (slant range) in metres between current aircraft location and the GBAS reference point indicated in the Type 2 message;

τ = is dependent on the active GAST.
For GAST A, B or C, τ =100 seconds (time constant used in 3.6.5.1); and
For GAST D, the value of τ depends on whether σ_{iono} is applied in measurement weighting or in integrity bounding. τ = 100 seconds when σ_{iono} is used for integrity bounding (per section 3.6.5.5.1.1.1) and τ = 30 seconds when σ_{iono} is used for measurement weighting (per section 3.6.5.5.1.1.2);

v_{air} = the aircraft horizontal approach velocity (metres per second).

3.6.5.5 *PROTECTION LEVELS*

3.6.5.5.1 *Protection levels for all GBAS approach service types.* The signal-in-space vertical and lateral protection levels (VPL and LPL) are upper confidence bounds on the error in the position relative to the GBAS reference point defined as:

$$\mathrm{VPL} = \mathrm{MAX}\{\mathrm{VPL}_{\mathrm{HO}}, \mathrm{VPL}_{\mathrm{H1}}\}$$

$$\mathrm{LPL} = \mathrm{MAX}\{\mathrm{LPL}_{\mathrm{HO}}, \mathrm{LPL}_{\mathrm{H1}}\}$$

3.6.5.5.1.1 *Normal measurement conditions*

3.6.5.5.1.1.1 The vertical protection level ($\mathrm{VPL}_{\mathrm{H0}}$) and lateral protection level ($\mathrm{LPL}_{\mathrm{H0}}$), assuming that normal measurement conditions (i.e. no faults) exist in all reference receivers and on all ranging sources, is calculated as:

$$\mathrm{VPL}_{\mathrm{H0}} = K_{ffmd}\sigma_{vert} + D_V$$

$$\mathrm{LPL}_{\mathrm{H0}} = K_{ffmd}\sigma_{lat} + D_L$$

where

$$\sigma_{vert} = \sqrt{\sum_{i=1}^{N} s\_vert_i^2 \times \sigma_i^2}$$

$$\sigma_{lat} = \sqrt{\sum_{i=1}^{N} s\_lat_i^2 \times \sigma_i^2}$$

$$\sigma^2_i = \sigma^2_{pr\_gnd,i} + \sigma^2_{tropo,i} + \sigma^2_{pr\_air,i} + \sigma^2_{iono,i};$$

and

$\sigma_{pr\_gnd,i}$ is dependent on the active GAST.
For GAST A, B or C: $\sigma_{pr\_gnd,i} = \sigma_{pr\_gnd}$ for the ith ranging source as defined in 3.6.4.2;
For GAST D: $\sigma_{pr\_gnd,i} = \sigma_{pr\_gnd\_D}$ for the ith ranging source (3.6.4.11);

$\sigma_{2tropo,i}$, $\sigma_{2pr\ air,i}$ and $\sigma_{2iono,i}$ are as defined in section 3.6.5.5.1.1.2;

K_{ffmd} = the multiplier derived from the probability of fault-free missed detection;

s_vert_i = $s_{v,i} + s_{x,i} \times \tan(GPA)$;

s_lat_i = $s_{y,i}$;

$s_{x,i}$ = the partial derivative of position error in the x-direction with respect to pseudo-range error on the i^{th} satellite;

$s_{y,i}$ = the partial derivative of position error in the y-direction with respect to pseudo-range error on the i^{th} satellite;

$s_{v,i}$ = the partial derivative of position error in the vertical direction with respect to pseudo-range error on the i^{th} satellite;

GPA = the glidepath angle for the final approach path (3.6.4.5.1);

N = the number of ranging sources used in the position solution; and

i = the ranging source index for ranging sources used in the position solution;

D_V = an airborne determined parameter depending on the active GAST.
For GAST A, B or C: $D_V = 0$;
For GAST D: D_V is calculated as the magnitude of the vertical projection of the difference between the 30-second and 100-second position solutions;

D_L = an airborne determined parameter depending on the active GAST.
For GAST A, B or C: $D_L = 0$;
For GAST D: D_L is calculated as the magnitude of the lateral projection of the difference between the 30second and 100-second position solutions.

Note 1.— The airborne 30-second and 100-second position solutions, D_V and D_L are defined in RTCA MOPS DO-253D.

Note 2.— The coordinate reference frame is defined such that x is along track positive forward, y is crosstrack positive left in the local level tangent plane and v is the positive up and orthogonal to x and y.

3.6.5.5.1.1.2 For a general-least-squares position solution, the projection matrix S is defined as:

$$S \equiv \begin{bmatrix} S_{x,1} & S_{x,2} & \cdots & S_{x,N} \\ S_{y,1} & S_{y,2} & \cdots & S_{y,N} \\ S_{v,1} & S_{v,2} & \cdots & S_{v,N} \\ S_{t,1} & S_{t,2} & \cdots & S_{t,N} \end{bmatrix} = (G^T \times W \times G)^{-1} \times G^T \times W$$

where

G_i = $[-\cos El_i \cos Az_i \ -\cos El_i \sin Az_i \ -\sin El_i \ 1]$ = i^{th} row of G; and

$$W = \begin{bmatrix} \sigma^2_{w,1} & 0 & \dots & 0 \\ 0 & \sigma^2_{w,2} & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma^2_{w,N} \end{bmatrix}^{-1}$$

where $\sigma^2_{w,i} = \sigma^2_{pr\_gnd,i} + \sigma^2_{tropo,i} + \sigma^2_{pr\_air,i} + \sigma^2_{iono,i}$;

where $\sigma_{pr\_gnd,i}$ = is dependent on the active GAST.

For GAST A, B or C or the GBAS positioning service: $\sigma_{pr\_gnd,i} = \sigma_{pr\_gnd}$ for the i^th ranging source as defined in (3.6.4.2);

For GAST D: $\sigma_{pr\ gnd,i} = \sigma_{pr\ gnd\ 30}$ for the i^th ranging source (3.6.4.11);

$\sigma_{tropo,i}$ = the residual tropospheric uncertainty for the i^th ranging source (3.6.5.3);

$\sigma_{iono,i}$ = the residual ionospheric delay (due to spatial decorrelation) uncertainty for the i^th ranging source (3.6.5.4); and

$\sigma_{pr\_air,i}$ = $\sqrt{\sigma^2_{receiver}(El_i) + \sigma^2_{multipath}(El_i)}$, the standard deviation of the aircraft contribution to the corrected pseudo-range error for the i^th ranging source. The total aircraft contribution includes the receiver contribution (3.6.8.2.1) and a standard allowance for airframe multipath;

where

$\sigma_{multipath}(El_i)$ = $0.13 + 0.53e^{-El_i/10\ deg}$, the standard model for the contribution of airframe multipath (in metres);

El_i = the elevation angle for the i^th ranging source (in degrees); and

Az_i = the azimuth for the i^th ranging source taken counterclockwise for the x axis (in degrees).

Note.— To improve readability, the subscript i *was omitted from the projection matrix's equation.*

3.6.5.5.1.2 *Faulted measurement conditions.* When the Type 101 message is broadcast without B parameter blocks, the values for VPL_{H1} and LPL_{H1} are defined as zero. Otherwise, the vertical protection level (VPL_{H1}) and lateral protection level (LPL_{H1}), assuming that a latent fault exists in one, and only one reference receiver, are:

$$VPL_{H1} = \max\,[VPL_j] + D_V$$

$$LPL_{H1} = \max\,[LPL_j] + D_L$$

where VPL_j and LPL_j for j = 1 to 4 are

VPL_j = $|B\_vert_j| + K_{md}\,\sigma_{vert,H1}$; and

LPL_j = $|B\_lat_j| + K_{md}\,\sigma_{lat,H1}$;

D_V = an airborne determined parameter depending on the active GAST (3.6.5.5.1.1.1);

D_L = an airborne determined parameter depending on the active GAST (3.6.5.5.1.1.1);

and

B_vert_j = $\sum_{i=1}^{N}(s\_vert \times B_{\,.})$;

B_lat_j = $\sum_{i=1}^{N}(s\_lat \times B_{\,.})$;

$B_{i,j}$ = the broadcast differences between the broadcast pseudo-range corrections and the corrections obtained excluding the j^th reference receiver measurement for the i^th ranging source;

K_{md} = the multiplier derived from the probability of missed detection given that the ground subsystem is faulted;

$\sigma^2_{vert,H1}$ = $\sum_{i=1}^{N}(s\_vert_i^2 \times \sigma\_H1_i^2)$;

$\sigma^2_{lat,H1}$ = $\sum_{i=1}^{N}(s\_lat_i^2 \times \sigma\_H1_i^2)$;

$\sigma\_H1^2_i$ = $\left(\frac{M_i}{U_i}\right)\sigma^2_{pr\_gnd,i} + \sigma^2_{pr\_air,i} + \sigma^2_{tropo,i} + \sigma^2_{iono,i}$;

$\sigma_{pr\_gnd,i}$ is dependent on the active GAST.

For GAST A, B or C: $\sigma_{pr\_gnd,i} = \sigma_{pr\_gnd}$ for the i^th ranging source as defined in (3.6.4.2);

For GAST D: $\sigma_{pr\ gnd,i} = \sigma_{pr\ gnd\ D}$ for the i^{th} ranging source (3.6.4.11);

$\sigma^2_{tropo,i}$, $\sigma^2_{pr\ air,i}$ and $\sigma^2_{iono,i}$ are as defined in section 3.6.5.5.1.1.2;

M_i = the number of reference receivers used to compute the pseudo-range corrections for the i^{th} ranging source (indicated by the B values); and

U_i = the number of reference receivers used to compute the pseudo-range corrections for the i^{th} ranging source, excluding the j^{th} reference receiver.

Note.— A latent fault includes any erroneous measurement(s) that is not immediately detected by the ground subsystem, such that the broadcast data are affected and there is an induced position error in the aircraft subsystem.

3.6.5.5.1.3 *Definition of K multipliers for GBAS approach services.* The multipliers are given in Table B-67.

Table B-67. K-multipliers for GBAS approach services

Multiplier	M_i			
	1(Note)	2	3	4
K_{ffmd}	6.86	5.762	5.81	5.847
K_{md}	Not used	2.935	2.898	2.878

Note.— For GAST A supported by Type 101 messages broadcast without the B parameter block.

3.6.5.5.2 *GBAS positioning service.* The signal-in-space horizontal protection level is an upper confidence bound on the horizontal error in the position relative to the GBAS reference point defined as:

$$HPL = MAX\{HPL_{H0}, HPL_{H1}, HEB\}$$

3.6.5.5.2.1 *Normal measurements conditions*. The horizontal protection level (HPL_{H0}), assuming that normal measurement conditions (i.e. no faults) exist in all reference receivers and on all ranging sources, is calculated as:

$$HPL_{H0} = K_{ffmd,\ POS}d_{major}$$

where:

$$d_{major} = \sqrt{\frac{d_x^2 + d_y^2}{2} + \sqrt{\left(\frac{d_x^2 - d_y^2}{2}\right)^2 + d_{xy}^2}}$$

$$d_x^2 = \sum_{i=1}^{N} s_{x,i}^2 \sigma_i^2$$

$$d_y^2 = \sum_{i=1}^{N} s_{y,i}^2 \sigma_i^2$$

$$d_{xy} = \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma_i^2$$

$s_{x,i}$ = the partial derivative of position error in the x-direction with respect to pseudo-range error on the i^{th} satellite

$s_{y,i}$ = the partial derivative of position error in the y-direction with respect to pseudo-range error on the i^{th} satellite

$K_{ffmd,POS}$ = the multiplier derived from the probability of fault-free missed detection

N = the number of ranging sources used in the position solution

i = the ranging source index for ranging sources used in the position solution

σ_i = the pseudo-range error term as defined in 3.6.5.5.1.1

Note.— For the GBAS positioning service, the x and y axes define an arbitrary orthogonal basis in the horizontal plane.

3.6.5.5.2.2 *Faulted measurement conditions.* When the Type 101 message is broadcast without B parameter blocks, the value for HPL_{H1} is defined as zero. Otherwise, the horizontal protection level (HPL_{H1}), assuming that a latent fault exists in one and only one reference receiver, is:

$$HPL_{H1} = \max\,[HPL_j]$$

where HPL_j for j = 1 to 4 is:

$$HPL_j = |B\_horz_j| + K_{md\_POS} d_{major,H1}$$

and

$$B\_horz_j = \sqrt{\left(\sum_{i=1}^{N} S_{x,i} B_{i,j}\right)^2 + \left(\sum_{i=1}^{N} S_{y,i} B_{i,j}\right)^2}$$

$B_{i,j}$ = the broadcast differences between the broadcast pseudo-range corrections and the corrections obtained excluding the j^{th} reference receiver measurement for the i^{th} ranging source.

$K_{md\ POS}$ = the multiplier derived from the probability of missed detection given that the ground subsystem is faulted.

$$d_{major,H1} = \sqrt{\frac{d\_H1_x^2 + d\_H1_y^2}{2} + \sqrt{\left(\frac{d\_H1_x^2 - d\_H1_y^2}{2}\right)^2 + d\_H1_{xy}^2}}$$

$$d\_H1_x^2 = \sum_{i=1}^{N} s_{x,i}^2 \sigma\_H1_i^2$$

$$d\_H1_y^2 = \sum_{i=1}^{N} s_{y,i}^2 \sigma\_H1_i^2$$

$$d\_H1_{xy} = \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma\_H1_i^2$$

Note.— For the GBAS positioning service, the x and y axes define an arbitrary orthogonal basis in the horizontal plane.

$$\sigma\_H1_i^2 = \left(\frac{M_i}{U_i}\right)\sigma_{pr\_gnd,i}^2 + \sigma_{pr\_air,i}^2 + \sigma_{tropo,i}^2 + \sigma_{iono}^2$$

M_i = the number of reference receivers used to compute the pseudo-range corrections for the ith ranging source (indicated by the B values).

U_i = the number of reference receivers used to compute the pseudo-range corrections for the ith ranging source, excluding the jth reference receiver.

Note.— A latent fault includes any erroneous measurement(s) that is not immediately detected by the ground subsystem, such that the broadcast data are affected and there is an induced position error in the aircraft subsystem.

3.6.5.5.2.3 *Definition of K multipliers for GBAS positioning service.* The multiplier K_{ffmd_POS} is equal to 10.0 and the multiplier K_{md_POS}, is equal to 5.3.

3.6.5.6 ALERT LIMITS

Note 1.— Guidance concerning the calculation of alert limits, including approaches associated with channel numbers 40 000 to 99 999, is provided in Attachment D, 7.13.

Note 2. — Computation of alert limits depends on the active service type.

3.6.5.6.1 *GAST C and D alert limits.* The alert limits are defined in Tables B-68 and B-69. For aircraft positions at which the lateral deviation exceeds twice the deviation at which full-scale lateral deflection of a course deviation indicator is achieved, or vertical deviation exceeds twice the deviation at which full-scale fly-down deflection of a course deviation indicator is achieved, both the lateral and vertical alert limits are set to the maximum values given in the tables.

3.6.5.6.2 *GAST A and B alert limits*. The alert limits are equal to the FASLAL and FASVAL taken from the Type 4 message for approaches with channel numbers in the range of 20 001 to 39 999. For approaches with channel numbers in the range 40 000 to 99 999, the alert limits are stored in the on-board database.

3.6.5.7 *Channel number.* Each GBAS approach transmitted from the ground subsystem is associated with a channel number in the range of 20 001 to 39 999. If provided, the GBAS positioning service is associated with a separate channel number in the range of 20 001 to 39 999. The channel number is given by:

$$\text{Channel number} = 20\,000 + 40(F - 108.0) + 411(S)$$

where

F = the data broadcast frequency (MHz)
S = RPDS or RSDS

and

RPDS = the reference path data selector for the FAS data block (as defined in 3.6.4.5.1)
RSDS = the reference station data selector for the GBAS ground subsystem (as defined in 3.6.4.3.1)

Table B-68. GAST C and D lateral alert limit

Horizontal distance of aircraft position from the LTP/FTP as translated along the final approach path (metres)	Lateral alert limit (metres)
$D \leq 873$	FASLAL
$873 < D \leq 7\,500$	0.0044D (m) + FASLAL – 3.85
$D > 7\,500$	FASLAL + 29.15

Table B-69. GAST C and D ve rtical alert limit

Height above LTP/FTP of aircraft position translated onto the final approach path (feet)	Vertical alert limit (metres)
$H \leq 200$	FASVAL
$200 < H \leq 1\,340$	0.02925H (ft) + FASVAL – 5.85
$H > 1\,340$	FASVAL + 33.35

For channel numbers transmitted in the additional data block 2 of Type 2 message (as defined in 3.6.4.3.2.1), only RSDS are used.

Note 1.— When the FAS is not broadcast for an approach supported by GAST A or B, the GBAS approach is associated with a channel number in the range 40 000 to 99 999.

Note 2.— Guidance material concerning channel number selection is provided in Attachment D, 7.7.

3.6.5.8 EPHEMERIS ERROR POSITION BOUND

Note.— Ephemeris error position bounds are computed only for core satellite constellation ranging sources used in the position solution (j index) and not for other types of ranging sources (SBAS satellites or pseudolites) that are not subject to undetected ephemeris failures. However, the calculations of these position bounds use information from all ranging sources used in the position solution (i index).

3.6.5.8.1 *GBAS approach*. The vertical and lateral ephemeris error position bounds are defined as:

$$VEBj = MAX\{VEB_j\} + D_V$$

$$LEBj = MAX\{LEB_j\} + D_L$$

The vertical and lateral ephemeris error position bounds for the j^{th} core satellite constellation ranging source used in the position solution are given by:

$$VEB_j = \left|s\_vert_j\right| x_{air} P_{ej} + K_{md\_ej} \sqrt{\sum_{i=1}^{N} s\_ve}$$

$$LEB_j = \left|s\_lat_j\right| x_{air} P_{ej} + K_{md\_ej} \sqrt{\sum_{i=1}^{N} s\_lat}$$

where:

D_V	= an airborne determined parameter depending on the active GAST (3.6.5.5.1.1.1);
D_L	= an airborne determined parameter depending on the active GAST (3.6.5.5.1.1.1);
$s\_vert_{i \text{ or } j}$	is defined in 3.6.5.5.1.1;
$s\_lat_{i \text{ or } j}$	is defined in 3.6.5.5.1.1;
x_{air}	is defined in 3.6.5.4;
N	is the number of ranging sources used in the position solution;
σ_i	is defined in 3.6.5.5.1.1;
P_{ej}	is the broadcast ephemeris decorrelation parameter for the jth ranging source. The source of this parameter depends on the active GBAS approach service type: GAST A, B or C: P_{ej} = P from the Type 1 or Type 101 Message corresponding to the jth ranging source. (section 3.6.4.2.3); GAST D: $P_{ej} = P_D$ from the Type 11 Message corresponding to the jth ranging source (section 3.6.4.11.3);
$K_{md\_e,j}$	is the broadcast ephemeris missed detection multiplier for GAST A-C associated with the satellite constellation for the jth ranging source. The source of this parameter depends on the active GBAS approach service type: GAST A, B or C: $K_{md\_e,j} = K_{md\_e,GPS}$ or $K_{md\_e,GLONASS}$ as obtained from the Type 2 Message Additional Data block 1 (section 3.6.4.3.1); GAST D: $K_{md\_e,j} = K_{md\_e\_D,GPS}$ or $K_{md\_e\_D,GLONASS}$ as obtained from the Type 2 Message Additional Data block 3 (section 3.6.4.3.2.2).

3.6.5.8.2 GBAS positioning service. The horizontal ephemeris error position bound is defined as:

$$HEBj = MAX\{HEB_j\}$$

The horizontal ephemeris error position bound for the jth core satellite constellation ranging source used in the position solution is given by:

$$HEB_j = \left|s_{horz,j}\right| x_{air} P_j + K_{md\_e\_POS} d_{major}$$

where:

$$s_{horz,j}{}^2 = s_{xj}{}^2 + s_{yj}{}^2$$

$s_{x,j}$	is as defined in 3.6.5.5.2.1
$s_{y,j}$	is as defined in 3.6.5.5.2.1
x_{air}	is defined in 3.6.5.4
P_j	is the broadcast ephemeris decorrelation parameter for the jth ranging source. The source of this parameter does not depend on the active GBAS approach service type. In all cases, P_j=P from the Type 1 or Type 101 Message (section 3.6.4.2.3) corresponding to the jth ranging source.
$K_{md\_e\_POS}$	is the broadcast ephemeris missed detection multiplier for the GBAS positioning service associated with the satellite constellation for the jth ranging source ($K_{md\ e\ POS,GPS}$ or $K_{md\ e\ POS,GLONASS}$)
d_{major}	is as defined in 3.6.5.5.2.1

3.6.5.9 *Ionospheric gradient error*

The maximum undetected 30-second smoothed corrected pseudo-range error due to an ionospheric gradient (E_{IG}) is calculated based on the broadcast parameters Y_{EIG} and M_{EIG}, as:

$$E_{IG} = Y_{EIG} + M_{EIG} \times D_{EIG}$$

where

Y_{EIG} = maximum value of E_{IG} (metres) in the Type 2 message;
M_{EIG} = slope of maximum E_{IG} (m/km) in the Type 2 message;
D_{EIG} = the distance in kilometres between the LTP location for the selected approach broadcast in the Type 4 Message and the GBAS reference point in the Type 2 message.

3.6.6 MESSAGE TABLES

Each GBAS message shall be coded in accordance with the corresponding message format defined in Tables B-70 through B-73.

Note.— Message type structure is defined in 3.6.4.1.

Table B-70. Type 1 pseudo-range corrections message

Data content	Bits used	Range of values	Resolution
Modified Z-count	14	0 to 1 199.9 s	0.1 s
Additional message flag	2	0 to 3	1
Number of measurements (N)	5	0 to 18	1
Measurement type	3	0 to 7	1
Ephemeris decorrelation parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m
Ephemeris CRC	16	—	—
Source availability duration For	8	0 to 2 540 s	10 s
N measurement blocks			
Ranging source ID	8	1 to 255	1
Issue of data (IOD)	8	0 to 255	1
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s
$\sigma_{pr\ gnd}$	8	0 to 5.08 m	0.02 m
B_1	8	±6.35 m	0.05 m
B_2	8	±6.35 m	0.05 m
B_3	8	±6.35 m	0.05 m
B_4	8	±6.35 m	0.05 m

Table B-70A. Type 101 GRAS pseudo-range corrections message

Data content	Bits used	Range of values	Resolution
Modified Z-count	14	0 to 1 199.9 s	0.1 s
Additional message flag	2	0 to 3	1
Number of measurements (N)	5	0 to 18	1
Measurement type	3	0 to 7	1
Ephemeris decorrelation parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m
Ephemeris CRC	16	—	—
Source availability duration	8	0 to 2540 s	10 s
Number of B parameters	1	0 or 4	—
Spare	7	—	—
For N measurement blocks			
Ranging source ID	8	1 to 255	1
Issue of data (IOD)	8	0 to 255	1
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s
$\sigma_{pr\ gnd}$	8	0 to 50.8 m	0.2 m
B parameter block (if provided)			
B_1	8	±25.4 m	0.2 m
B_2	8	±25.4 m	0.2 m
B_3	8	±25.4 m	0.2 m
B_4	8	±25.4 m	0.2 m

Table B-70B. Type 11 pseudo-range corrections (30-second smoothed pseudo-ranges) message

Data content	Bits used	Range of values	Resolution
Modified Z-count	14	0 – 1199.9 sec	0.1 sec
Additional message flag	2	0 – 3	1
Number of measurements	5	0 – 18	1
Measurement type	3	0 – 7	1
Ephemeris decorrelation parameter D (P_D) (Notes 1, 3)	8	0 – 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m
For N measurement blocks:			
Ranging source ID	8	1 – 255	1
Pseudo-range correction (PRC_{30})	16	±327.67 m	0.01 m
Range rate correction (RRC_{30})	16	±32.767 m/s	0.001 m/s
Sigma_PR_gnd_D ($\sigma_{pr\ gnd\ D}$) (Note 2)	8	0 – 5.08 m	0.02 m
Sigma_PR_gnd_30 ($\sigma_{pr\_gnd\_30}$) (Note 2)	8	0 – 5.08 m	0.02 m

Notes:

1. *For SBAS satellites, the parameter is set to all zeros.*
2. *1111 1111 indicates the source is invalid.*
3. *Parameter is associated with th e first transmitted measurement block.*

Table B-71A. Type 2 GBAS-related data message

Data content	Bits used	Range of values	Resolution
GBAS reference receivers	2	2 to 4	—
Ground accuracy designator letter	2	—	—
Spare	1	—	—
GBAS continuity/integrity designator	3	0 to 7	1
Local magnetic variation	11	±180°	0.25°
Reserved and set to zero (00000)	5	—	—
$\sigma_{\text{vert iono gradient}}$	8	0 to 25.5×10^{-6} m/m	0.1×10^{-6} m/m
Refractivity index	8	16 to 781	3
Scale height	8	0 to 25 500 m	100 m
Refractivity uncertainty	8	0 to 255	1
Latitude	32	±90.0°	0.0005 arcsec
Longitude	32	±180.0°	0.0005 arcsec
GBAS reference point height	24	±83 886.07 m	0.01 m
Additional data block 1 (if provided)			
Reference station data selector	8	0 to 48	1
Maximum use distance (D_{max})	8	2 to 510 km	2 km
$K_{\text{md e POS,GPS}}$	8	0 to 12.75	0.05
$K_{\text{md e,GPS}}$	8	0 to 12.75	0.05
Additional data blocks (repeated for all provided)			
Additional data block length	8	2 to 255	1
Additional data block number	8	2 to 255	1
Additional data parameters	Variable	—	—

Note.— Multiple additional data blocks may be appended to a Type 2 message.

Table B-71B. Type 3 null message

Data content	Bits used	Range of values	Resolution
Filler	Variable (Note)	N/A	N/A

Note.— The number of bytes in the filler field is 10 less than the message length field in the message header as defined in section 3.6.3.4.

Table B-72. Type 4 FAS data message

Data content	Bits used	Range of values	Resolution
For N data sets			
Data set length	8	2 to 212	1 byte
FAS data block	304	—	—
FAS vertical alert limit/approach status	8		
(1) when associated approach performance designator (APD) is coded as 0		0 to 50.8 m	0.2 m
(2) when associated approach performance designator(APD) is not coded as 0		0 to 25.4 m	0.1 m
FAS lateral alert limit/approach status	8	0 to 50.8 m	0.2 m

Table B-73. Type 5 predicted ranging source availability message

Data content	Bits used	Range of values	Resolution
Modified Z-count	14	0 to 1 199.9 s	0.1 s
Spare	2	—	—
Number of impacted sources (N)	8	0 to 31	1
For N impacted sources			
Ranging source ID	8	1 to 255	1
Source availability sense	1	—	—
Source availability duration	7	0 to 1 270 s	10 s
Number of obstructed approaches (A)	8	0 to 255	1
For A obstructed approaches			
Reference path data selector	8	0 to 48	—
Number of impacted sources for this approach (N_A)	8	1 to 31	1
For N_A impacted ranging sources for this approach			
Ranging source ID	8	1 to 255	1
Source availability sense	1	—	—
Source availability duration	7	0 to 1 270 s	10 s

3.6.7 NON-AIRCRAFT ELEMENTS

3.6.7.1 *PERFORMANCE*

3.6.7.1.1 *Accuracy*

3.6.7.1.1.1 The root-mean-square (RMS) (1 sigma) of the ground subsystem contribution to the corrected 100-second smoothed pseudo-range accuracy for GPS satellites shall be:

$$\mathrm{RMS}_{\mathrm{pr\_gnd}} \leq \sqrt{\frac{(a_0 + a_1 e^{-\theta_n/\theta_0})^2}{M} + (a_2)^2}$$

where

M = the number of GNSS reference receivers, as indicated in the Type 2 message parameter (3.6.4.3), or, when this parameter is coded to indicate "not applicable", the value of M is defined as 1;

n = n^{th} ranging source;

θ_n = elevation angle for the n^{th} ranging source; and

a_0, a_1, a_2, and θ_0 = parameters defined in Tables B-74 and B-75 for each of the defined ground accuracy designators (GADs).

Note 1.— The GBAS ground subsystem accuracy requirement is determined by the GAD letter and the number of reference receivers.

Note 2.— The ground subsystem contribution to the corrected 100-second smoothed pseudo-range error specified by the curves defined in Tables B-74 and B-75 and the contribution to the SBAS satellites do not include aircraft noise and aircraft multipath.

Table B-74. GBAS — GPS accuracy requirement parameters

Ground accuracy designator letter	θ_n (degrees)	a_0 (metres)	a_1 (metres)	θ_0 (degrees)	a_2 (metres)
A	≥ 5	0.5	1.65	14.3	0.08
B	≥ 5	0.16	1.07	15.5	0.08
C	> 35	0.15	0.84	15.5	0.04
	5 to 35	0.24	0	—	0.04

Table B-75. Reserved

3.6.7.1.1.2 The RMS of the ground subsystem contribution to the corrected 100-second smoothed pseudo-range accuracy for SBAS satellites shall be:

$$\mathrm{RMS}_{\mathrm{pr\_gnd}} \leq \frac{1.8}{\sqrt{\mathrm{M}}}\,(\mathrm{metres})$$

Where M is as defined in 3.6.7.1.1.1.

Note.— GAD classifications for SBAS ranging sources are under development.

3.6.7.1.2 *Integrity*

3.6.7.1.2.1 *GBAS ground subsystem integrity risk*

3.6.7.1.2.1.1 *Ground subsystem integrity risk for GBAS approach services*

3.6.7.1.2.1.1.1 *Ground subsystem signal-in-space integrity risk for GBAS approach service types A, B or C*. For a GBAS ground subsystem classified as FAST A, B or C, the integrity risk shall be less than 1.5×10^{-7} per approach.

Note 1.— The integrity risk assigned to the GBAS ground subsystem is a subset of the GBAS signal-in-space integrity risk, where the protection level integrity risk (3.6.7.1.2.2.1) has been excluded and the effects of all other GBAS, SBAS and core satellite constellations failures are included. The GBAS ground subsystem integrity risk includes the integrity risk of satellite signal monitoring required in 3.6.7.3.3.

Note 2.— GBAS signal-in-space integrity risk is defined as the probability that the ground subsystem provides information which when processed by a fault-free receiver, using any GBAS data that could be used by the aircraft in the service volume, results in an out-of-tolerance lateral or vertical relative position error without annunciation for a period longer than the maximum signal-in-space time-to-alert. An out-of-tolerance lateral or vertical relative position error is defined as an error that exceeds the GBAS approach services protection level and, if additional data block 1 is broadcast, the ephemeris error position bound.

3.6.7.1.2.1.1.2 *Ground subsystem signal-in-space integrity risk for GBAS approach service type D*. For a GBAS ground subsystem classified as FAST D, the integrity risk for all effects other than errors induced by anomalous ionospheric conditions shall be less than 1.5×10^{-7} per approach.

Note 1.— The integrity risk assigned to the GBAS ground subsystem classified as FAST D is a subset of the GBAS signal-in-space integrity risk, where the protection level integrity risk (3.6.7.1.2.2.1) has been excluded and the effects of all other GBAS, SBAS and core satellite constellations failures are included.

Note 2.— For GAST D, the GBAS signal-in-space integrity risk is defined as the probability that the ground subsystem provides information which when processed by a fault-free receiver, using any GBAS data that could be used by the aircraft in the service volume, in the absence of an ionospheric anomaly, results in an out-of-tolerance lateral or vertical relative position error without annunciation, for a period longer than the maximum signal-in-space time-to-alert. An out-of-tolerance lateral or vertical relative position error is defined as an error that exceeds the GBAS approach services protection level and the ephemeris error position bound. For GAST D, out-of-tolerance conditions caused by anomalous ionospheric errors are excluded from this integrity risk as the risk due to ionospheric anomalies has been allocated to and is mitigated by the airborne segment.

3.6.7.1.2.1.1.3 *Ground subsystem integrity risk for GAST D*. For a GBAS ground subsystem classified as FAST D, the probability that the ground subsystem internally generates and transmits non-compliant information for longer than 1.5 seconds shall be less than 1×10^{-9} in any one landing.

Note 1.— This additional integrity risk requirement assigned to FAST D GBAS ground subsystems is defined in terms of the probability that internal ground subsystem faults generate non-compliant information. Non-compliant information in this context is defined in terms of the intended function of the ground subsystem to support landing operations in Category III minima. For example, non-compliant information includes any broadcast signal or broadcast information that is not monitored in accordance with the standard.

Note 2.— Environmental conditions (anomalous ionosphere, troposphere, radio frequency interference, GNSS signal multipath, etc.) are not considered faults; however, faults in ground subsystem equipment, used to monitor for or mitigate the effects of these environmental conditions, are included in this requirement. Similarly, the core satellite constellation ranging source faults are excluded from this requirement; however, the ground subsystem's capability to provide integrity monitoring for these ranging sources is included. Monitoring requirements for ranging source faults and ionosphere environmental conditions are separately specified in 3.6.7.3.3.2, 3.6.7.3.3.3 and 3.6.7.3.4.

Note 3.— Faults that occur in ground receivers used to generate the broadcast corrections are excluded from this requirement if they occur in any one, and only one, ground receiver at any time. Such faults are constrained by the requirement in 3.6.7.1.2.2.1.2 and the associated integrity risk requirements in 3.6.7.1.2.2.1 and 3.6.7.1.2.2.1.1.

3.6.7.1.2.1.2 *Ground subsystem time-to-alert for GBAS approach services*

3.6.7.1.2.1.2.1 *Maximum time-to-alert for approach services*

3.6.7.1.2.1.2.1.1 For a ground segment classified as FAST A, B, C or D, the GBAS ground subsystem maximum timeto-alert shall be less than or equal to 3 seconds for all signal-in-space integrity requirements (see Appendix B, 3.6.7.1.2.1.1.1, 3.6.7.1.2.1.1.2, 3.6.7.1.2.2.1) when Type 1 messages are broadcast.

Note 1.— The ground subsystem time-to-alert above is the time between the onset of the out of tolerance lateral or vertical relative position error and the transmission of the last bit of the message that contains the integrity data that reflects the condition (see Attachment D, 7.5.14).

Note 2.— For FAST D ground subsystems, additional range domain monitoring requirements apply as defined in section 3.6.7.3.3.2, 3.6.7.3.3.3 and 3.6.7.3.4. In these sections, time limits are defined for the ground system to detect and alert the airborne receiver of out-of-tolerance differential pseudo-range errors.

3.6.7.1.2.1.2.1.2 For a ground segment classified as FAST A, the GBAS ground subsystem maximum signal-in-space time-to-alert shall be less than or equal to 5.5 seconds when Type 101 messages are broadcast.

3.6.7.1.2.1.3 *Ground subsystem FASLAL and FASVAL*

3.6.7.1.2.1.3.1 For message Type 4 FAS data blocks with APD coded as 1, 2, 3 or 4, the value FASLAL for each FAS block, as defined in the FAS lateral alert limit field of the Type 4 message shall be no greater than 40 metres, and the value FASVAL for each FAS block, as defined in the FAS vertical alert limit field of the Type 4 message, shall be no greater than 10 metres.

3.6.7.1.2.1.3.2 For message Type 4 FAS data blocks with APD coded as zero, the value FASLAL and FASVAL shall be no greater than the lateral and vertical alert limits given in Annex 10, Volume I, 3.7.2.4 for the intended operational use.

3.6.7.1.2.1.4 *Ground subsystem signal-in-space integrity risk for GBAS positioning service*. For GBAS ground subsystem that provides the GBAS positioning service, integrity risk shall be less than 9.9×10^{-8} per hour.

Note 1.— The integrity risk assigned to the GBAS ground subsystem is a subset of the GBAS signal in-space integrity risk, where the protection level integrity risk (3.6.7.1.2.2.2) has been excluded and the effects of all other GBAS, SBAS and core satellite constellations failures are included. The GBAS ground subsystem integrity risk includes the integrity risk of satellite signal monitoring required in 3.6.7.3.3 .

Note 2.— GBAS signal-in-space integrity risk is defined as the probability that the ground subsystem provides information which when processed by a fault-free receiver, using any GBAS data that could be used by the aircraft, results in an out-of-tolerance horizontal relative position error without annunciation for a period longer than the maximum time-toalert. An out-of-tolerance horizontal relative position error is defined as an error that exceeds both the horizontal protection level and the horizontal ephemeris error position bound.

3.6.7.1.2.1.4.1 *Time-to-alert for GBAS positioning service*. The GBAS ground subsystem maximum time-to-alert shall be less than or equal to 3 seconds when Type 1 messages are broadcast and less than or equal to 5.5 seconds when Type 101 messages are broadcast.

Note.— The time-to-alert above is the time between the onset of the out-of-tolerance horizontal relative position error and the transmission of the last bit of the message that contains the integrity data that reflects the condition.

3.6.7.1.2.2 *Protection level integrity risk*

3.6.7.1.2.2.1 For a GBAS ground subsystem that provides GBAS approach services, the protection level integrity risk shall be less than 5×10^{-8} per approach.

Note.— For approach services, the protection level integrity risk is the integrity risk due to undetected errors in the 100second smoothed position solution relative to the GBAS reference point greater than the associated protection levels under the two following conditions:

a) *normal measurement conditions defined in 3.6.5.5.1.1 with D_V and D_L set to zero; and*

b) *faulted measurement conditions defined in 3.6.5.5.1.2 with D_V and D_L set to zero.*

Note.— The ground subsystem bounding of the 100-second smoothed GAST D position solution will ensure that the 30 smoothed GAST D position solution is bounded.

3.6.7.1.2.2.1.1 *Additional bounding requirements for FAST D ground subsystems.* The σ_{vert} (used in computing the protection level VPL_{H0}) and σ_{lat} (used in computing the protection level LPL_{H0}) for GAST D formed, based on the broadcast parameters (defined in 3.6.5.5.1.1.1) and excluding the airborne contribution, shall satisfy the condition that a normal distribution with zero mean and a standard deviation equal to σ_{vert} and σ_{lat} bounds the vertical and lateral error distributions of the combined differential correction errors as follows:

$$\int_{y}^{\infty} f_n(x)dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0 \text{ and}$$

$$\int_{-\infty}^{-y} f_n(x)dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0$$

where

$f_n(x)$ = probability density function of the differential vertical or lateral position error excluding the airborne contribution, and

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_{x}^{\infty} e^{-\frac{t^2}{2}}dt$$

The $\sigma_{vert,H1}$ (used in computing the protection level VPL_{H1}) and $\sigma_{lat,H1}$ (used in computing the protection level LPL_{H1}) for GAST D formed, based on the broadcast parameters (defined in 3.6.5.5.1.2) and excluding the airborne contribution, shall bound the combined differential correction errors (as defined above) formed by all possible subsets with one reference receiver excluded.

Note 1.— The airborne contribution is addressed in 3.6.8.3.2.1 in combination with the use of the standard airborne multipath model defined in 3.6.5.5.1.1.2.

Note 2.— The combined differential correction errors refer to code-carrier-smoothed corrections based on 100-second smoothing time constant.

3.6.7.1.2.2.1.2 For a GBAS ground subsystem classified as FAST D, the rate of faulted measurements from any one, and only one, reference receiver shall be less than 1×10^{-5} per 150 seconds.

Note.— Faulted measurements can occur from faults within the receiver or from environmental conditions unique to a single reference receiver location.

3.6.7.1.2.2.2 For a GBAS ground subsystem that provides the positioning service, protection level integrity risk shall be less than 10^{-9} per hour.

Note.— The GBAS positioning service protection level integrity risk is the integrity risk due to undetected errors in the horizontal position relative to the GBAS reference point greater than the GBAS positioning service protection level under the two following conditions:

a) normal measurement conditions defined in 3.6.5.5.2.1; and

b) faulted measurement conditions defined in 3.6.5.5.2.2.

3.6.7.1.3 *Continuity of service*

3.6.7.1.3.1 *Continuity of service for approach services*. The GBAS ground subsystem continuity of service shall be greater than or equal to $1 - 8.0 \times 10^{-6}$ per 15 seconds.

Note.— The GBAS ground subsystem continuity of service is the average probability per 15-second period that the VHF data broadcast transmits data in tolerance, VHF data broadcast field strength is within the specified range and the protection levels are lower than the alert limits, including configuration changes that occur due to the space segment. This continuity of service requirement is the entire allocation of the signal-in-space continuity requirement from Chapter 3, Table 3.7.2.4-1, and therefore all continuity risks included in that requirement must be accounted for by the ground subsystem provider.

3.6.7.1.3.2 *Additional continuity of service requirements for FAST D*. The probability of a GBAS ground subsystem failure or false alert, excluding ranging source monitoring, causing an unscheduled interruption of service for a period equal to or greater than 1.5 seconds shall not exceed 2.0×10^{-6} during any 15 second interval. The probability that the ground subsystem excludes any individual fault-free ranging source from the Type 1 or Type 11 corrections due to a false detection by the ground integrity monitors shall not exceed 2.0×10^{-7} during any 15 second interval.

Note 1.— Loss of service includes failures resulting in loss of the VHF data broadcast, failure to meet the VHF data broadcast field strength, failures resulting in transmission of out-of-tolerance VHF broadcast data, and alert due to an integrity failure. Guidance material on the potential causes of loss of service and monitor false detections are contained in Attachment D, 7.6.2.1.

Note 2. – Continuity for FAST D is defined as the probability that the ground subsystem continues to provide the services associated with the intended ground subsystem functions. Total aircraft continuity of navigation system performance in the position domain must be evaluated in the context of a specific satellite geometry and aeroplane integration. Evaluation of position domain navigation service continuity is the responsibility of the airborne user for GAST D. Additional information regarding continuity is given in Attachment D, 7.6.2.1.

3.6.7.1.3.3 *Continuity of service for positioning service*

Note.— For GBAS ground subsystems that provide the GBAS positioning service, there may be additional continuity requirements depending on the intended operations.

3.6.7.2 FUNCTIONAL REQUIREMENTS

3.6.7.2.1 *General*

3.6.7.2.1.1 *Data broadcast requirements.*

3.6.7.2.1.1.1 A GBAS ground subsystem shall broadcast message types as defined in Table B-75A according to the service types supported by the ground subsystem.

3.6.7.2.1.1.2 Each GBAS ground subsystem shall broadcast Type 2 messages with additional data blocks as required to support the intended operations.

Note.— Guidance material concerning usage of the Type 2 message additional data blocks is provided in Attachment D, 7.17.

3.6.7.2.1.1.3 Each GBAS ground subsystem which supports GBAS approach service type (GAST) B, C or D shall broadcast FAS blocks in Type 4 messages for these approaches. If a GBAS ground subsystem supports any approach using GAST A or B and does not broadcast FAS blocks for the corresponding approaches, it shall broadcast additional data block 1 in the Type 2 message.

Note.— FAS blocks for APV procedures may be held within a database on board the aircraft. Broadcasting additional data block 1 allows the airborne receiver to select the GBAS ground subsystem that supports the approach procedures in the airborne database. FAS blocks may also be broadcast to support operations by aircraft without an airborne database. These procedures use different channel numbers as described in Attachment D, 7.7.

3.6.7.2.1.1.4 When the Type 5 message is used, the ground subsystem shall broadcast the Type 5 message at a rate in accordance with Table B-76.

Note.— When the standard 5 degree mask is not adequate to describe satellite visibility at either the ground subsystem antennas or at an aircraft during a specific approach, the Type 5 message may be used to broadcast additional information to the aircraft.

3.6.7.2.1.1.5 *Data broadcast rates.* For all message types required to be broadcast, messages meeting the field strength requirements of Chapter 3, 3.7.3.5.4.4.1.2 and 3.7.3.5.4.4.2.2 and the minimum rates shown in Table B-76 shall be provided at every point within the service volume. The total message broadcast rates from all antenna systems of the ground subsystem combined shall not exceed the maximum rates shown in Table B-76.

Note.— Guidance material concerning the use of multiple antenna systems is provided in Attachment D, 7.12.4.

3.6.7.2.1.2 *Message block identifier.* The MBI shall be set to either normal or test according to the coding given in 3.6.3.4.1.

Table B-75A. GBAS message types for supported service types

Message type	GAST A – Note 1	GAST B – Note 1	GAST C – Note 1	GAST D – Note 1
MT 1	Optional – Note 2	Required	Required	Required
MT 2	Required	Required	Required	Required
MT2-ADB 1	Optional – Note 3	Optional – Note 3	Optional – Note 3	Required
MT2-ADB 2	Optional – Note 4	Optional – Note 4	Optional – Note 4	Optional
MT2-ADB 3	Not used	Not used	Not used	Required
MT2-ADB 4	Recommended	Recommended	Recommended	Required
MT3-Note 5	Recommended	Recommended	Recommended	Required
MT 4	Optional	Required	Required	Required
MT 5	Optional	Optional	Optional	Optional
MT11 – Note 6	Not used	Not used	Not used	Required
MT 101	Optional – Note 2	Not allowed	Not allowed	Not allowed

Note 1.— Definition of terms:

- *Required: Message needs to be transmitted when supporting the service type;*
- *Optional: Message transmission is optional when supporting the service type (not used by some or all airborne subsystems);*
- *Recommended: Use of the message is optional, but recommended, when supporting the service type;*
- *Not used: Message is not used by airborne subsystems for this service type;*
- *Not allowed: Message transmission is not allowed when supporting the service type.*

Note 2.— Ground subsystems supporting GAST A service types may broadcast Type 1 or 101 Messages, but not both. Guidance material concerning usage of the Type 101 message is provided in Attachment D, 7.18.

Note 3.— MT2-ADB1 is required if positioning service is offered.

Note 4.— MT2-ADB2 is required if GRAS service is offered.

Note 5.— MT3 is recommended (GAST A, B, C) or required (GAST-D) to be used only in order to meet slot occupancy requirements in 3.6.7.4.1.3.

Note 6.— Guidance material concerning usage of the Type 11 message is provided in Attachment D, 7.20.

Table B-76. GBAS VHF data broadcast rates

Message type	Minimum broadcast rate	Maximum broadcast rate
1 or 101	For each measurement type: All measurement blocks once per frame (Note)	For each measurement type: All measurement blocks once per slot
2	Once per 20 consecutive frames	Once per frame (except as stated in 3.6.7.4.1.2)
3	Rate depends on message length and scheduling of other messages (see section 3.6.7.4.1.3)	Once per slot and eight times per frame
4	All FAS blocks once per 20 consecutive frames	All FAS blocks once per frame
5	All impacted sources once per 20 consecutive frames	All impacted sources once per 5 consecutive frames

11	For each measurement type: All measurement blocks once per frame (see Note)	For each measurement type: All measurement blocks once per slot

Note.— One Type 1, Type 11 or Type 101 message or two Type 1, Type 11 or Type 101 messages that are linked using the additional message flag described in 3.6.4.2, 3.6.4.10.3 or 3.6.4.11.3.

3.6.7.2.1.3 *VDB authentication*

3.6.7.2.1.3.1 All GBAS ground subsystems shall support VDB authentication (see 3.6.7.4).

3.6.7.2.1.3.2 All ground subsystems classified as FAST D shall support VDB authentication (see 3.6.7.4).

3.6.7.2.2 *Pseudo-range corrections*

3.6.7.2.2.1 *Message latency*. The time between the time indicated by the modified Z-count and the last bit of the broadcast Type 1, Type 11 or Type 101 message shall not exceed 0.5 seconds.

3.6.7.2.2.2 *Low-frequency data*. Except during an ephemeris change, the first ranging source in the Type 1, Type 11 or Type 101 message shall sequence so that the ephemeris decorrelation parameter, ephemeris CRC and source availability duration for each core satellite constellation's ranging source are transmitted at least once every 10 seconds. During an ephemeris change, the first ranging source shall sequence so that the ephemeris decorrelation parameter, ephemeris CRC and source availability duration for each core satellite constellation's ranging source are transmitted at least once every 27 seconds. When new ephemeris data are received from a core satellite constellation's ranging source, the ground subsystem shall use the previous ephemeris data from each satellite until the new ephemeris data have been continuously received for at least 2 minutes but shall make a transition to the new ephemeris data before 3 minutes have passed. When this transition is made to using the new ephemeris data for a given ranging source, the ground subsystem shall broadcast the new ephemeris CRC and associated low-frequency information, notably P and P_D for all occurrences of that ranging source in the lowfrequency information of Type 1, Type 11 or Type 101 message in the next 3 consecutive frames. For a given ranging source, the ground subsystem shall continue to transmit data corresponding to the previous ephemeris data until the new CRC ephemeris is transmitted in the low-frequency data of Type 1, Type 11 or Type 101 message (see *Note*). If the ephemeris CRC changes and the IOD does not, the ground subsystem shall consider the ranging source invalid.

Note.— The delay before the ephemeris transition allow sufficient time for the aircraft subsystem to collect new ephemeris data.

3.6.7.2.2.2.1 **Reserved.**

3.6.7.2.2.3 *Broadcast pseudo-range correction*. Each broadcast pseudo-range correction shall be determined by combining the pseudo-range correction estimates for the relevant ranging source calculated from each of the reference receivers. For each satellite, the measurements used in this combination shall be obtained from the same ephemeris data. The corrections shall be based on smoothed code pseudo-range measurements for each satellite using the carrier measurement from a smoothing filter and the approach service type specific smoothing parameters in accordance with Appendix B, section 3.6.5.1.

3.6.7.2.2.4 *Broadcast signal-in-space integrity parameters*. The ground subsystem shall provide σ_{pr_gnd} and B parameters for each pseudo-range correction in Type 1 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 for GAST A, B, and C are satisfied. At least two B values that are not using the special coding (as defined in section 3.6.4.2.4) shall be provided with each pseudo-range correction. The ground subsystem shall provide σ_{pr_gnd} and, if necessary, B parameters for each pseudo-range correction in Type 101 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

Note.— Broadcast of the B parameters are optional for Type 101 messages. Guidance material regarding the B parameters in Type 101 messages is contained in Attachment D, 7.5.11.

3.6.7.2.2.4.1 *Broadcast signal-in-space integrity parameters for FAST D ground subsystems.* Ground subsystems that support GAST D shall provide Sigma_PR_gnd_D in the Type 11 message and B parameters for each pseudo-range correction in the Type 1 message, such that the protection level integrity risk requirement defined in 3.6.7.1.2.2.1 is satisfied.

3.6.7.2.2.4.2 For FAST D systems broadcasting the Type 11 message, if σ_{pr_gnd} is coded as invalid in the Type 1 message, then the Sigma_PR_gnd_D for the associated satellite in the Type 11 message shall also be coded as invalid.

3.6.7.2.2.5 Reference receiver measurements shall be monitored. Faulted measurements or failed reference receivers shall not be used to compute the pseudo-range corrections.

3.6.7.2.2.6 *Repeated transmission of Type 1, Type 2, Type 11 or Type 101 messages.* For a given measurement type and within a given frame, all broadcasts of Type 1, Type 2, Type 11 or Type 101 messages or linked pairs from all GBAS broadcast stations that share a common GBAS identification, shall have identical data content.

3.6.7.2.2.7 *Issue of data.* The GBAS ground subsystem shall set the IOD field in each ranging source measurement block to be the IOD value received from the ranging source that corresponds to the ephemeris data used to compute the pseudo-range correction.

3.6.7.2.2.8 *Application of signal error models*. Ionospheric and tropospheric corrections shall not be applied to the pseudo-ranges used to calculate the pseudo-range corrections.

3.6.7.2.2.9 *Linked pair of Type 1, Type 11 or Type 101 messages.* If a linked pair of Type 1, Type 11 or Type 101 messages is transmitted then,

a) the two messages shall have the same modified Z-count;

b) the minimum number of pseudo-range corrections in each message shall be one;

c) the measurement block for a given satellite shall not be broadcast more than once in a linked pair of messages;

d) the two messages shall be broadcast in different time slots;

e) the order of the B values in the two messages shall be the same;

f) for a particular measurement type, the number of measurements and low-frequency data shall be computed separately for each of the two individual messages;

g) in the case of FAST D, when a pair of linked Type 1 messages are transmitted, there shall also be a linked pair of Type 11 messages; and

h) if linked message types of Type 1 or Type 11 are used, the satellites shall be divided into the same sets and order in both Type 1 and Type 11 messages.

Note.— Type 1 messages may include additional satellites not available in Type 11 messages, but the relative order of those satellites available in both messages is the same in Type 1 and Type 11 messages. Airborne processing is not possible for satellites included in the Type 11 message, but also not included in the associated Type 1 message.

3.6.7.2.2.9.1 **Reserved**.

3.6.7.2.2.10 *Modified Z-count requirements*

3.6.7.2.2.10.1 *Modified Z-count update.* The modified Z-count for Type 1, Type 11 or Type 101 messages of a given measurement type shall advance every frame.

3.6.7.2.2.10.2 If message Type 11 is broadcast, the associated Type 1 and Type 11 messages shall have the same modified Z-count.

3.6.7.2.2.11 *Ephemeris decorrelation parameters*

3.6.7.2.2.11.1 *Ephemeris decorrelation parameter for approach services.* For ground subsystems that broadcast the additional data block 1 in the Type 2 message, the ground subsystem shall broadcast the ephemeris decorrelation parameter in the Type 1 message for each core satellite constellation ranging source such that the ground subsystem integrity risk of 3.6.7.1.2.1.1.1 is met.

3.6.7.2.2.11.2 *Ephemeris decorrelation parameter for GAST D*. Ground subsystems classified as FAST D shall broadcast the ephemeris decorrelation parameter in the Type 11 message for each core satellite constellation ranging source such that the ground subsystem signal-in-space integrity risk of 3.6.7.1.2.1.1.2 is met.

3.6.7.2.2.11.3 *GBAS positioning service*. For ground subsystems that provide the GBAS positioning service, the ground subsystem shall broadcast the ephemeris decorrelation parameter in the Type 1 message for each core satellite constellation's ranging source such that the ground subsystem signal-in-space integrity risk of 3.6.7.1.2.1.4 is met.

3.6.7.2.3 *GBAS-related data*

3.6.7.2.3.1 *Tropospheric delay parameters.* The ground subsystem shall broadcast a refractivity index, scale height, and refractivity uncertainty in a Type 2 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

3.6.7.2.3.2 *GCID indication*

3.6.7.2.3.2.1 *GCID indication for FAST A, B or C.* If the ground subsystem meets the requirements of 3.6.7.1.2.1.1.1, 3.6.7.1.2.2.1, 3.6.7.1.3.1, 3.6.7.3.2 and 3.6.7.3.3.1 but not all of 3.6.7.1.2.1.1.2, 3.6.7.1.2.1.1.3, 3.6.7.1.2.2.1.1, and 3.6.7.1.3.2 the GCID shall be set to 1, otherwise it shall be set to 7.

Note.— Some of the requirements applicable to FAST D are redundant with the FAST A, B and C requirements. The phrase "not all of" refers to the condition where a ground subsystem may meet some of the requirements applicable to FAST D but not all of them. Therefore, in that condition, the GCID would be set to 1, indicating that the ground subsystem meets only FAST A, B or C.

3.6.7.2.3.2.2 *GCID indication for FAST D*. If the ground subsystem meets the requirements of 3.6.7.1.2.1.1.1, 3.6.7.1.2.1.1.2, 3.6.7.1.2.1.1.3, 3.6.7.1.2.2.1.1, 3.6.7.1.2.2.1, 3.6.7.1.3.1, 3.6.7.1.3.2, 3.6.7.3.2 and 3.6.7.3.3, the GCID shall be set to 2, otherwise it shall be set in accordance with 3.6.7.2.3.2.1.

3.6.7.2.3.2.3 GCID values of 3 and 4 are reserved for future service types and shall not be used.

3.6.7.2.3.3 *GBAS reference antenna phase centre position accuracy*. For each GBAS reference receiver, the reference antenna phase centre position error shall be less than 8 cm relative to the GBAS reference point.

3.6.7.2.3.4 GBAS reference point survey accuracy. The survey error of the GBAS reference point, relative to WGS-84, shall be less than 0.25 m vertical and 1 m horizontal.

Note.— Relevant guidance material is given in Attachment D, 7.16.

3.6.7.2.3.5 *Ionospheric uncertainty estimate parameter*

3.6.7.2.3.5.1 *Ionospheric uncertainty estimate parameter for all ground subsystems.* The ground subsystem shall broadcast an ionospheric delay gradient parameter in the Type 2 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

3.6.7.2.3.5.2 *Ionospheric uncertainty estimate parameter for FAST D ground subsystems.* The ground subsystem shall broadcast an ionospheric delay gradient parameter in the Type 2 message, additional data block 3, such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

Note.— Guidance material concerning FAST D position domain error bounding for ionospheric errors may be found in Attachment D, 7.5.6.1.3 and 7.5.6.1.4.

3.6.7.2.3.6 For ground subsystems that provide the GBAS positioning service, the ground subsystem shall broadcast the ephemeris error position bound parameters using additional data block 1 in the Type 2 message.

3.6.7.2.3.7 Reserved.

3.6.7.2.3.8 For ground subsystems that broadcast additional data block 1 in the Type 2 message, the following requirements shall apply:

3.6.7.2.3.8.1 *Maximum use distance*. The ground subsystem shall provide the maximum use distance (D_{max}). When the positioning service is provided the ground subsystem integrity risk in 3.6.7.1.2.1.4 and the protection level integrity risk in 3.6.7.1.2.2.2 shall be met within D_{max}. When approach service is provided, the maximum use distance shall at least encompass all approach service volumes supported.

3.6.7.2.3.8.2 *Ephemeris missed detection parameters*. The ground subsystem shall broadcast the ephemeris missed detection parameters for each core satellite constellation such that the ground subsystem integrity risk of 3.6.7.1.2.1 is met.

3.6.7.2.3.8.3 *GBAS positioning service indication*. If the ground subsystem does not meet the requirements of 3.6.7.1.2.1.4 and 3.6.7.1.2.2.2, the ground subsystem shall indicate using the RSDS parameter that the GBAS positioning service is not provided.

3.6.7.2.3.9 If the VHF data broadcast is transmitted at more than one frequency within the GRAS service area, each GBAS broadcast station within the GRAS ground subsystem shall broadcast additional data blocks 1 and 2.

3.6.7.2.3.9.1 Reserved.

Note.— This facilitates the transition from one GBAS broadcast station to other GBAS broadcast stations in the GRAS ground subsystem.

3.6.7.2.4 *Final approach segment data*

3.6.7.2.4.1 *FAS data points accuracy*. The relative survey error between the FAS data points and the GBAS reference point shall be less than 0.25 metres vertical and 0.40 metres horizontal.

3.6.7.2.4.2 The final approach segment CRC shall be assigned at the time of procedure design, and kept as an integral part of the FAS data block from that time onward.

3.6.7.2.4.3 The GBAS shall allow the capability to set the FASVAL and FASLAL for any FAS data block to “1111 1111” to limit the approach to lateral only or to indicate that the approach must not be used, respectively.

3.6.7.2.4.4 *LTP/FTP for FAST D*. For an approach that supports GAST D, the LTP/FTP point in the corresponding FAS definition shall be located at the intersection of the runway centre line and the landing threshold.

Note.— Airborne systems may compute the distance to the landing threshold using the LTP/FTP. For GAST D approaches, the LTP/FTP is to be at the threshold so that these distance-to-go computations reliably reflect the distance to the threshold.

3.6.7.2.4.5 *FPAP location for FAST D*. For an approach that supports GAST D, the FPAP point in the corresponding FAS definition shall be located on the extended runway centre line and the ΔLength offset parameter shall be coded to correctly indicate the stop end of the runway.

3.6.7.2.5 *Predicted ranging source availability data*

Note.— Ranging source availability data are optional for FAST A, B, C or D ground subsystems and may be required for possible future operations.

3.6.7.2.6 *General functional requirements on augmentation*

3.6.7.2.6.1 GBAS ground subsystems classified as FAST C or FAST D shall provide augmentation based on GPS at a minimum.

3.6.7.2.6.2 Ground subsystems classified as FAST C shall be able to process and broadcast corrections for at least 12 satellites of each core constellation for which differential corrections are provided.

3.6.7.2.6.3 Ground subsystems classified as FAST D shall be able to process and broadcast differential corrections for at least 12 satellites of one core constellation.

Note.— Technical validation has only been completed for GAST D when applied to GPS.

3.6.7.2.6.4 Whenever possible, differential corrections for all visible satellites with an elevation greater than 5 degrees above the local horizontal plane tangent to the ellipsoid at the ground subsystem reference location shall be provided for each core constellation for which augmentation is provided.

Note.— The phrase "whenever possible" in this context means whenever meeting another requirement in these SARPs (e.g. 3.6.7.3.3.1) does not preclude providing a differential correction for a particular satellite.

3.6.7.3 *MONITORING*

3.6.7.3.1 *RF monitoring*

3.6.7.3.1.1 *VHF data broadcast monitoring.* The data broadcast transmissions shall be monitored. The transmission of the data shall cease within 0.5 seconds in case of continuous disagreement during any 3-second period between the transmitted application data and the application data derived or stored by the monitoring system prior to transmission. For FAST D ground subsystems, the transmission of the data shall cease within 0.5 seconds in case of continuous disagreement during any 1-second period between the transmitted application data and the application data derived or stored by the monitoring system prior to transmission.

Note.— For ground subsystems that support authentication, ceasing the transmission of data means ceasing the transmission of Type 1 messages and Type 11 messages if applicable or ceasing the transmission of Type 101 messages. In accordance with

3.6.7.4.1.3, the ground subsystem must still transmit messages such that the defined percentage or more of every assigned slot is occupied. This can be accomplished by transmitting Type 2, Type 3, Type 4 and/or Type 5 messages.

3.6.7.3.1.2 *TDMA slot monitoring*. The risk that the ground subsystem transmits a signal in an unassigned slot and fails to detect an out-of-slot transmission, which exceeds that allowed in 3.6.2.6, within 1 second, shall be less than 1×10^{-7} in any 30-second period. If out-of-slot transmissions are detected, the ground subsystem shall terminate all data broadcast transmissions within 0.5 seconds.

3.6.7.3.1.3 *VDB transmitter power monitor.* The probability that the horizontally or elliptically polarized signal's transmitted power increases by more than 3 dB from the nominal power for more than 1 second shall be less than 2.0×10^{-7} in any 30-second period.

Note.— The vertical component is only monitored for GBAS/E equipment.

3.6.7.3.2 *Data monitoring*

3.6.7.3.2.1 *Broadcast quality monitor*. The ground subsystem monitoring shall comply with the time-to-alert requirements given in 3.6.7.1.2.1. The monitoring action shall be one of the following:

a) to broadcast Type 1 (and Type 11 if broadcast) or Type 101 messages with no measurement blocks; or

b) to broadcast Type 1 (and Type 11 if broadcast) or Type 101 messages with the $\sigma_{pr\_gnd,i}$ (and $\sigma_{pr\_gnd\_D,I}$ if broadcast) field set to indicate the ranging source is invalid for every ranging source included in the previously transmitted frame; or

c) to terminate the data broadcast.

Note.— Monitoring actions a) and b) are preferred to c) if the particular failure mode permits such a response, because actions a) and b) typically have a reduced signal-in-space time-to-alert.

3.6.7.3.3 *Integrity monitoring for GNSS ranging sources*

3.6.7.3.3.1 The ground subsystem shall monitor the satellite signals to detect conditions that will result in improper operation of differential processing for airborne receivers complying with the tracking constraints in Attachment D, 8.11. The monitor time-to-alert shall comply with 3.6.7.1.2. The monitor action shall be to set σ_{pr_gnd} to the bit pattern "1111 1111" for the satellite or to exclude the satellite from the Type 1, Type 11 or Type 101 message.

3.6.7.3.3.1.1 The ground subsystem shall use the strongest correlation peak in all receivers used to generate the pseudorange corrections. The ground subsystem shall also detect conditions that cause more than one zero crossing for airborne receivers that use the early-late discriminator function as described in Attachment D, 8.11.

3.6.7.3.3.2 For FAST D ground subsystems, the probability that the error at the landing threshold point (LTP) of any runway for which the ground subsystem supports GAST D, $|Er|$, on the 30-second smoothed corrected pseudo-range (see 3.6.5.2) caused by a ranging source fault, is not detected and reflected in the broadcast Type 11 message within 1.5 s shall fall within the region specified in Table B-76A. Ranging source faults for which this requirement applies are:

a) signal deformation (Note 1.);

b) code/carrier divergence;

c) excessive pseudo-range acceleration, such as a step or other rapid change; and

d) erroneous broadcast of ephemeris data from the satellite.

Note 1.— Refer to Attachment D, 8.11 for further information on GAEC-D avionics relating to signal deformation fault.

Note 2.— Upon detection, a ranging source fault may be reflected in the Type 11 message by either:

a) removing the correction for the associated satellite from the Type 11 message; or

b) marking the satellite as invalid using the coding of $\sigma_{pr\_gnd\_D}$ *(see 3.6.4.11.4).*

Note 3.— The acceptable probability of a missed detection region is defined with respect to differentially corrected pseudo-range error. The differentially corrected pseudo-range error, |Er|, includes the error resulting from a single ranging source fault, given the correct application of GBAS ground subsystem message Type 11 broadcast corrections (i.e. pseudorange correction and range rate corrections defined in section 3.6.4.11) by the aircraft avionics as specified within section 3.6.8.3. Evaluation of P_{md} *performance includes GBAS ground subsystem fault-free noise. The growth of |Er| with time should consider the data latency of the ground subsystem, but not the airborne latency, as described in Attachment D, 7.5.14.*

Note 4.— Additional information regarding the ranging source fault conditions and monitoring requirements for FAST D ground subsystems may be found in Attachment D, 7.5.14. Missed messages do not need to be considered as part of compliance with this requirement.

Table B-76A. $\mathbf{P_{md\_limit}}$ **parameters**

Probability of Missed Detection	Pseudo-range Error (metres)
$P_{md\_limit} \le 1$	$0 \le \lvert E_r \rvert < 0.75$
$P_{md\_limit} \le 10^{(-2.56\times\lvert Er \rvert + 1.92)}$	$0.75 \le \lvert E_r \rvert < 2.7$
$P_{md\_limit} \le 10^{-5}$	$2.7 \le \lvert E_r \rvert < \infty$

3.6.7.3.3.3 For FAST D ground subsystems, the probability that an error at the landing threshold point (LTP) of any runway for which the ground subsystem supports GAST D, |Er|, greater than 1.6 metres on the 30-second smoothed corrected pseudo-range (see 3.6.5.2), caused by a ranging source fault, is not detected and reflected in the broadcast Type 11 message within 1.5 seconds shall be less than 1×10^{-9} in any one landing when multiplied by the prior probability ($P_{apriori}$). Ranging source faults for which this requirement applies are:

a) signal deformation (Note 1);

b) code/carrier divergence;

c) excessive pseudo-range acceleration, such as a step or other rapid change; and

d) erroneous broadcast of ephemeris data from the satellite.

Note 1.— Refer to Attachment D, 8.11 for further information on GAEC-D avionics relating to signal deformation fault.

Note 2.— It is intended that the prior probability of each ranging source fault ($P_{apriori}$*) be the same value that is used in the analysis to show compliance with error bounding requirements for FAST C and D (see Appendix B, 3.6.5.5.1.1.1).*

Note 3.— Upon detection, a ranging source fault may be reflected in the Type 11 message by either:

a) removing the faulty satellite correction from the Type 11 message; or

b) marking the satellite as invalid using the coding of $\sigma_{pr\_gnd\_D}$ (see 3.6.4.11.4).

Note 4.— Additional information regarding the ranging source fault conditions and monitoring requirements for FAST D ground subsystems may be found in Attachment D, 7.5.14. Missed messages do not need to be considered as part of compliance with this requirement.

3.6.7.3.4 *Ionospheric gradient mitigation*

For FAST D ground subsystems, the probability of an error (|Er|) in the 30-second smoothed corrected pseudo-range at the landing threshold point (LTP) for every GAST D supported runway that: a) is caused by a spatial ionospheric delay gradient, b) is greater than the E_{IG} value computed from a broadcast Type 2 message, and c) is not detected and reflected in the broadcast Type 11 message within 1.5 seconds shall be less than 1×10^{-9} in any one landing. The FAST D ground subsystem shall limit the Type 2 broadcast parameters to ensure that the maximum E_{IG} at every LTP supporting GAST D operations shall not exceed 2.75 metres.

Note 1.— The total probability of an undetected delay gradient includes the prior probability of the gradient and the monitor(s) probability of missed detection.

Note 2.— Validation guidance for this requirement can be found in 7.5.6.1.8.

3.6.7.4 *FUNCTIONAL REQUIREMENTS FOR AUTHENTICATION PROTOCOLS*

3.6.7.4.1 *Functional requirements for ground subsystems that support authentication*

3.6.7.4.1.1 The ground system shall broadcast the additional data block 4 with the Type 2 message with the slot group definition field coded to indicate which slots are assigned to the ground station.

3.6.7.4.1.2 The ground subsystem shall broadcast every Type 2 message only in one of a set of slots defined as the MT 2 sanctioned slots. The first slot in the group of MT 2 sanctioned slots corresponds to the SSID coding for the ground subsystem. Slot A is represented by SSID = 0, B by 1, C by 2, and H by 7. The group of MT 2 sanctioned slots then also includes the next slot after the slot corresponding to the station SSID if it exists in the frame. If there is not an additional slot before the end of the frame, only the SSID is included in the set.

Note.— For example, the MT 2 sanctioned slot group for SSID = 0 would include slots {A, B} while the MT 2 sanctioned slot group for SSID = 6 would include slots {G, H}. The MT 2 sanctioned slot group for SSID = 7 includes slot {H} only.

3.6.7.4.1.2.1 The set of slots assigned to a ground station shall include at a minimum all the slots in the MT 2 sanctioned slots as described in section 3.6.7.4.1.2.

3.6.7.4.1.3 *Assigned slot occupancy*. The ground subsystem shall transmit messages such that 89 per cent or more of every assigned slot is occupied. If necessary, Type 3 messages may be used to fill unused space in any assigned time slot.

Note 1.— More information on the calculation of the slot occupancy is provided in Attachment D, 7.21.

Note 2.— The requirement applies to the aggregate transmissions from all transmitters of a GBAS ground subsystem. Due to signal blockage, not all of those transmissions may be received in the service volume.

3.6.7.4.1.4 *Reference path identifier coding*. Every reference path identifier included in every final approach segment data block broadcast by the ground subsystem via the Type 4 messages shall have the first letter selected to indicate the SSID of the ground subsystem in accordance with the following coding.

Coding:
A = SSID of 0
X = SSID of 1
Z = SSID of 2
J = SSID of 3
C = SSID of 4
V = SSID of 5
P = SSID of 6
T = SSID of 7

3.6.7.4.2 *Functional requirements for ground subsystems that do not support authentication*

3.6.7.4.2.1 *Reference path identifier coding.* Characters in this set: {A X Z J C V P T} shall not be used as the first character of the reference path identifier included in any FAS block broadcast by the ground subsystem via the Type 4 messages.

3.6.8 AIRCRAFT ELEMENTS

3.6.8.1 *GNSS receiver.* The GBAS-capable GNSS receiver shall process signals of GBAS in accordance with the requirements specified in this section as well as with requirements in 3.1.3.1 and/or 3.2.3.1 and/or 3.5.8.1.

Note.— In order to ensure the required performance and functional objectives for GAST D are achieved, it is necessary for the airborne equipment to meet defined performance and functional standards. The relevant minimum operational performance standards are detailed in RTCA DO-253D.

3.6.8.2 *PERFORMANCE REQUIREMENTS*

3.6.8.2.1 *GBAS aircraft receiver accuracy*

3.6.8.2.1.1 The RMS of the total aircraft receiver contribution to the error for GPS shall be:

$$RMS_{pr\_air}(\theta_n) \le a_0 + a_1 \times e^{-(\theta_n/\theta_0)}$$

where

n = the nth ranging source;
θ_n = the elevation angle for the nth ranging source; and
a_0, a_1, and θ_0 = as defined in Table B-77 for GPS.

3.6.8.2.1.2 The RMS of the total aircraft receiver contribution to the error for SBAS satellites shall be as defined in 3.5.8.2.1 for each of the defined aircraft accuracy designators.

Note.— The aircraft receiver contribution does not include the measurement error induced by airframe multipath.

Table B-77. Aircraft GPS receiver accuracy requirement

Aircraft accuracy designator	θ_n (degrees)	a_0 (metres)	a_1 (metres)	θ_0 (degrees)
A	≥5	0.15	0.43	6.9
B	≥5	0.11	0.13	4

3.6.8.2.2 *VHF data broadcast receiver performance*

3.6.8.2.2.1 *VHF data broadcast tuning range.* The VHF data broadcast receiver shall be capable of tuning frequencies in the range of 108.000 – 117.975 MHz in increments of 25 kHz.

3.6.8.2.2.2 *VHF data broadcast capture range.* The VHF data broadcast receiver shall be capable of acquiring and maintaining lock on signals within ±418 Hz of the nominal assigned frequency.

Note.— The frequency stability of the GBAS ground subsystem, and the worst-case doppler shift due to the motion of the aircraft, are reflected in the above requirement. The dynamic range of the automatic frequency control should also consider the frequency-stability error budget of the aircraft VHF data broadcast receiver.

3.6.8.2.2.3 *VHF data broadcast message failure rate.* The VHF data broadcast receiver shall achieve a message failure rate less than or equal to one failed message per 1 000 full-length (222 bytes) application data messages, within the range of the RF field strength defined in 3.7.3.5.4.4 as received by the airborne antenna, provided that the variation in the average received signal power between successive bursts in a given time slot does not exceed 40 dB. Failed messages include those lost by the VHF data broadcast receiver system or which do not pass the CRC after application of the FEC.

Note 1.— An aircraft VHF data broadcast receiving antenna can be horizontally or vertically polarized. Due to the difference in the signal strength of horizontally and vertically polarized components of the broadcast signal, the maximum total aircraft implementation loss for horizontally polarized receiving antennas is 4 dB higher than the maximum loss for vertically polarized receiving antennas. For guidance in determining aircraft implementation loss see Attachment D, 7.2.

Note 2.— It is acceptable to exceed the signal power variation requirement in limited parts of the service volume when operational requirements permit. Refer to Attachment D, 7.12.4.1 for guidance.

3.6.8.2.2.4 *VHF data broadcast time slot decoding.* The VHF data broadcast receiver shall meet the requirements of 3.6.8.2.2.3 for all message types required (see 3.6.8.3.1.2.1) from the selected GBAS ground subsystem. These requirements shall be met in the presence of other GBAS transmissions in any and all time slots respecting the levels as indicated in 3.6.8.2.2.5.1 b).

Note.— Other GBAS transmissions may include: a) other message types with the same SSID, and b) messages with different SSIDs.

3.6.8.2.2.5 *Co-channel rejection*

3.6.8.2.2.5.1 *VHF data broadcast as the undesired signal source.* The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of an undesired co-channel VHF data broadcast signal that is either:

a) assigned to the same time slot(s) and 26 dB below the desired VHF data broadcast signal power at the receiver input or lower; or

b) assigned different time slot(s) and no more than 72 dB above the minimum desired VHF data broadcast signal field strength defined in 3.7.3.5.4.4 .

3.6.8.2.2.5.2 *VOR as the undesired signal.* The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of an undesired co-channel VOR signal that is 26 dB below the desired VHF data broadcast signal power at the receiver input.

3.6.8.2.2.6 *Adjacent channel rejection*

3.6.8.2.2.6.1 *First adjacent 25 kHz channels (±25 kHz).* The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of a transmitted undesired signal offset by 25 kHz on either side of the desired channel that is either:

a) 18 dB above the desired signal power at the receiver input when the undesired signal is another VHF data broadcast signal assigned to the same time slot(s); or

b) equal in power at the receiver input when the undesired signal is VOR.

3.6.8.2.2.6.2 *Second adjacent 25 kHz channels (±50 kHz).* The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of a transmitted undesired signal offset by 50 kHz on either side of the desired channel that is either:

a) 43 dB above the desired signal power at the receiver input when the undesired signal is another VHF data broadcast source assigned to the same time slot(s); or

b) 34 dB above the desired signal power at the receiver input when the undesired signal is VOR.

3.6.8.2.2.6.3 *Third and beyond adjacent 25 kHz channels (±75 kHz or more).* The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of a transmitted undesired signal offset by 75 kHz or more on either side of the desired channel that is either:

a) 46 dB above the desired signal power at the receiver input when the undesired signal is another VHF data broadcast signal assigned to the same time slot(s); or

b) 46 dB above the desired signal power at the receiver input when the undesired signal is VOR.

3.6.8.2.2.7 *Rejection of off-channel signals from sources inside the 108.000 – 117.975 MHz band*. With no on-channel VHF data broadcast signal present, the VHF data broadcast receiver shall not output data from an undesired VHF data broadcast signal on any other assignable channel.

3.6.8.2.2.8 *Rejection of signals from sources outside the 108.000 – 117.975 MHz band*

3.6.8.2.2.8.1 *VHF data broadcast interference immunity*. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of one or more signals having the frequency and total interference levels specified in Table B-79.

3.6.8.2.2.8.2 *Desensitization.* The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of VHF FM broadcast signals with signal levels shown in Tables B-80 and B-81.

Table B-79. Maximum levels of undesired signals

Frequency	Maximum level of undesired signals at the receiver input (dB above S_{max})
50 kHz up to 88 MHz	–12
88 MHz – 107.900 MHz	(see 3.6.8.2.2.8.2 and 3.6.8.2.2.8.3)
108.000 MHz – 117.975 MHz	Excluded
118.000 MHz	–43
118.025 MHz	–40
118.050 MHz up to 1 660.5 MHz	–12

Frequency	Maximum level of undesired signals at the receiver input (dB above S_{max})
50 kHz up to 88 MHz	–12
88 MHz – 107.900 MHz	(see 3.6.8.2.2.8.2)
108.000 MHz – 117.975 MHz	Excluded
118.000 MHz	–43
118.025 MHz	–40
118.050 MHz up to 1 660.5 MHz	–12

Notes.—

1. *The relationship is linear between single adjacent points designated by the above frequencies.*

2. *These interference immunity requirements may not be adequate to ensure compatibility between VHF data broadcast receivers and VHF communication systems, particularly for aircraft that use the vertically polarized component of the VHF data broadcast. Without coordination between COM and NAV frequencies assignments or respect of a guard band at the top end of the 112 – 117.975 MHz band, the maximum levels quoted at the lowest COM VHF channels (118.000, 118.00833, 118.01666, 118.025, 118.03333, 118.04166, 118.05) may be exceeded at the input of the VDB receivers. In that case, some means to attenuate the COM signals at the input of the VDB receivers (e.g. antenna separation) will have to be implemented. The final compatibility will have to be assured when equipment is installed on the aircraft.*

3. *S_{max} is the maximum desired VHF data broadcast signal power at the receiver input.*

Table B-80. Desensitization frequency and power requirements that apply for VDB frequencies from 108.025 to 111.975 MHz

Frequency	Maximum level of undesired signals at the receiver input (dB above S_{max})

88 MHz ≤ f ≤ 102 MHz	16
104 MHz	11
106 MHz	6
107.9 MHz	–9

Notes.—
1. *The relationship is linear between single adjacent points designated by the above frequencies.*

2. *This desensitization requirement is not applied for FM carriers above 107.7 MHz and VDB channels at 108.025 or 108.050 MHz. See Attachment D, 7.2.1.2.2.*

3. S_{max} *is the maximum desired VHF data broadcast signal power at the receiver input.*

Table B-81. Desensitization frequency and power requirements that apply for VDB frequencies from 112.000 to 117.975 MHz

Frequency	Maximum level of undesired signals at the receiver input (dB above S_{max})
88 MHz ≤ f ≤ 104 MHz	16
106 MHz	11
107 MHz	6
107.9 MHz	1

Notes.—
1. *The relationship is linear between single adjacent points designated by the above frequencies.*

2. S_{max} *is the maximum desired VHF data broadcast signal power at the receiver input.*

3.6.8.2.2.8.3 *VHF data broadcast FM intermodulation immunity*. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of interference from two-signal, third-order intermodulation products of two VHF FM broadcast signals having levels in accordance with the following:

$$2N_1 + N_2 + 3\,[23 - S_{max}] \leqslant 0$$

for VHF FM sound broadcasting signals in the range 107.7 – 108.0 MHz and

$$2N_1 + N_2 + 3\,[23 - S_{max} - 20\,\mathrm{Log}\,(\Delta f / 0.4)] \leq 0$$

for VHF FM sound broadcasting signals below 107.7 MHz

where the frequencies of the two VHF FM sound broadcasting signals produce, within the receiver, a two signal, third-order intermodulation product on the desired VDB frequency.

N_1 and N_2 are the levels (dBm) of the two VHF FM sound broadcasting signals at the VHF data broadcast receiver input. Neither level shall exceed the desensitization criteria set forth in 3.6.8.2.2.8.2.

$\Delta f = 108.1 - f_1$, where f_1 is the frequency of N_1, the VHF FM sound broadcasting signal closer to 108.1 MHz.

S_{max} is the maximum desired VHF data broadcast signal power at the receiver input.

Note.— The FM intermodulation immunity requirements are not applied to a VHF data broadcast channel operating below 108.1 MHz, hence frequencies below 108.1 MHz are not intended for general assignments. Additional information is provided in Attachment D, 7.2.1.2.

3.6.8.3 *AIRCRAFT FUNCTIONAL REQUIREMENTS*

Note.— Unless otherwise specified, the following requirements apply to all GBAS airborne equipment classifications as described in Attachment D, 7.1.4.3.

3.6.8.3.1 *Conditions for use of data*

3.6.8.3.1.1 The receiver shall use data from a GBAS message only if the CRC of that message has been verified.

3.6.8.3.1.2 The receiver shall use message data only if the message block identifier is set to the bit pattern “1010 1010”.

3.6.8.3.1.2.1 *GBAS message processing capability.* The GBAS receiver shall at a minimum process GBAS message types in accordance with Table B-82.

Table B-82. Airborne equipment message type processing

GBAS airborne equipment classification (GAEC)	Minimum message types processed
GAEC A	MT 1 or 101, MT 2 (including ADB 1 and 2 if provided)
GAEC B	MT 1, MT 2 (including ADB 1 and 2 if provided), MT 4
GAEC C GAEC	MT 1, MT 2 (including ADB 1 if provided), MT 4
D	MT 1, MT 2 (including ADB 1, 2, 3 and 4), MT 4, MT 11

3.6.8.3.1.2.2 *Airborne processing for forward compatibility*

Note.— Provisions have been made to enable future expansion of the GBAS Standards to support new capabilities. New message types may be defined, new additional data blocks for message Type 2 may be defined and new data blocks defining reference paths for inclusion within message Type 4 may be defined. To facilitate these future expansions, all equipment should be designed to properly ignore all data types that are not recognized.

3.6.8.3.1.2.2.1 *Processing of unknown message types.* The existence of messages unknown to the airborne receiver shall not prevent correct processing of the required messages.

3.6.8.3.1.2.2.2 *Processing of unknown Type 2 extended data blocks.* The existence of message Type 2 additional data blocks unknown to the airborne receiver shall not prevent correct processing of the required messages.

3.6.8.3.1.2.2.3 *Processing of unknown Type 4 data blocks.* The existence of message Type 4 data blocks unknown to the airborne receiver shall not prevent correct processing of the required messages.

Note.— While the current SARPs include only one definition of a data block for inclusion within a Type 4 message, future GBAS Standards may include other reference path definitions.

3.6.8.3.1.3 The receiver shall use only ranging source measurement blocks with matching modified Z-counts.

3.6.8.3.1.4 If D_{max} is broadcast by the ground subsystem, the receiver shall only apply pseudo-range corrections when the distance to the GBAS reference point is less than D_{max}.

3.6.8.3.1.5 The receiver shall only apply pseudo-range corrections from the most recently received set of corrections for a given measurement type. If the number of measurement fields in the most recently received message types (as required in Appendix B, section 3.6.7.2.1.1.1 for the active service type) indicates that there are no measurement blocks, then the receiver shall not apply GBAS corrections for that measurement type.

3.6.8.3.1.6 *Validity of pseudo-range corrections*

3.6.8.3.1.6.1 When the active service type is A, B or C, the receiver shall exclude from the differential navigation solution any ranging sources for which σ_{pr_gnd} in the Type 1 or Type 101 messages is set to the bit pattern “1111 1111”.

3.6.8.3.1.6.2 If the active service type is D, the receiver shall exclude from the differential navigation solution any ranging source for which $\sigma_{pr\_gnd\_D}$ in the Type 11 message or σ_{pr_gnd} in the Type 1 message is set to the bit pattern “1111 1111”.

3.6.8.3.1.7 The receiver shall only use a ranging source in the differential navigation solution if the time of applicability indicated by the modified Z-count in the Type 1, Type 11 or Type 101 message containing the ephemeris decorrelation parameter for that ranging source is less than 120 seconds old.

3.6.8.3.1.8 *Conditions for use of data to support approach services*

3.6.8.3.1.8.1 During the final stages of an approach, the receiver shall use only measurement blocks from Type 1, Type 11 or Type 101 messages that were received within the last 3.5 seconds.

Note.— Guidance concerning time-to-alert is given in Attachment D, 7.5.14.

3.6.8.3.1.8.2 *GCID indications*

3.6.8.3.1.8.2.1 When the active service type is A, B or C, the receiver shall use message data from a GBAS ground subsystem for guidance only if the GCID indicates 1, 2, 3 or 4 prior to initiating the final stages of an approach.

3.6.8.3.1.8.2.2 When the active service type is D, the receiver shall use message data from a GBAS ground subsystem for guidance only if the GCID indicates 2, 3 or 4 prior to initiating the final stages of an approach.

3.6.8.3.1.8.3 The receiver shall ignore any changes in GCID during the final stages of an approach.

3.6.8.3.1.8.4 The receiver shall not provide approach vertical guidance based on a particular FAS data block transmitted in a Type 4 message if the FASVAL received prior to initiating the final stages of the approach is set to “1111 1111”.

3.6.8.3.1.8.5 The receiver shall not provide approach guidance based on a particular FAS data block transmitted in a Type 4 message if the FASLAL received prior to initiating the final stages of the approach is set to “1111 1111”.

3.6.8.3.1.8.6 Changes in the values of FASLAL and FASVAL data transmitted in a Type 4 message during the final stages of an approach shall be ignored by the receiver.

3.6.8.3.1.8.7 The receiver shall use FAS data only if the FAS CRC for that data has been verified.

3.6.8.3.1.8.8 The receiver shall only use messages for which the GBAS ID (in the message block header) matches the GBAS ID in the header of the Type 4 message which contains the selected FAS data or the Type 2 message which contains the selected RSDS.

3.6.8.3.1.8.9 *Use of FAS data*

3.6.8.3.1.8.9.1 The receiver shall use the Type 4 messages to determine the FAS for precision approach.

3.6.8.3.1.8.9.2 The receiver shall use the Type 4 messages to determine the FAS for approaches which are supported by GBAS approach service type (GAST) A or B associated with a channel number between 20 001 and 39 999.

3.6.8.3.1.8.9.3 The receiver shall use the FAS held within the on-board database for approaches which are supported by GBAS approach service type (GAST) A associated with a channel number between 40 000 and 99 999.

3.6.8.3.1.8.10 When the GBAS ground subsystem does not broadcast the Type 4 message and the selected FAS data are available to the receiver from an airborne database, the receiver shall only use messages from the intended GBAS ground subsystem.

3.6.8.3.1.9 *Conditions for use of data to provide the GBAS positioning service*

3.6.8.3.1.9.1 The receiver shall only use measurement blocks from Type 1 messages that were received within the last 7.5 seconds.

3.6.8.3.1.9.2 The receiver shall only use measurement blocks from Type 101 messages that were received within the last 5 seconds.

3.6.8.3.1.9.3 The receiver shall only use message data if a Type 2 message containing additional data block 1 has been received and the RSDS parameter in this block indicates that the GBAS positioning service is provided.

3.6.8.3.1.9.4 The receiver shall only use messages for which the GBAS ID (in the message block header) matches the GBAS ID in the header of the Type 2 message which contains the selected RSDS.

3.6.8.3.2 *Integrity*

3.6.8.3.2.1 *Bounding of aircraft errors.* For each satellite used in the navigation solution, the receiver shall compute a $\sigma_{receiver}$ such that a normal distribution with zero mean and a standard deviation equal to $\sigma_{receiver}$ bounds the receiver contribution to the corrected pseudo-range error as follows:

$$\int_{y}^{\infty} f(x)\,dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0 \text{ and}$$

$$\int_{-\infty}^{-y} f(x)\,dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0$$

where

f(x) = probability density function of the residual aircraft pseudo-range error and

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_{x}^{\infty} e^{-\frac{t^2}{2}}\,dt.$$

3.6.8.3.2.2 *Use of GBAS integrity parameters*. The aircraft element shall compute and apply the vertical, lateral and horizontal protection levels described in 3.6.5.5. If a $B_{i,j}$ parameter is set to the bit pattern "1000 0000" indicating that the measurement is not available, the aircraft element shall assume that $B_{i,j}$ has a value of zero. For any active service type, the aircraft element shall verify that the computed vertical and lateral protection levels are no larger than the corresponding vertical and lateral alert limits defined in 3.6.5.6.

3.6.8.3.3 *Use of satellite ephemeris data*

3.6.8.3.3.1 *IOD check.* The receiver shall only use satellites for which the IOD broadcast by GBAS in the Type 1 or Type 101 message matches the core satellite constellation IOD for the clock and ephemeris data used by the receiver.

3.6.8.3.3.2 *CRC check*. The receiver shall compute the ephemeris CRC for each core satellite constellation's ranging source used in the position solution. The computed CRC shall be validated against the ephemeris CRC broadcast in the Type 1 or Type 101 messages prior to use in the position solution and within one second of receiving a new broadcast CRC. The receiver shall immediately cease using any satellite for which the computed and broadcast CRC values fail to match.

3.6.8.3.3.3 *Ephemeris error position bounds*

3.6.8.3.3.3.1 *Ephemeris error position bounds for GBAS approach services*. If the ground subsystem provides additional data block 1 in the Type 2 messages, the aircraft element shall compute the ephemeris error position bounds defined in 3.6.5.8.1 for each core satellite constellation's ranging source used in the approach position solution within 1s of receiving the necessary broadcast parameters. The aircraft element shall verify that the computed vertical and lateral ephemeris error position bounds (VEB_j and LEB_j) are no larger than the corresponding vertical and lateral alert limits defined in 3.6.5.6.

3.6.8.3.3.3.2 *Ephemeris error position bound for the GBAS positioning service*. The aircraft element shall compute and apply the horizontal ephemeris error position bound (HEB_j) defined in 3.6.5.8.2 for each core satellite constellation's ranging source used in the positioning service position solution.

3.6.8.3.4 *Message loss*

3.6.8.3.4.1 For airborne equipment operating with GAST C as the active service type, the receiver shall provide an appropriate alert if no Type 1 message was received during the last 3.5 seconds.

3.6.8.3.4.2 For airborne equipment operating with GAST A or B as the active service type, the receiver shall provide an appropriate alert if no Type 1 and no Type 101 message was received during the last 3.5 seconds.

3.6.8.3.4.3 For the airborne equipment operating with GAST D as the active service type, the receiver shall provide an appropriate alert or modify the active service type if any of the following conditions are met:

a) The computed position solution is less than 200 ft above the LTP/FTP for the selected approach and no Type 1 message was received during the last 1.5 seconds.

b) The computed position solution is less than 200 ft above the LTP/FTP for the selected approach and no Type 11 message was received during the last 1.5 seconds.

c) The computed position solution is 200 ft or more above the LTP/FTP of the selected approach and no Type 1 message was received during the last 3.5 seconds.

d) The computed position solution is 200 ft or more above the LTP/FTP of the selected approach and no Type 11 message was received during the last 3.5 seconds.

3.6.8.3.4.4 For the GBAS positioning service using Type 1 messages, the receiver shall provide an appropriate alert if no Type 1 message was received during the last 7.5 seconds.

3.6.8.3.4.5 For the GBAS positioning service using Type 101 messages, the receiver shall provide an appropriate alert if no Type 101 message was received during the last 5 seconds.

3.6.8.3.5 *Airborne pseudo-range measurements*

3.6.8.3.5.1 *Carrier smoothing for airborne equipment.* Airborne equipment shall utilize the standard 100-second carrier smoothing of code phase measurements defined in 3.6.5.1. During the first 100 seconds after filter start-up, the value of α shall be either:

a) a constant equal to the sample interval divided by 100 seconds; or

b) a variable quantity defined by the sample interval divided by the time in seconds since filter start-up.

3.6.8.3.5.2 *Carrier smoothing of airborne equipment operating with GAST D as the active service type*. Airborne equipment operating with GAST D as the active service type shall utilize 30-second carrier smoothing of code phase measurements as defined in 3.6.5.1.

Note.— For equipment that supports GAST D, two sets of smoothed pseudo-ranges are used. The form of the smoothing filter given in section 3.6.5.1 is the same for both sets, and only the time constant differs (i.e. 100 seconds and 30 seconds). Guidance concerning carrier-smoothing for GAST D is given in Attachment D, 7.19.3.

3.6.8.3.6 *Service type specific differential position solution requirements.* The airborne equipment shall compute all position solutions in a manner that is consistent with the protocols for application of the data (see 3.6.5.5.1.1.2).

Note.— The general form for the weighting used in the differential position solution is given in 3.6.5.5.1.1.2. Exactly which information from the ground subsystem is used in the differential position solution depends on the type of service (i.e. positioning service vs. approach service) and the active approach service type. The specific requirements for each service type are defined in RTCA DO 253D. Additional information concerning the normal processing of position information is given in Attachment D, 7.19.

3.7 Resistance to interference

3.7.1 PERFORMANCE OBJECTIVES

Note 1.— For unaugmented GPS receivers the resistance to interference is measured with respect to the following performance parameters:

	GPS
Tracking error (1 sigma)	*0.36 m*

Note 2.— This tracking error neither includes contributions due to signal propagation such as multipath, tropospheric and ionospheric effects nor ephemeris and GPS satellite clock errors.

Note 3.— For SBAS receivers, the resistance to interference is measured with respect to parameters specified in 3.5.8.2.1 and 3.5.8.4.1.

Note 4.— For GBAS receivers, the resistance to interference is measured with respect to parameters specified in 3.6.7.1.1 and 3.6.8.2.1.

Note 5.— The signal levels specified in this section are defined at the antenna port. Assumed maximum aircraft antenna gain in the lower hemisphere is –10 dBic.

Note 6.— The performance requirements are to be met in the interference environments defined below. This defined interference environment is relaxed during initial acquisition of GNSS signals when the receiver cannot take advantage of a steady-state navigation solution to aid signal acquisition.

3.7.2 CONTINUOUS WAVE (CW) INTERFERENCE

3.7.2.1 *GPS AND SBAS RECEIVERS*

3.7.2.1.1 After steady-state navigation has been established, GPS and SBAS receivers shall meet the performance objectives with CW interfering signals present with a power level at the antenna port equal to the interference thresholds specified in Table B-83 and shown in Figure B-15 and with a desired signal level of –164 dBW at the antenna port.

3.7.2.1.2 During initial acquisition of the GPS and SBAS signals prior to steady-state navigation, GPS and SBAS receivers shall meet the performance objectives with interference thresholds 6 dB less than those specified in Table B-83.

3.7.2.2 *Reserved.*

3.7.3 BAND-LIMITED NOISE-LIKE INTERFERENCE

3.7.3.1 *GPS AND SBAS RECEIVERS*

3.7.3.1.1 After steady-state navigation has been established, GPS and SBAS receivers shall meet the performance objectives with noise-like interfering signals present in the frequency range of 1 575.42 MHz ±$Bw_i/2$ and with power levels at the antenna port equal to the interference thresholds specified in Table B-85 and shown in Figure B-17 and with the desired signal level of –164 dBW at the antenna port.

Note.— Bw_i is the equivalent noise bandwidth of the interference signal.

3.7.3.1.2 During initial acquisition of the GPS and SBAS signals prior to steady-state navigation, GPS and SBAS receivers shall meet the performance objectives with interference thresholds 6 dB less than those specified in Table B-85.

3.7.3.2 *Reserved.*

3.7.3.3 *Pulsed interference*. After steady-state navigation has been established, the receiver shall meet the performance objectives while receiving pulsed interference signals with characteristics according to Table B-87 where the interference threshold is defined at the antenna port.

3.7.3.4 SBAS and GBAS receivers shall not output misleading information in the presence of interference including interference levels above those specified in 3.7.

Note.— Guidance material on this requirement is given in Attachment D, 10.5.

3.8 GNSS aircraft satellite receiver antenna

3.8.1 *Antenna coverage*. The GNSS antenna shall meet the performance requirements for the reception of GNSS satellite signals from 0 to 360 degrees in azimuth and from 0 to 90 degrees in elevation relative to the horizontal plane of an aircraft in level flight.

3.8.2 *Antenna gain.* The minimum antenna gain shall not be less than that shown in Table B-88 for the specified elevation angle above the horizon. The maximum antenna gain shall not exceed +4 dBic for elevation angles above 5 degrees.

3.8.3 *Polarization*. The GNSS antenna polarization shall be right-hand circular (clockwise with respect to the direction of propagation).

3.8.3.1 The antenna axial ratio shall not exceed 3.0 dB as measured at boresight.

3.9 Cyclic redundancy check

Each CRC shall be calculated as the remainder, R(x), of the Modulo-2 division of two binary polynomials as follows:

$$\left\{\frac{[x^k M(x)]}{G(x)}\right\}_{\text{mod } 2} = Q(x) + \frac{R(x)}{G(x)}$$

where

k = the number of bits in the particular CRC;

M(x) = the information field, which consists of the data items to be protected by the particular CRC represented as a polynomial;
G(x) = the generator polynomial specified for the particular CRC;
Q(x) = the quotient of the division; and
R(x) = the remainder of the division, contains the CRC:

$$R(x) = \sum_{i=1}^{k} r_i x^{k-i} = r_1 x^{k-1} + r_2 x^{k-2} + \dots + r_k x^0$$

Table B-85. Interference threshold for band-limited noise-like interference to GPS and SBAS receivers in steady-state navigation

Interference bandwidth	Interference threshold for receivers in steady-state navigation
0 Hz < $Bw_i \le$ 700 Hz	–150.5 dBW
700 Hz < $Bw_i \le$ 10 kHz	Linearly increasing from –150.5 to –143.5 dBW
10 kHz < $Bw_i \le$ 100 kHz	Linearly increasing from –143.5 to –140.5 dBW
100 kHz < $Bw_i \le$ 1 MHz	–140.5 dBW
1 MHz < $Bw_i \le$ 20 MHz	Linearly increasing from –140.5 to –127.5 dBW*
20 MHz < $Bw_i \le$ 30 MHz	Linearly increasing from –127.5 to –121.1 dBW*
30 MHz < $Bw_i \le$ 40 MHz	Linearly increasing from –121.1 to –119.5 dBW*
40 MHz < Bw_i	–119.5 dBW*

* The interference threshold is not to exceed –140.5 dBW/MHz in the frequency range 1 575.42 ±10 MHz.

Table B-87. Interference thresholds for pulsed interference

	GPS and SBAS
Frequency range for in-band and near-band	1 575.42 MHz ± 20 MHz
Interference threshold (Pulse peak power) for in-band and near-band interference	–20 dBW
Interference threshold (Pulse peak power) outside the in-band and near-band frequency ranges (out-of-band interference)	0 dBW
Pulse width	≤125 μs
Pulse duty cycle	≤1%
Interference signal bandwidth for in-band and	≥1 MHz

Note 1.— The interference signal is additive white Gaussian noise centred around the carrier frequency and with bandwidth and pulse characteristics specified in the table.

Note 2.— In-band, near-band and out-of-band interference refers to the centre frequency of the interference signal.

Table B-88. Minimum antenna gain — GPS and SBAS

Elevation angle degrees	Minimum gain dBic
0	–7
5	–5.5
10	–4
15 to 90	–2.5

Note.— The –5.5 dBic gain at 5 degrees elevation angle is appropriate for an L1 antenna. A higher gain may be required in the future for GNSS signals in the L5/E5 band.

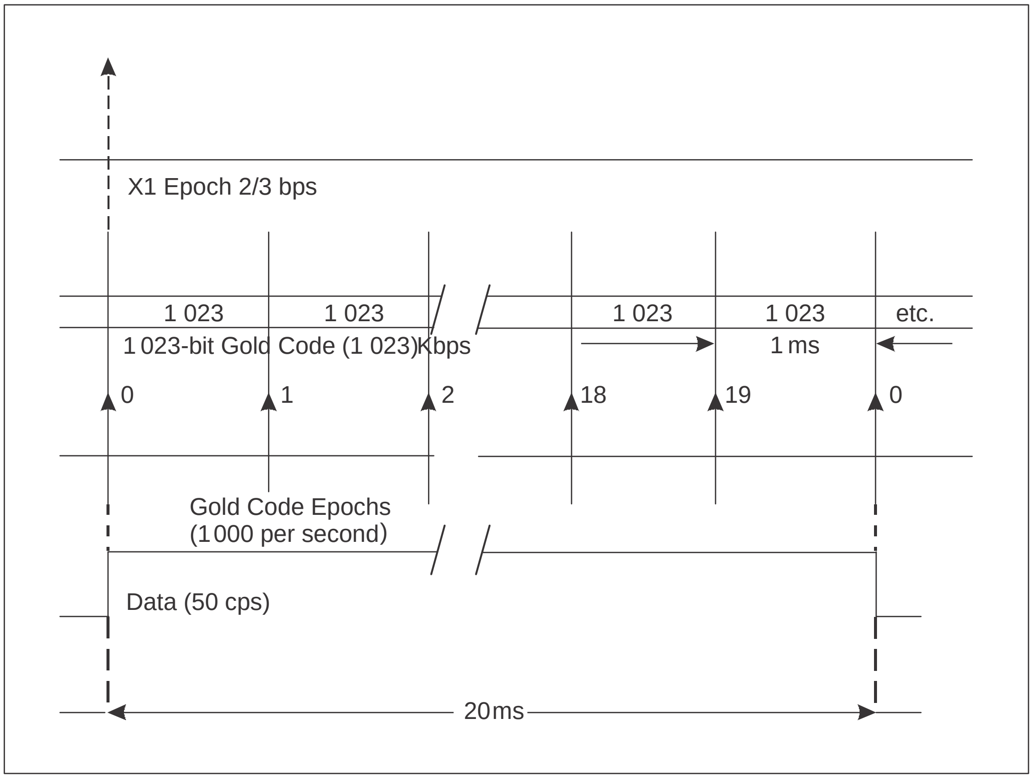


Figure B-1. C/A code timing relationships

SUBFRAME	TLM	HOW	GPS week number, SV accuracy and health	1
SUBFRAME	TLM	HOW	Ephemeris parameters	2
SUBFRAME	TLM	HOW	Ephemeris parameters	3
SUBFRAME (25 pages)	TLM	HOW	Almanac and health for satellites 25–32, special messages, satellite configuration, flags, ionospheric and UTC	4
SUBFRAME (25 pages)	TLM	HOW	Almanac and health for satellites 1–24 and almanac reference time and GPS week number	5

Figure B-2. Frame structure

Preamble								Reserved																Parity					
1	0	0	0	1	0	1	1	MSB															LSB						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Figure B-3. TLM word format

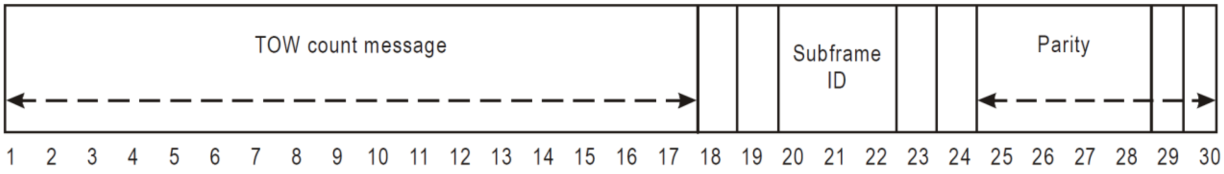
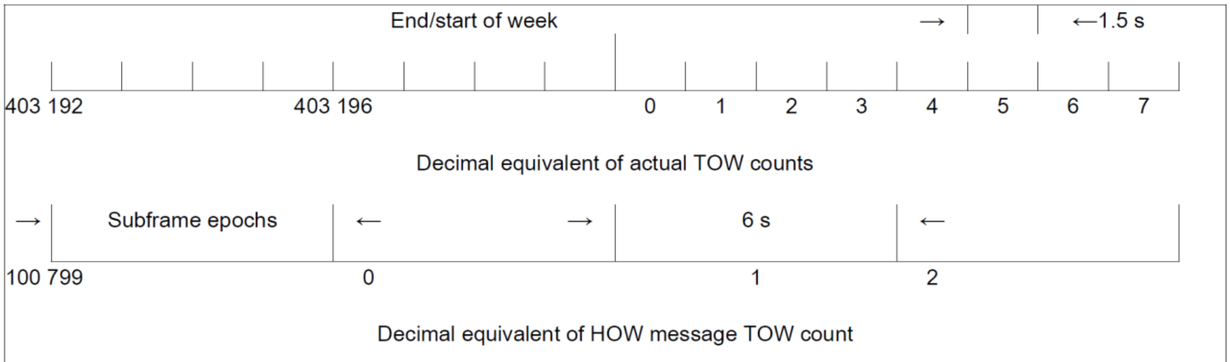


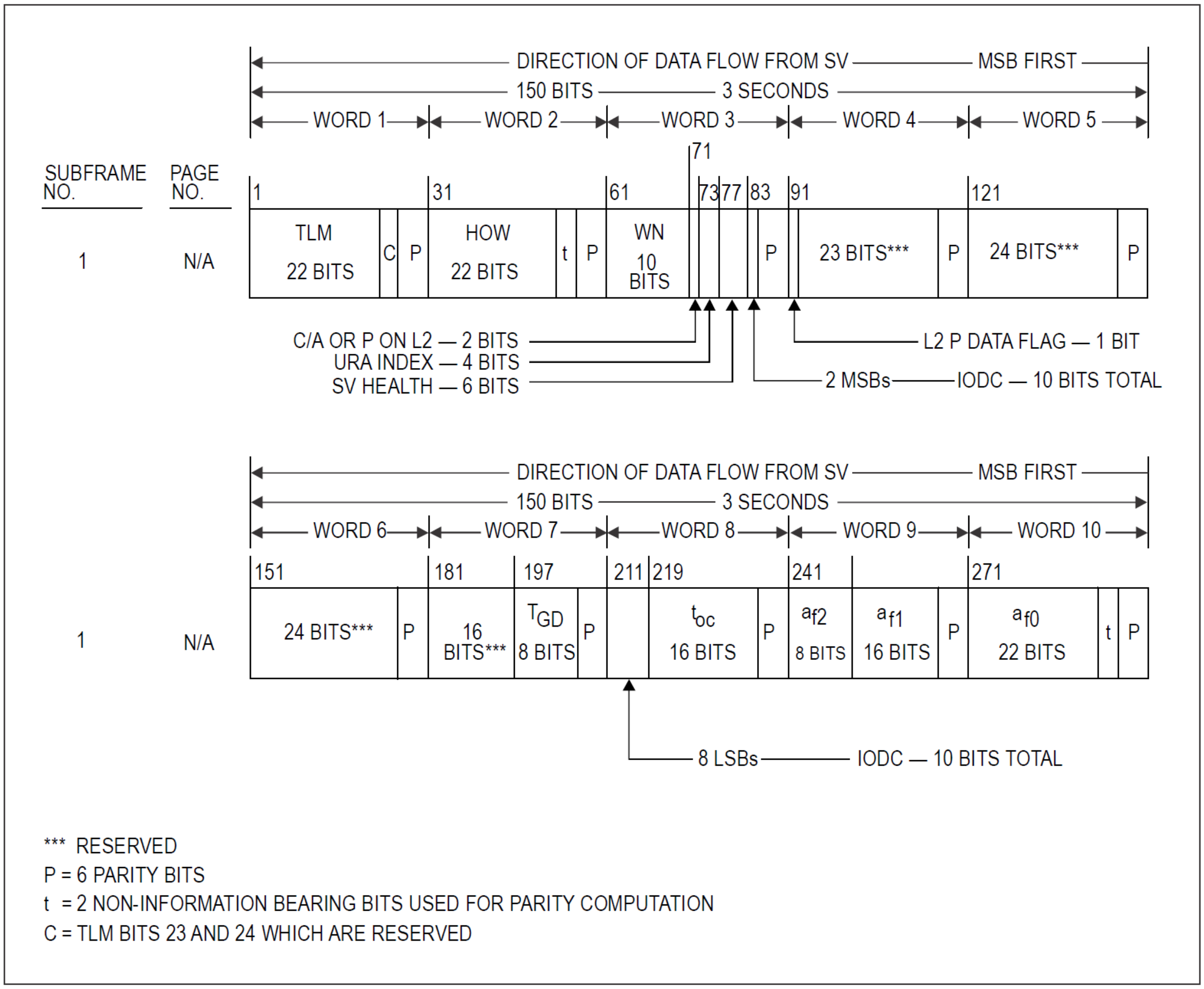
Figure B-4. HOW format



Notes:

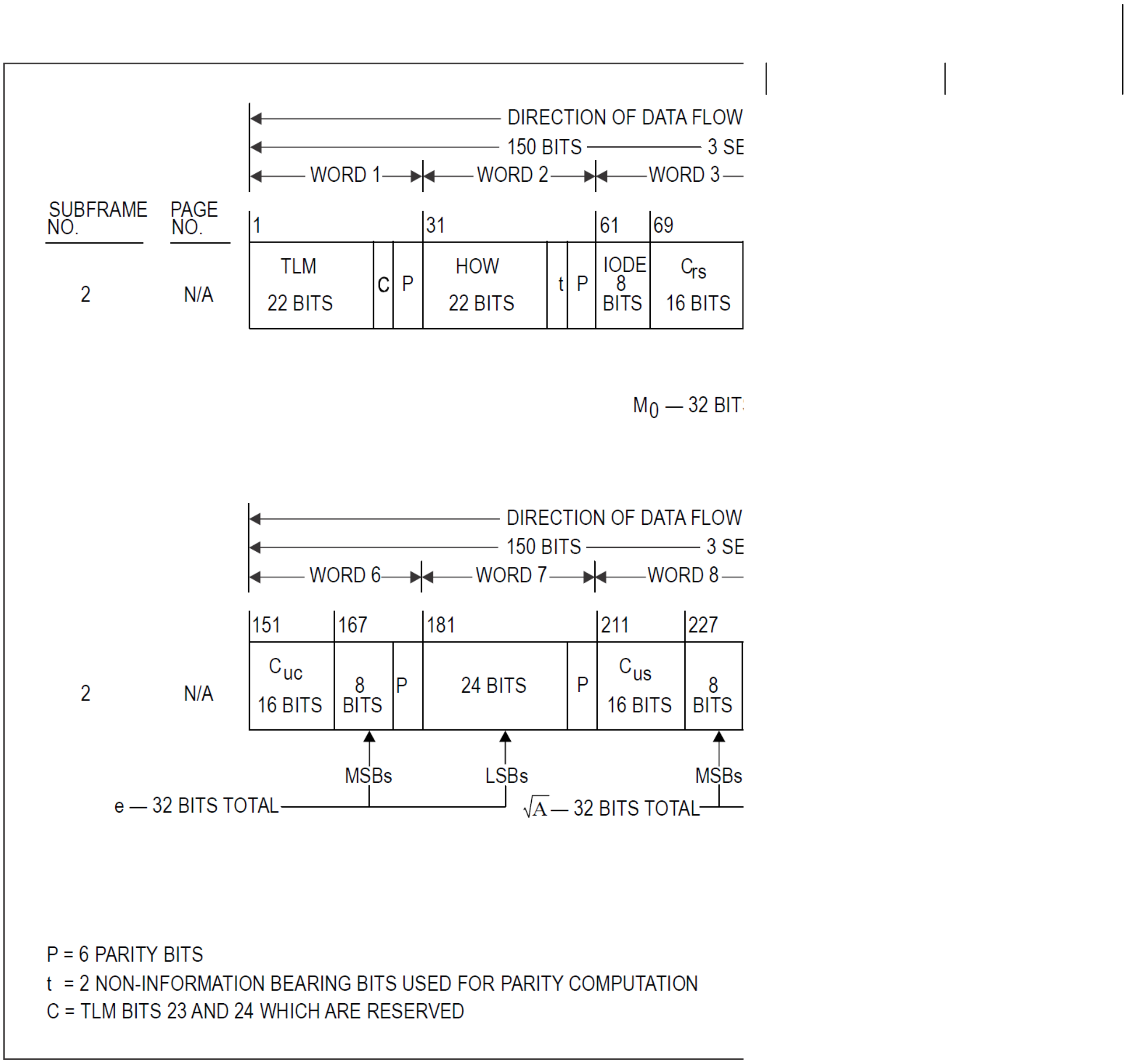
1. *To aid in rapid ground lock-on, the HOW of each subframe contains a truncated TOW count.*
2. *The HOW is the second word in each subframe.*
3. *The HOW message TOW count consists of the 17 MSBs of the actual TOW count at the start of the next subframe.*
4. *To convert from the HOW message TOW count to the actual count at the start of the next subframe, multiply by four.*
5. *The first subframe starts synchronously with the end/start of each epoch.*

Figure B-5. Time line relationship of HOW



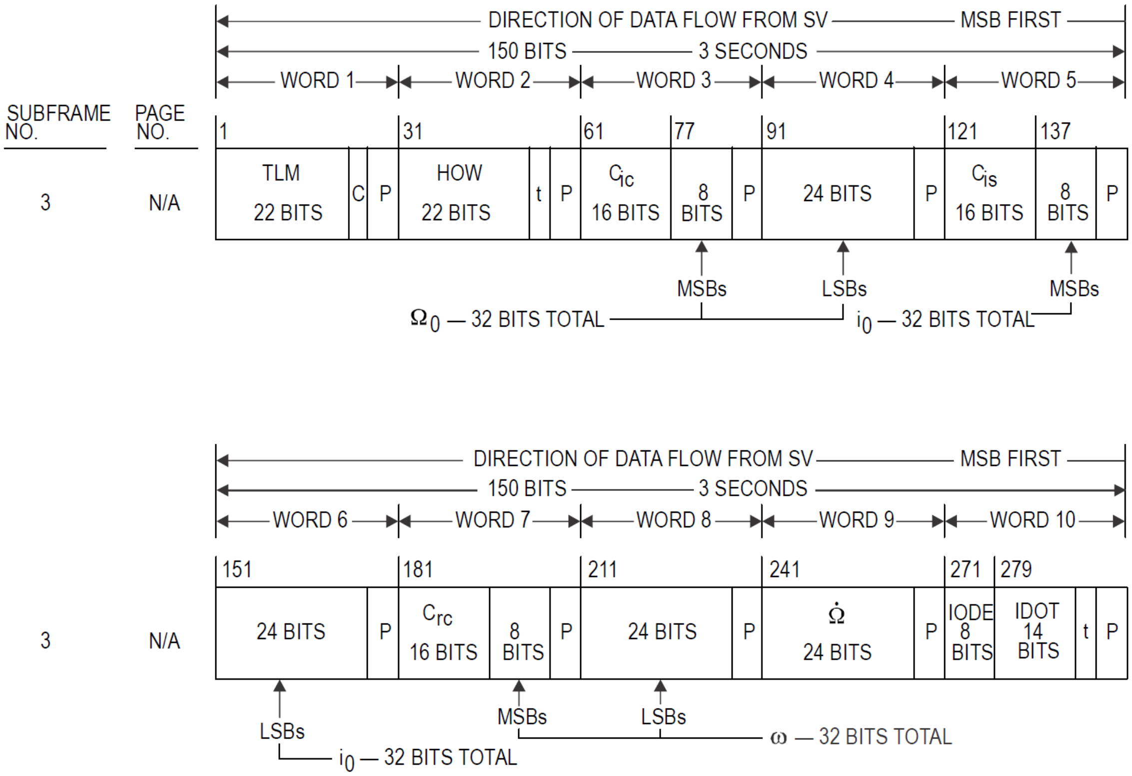
*** RESERVED
P = 6 PARITY BITS
t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION
C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (1 of 11)



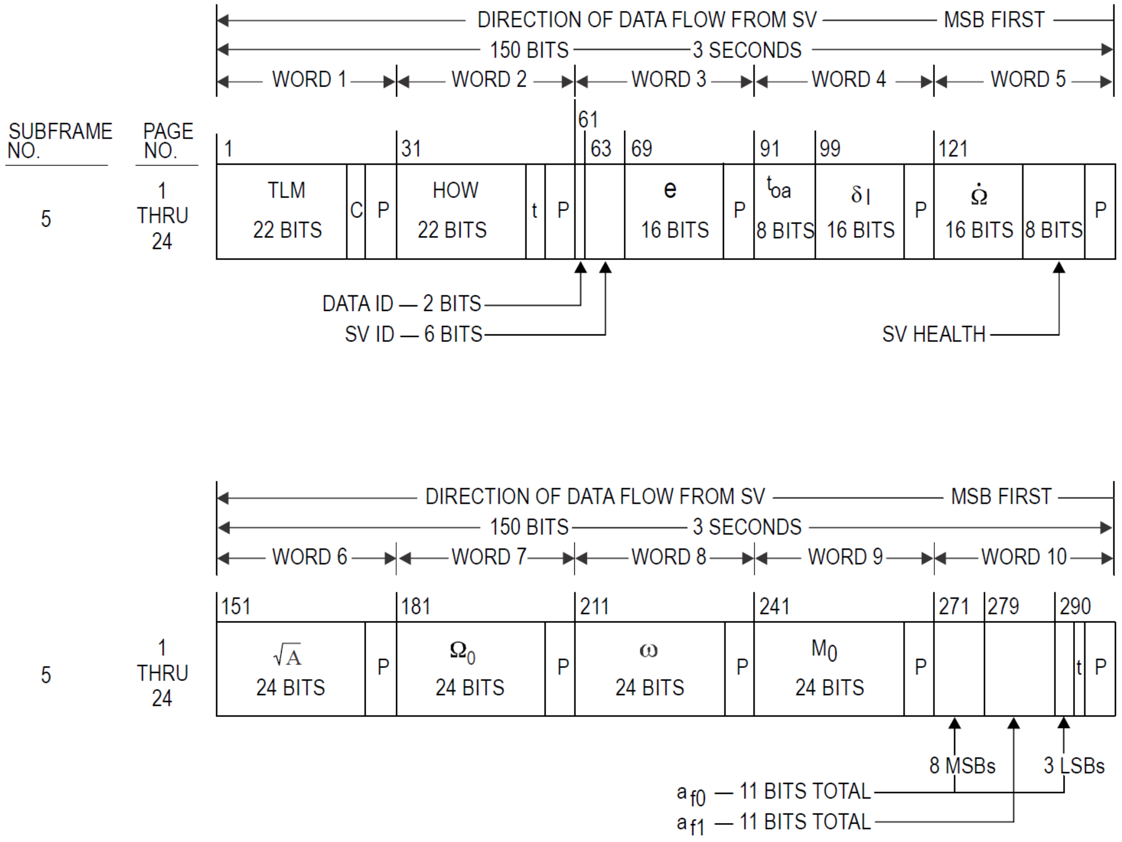
P = 6 PARITY BITS
t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION
C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (2 of 11)



P = 6 PARITY BITS
t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION
C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (3 of 11)



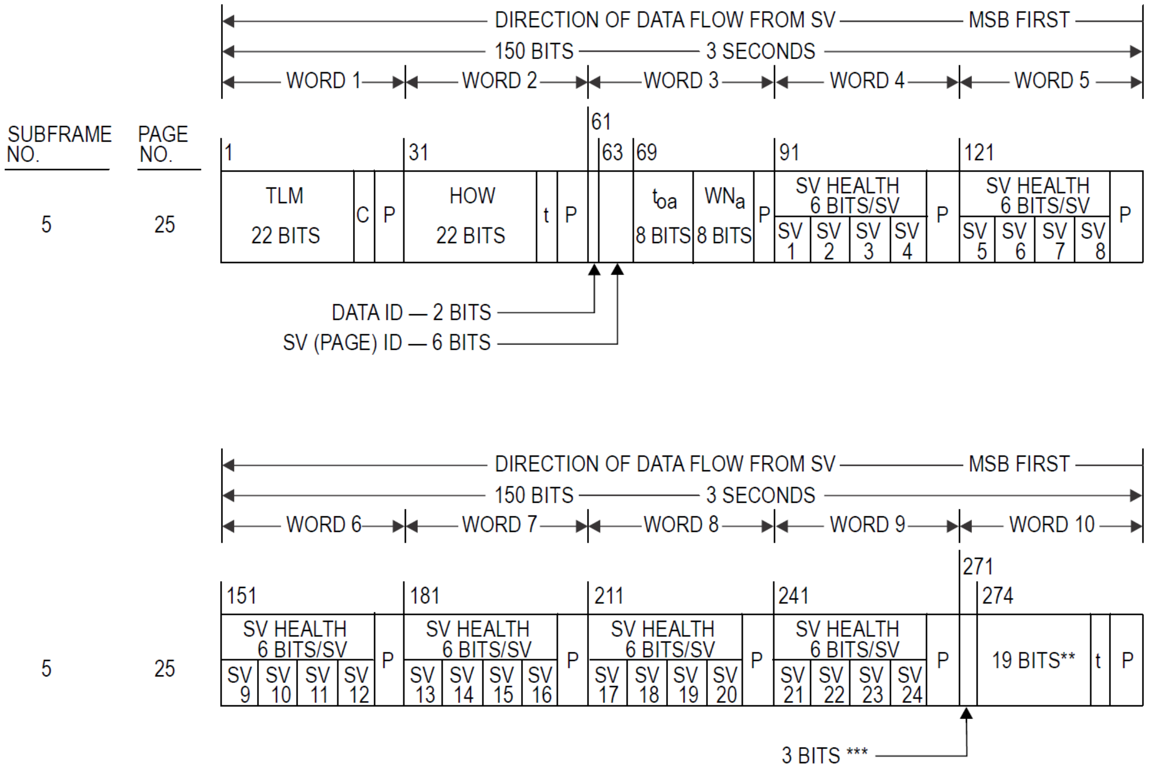
P = 6 PARITY BITS

t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION

C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Note.— Pages 2, 3, 4, 5, 7, 8, 9 and 10 of subframe 4 have the same format as pages 1 through 24 of subframe 5.

Figure B-6. Data format (4 of 11)



** RESERVED FOR SYSTEM USE

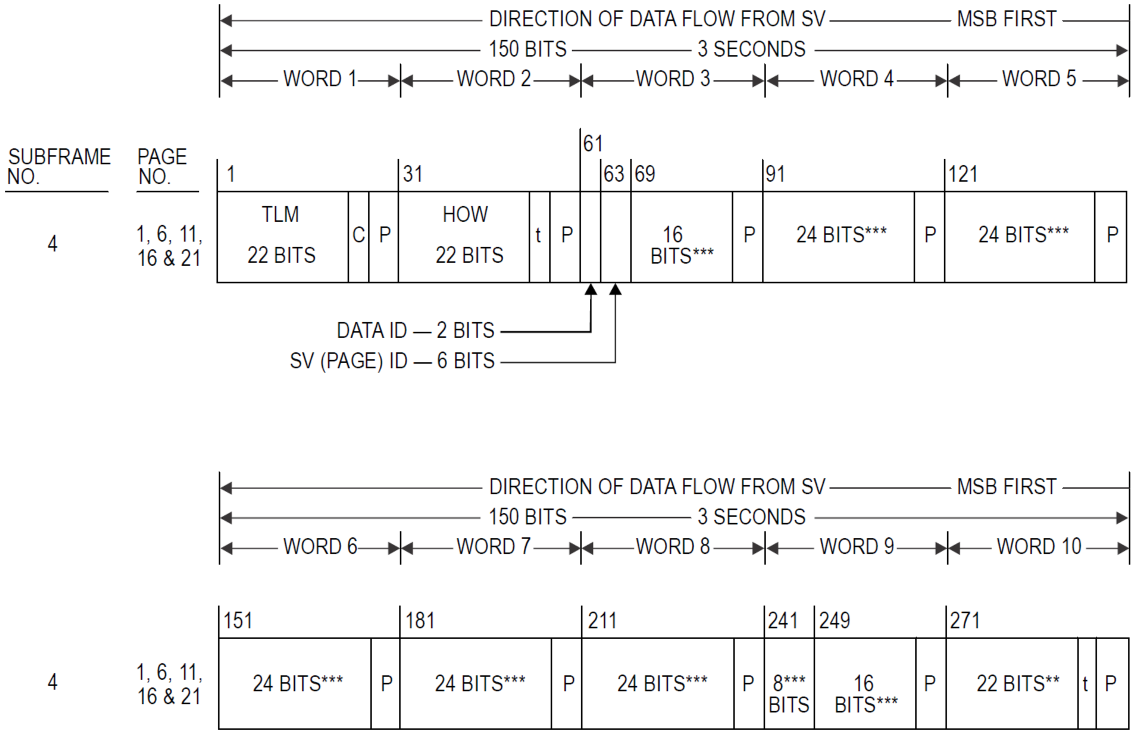
*** RESERVED

P = 6 PARITY BITS

t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION

C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (5 of 11)



** RESERVED FOR SYSTEM USE

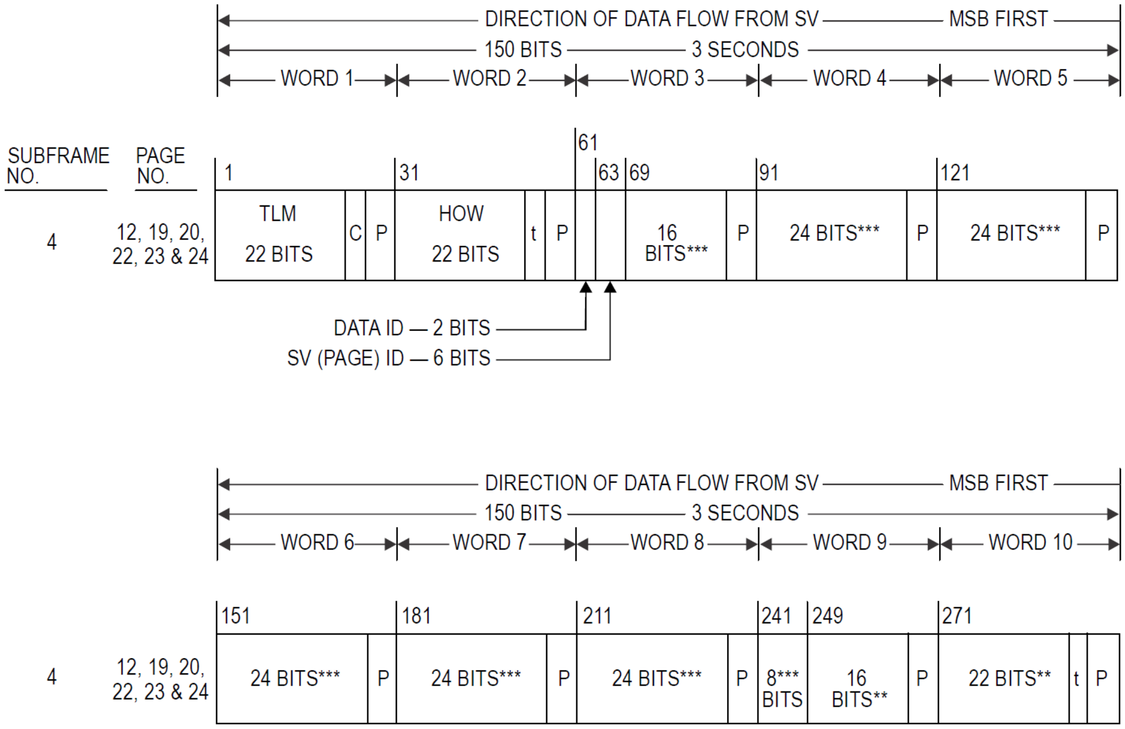
*** RESERVED

P = 6 PARITY BITS

t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION

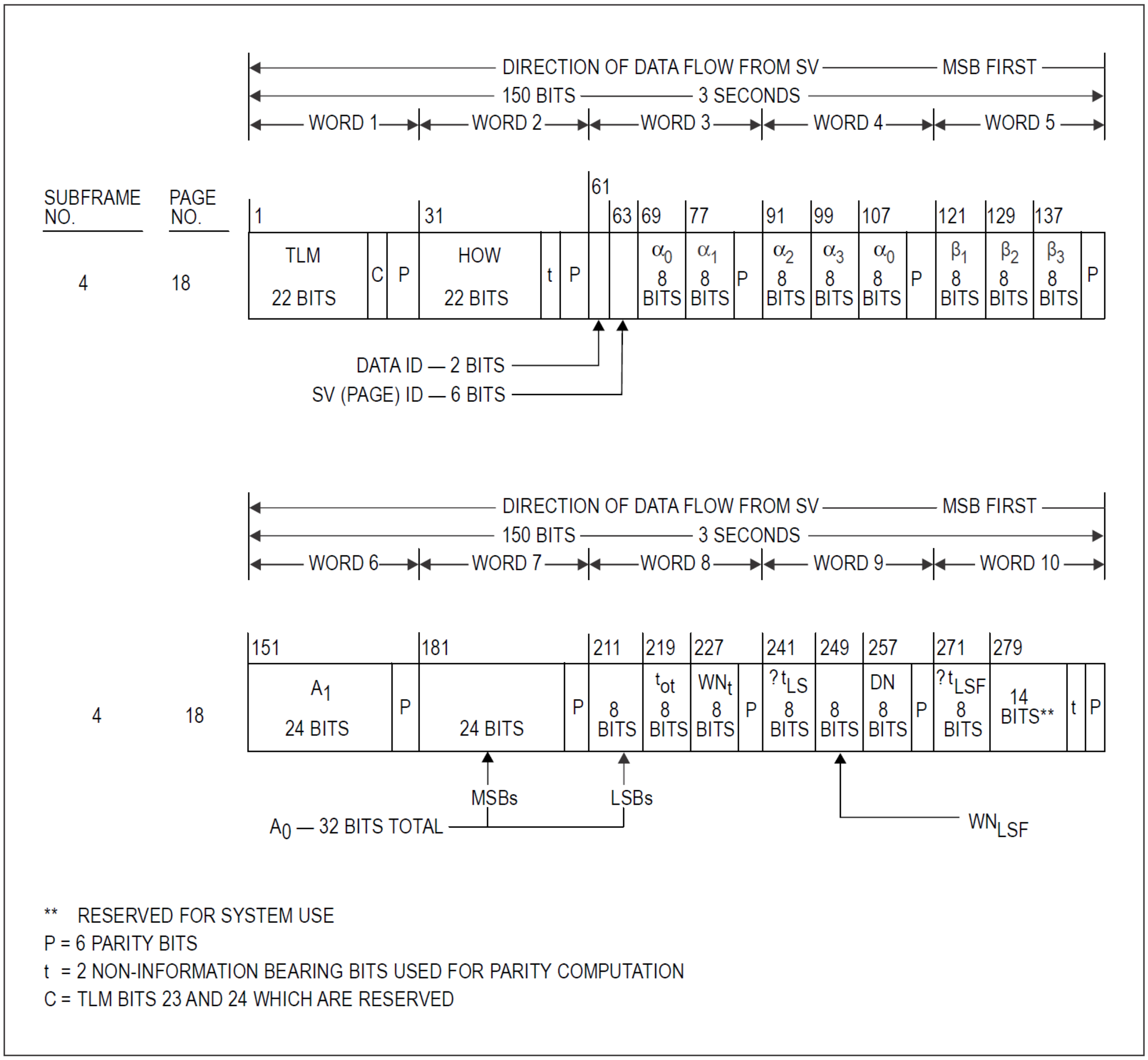
C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (6 of 11)



** RESERVED FOR SYSTEM USE
*** RESERVED
P = 6 PARITY BITS
t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION
C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (7 of 11)



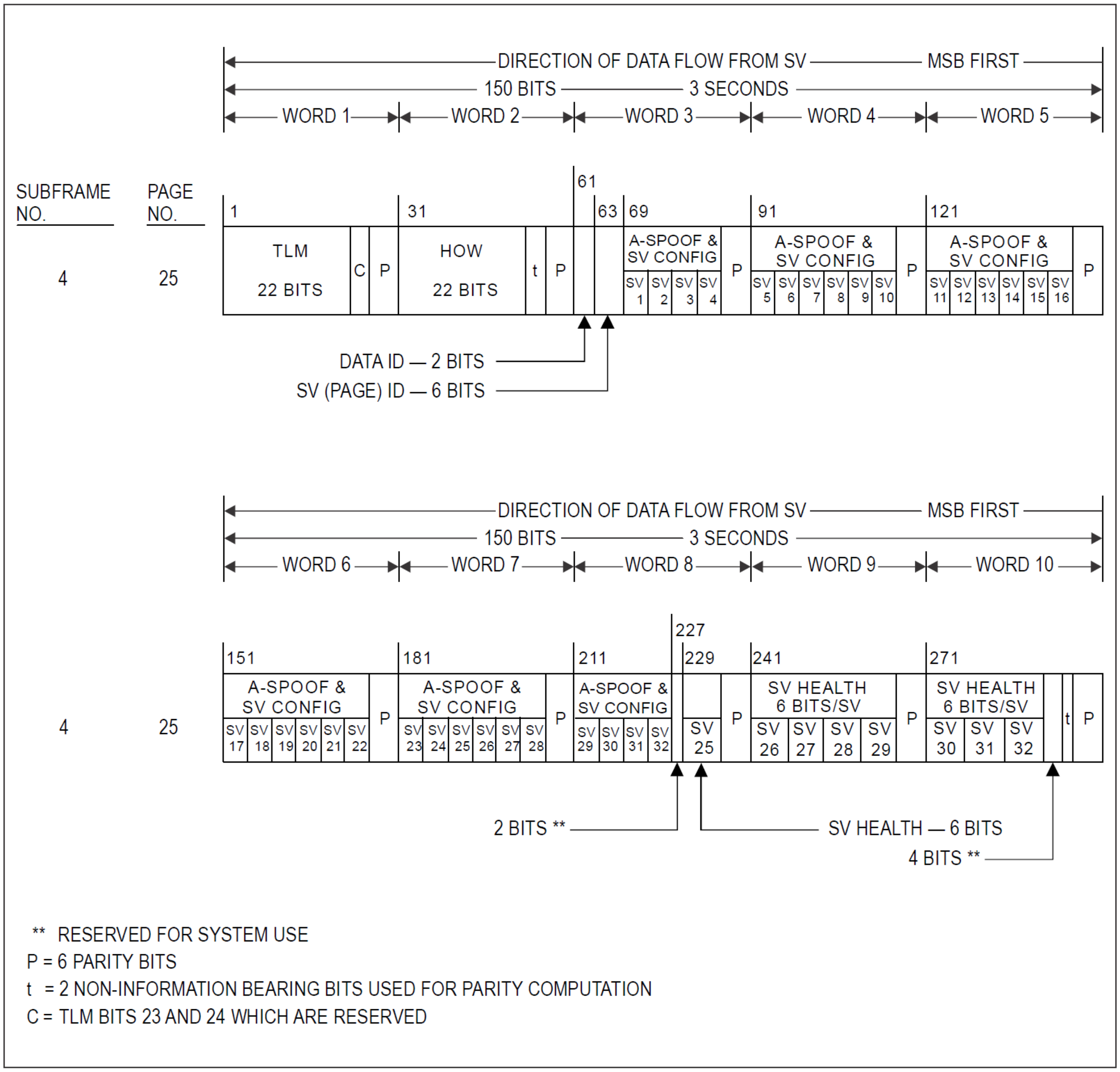
** RESERVED FOR SYSTEM USE

P = 6 PARITY BITS

t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION

C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (8 of 11)

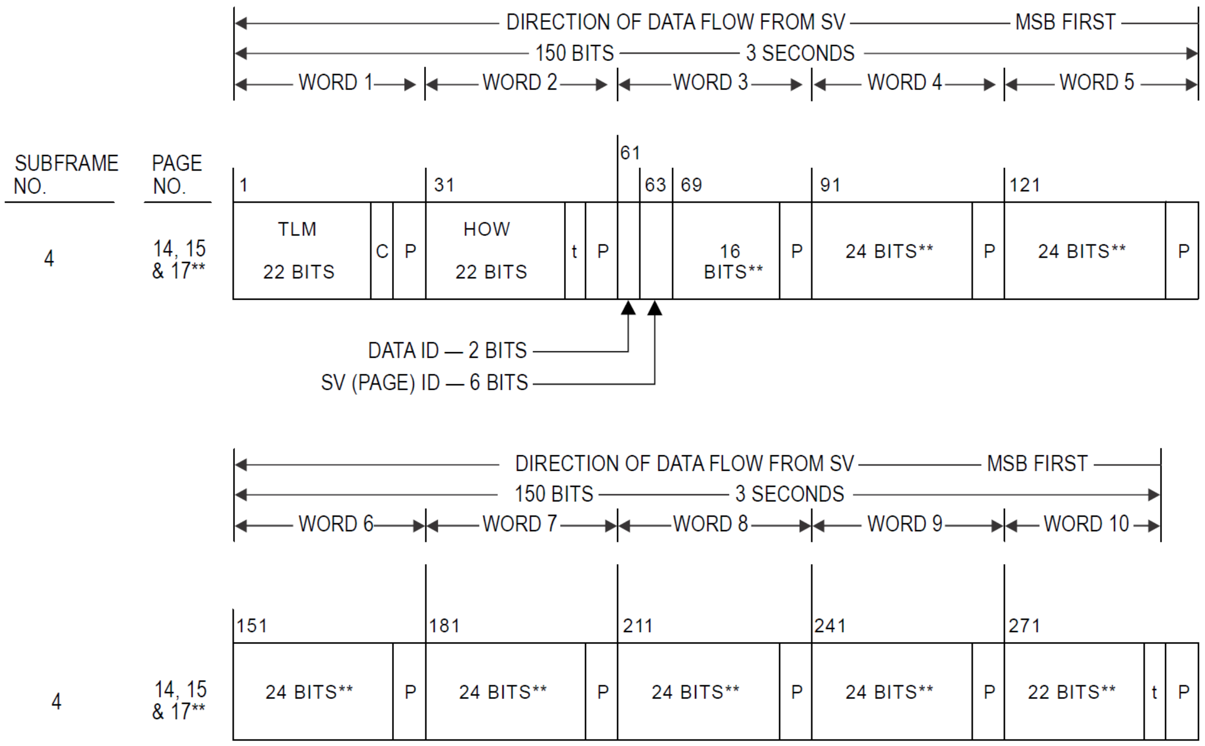


** RESERVED FOR SYSTEM USE
P = 6 PARITY BITS
t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION
C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (9 of 11)

[redacted]

Figure B-6. Data format (10 of 11)



** THE INDICATED PORTIONS OF WORDS 3 THROUGH 10 OF PAGES 14 AND 15 ARE RESERVED FOR SYSTEM USE, WHILE THOSE OF PAGE 17 ARE RESERVED FOR SPECIAL MESSAGES

P = 6 PARITY BITS

t = 2 NON-INFORMATION BEARING BITS USED FOR PARITY COMPUTATION

C = TLM BITS 23 AND 24 WHICH ARE RESERVED

Figure B-6. Data format (11 of 11)

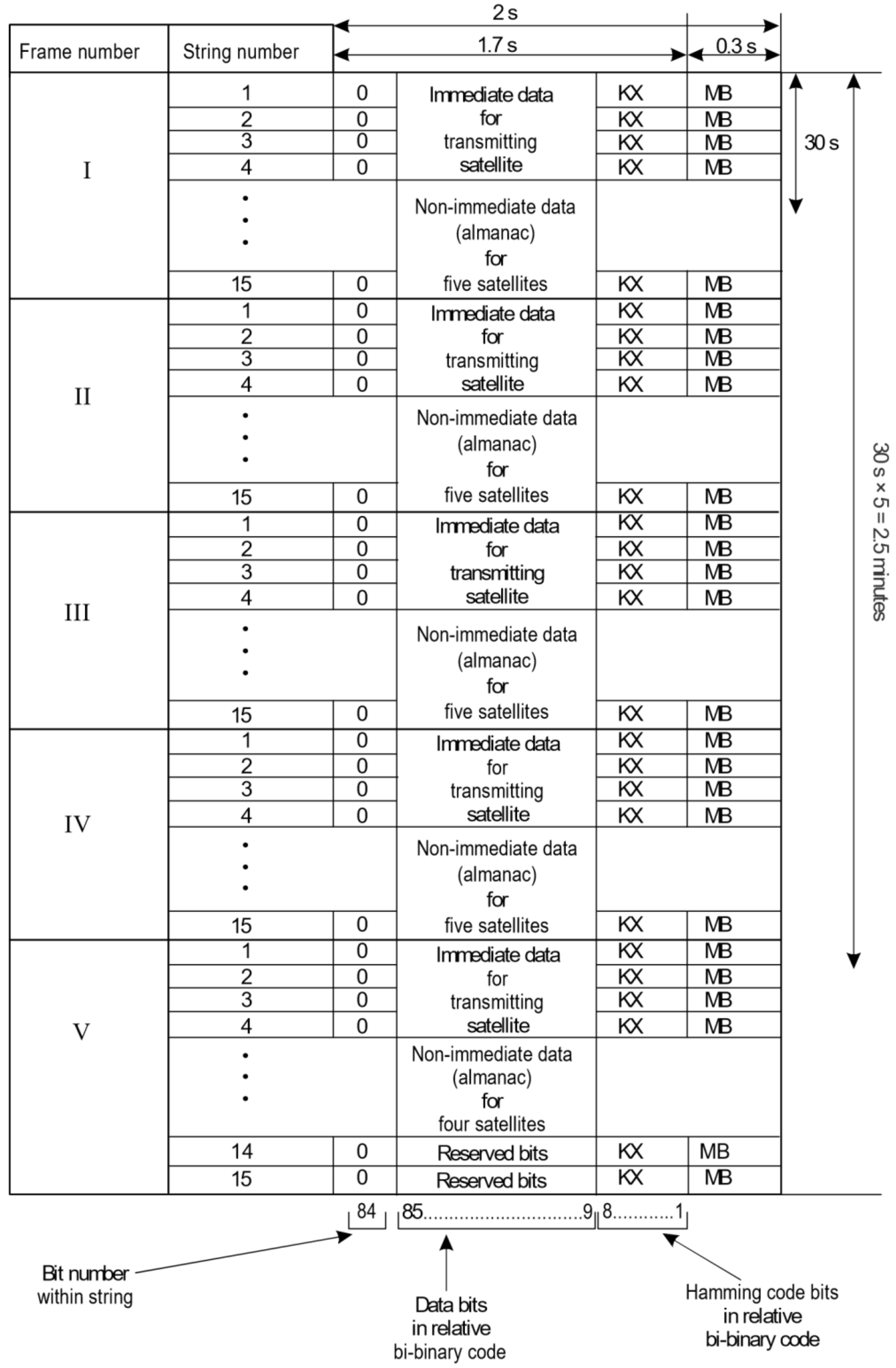
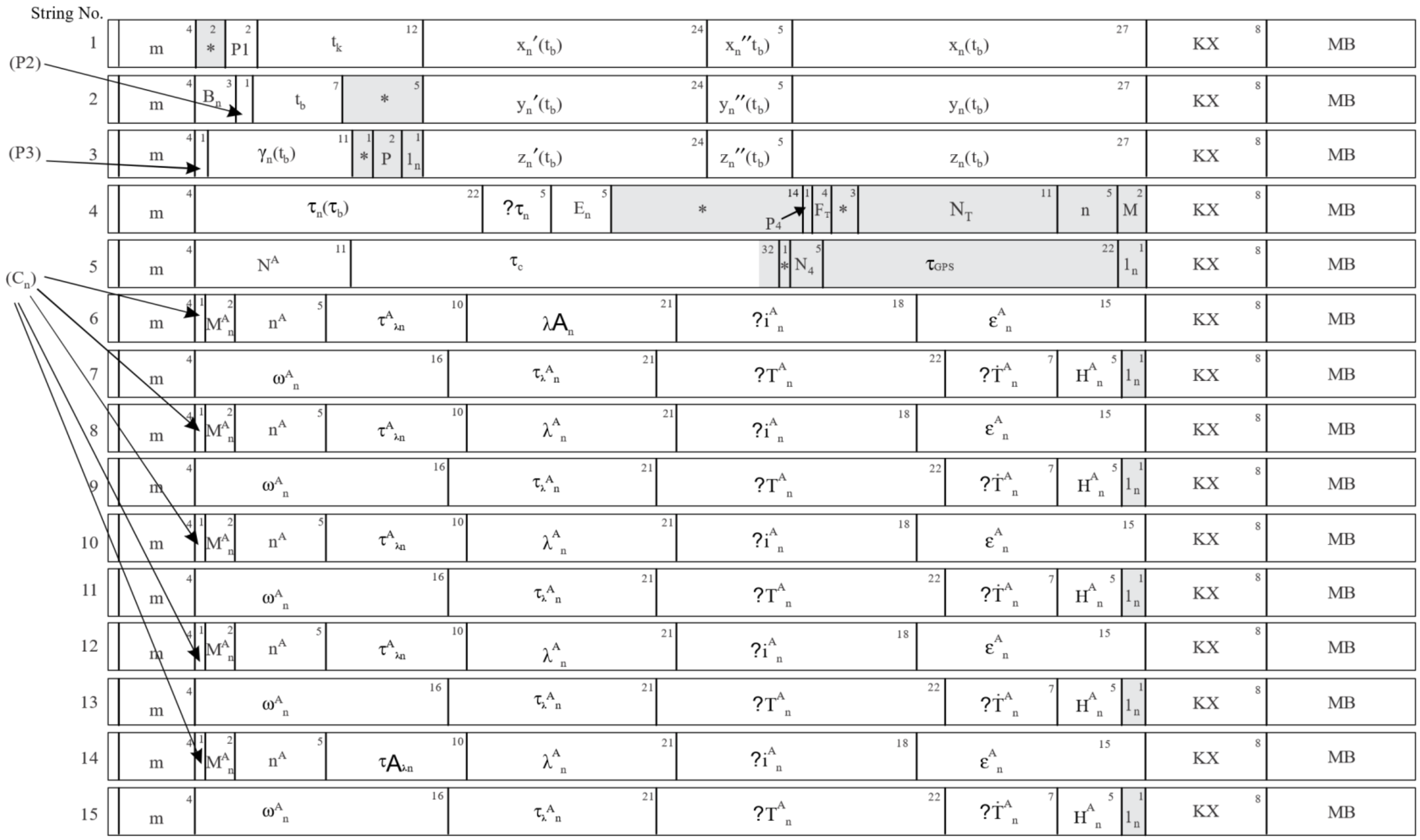


Figure B-7. Superframe structure



* Reserved bits within frame

Note.— Data content, definitions and explanations of parameters are given in 3.2.1.3 and 3.2.1.4. Additional data transmitted by GLONASS-M are highlighted in this figure.

Figure B-8. Frame structure (frames 1 to 4)

* Reserved bits within frame

Note.— Data content, definitions and explanations of parameters are given in 3.2.1.3 and 3.2.1.4. Additional data transmitted by GLONASS-M are highlighted in this figure.

Figure B-9. Frame structure (frame 5)

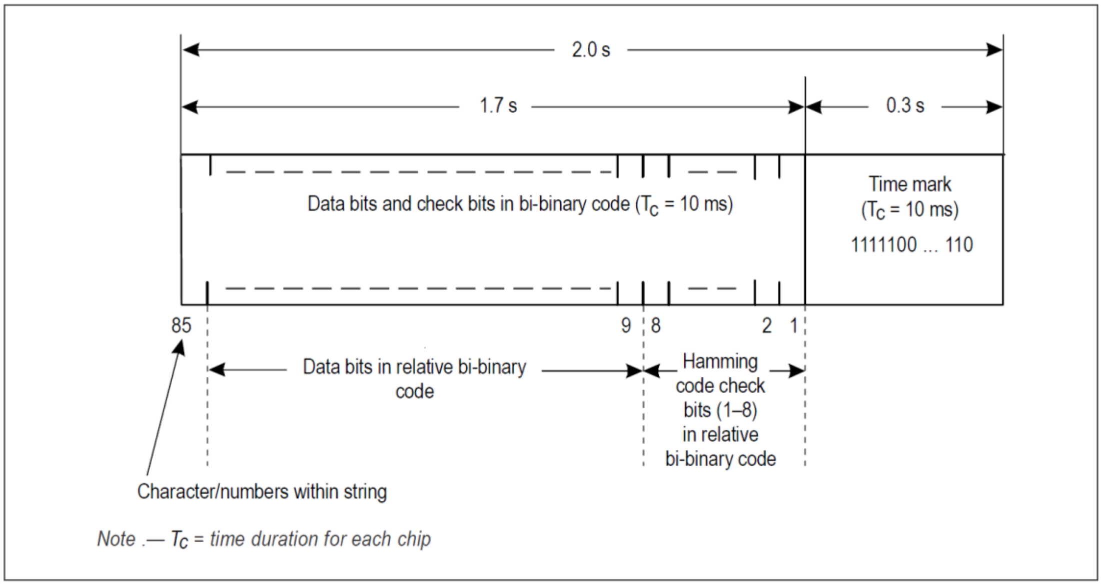


Figure B-10. Data string structure

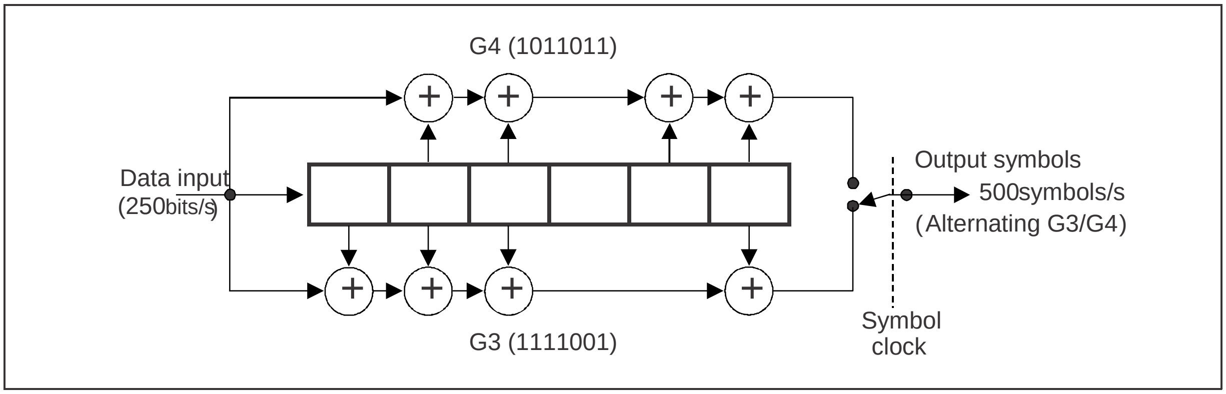


Figure B-11. Convolutional encoding

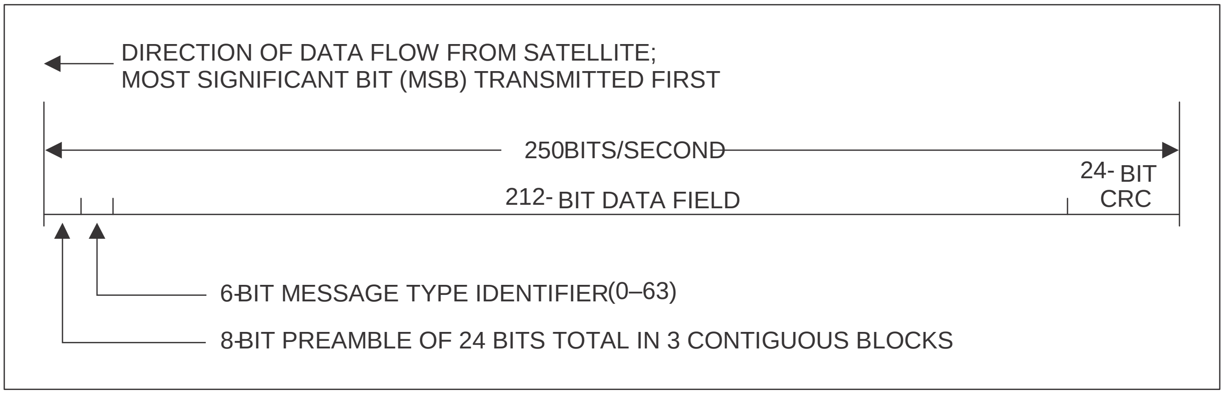


Figure B-12. Data block format

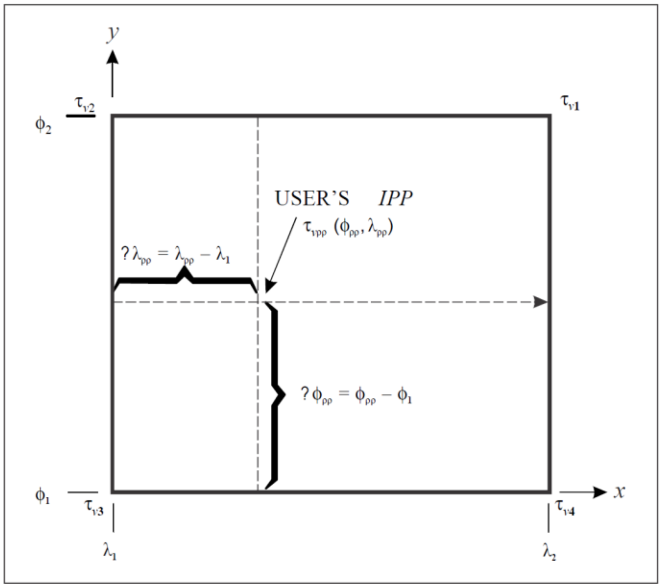


Figure B-13. IGP numbering convention (four IGPs)

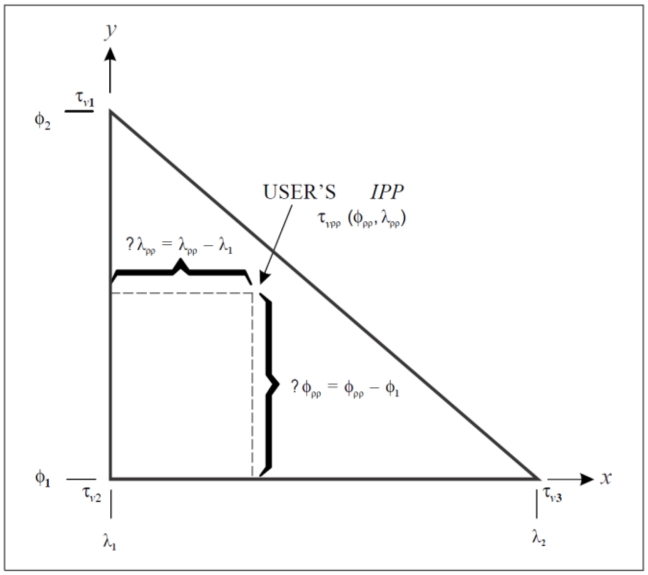


Figure B-14. IGP numbering convention (three IGPs)

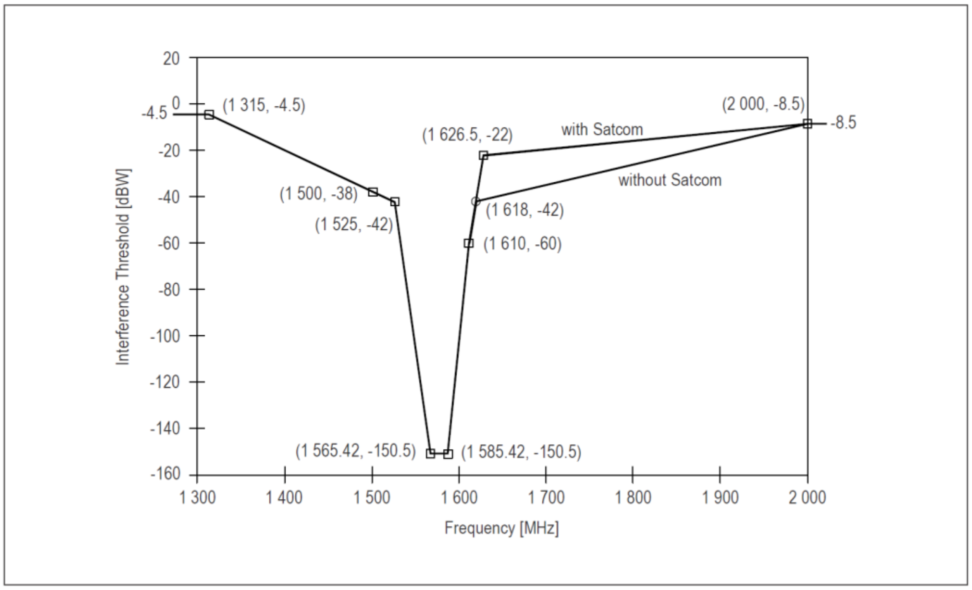


Figure B-15. CW interference thresholds for GPS and SBAS receivers in steady-state navigation

Figure B-16. Reserved

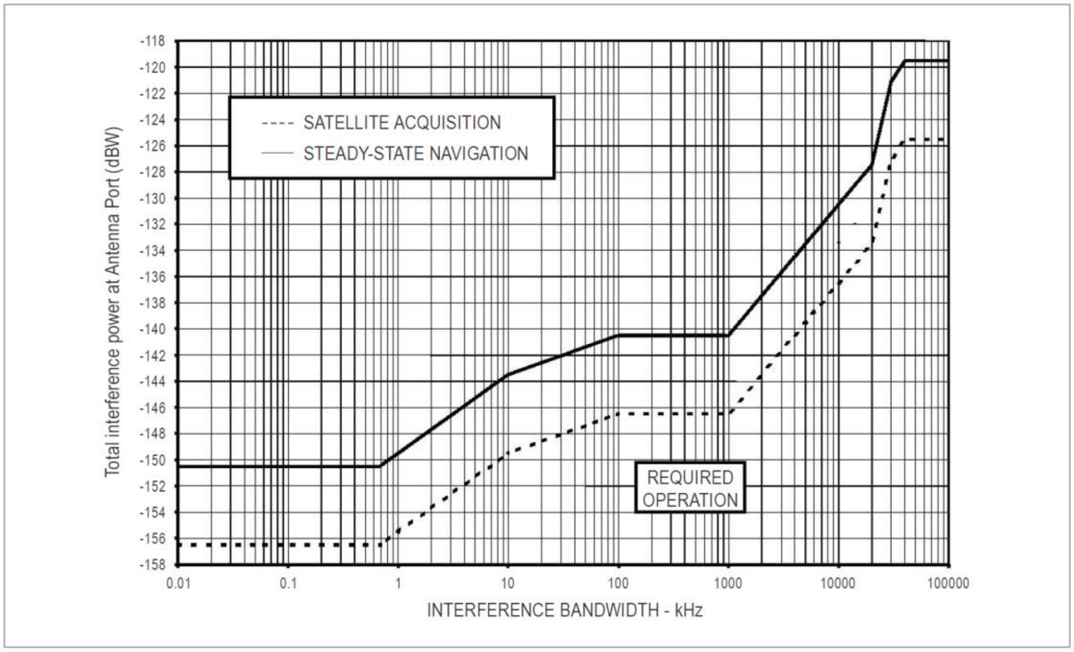


Figure B-17. Interference thresholds versus bandwidth for

GPS and SBAS receivers

Figure B-18 Reserved

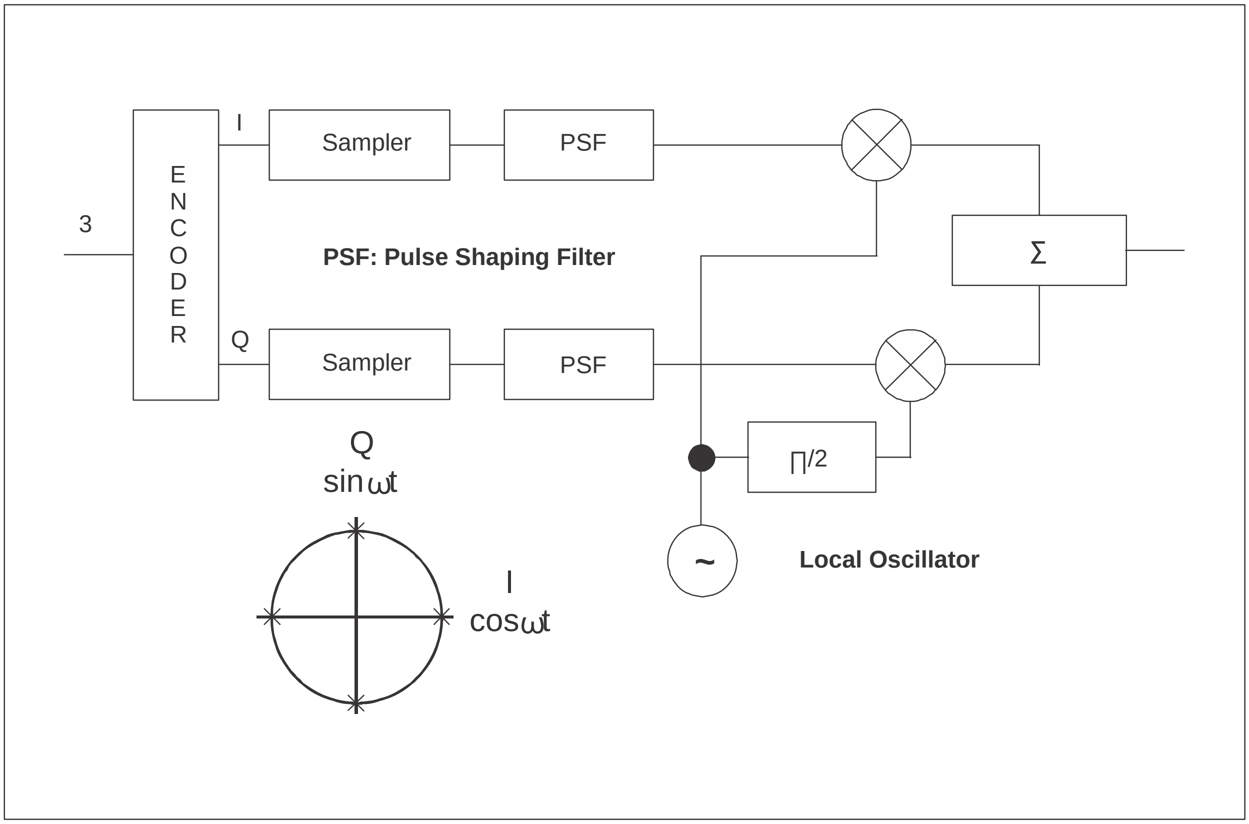


Figure B-19. Example data modulation

Table of Contents

ATTACHMENT A. DETERMINATION OF INTEGRITY AND CONTINUITY OF SERVICE OBJECTIVES USING THE RISK TREE METHOD

1. The risk tree method is a graphical method of expressing the logical relationship between a particular failure condition and the causes or failures leading to this condition. It is an application of fault tree analysis being used in the aerospace industry.

1.1 The method employs a set of logic symbols to show the relationship between the various causes of failure. The following symbols are used in this guidance material.

The “AND” gate describes the logical operation whereby the coexistence of all input events is required to produce the output event.

The “OR” gate defines a situation whereby the output event will exist if one or more of the input events exist.

The rectangle identifies an event that results from the combination of fault or failure events through the input logic gate.

The circle describes a primary failure event that requires no further development. Frequency and mode of failure of items so identified are derived from empirical data.

1.2 The method gives a visual representation of sequences and combinations of events leading to the top failure event. The method can also be used to determine the probability of the top event occurring, provided that the probabilities of the individual events are known or can be estimated. In the case of simple fault trees probabilities can be directly calculated, but care must be taken if the primary failure events are not independent, i.e. if failure events are common to more than one path.

1.3 In this guidance material the acceptable probability of the top level event occurring is determined by the risk allocation and the fault tree is used to further partition the risk into integrity and continuity of service risks. Therefore, the term “risk tree” is used rather than “fault tree”.

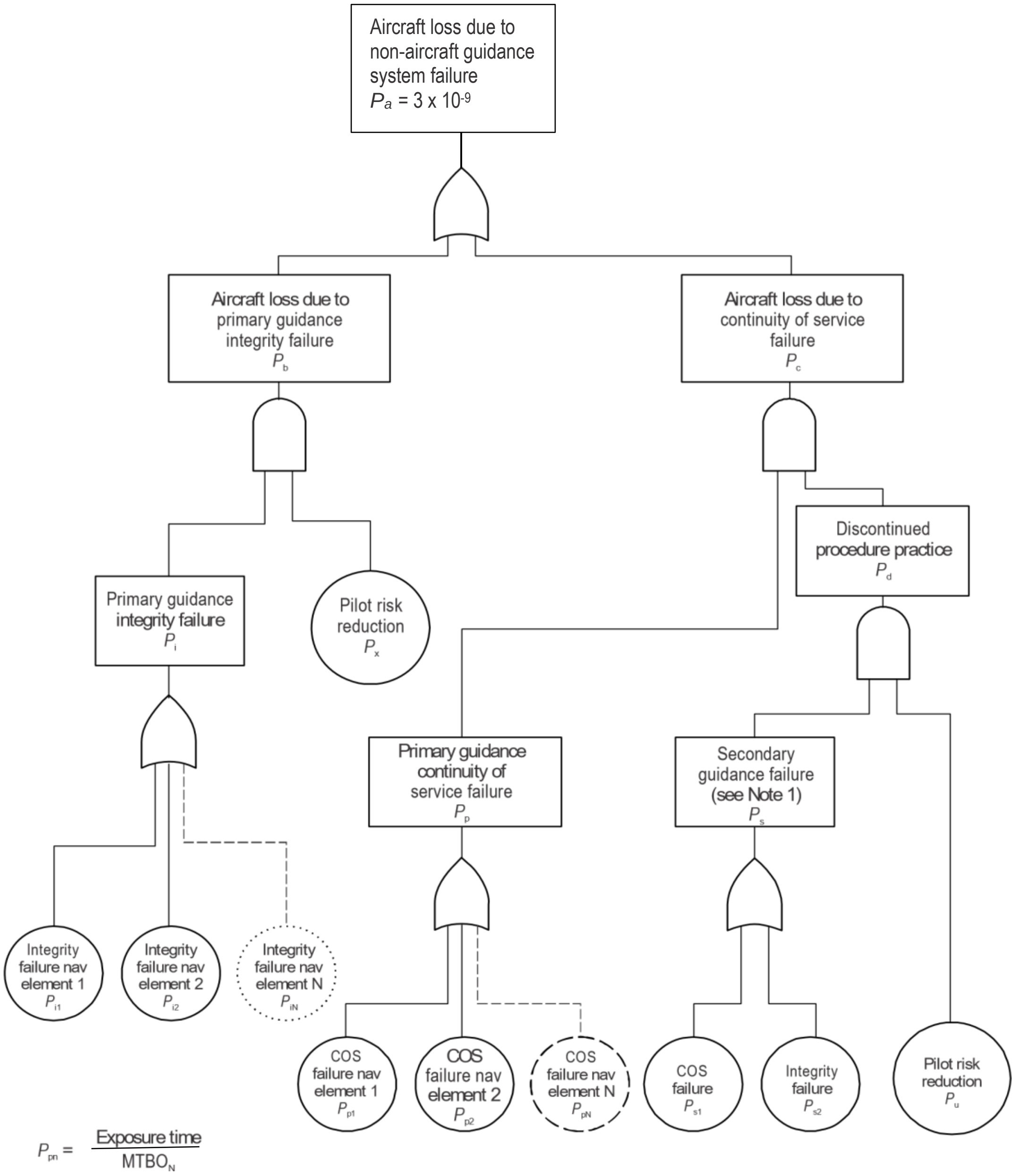
2. A generic risk tree for aircraft landing operations is given in Figure A-1. The top event for this tree is taken to be the loss of the aircraft due to a failure of the non-aircraft guidance system. The causes of this event are either an integrity failure of the primary non-aircraft guidance equipment or a continuity of service (COS) failure of the non-aircraft guidance system (i.e. both the primary system and any secondary system used to support a discontinued approach/missed approach). The primary non-aircraft guidance system is considered to have a number of elements, 1 to N, for example azimuth, elevation and DME/P in the case of MLS. The secondary guidance system may be an alternative non-aircraft system, or in some cases an aircraft navigation system such as an inertial reference system.

2.1 The following probabilities can be defined:

P_a = Probability of aircraft loss due to a failure of the non-aircraft guidance system.

P_b = Probability of aircraft loss due to primary guidance integrity failure.

P_c = Probability of aircraft loss due to COS failure.



$$P_{pn} = \frac{\text{Exposure time}}{\text{MTBO}_N}$$

Note 1: Secondary guidance may be aircraft or non-aircraft guidance system.

Figure A-1. Generic risk tree

P_x =	Probability that the pilot is unable to detect and intervene successfully following a primary guidance integrity failure. This risk reduction factor is only relevant in those cases where an integrity failure of the guidance system may be detected by the pilot, e.g. at decision height in a Category I ILS approach.
P_p =	Probability of primary guidance COS failure.
P_d =	Probability of aircraft loss during a discontinued approach/missed approach procedure.
P_i =	Probability of primary guidance integrity failure.
P_{iN} =	Probability of integrity failure in Nav element N.
P_{pN} =	Probability of COS failure in Nav element N.
P_s =	Probability of aircraft loss during a discontinued approach/missed approach with secondary guidance.
P_{s1} =	Probability of secondary guidance COS failure.
P_{s2} =	Probability of secondary guidance integrity failure.
P_u =	Probability that the pilot is unable to intervene successfully following primary guidance COS failure with no secondary guidance available.

Where:

$P_a = P_b + P_c$
$P_b = P_i \times P_x$
$P_i = P_{i1} + P_{i2} + \dots P_{iN}$
$P_c = P_p \times P_d$
$P_p = P_{p1} + P_{p2} + \dots P_{pN}$
$P_d = P_s \times P_u$
$P_s = P_{s1} + P_{s2}$

2.2 The acceptable probability of the top event, P_a, can be determined by partitioning the global risk factor for the approach and landing operation to the various classes of accident. Using this method an acceptable value for P_a of 3×10^{-9} has been determined. This is consistent with the smallest probability that can be assigned to each ground navigation element, which is 1×10^{-9} (normally divided equally between integrity and COS failures).

2.3 The risk analysis above assumes no equipment design errors.

3. *Reserved*

4. *Reserved*

.

ATTACHMENT B. STRATEGY FOR INTRODUCTION AND APPLICATION OF NON-VISUAL AIDS TO APPROACH AND LANDING

(see Chapter 2, 2.1)

1. Introduction

1.1 Various elements have an influence on all weather operations in terms of safety, efficiency and flexibility. The evolution of new techniques requires a flexible approach to the concept of all weather operations to obtain full benefits of technical development. To create this flexibility a strategy enables, through identification of its objectives and thoughts behind the strategy, incorporation of new technical developments or ideas into this strategy. The strategy does not assume a rapid transition to a single globally established system or selection of systems to support approach and landing operations.

1.2 The strategy addresses the application of non-visual aids to approach and landing with vertical guidance (APV) and precision approach and landing operations.

2. Objectives of strategy

The strategy must:

a) maintain at least the current safety level of all weather operations;

b) retain at least the existing level or planned improved level of service;

c) support lateral and vertical path guidance as outlined in Resolution A37-11;

d) maintain global interoperability;

e) provide regional flexibility based on coordinated regional planning;

f) support infrastructure investment planning cycles;

g) be maintained by periodic review; and

h) take account of economic, operational and technical issues.

3. Considerations

3.1 General

The following considerations are based on the assumption that the operational requirement and the required commitment are available and the required effort is applied.

3.2 ILS-related considerations

a) There is a limited risk that ILS Category II or III operations cannot be safely sustained at specific locations;

b) ILS receivers have implemented interference immunity performance Standards contained in Annex 10, Volume I, Chapter 3, 3.1.4;

c) in some regions, expansion of ILS is limited by channel availability (40 paired ILS/DME channels);

d) in most areas of the world, ILS can be maintained in the foreseeable future;

e) due to cost and efficiency considerations, some States are rationalizing some of their ILS infrastructure at Category I airports with limited operational usage; and

f) based on user-equipage considerations, GNSS-based approaches providing lateral and vertical path guidance may offer a cost-effective option when considering introduction of Category I approach service or when replacing or removing an existing ILS.

3.3 Reserved

3.4 GNSS-related considerations

a) Standards and Recommended Practices (SARPs) are in place for GNSS with augmentation to support APV and Category I precision approach;

b) GNSS with satellite-based augmentation system (SBAS) for APV and Category I precision approach operations is operational;

c) GNSS with ground-based augmentation system (GBAS) for Category I precision approach operations is operational;

d) it is expected that an internationally accepted GBAS will be available for Category II and III operations in the 2018-2020 timeframe;

e) ongoing dual-frequency, multi-constellation (DFMC) GNSS developments will enhance performance of GNSS augmentations as well as enable new operational capabilities in the 2025 timeframe

f) technical and operational issues associated with GNSS approach, landing and departure operations, such as vulnerabilities due to ionospheric propagation and radio frequency interference, must be addressed in a timely manner; and

g) issues associated with DFMC GNSS must be addressed in a timely manner.

3.5 Multi-modal airborne approach and landing capability considerations

To enable this strategy, a multi-modal airborne approach and landing capability is necessary and is expected to be available.

3.6 Other considerations

a) There is an increasing demand for Category II and/or III operations in some areas;

b) GNSS can potentially offer unique operational benefits for low-visibility operations, including new procedures, flexible siting requirements and provision of airport surface guidance;

c) only the three standard systems (ILS, and GNSS with augmentation as required) are considered to play a role in supporting all weather operations. The use of head-up displays in conjunction with enhanced and synthetic vision systems may provide operational benefits;

d) a consequence of the global strategy is that there will not be a rapid or complete transition from ILS to GNSS. It is therefore essential for the implementation of the strategy that the radio frequency spectrum used by all of these systems be adequately protected;

e) the potential operational benefits resulting from the introduction of new landing systems may be limited by the constraints of mixed-system aircraft equipage;

f) APV operations may be conducted using GNSS with augmentation as required or barometric vertical guidance, and GNSS with ABAS lateral guidance;

g) APV operations provide enhanced safety and generally lower operational minima as compared to non-precision approaches;

h) adequate redundancy should be provided when terrestrial navigation aids are withdrawn; and

i) rationalization should be part of a national or regional strategy on terrestrial navigation aids; guidance is provided in Attachment H.

4. Strategy

Based on the considerations above, the need to consult aircraft operators, airport operators and international organizations, and to ensure safety, efficiency and cost-effectiveness of the proposed solutions, the global strategy is to:

a) continue ILS operations to the highest level of service as long as operationally acceptable and economically beneficial;

b) reserved;

c) implement GNSS with augmentation (i.e. ABAS, SBAS, GBAS) as required for APV and precision approach operations where operationally required and economically beneficial;

d) promote the continuing development and use of a multi-modal airborne approach and landing capability;

e) promote the use of APV operations, particularly those using GNSS vertical guidance, to enhance safety and accessibility; and

f) enable each region to develop an implementation strategy for these systems in line with this global strategy.

ATTACHMENT C. INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE STANDARDS AND RECOMMENDED PRACTICES FOR ILS, VOR, PAR, 75 MHz MARKER BEACONS (EN-ROUTE), NDB AND DME

1. Introduction

The material in this Attachment is intended for guidance and clarification purposes and is not to be considered as part of the specifications or as part of the Standards and Recommended Practices contained in Volume I.

For the clarity of understanding of the text that follows and to facilitate the ready exchange of thoughts on closely associated concepts, the following definitions are included.

Definitions relating to the Instrument Landing System (ILS)

Note.— The terms given here are in most cases capable of use either without prefix or in association with the prefix "indicated". Such usages are intended to convey the following meanings:

No prefix: *the achieved characteristics of an element or concept.*

The prefix "indicated": *the achieved characteristics of an element or concept, as indicated on a receiver (i.e. including the errors of the receiving installation).*

Localizer system	ILS glide path system
Indicated course line. The locus of points in any horizontal plane at which the receiver indicator deflection is zero.	
Indicated course sector. A sector in any horizontal plane containing the indicated course line in which the receiver indicator deflection remains within fullscale values.	
Localizer course bend. A course bend is an aberration of the localizer course line with respect to its nominal position.	***ILS glide path bend.*** An ILS glide path bend is an aberration of the ILS glide path with respect to its nominal position.

2. Material concerning ILS installations

2.1 Operational objectives, design and maintenance objectives, and definition of course structure for Facility Performance Categories

2.1.1 The Facility Performance Categories defined in Chapter 3, 3.1.1 have operational objectives as follows:

Category I operation: A precision instrument approach and landing with a decision height not lower than 60 m (200 ft) and with either a visibility not less than 800 m or a runway visual range not less than 550 m.

Category II operation: A precision instrument approach and landing with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft), and a runway visual range not less than 300 m.

Category IIIA operation: A precision instrument approach and landing with:

a) a decision height lower than 30 m (100 ft), or no decision height; and

b) a runway visual range not less than 175 m.

Category IIIB operation: A precision instrument approach and landing with:

a) a decision height lower than 15 m (50 ft), or no decision height; and

b) a runway visual range less than 175 m but not less than 50 m.

Category IIIC operation: A precision instrument approach and landing with no decision height and no runway visual range limitations.

2.1.2 *Capabilities.* Relevant to these objectives will be the type of aircraft using the ILS and the capabilities of the aircraft flight guidance system(s). Modern aircraft fitted with equipment of appropriate design are assumed in these objectives. In practice, however, operational capabilities may extend beyond the specific objectives given at 2.1.1.

2.1.2.1 *Equipage for additional objectives.* The availability of fail-passive and fail-operational flight guidance systems in conjunction with an ILS ground system which provides adequate guidance with an appropriate level of continuity of service and integrity for the particular case can permit the attainment of operational objectives which do not coincide with those described at 2.1.1.

2.1.2.2 *Advanced operations.* For modern aircraft fitted with automatic approach and landing systems, the routine use of such systems is being encouraged by aircraft operating agencies in conditions where the progress of the approach can be visually monitored by the flight crew. For example, such operations may be conducted on Facility Performance Category I — ILS where the guidance quality and coverage exceeds basic requirements given at Chapter 3, 3.1.3.4.1 and extends down to the runway.

2.1.2.3 *ILS classification system.* In order to fully exploit the potential benefits of modern aircraft automatic flight control systems, there is a related need for a method of describing ground-based ILS more completely than can be achieved by reference solely to the Facility Performance Category. This is achieved by the ILS classification system using the three designated characters. It provides a description of those performance aspects which are required to be known from an operations viewpoint in order to decide the operational applications which a specific ILS could support.

2.1.2.4 The ILS classification scheme provides a means to make known the additional capabilities that may be available from a particular ILS ground facility, beyond those associated with the facilities defined in Chapter 3, 3.1.1. These additional capabilities can be exploited in order to permit operational use according to 2.1.2.1 and 2.1.2.2 to be approved down to and below the values stated in the operational objectives described in 2.1.1.

2.1.2.5 An example of the classification system is presented in 2.14.3.

Note.— The following guidance material is intended to assist States when they are evaluating the acceptability of ILS localizer courses and glide paths having bends. Although, by definition, course bends and glide path bends are related to the nominal positions of the localizer course and glide path respectively, the evaluation of high frequency aberrations is based on the deviations from the mean course or path. The material in 2.1.5 and Figure C-2 regarding the evaluation of bends indicates how the bends relate to the mean position of the course and path. Aircraft recordings will normally be in this form.

2.1.3 *Course bends.* Localizer course bends should be evaluated in terms of the course structure specified in Chapter 3, 3.1.3.4. With regard to landing and roll-out in Category III conditions, this course structure is based on the desire to provide adequate guidance for manual and/or automatic operations along the runway in low visibility conditions. With regard to Category I performance in the approach phase, this course structure is based on the desire to restrict aircraft deviations, due to course bends (95 per cent probability basis) at the 30 m (100 ft) height, to lateral displacement of less than 10 m (30 ft). With regard to Categories II and III performance in the approach phase, this course structure is based on the desire to restrict aircraft deviations due to course bends (95 per cent probability basis) in the region between ILS Point B and the ILS reference datum (Category II facilities) or Point D (Category III facilities), to less than 2 degrees of roll and pitch attitude and to lateral displacement of less than 5 m (15 ft).

Note 1.— Course bends are unacceptable when they preclude an aircraft under normal conditions from reaching the decision height in a stable attitude and at a position, within acceptable limits of displacement from the course line, from which a safe landing can be effected. Automatic and semi-automatic coupling is affected to a greater degree than manual coupling by the presence of bends. Excessive control activity after the aircraft has settled on an approach may preclude it from satisfactorily completing an approach or landing. Additionally, when automatic coupling is used, there may be an operational requirement to continue the approach below the decision height. Aircraft guidance can be satisfied if the specification for course structure in Chapter 3, 3.1.3.4, is met.

Note 2.— Bends or other irregularities that are not acceptable will normally be ascertained by flight tests in stable air conditions requiring precision flight check techniques.

2.1.4 *ILS glide path bends.* Bends should be evaluated in terms of the ILS glide path structure specified in Chapter 3, 3.1.5.4. With regard to Category I performance, this glide path structure is based on the desire to restrict aircraft deviations due to glide path bends (95 per cent probability basis) at the 30 m (100 ft) height, to vertical displacements of less than 3 m (10 ft). With regard to Categories II and III performance, this glide path structure is based on the desire to restrict aircraft deviations due to path bends (95 per cent probability basis) at the 15 m (50 ft) height, to less than 2 degrees of roll and pitch attitude and to vertical displacements of less than 1.2 m (4 ft).

Note 1.— Path bends are unacceptable when they preclude an aircraft under normal conditions from reaching the decision height in a stable attitude and at a position, within acceptable limits of displacement from the ILS glide path, from which a safe landing can be effected. Automatic and semi-automatic coupling is affected to a greater degree than manual coupling by the presence of bends. Additionally, when automatic coupling is used, there may be an operational requirement to continue the approach below the decision height. Aircraft guidance can be satisfied if the specification for ILS glide path structure in Chapter 3, 3.1.5.4, is met.

Note 2.— Bends or other irregularities that are not acceptable will normally be ascertained by precision flight tests, supplemented as necessary by special ground measurements.

2.1.5 *Application of localizer course/glide path bend amplitude Standard.* In applying the specification for localizer course structure (Chapter 3, 3.1.3.4) and ILS glide path structure (Chapter 3, 3.1.5.4), the following criteria should be employed:

— Figure C-1 shows the relationship between the maximum (95 per cent probability) localizer course/glide path bend amplitudes and distances from the runway threshold that have been specified for Categories I, II and III performance.

— If the bend amplitudes are to be evaluated in any region of the approach, the flight recordings, corrected for aircraft angular position error, should be analysed for a time interval of plus or minus 20 seconds about the midpoint of the region to be evaluated. The foregoing is based on an aircraft ground speed of 195 km/h (105 knots) plus or minus 9 km/h (5 knots).

The 95 per cent maximum amplitude specification is the allowable percentage of total time interval in which the course/path bend amplitude must be less than the amount specified in Figure C-1 for the region being evaluated. Figure C-2 presents a typical example of the method that can be employed to evaluate the course/path bend amplitude at a particular facility. If the sum of the time intervals t_1, t_2, t_3, where the given specification is exceeded, is equal to or less than 5 per cent of the total time T, the region that is being evaluated is acceptable. Therefore:

$$100 \quad \frac{T - [(t_1 + t_2 + ...)]}{T} \quad \geq 95\%$$

Analysis of ILS glide path bends should be made using as a datum the mean glide path and not the downward extended straight line. The extent of curvature is governed by the offset displacement of the ground equipment glide path antenna system, the distance of this antenna system from the threshold, and the relative heights of the ground along the final approach route and at the glide path site (see 2.4).

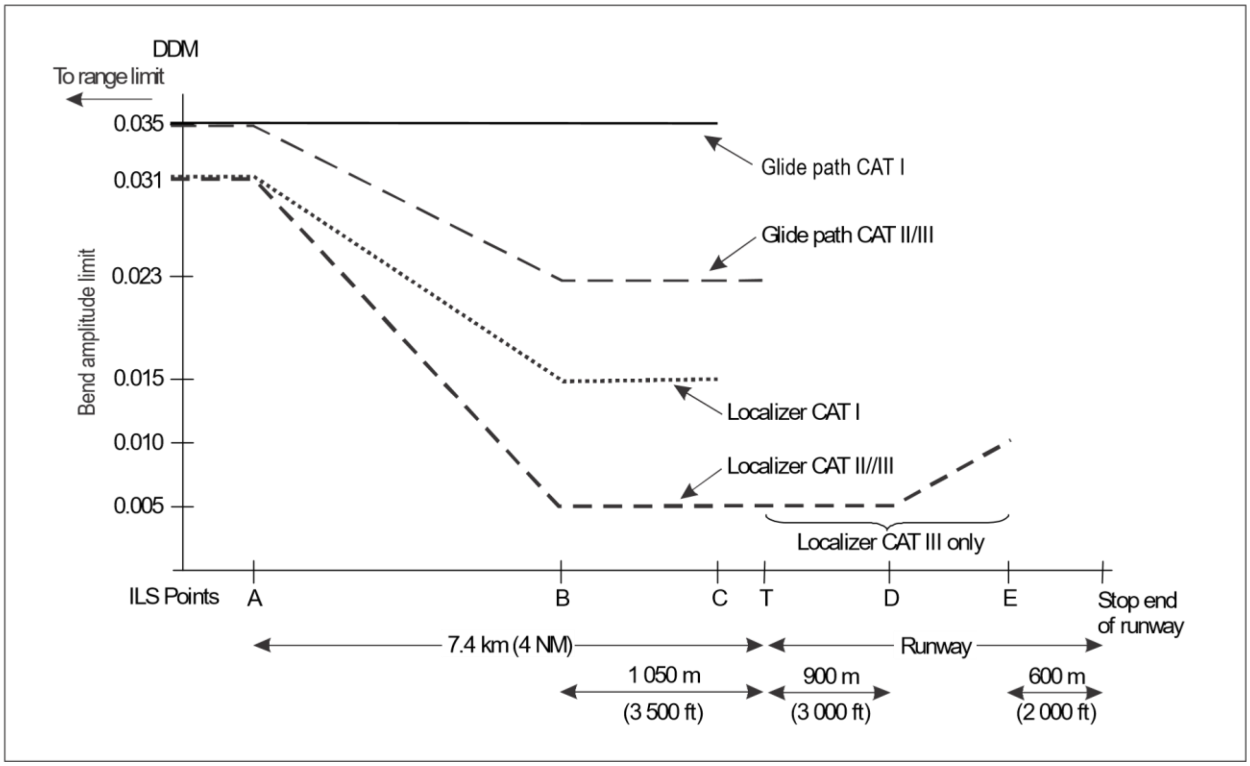


Figure C-1. Localizer course and glide path bend amplitude limits

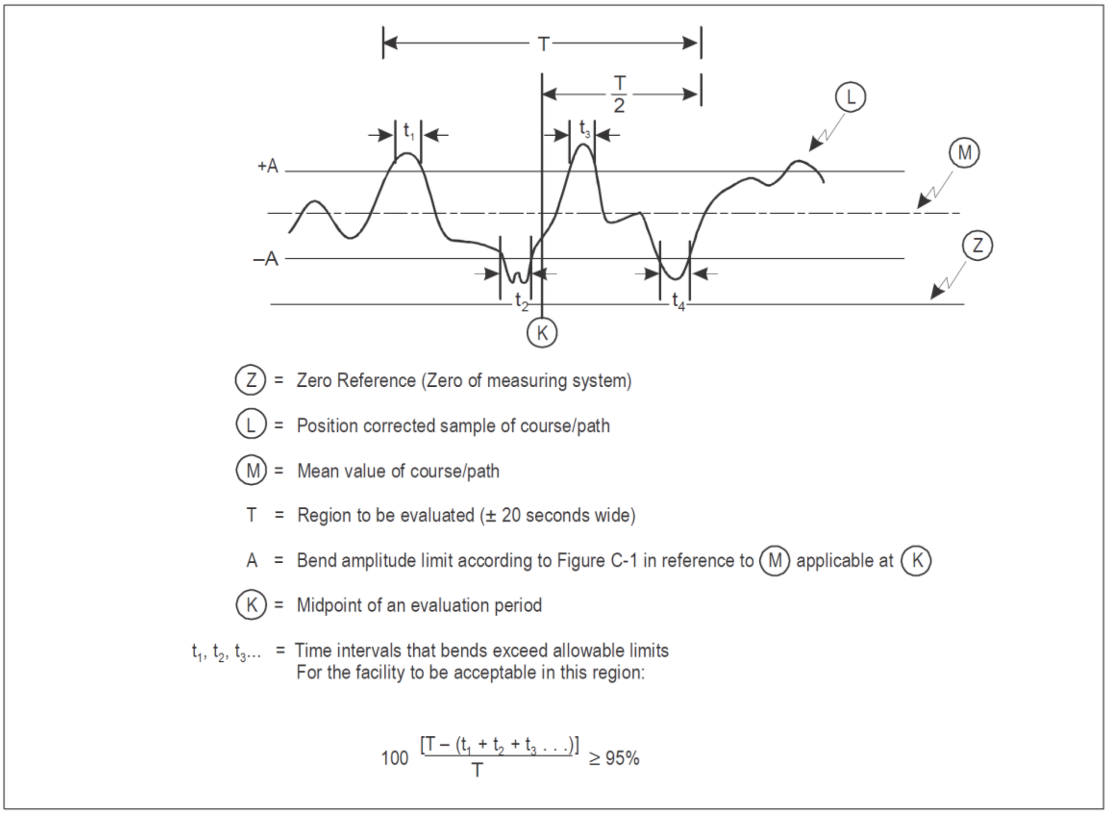


Figure C-2. Evaluation of course/path bend amplitude

2.1.6 *Measurements filter.* Owing to the complex frequency components present in the ILS beam bend structures, measured values of beam bends are dependent on the frequency response of the airborne receiving and recording equipment. It is intended that beam bend measurements be obtained by using a low-pass filter corner frequency (radians per second) for the receiver DDM output circuits and associated recording equipment of $V/92.6$, where V is the velocity in km/h of the aircraft or ground vehicle as appropriate.

2.1.7 *Monitor systems.* Available evidence indicates that performance stability within the limits defined in Chapter 3, 3.1.3.6, 3.1.3.7 and 3.1.5.6, i.e. well within the monitor limit, can readily be achieved.

2.1.7.1 The choice of monitor limits is based on judgment, backed by knowledge of the safety requirements for the category of operation. However, the specifications of such monitoring limits do not indicate the magnitude of the normal dayto-day variations in performance which result from setting-up errors and equipment drift. It is necessary to investigate and take corrective action if the day-to-day performance frequently drifts beyond the limits specified in Chapter 3, 3.1.3.6, 3.1.3.7 and 3.1.5.6. The causes of such drifts should be eliminated:

a) to reduce greatly the possibility of critical signal parameters hovering near the specified monitor limits;

b) to ensure a high continuity of ILS service.

2.1.7.2 Following are some general guidelines for the design, operation and maintenance of monitor systems to meet the requirements in Chapter 3, 3.1.3.11 and 3.1.5.7.

1) Great care should be exercised to ensure that monitor systems respond to all those variations of the ground facility which adversely affect the operation of the airborne system during ILS approach.

2) Monitor systems should not react to local conditions which do not affect the navigational information as seen by airborne systems.

3) Drifts of the monitor system equipment should not appreciably reduce or increase the monitoring limits specified.

4) Special care must be taken in the design and operation of the monitor system with the aim of ensuring that the navigational components will be removed or radiation cease in the event of a failure of the monitor system itself.

5) Some monitors rely on devices which sample the signal in the vicinity of the transmitter antenna system. Experience has shown that such monitor systems require special attention in the following aspects:

   a) where large-aperture antenna systems are used, it is often not possible to place the monitor sensors in such a position that the phase relationship observed in the far field on the course exists at the sensing point. Nevertheless, the monitor system should also detect antenna and associated feeder system changes which significantly affect the course in the far field;

   b) changes in effective ground level caused by snow, flooding, etc., may affect glide path monitor systems, and the actual course in space differently, particularly when reliance is placed on the ground plane to form the desired glide path pattern;

   c) attention should be paid to other causes which may disturb the monitor sensing of the radiated signal, such as icing and birds;

   d) in a system where monitoring signals are used in a feedback loop to correct variations of the corresponding equipment, special care should be taken that extraneous influence and changes in the monitor system itself do not cause course or ILS glide path variations outside the specified limits without alarming the monitor.

6) One possible form of monitor is an integral monitor in which the contribution of each transmitting antenna element to the far-field course signal is measured at the antenna system. Experience has shown that such monitoring systems, properly designed, can give a close correlation between the monitor indication and the radiated signal in the far field. This type of monitor, in certain circumstances, overcomes the problem outlined in 5) a), b) and c).

2.1.7.3 It will be realized that the DDM measured at any one point in space is a function of displacement sensitivity and the position of the course line or ILS glide path. This should be taken into account in the design and operation of monitor systems.

2.1.8 *Radiation by ILS localizers not in operational use.* Severe interference with operational ILS localizer signals has been experienced in aircraft carrying out approaches to low levels at runways equipped with localizer facilities serving the reciprocal direction to the approach. Interference in aircraft overflying this localizer antenna system is caused by cross modulation due to signals radiated from the reciprocal approach localizer. Such interference, in the case of low level operations, could seriously affect approach or landing, and may prejudice safety. Chapter 3, 3.1.2.7, 3.1.2.7.1 and 3.1.2.7.2 specify the conditions under which radiation by localizers not in operational use may be permitted.

2.1.9 *ILS multipath interference*

Note 1.— This guidance material reflects how new larger aeroplanes (NLA) may impact the size of the ILS critical and sensitive areas. It also documents established engineering practices for determining critical and sensitive area dimensions, outlines the associated operational trade-offs, and presents indicative examples of the resulting sizes of the areas. In practice, however, the size of critical and sensitive areas at an aerodrome may need to be determined by specific assessments at that aerodrome.

Note 2.— This guidance material is not intended to create a need to review established critical and sensitive area dimensions which have been demonstrated to be satisfactory at a particular aerodrome, unless the operational environment has evolved significantly (such as through the introduction of NLA operations at the aerodrome or the construction of new buildings) or the ILS installation has been changed in a way that may affect the dimensions of the areas.

2.1.9.1 *ILS environmental effects.* Large reflecting objects within the ILS coverage volume, whether fixed objects or vehicles, including aircraft, can potentially cause degradation of the signal-in-space, through signal blockage and/or multipath interference, with the consequence that the signal-in-space tolerances defined in Chapter 3, 3.1 may be exceeded. The amount of degradation is a function of the location, size and orientation of the reflecting surfaces, and of the ILS antenna characteristics. The objective of identifying critical and sensitive areas (see 2.1.9.2) and associated management procedures is to prevent such degradation and ensure that aircraft using the ILS can rely on the signal-in-space meeting the requirements of Chapter 3, 3.1.

2.1.9.2 *ILS critical and sensitive areas.* States differ in the way they choose to identify ILS protection areas. Practices also differ in how vehicle movement restrictions are managed. One method is to identify critical areas and sensitive areas as follows:

a) the ILS critical area is an area of defined dimensions about the localizer and glide path antennas where vehicles, including aircraft, are excluded during all ILS operations. The critical area is protected because the presence of vehicles and/or aircraft inside its boundaries will cause unacceptable disturbance to the ILS signal-in-space;

b) the ILS sensitive area is an area where the parking and/or movement of vehicles, including aircraft, is controlled to prevent the possibility of unacceptable interference to the ILS signal during ILS operations. The sensitive area is protected against interference caused by large moving objects outside the critical area but still normally within the airfield boundary.

Note 1.— In some States, the term "critical area" is used to describe an area that combines the critical and sensitive areas identified in this guidance material. In cases where the critical area overlaps operational areas, specific operational management procedures are required to ensure protection of aircraft using the ILS for intercept and final approach guidance.

2.1.9.3 *Technical and operational logic associated with critical and sensitive areas*. Ideally, the critical area is enforced during all ILS operations with protection afforded down to at least the Category I decision height. A critical area disturbance would normally impact all aircraft using the ILS signal at a given time (entire approach). The critical area is typically safeguarded through marked boundaries, limiting access to the area or through procedural means if there are overlaps into operational areas. From an operational perspective, the sensitive area would ideally protect aircraft operations at least from the Category I decision height down to the runway, and be activated during low visibility conditions only (e.g. Category II and III). A sensitive area disturbance would normally be of a transient nature, and produce a local disturbance affecting a single aircraft only. However, at many locations, it may not be possible to achieve this ideal situation, and corresponding technical and operational mitigations will be required.

*Note.— Guidance on operational procedures for the protection of critical and sensitive areas is provided in ICAO EUR DOC 013, "*European Guidance Material on All Weather Operations at Aerodromes*".*

2.1.9.4 *Technical determination of critical and sensitive area dimensions*. Critical and sensitive areas are normally calculated in the planning stage, prior to ILS installation, using computer simulation. A similar process is used when there are changes to the installation or to the environment. When using computer simulations, it is necessary to allocate the protection of individual parts of the approach to either the critical or sensitive area. It is desirable to ensure that the combined critical and sensitive areas protect the entire approach. However, this may not be possible in all cases. Furthermore, if the logic described in 2.1.9.3 is used, this may lead to restrictively large critical areas. Some States have found that a reasonable compromise can be achieved using a different logic, whereby the critical area protects the segment from the edge of coverage down to 2 NM from the runway threshold, while the sensitive area protects the approach from 2 NM down to the runway. In this case, a Category I sensitive area will exist and may require operational mitigation. Depending on the operational environment (such as timing between leading aircraft on runway roll-out and trailing aircraft on final approach), no particular measures may be needed. There may not necessarily be a direct link between the approach allocation used in simulations to determine critical and sensitive areas, and their operational management. It is a State's responsibility to define the relevant areas. If different disturbance acceptance criteria or different flight segment protections are to be applied, they must be validated through a safety analysis. The safety analysis must take all relevant factors into account, including the aerodrome configuration, traffic density and any operational issues or capacity restrictions.

2.1.9.5 *Factors impacting the sizes of critical and sensitive areas*. Localizer and glide path antennas with optimized radiation patterns, especially when combined with two-frequency transmitters, can be very effective in reducing the potential for signal disturbance and hence the sizes of the critical and sensitive areas. Other factors affecting the sizes of the areas include the category of approach and landing operation to be supported, the amount of static disturbance, locations, sizes and orientations of aircraft and other vehicles (particularly of their vertical surfaces), runway and taxiway layout, and antenna locations. In particular, the maximum heights of vertical aircraft tail surfaces likely to be encountered must be established, together with all possible orientations at a given location, which may include non-parallel or non-perpendicular orientations with respect to the runway. While critical and sensitive areas are evaluated in a two-dimensional (horizontal) context, protection should actually be extended to volumes, as departing aircraft and/or manoeuvring helicopters/aircraft can also cause disturbances to the ILS signals. The vertical profiles of the protection volumes depend on the vertical patterns of the transmitting arrays.

2.1.9.6 *Allocation of multipath error budget*. It is convenient to consider disturbances caused by mobile objects such as aircraft and other vehicles separately from the static disturbances caused by fixed objects such as buildings and terrain. Once the static multipath is known, the remainder can be allocated to dynamic disturbances. If measurements indicate that the real static multipath is significantly different from that assumed in the simulations, the allocation may need to be revised. In most cases, the root sum square combination of the disturbances due to fixed and mobile objects gives a more statistically valid representation of the total disturbance than an algebraic sum. For example, a limit of plus or minus 5µA for localizer course structure would be respected with plus or minus 3µA of disturbance due to static objects and an allowance of plus or minus 4µA for dynamic objects:

$$\sqrt{(3\mu A)^2 + (4\mu A)^2} = 5\mu\text{A}$$

2.1.9.7 *Site study and computer simulations.* Normally, a site specific study is conducted for a particular airport installation. The study will take into account different assumptions for the static multipath environment, airport topography, types and effective heights of ILS arrays, and orientations of manoeuvring aircraft, such as runway crossings, 180° turns at threshold or holding orientations other than parallel or perpendicular. Simulation models can be employed to calculate the probable location, magnitude and duration of ILS disturbances caused by objects, whether by structures or by aircraft of various sizes and orientation at different locations. Air navigation service providers (ANSPs) will need to ensure that simulation models used have been validated by direct comparison with ground and flight measurements for a variety of specific situations and environments, and that the subsequent application of such models is conducted by personnel with appropriate engineering knowledge and judgement to take into account the assumptions and limitations of applying such models to specific multipath environments.

2.1.9.8 *Changes in airport environment*. Should major changes in the airport environment cause an increase in the static disturbances of the localizer and/or glide path, the sizes of the critical and sensitive areas may need to be redefined, with potential impact on airport efficiency or capacity. This is particularly significant when considering the location, size and orientation of proposed new buildings within or outside the airport boundary. It is recommended that suitable safeguarding criteria be employed to protect the ILS operations.

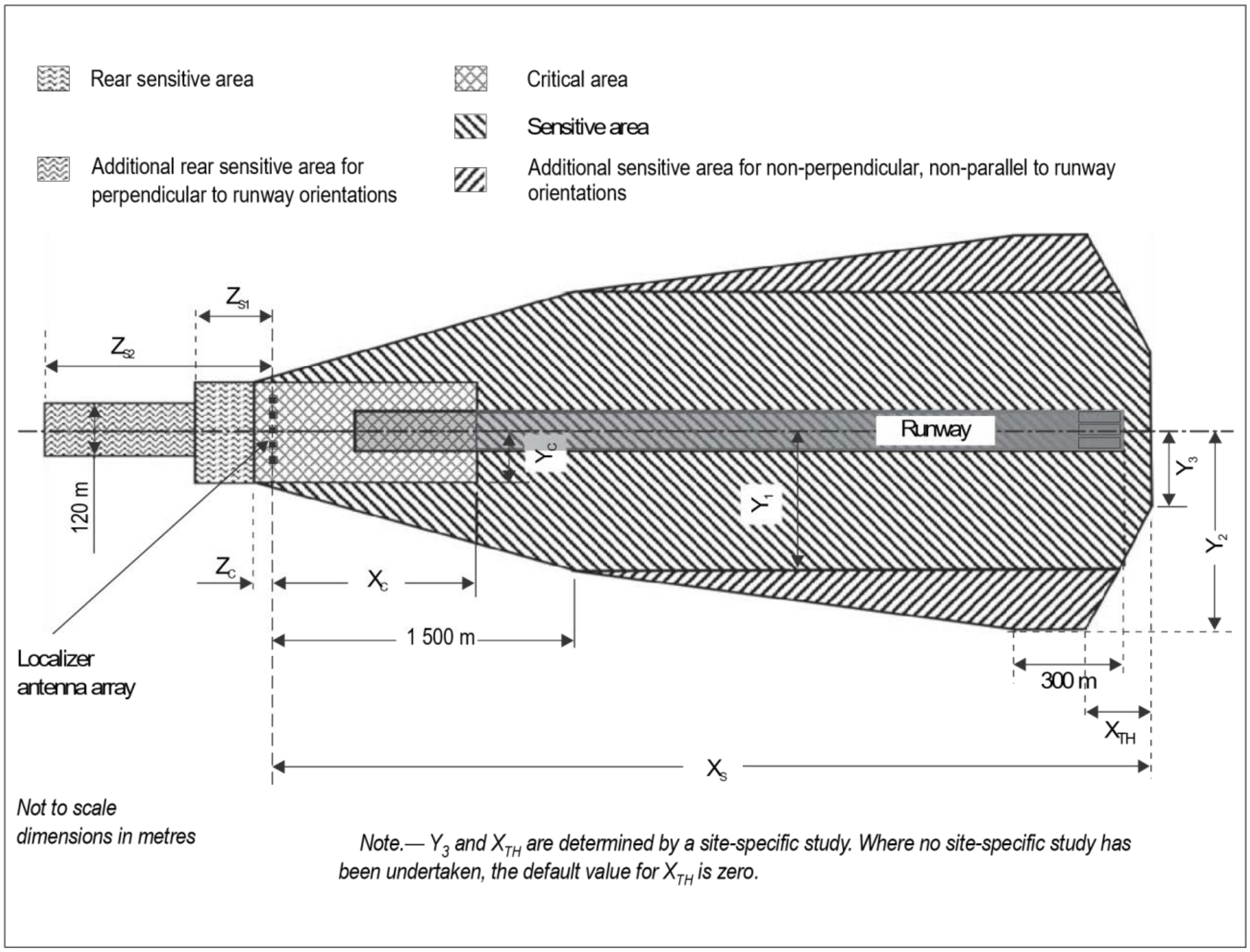
*Note.— Example guidance can be found in ICAO EUR DOC 015 "*European Guidance Material on Managing Building Restricted Areas*".*

2.1.9.9 *Typical examples of critical and sensitive areas.* Figures C-3 and C-4 (including associated Tables C-1, C2-A and C2-B)) show examples of critical and sensitive areas for different classes of vehicle/aircraft heights and several localizer and glide path antenna types. The calculation of these examples has been done with a simulation model using an exact method of resolution of ILS propagation equations applied to a 3D model of corresponding aircraft. The dimensions are based on assumptions of flat terrain, 3.0° glide path, allocations of 60 per cent of applicable tolerances for static multipath and 80 per cent for dynamic multipath, an approaching aircraft at 105 knots, i.e. with a 2.1 rad/s low-pass filter and an omnidirectional receiving antenna pattern. The examples consider typical orientations of reflecting surfaces of taxiing, holding and manoeuvring aircraft/large ground vehicles. The tail heights for the ground vehicles/small aircraft, medium, large and very large aircraft categories correspond to Annex 14 aerodrome reference code letters A, B/C, D/E and F, respectively, as detailed within FAA Advisory Circular 150/5300-13. In case of uncertainty about which category an aircraft belongs to for the purposes of critical and sensitive areas assessment, the tail height is the determining feature.

2.1.9.9.1 *Purpose and correct application of typical examples*. Since it will be rare that an actual installation fits exactly the assumptions used in these examples, adaptation to local conditions will be required. The examples serve to provide a rough order of magnitude indication of critical and sensitive area sizes, depending on how much local conditions differ from assumptions used in these examples. The example tables may also be used to assess the tools used in simulations, using the listed assumptions. In many installations, airports have established critical and sensitive areas which are different from those listed in these examples, through a combination of further technical optimizations, operational mitigations, experience, and safety assessments applicable to the particular operational environment. In the case of new airport construction projects, potential conflicts of the example areas provided here with planned operational uses should lead to further evaluations, and may lead to implementing more advanced ILS antenna systems, for example wider aperture localizer antennas, including advanced designs such as very large aperture arrays. The typical examples provided here do not take such specific optimized systems into account. The tables differ slightly between the localizer and the glide path in terms of how different aircraft orientations are considered. These details are explained in the notes to Tables C-1 (note 9), C-2A and C-2B (note 8). In accordance with these notes, in some glide path cases the half-wingspan of aircraft needs to be added to ensure that no portion of the aircraft enters the critical or sensitive areas.

2.1.9.9.2 *Limits of multipath assumptions used in example simulations.* The allocation of 60 per cent for static and 80 per cent for dynamic multipath used in 2.1.9.6 represents a conservative approach which is suitable in locations where both types of multipath coincide. A different allocation may be appropriate for the glide path, especially in the case of flat terrain, as in that case the static multipath will be very small. In locations where static and dynamic multipath do not coincide, due to the specific layout of the airport, the full tolerance can be consumed by the dynamic multipath. A simulation tool able to model the complete environment (static and dynamic reflection sources) and to compute the combined effect may avoid having to apply the root sum square approximation. This may lead to an optimization of the critical and/or sensitive area dimensions.

2.1.9.9.3 *Flight segment protection allocations used in example simulations.* The examples given in Figure C-3 for the localizer use a 2 NM transition point as described in 2.1.9.4. The examples given in Figure C-4 for the glide path use a 0.6 NM transition point (corresponding to the Category I decision height). Depending on local operations, other transition points may be more suitable.



Not to scale
dimensions in metres

Note.— Y_3 and X_{TH} are determined by a site-specific study. Where no site-specific study has been undertaken, the default value for X_{TH} is zero.

Figure C-3. Example of localizer critical and sensitive area dimensions (values in associated Table C-1 below)

Table C-1. Typical localizer critical and sensitive area sizes

Aircraft/vehicle height	H ≤ 6 m (see Note 1) Ground vehicle			6 m < H ≤ 14 m Medium aircraft			14 m < H ≤ 20 m Large aircraft		20 m < H ≤ 25 m Very large aircraft	
Antenna aperture (see Note 3)	Small	Medium	Large	Small	Medium	Large	Medium	Large	Medium	Large
Critical area CAT I X_C	180 m	65 m	45 m	360 m	200 m	150 m	500 m	410 m	660 m	580 m
Z_C	10 m	10 m	10 m	35 m	35 m	35 m	50 m	50 m	60 m	60 m
(see Note 10) Y_C	50 m	15 m	20 m	110 m	25 m	25 m	50 m	30 m	55 m	40 m
Sensitive area CAT I X_S	200 m	No sensitive area		500 m	No sensitive area		No sensitive area		1 300 m	1 100 m
Y_1	40 m			90 m					90 m	50 m
Y_2	40 m			90 m					90 m	50 m
Z_{S1}	15 m			35 m					60 m	60 m
(see Note 7) Z_{S2}	15 m			35 m					60 m	60 m

Aircraft/vehicle height	H ≤ 6 m (see Note 1) Ground vehicle		6 m < H ≤ 14 m Medium aircraft		14 m < H ≤ 20 m Large aircraft		20 m < H ≤ 25 m Very large aircraft	
Antenna aperture (see Note 3)	Medium	Large	Medium	Large	Medium	Large	Medium	Large
Critical area CAT II X_C	75 m	55 m	200 m	200 m	500 m	475 m	750 m	675 m
Z_C	10 m	10 m	35 m	35 m	50 m	50 m	60 m	60 m
(see Note 10) Y_C	15 m	20 m	25 m	25 m	50 m	30 m	70 m	50 m
Sensitive area CAT II X_S	75 m	No sensitive area	500 m	No sensitive area	2 100 m	1 400 m	Localizer to threshold distance	Localizer to threshold distance
Y_1	15 m		50 m		125 m × K	60 m × K	180 m × K	100 m × K
Y_2	15 m		50 m		125 m × K	60 m × K	180 m × K	125 m × K
Z_{S1}	15 m	15 m	35 m	35 m	60 m	60 m	70 m	70 m
(see Note 7) Z_{S2}	15 m	15 m	45 m	45 m	160 m	160 m	250 m	250 m

Notes:

1. *For vehicles smaller than 2.5 m in height, ZC = 3 m, assuming a 23 dB front/back ratio for the transmitting antenna for both course and clearance signals.*
2. *For systems with near-field monitor antennas, vehicles must not enter between the monitor antennas and the transmitting antenna.*
3. *Small aperture: 11 elements or less. Medium aperture: 12 to 15 elements. Large aperture: 16 elements or more. Simulations have been conducted using a commonly installed 12 element system for the medium and a commonly installed 20 element system for the large aperture cases. It is assumed that Category II/III operations are not conducted on runways equipped with small aperture localizers, and that aircraft as large as a 747 are not operating on such runways.*
4. *For localizer arrays with very low height, additional critical area will be needed due to the greater attenuation of the direct signal at low vertical angles.*
5. *A specific study for a particular airport, considering realistic orientations, static multipath environment, and airport topography and type of ILS antennas, may define different critical areas.*
6. $K = \sqrt{\frac{\text{localizer to threshold distance}}{3\,300\text{ m}}}$
7. *The rear dimensions for sensitive areas may be changed based on specific study results considering fielded antenna pattern characteristics. A directional array with a 23 dB front/back ratio is assumed for course and clearance signals.*
8. *Single aircraft taxiing or holding parallel to the runway does not generate out-of-tolerance signals.*
9. *Boundaries for critical areas or rear sensitive areas apply to the entire longitudinal axis (both tail and fuselage) of the interfering aircraft. Boundaries for sensitive areas apply only to the tail of the interfering aircraft.*
10. *The critical area semi-width, Y_c, should exceed the actual physical dimension of the localizer antenna array by at least 10 m laterally (on both sides) in its portion between the localizer antenna array and the stop end of the runway*

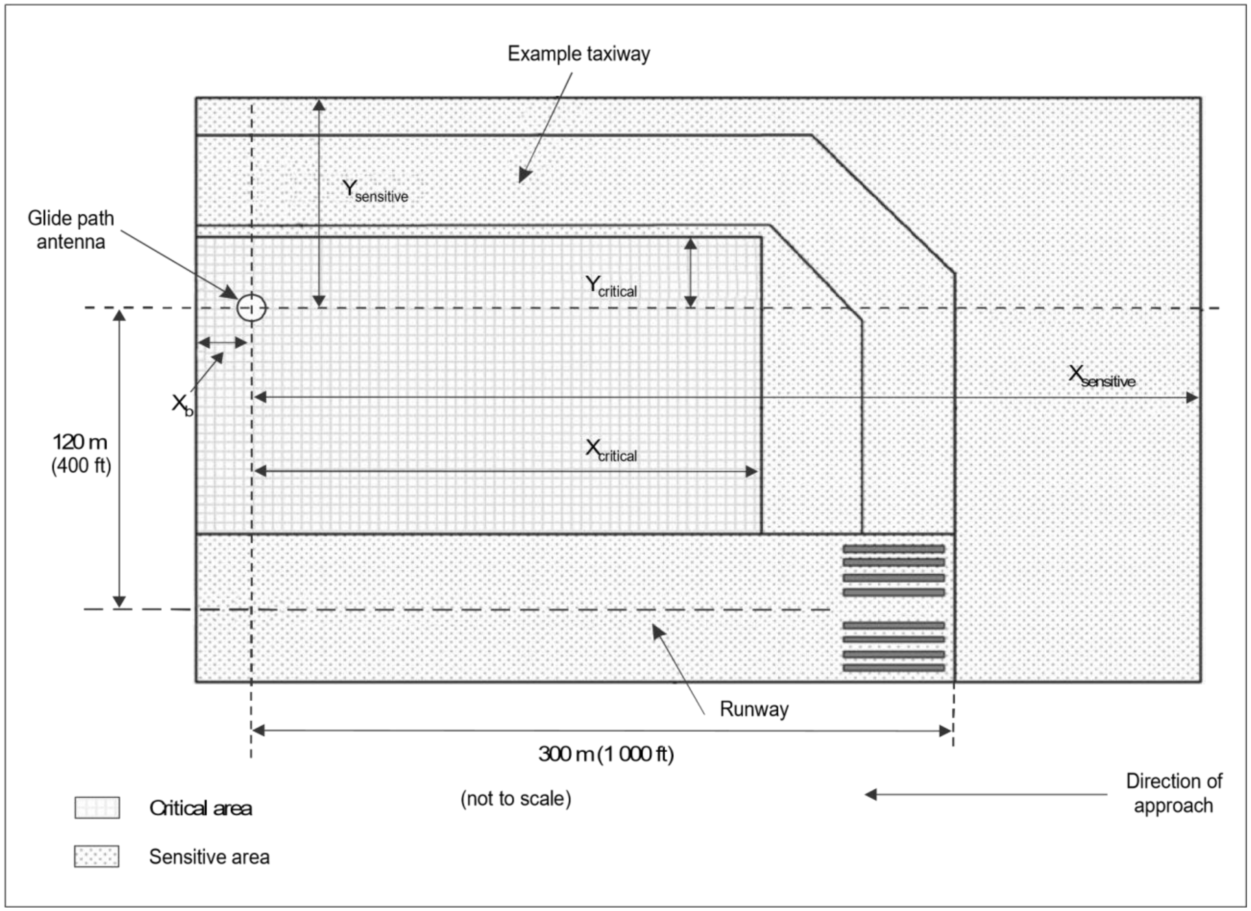


Figure C-4. Example of glide path critical and sensitive area dimensions (values in associated Table C-2A below)

Table C-2A. Example of glide path critical and sensitive area dimensions for parallel and perpendicular orientations

Aircraft/vehicle height	Ground vehicle		Medium aircraft		Large aircraft		Very large aircraft	
	$H \leq 6$ m		6 m $< H \leq 14$ m		14 m $< H \leq 20$ m		20 m $< H \leq 25$ m	
Glide path type	M-array	Null-ref	M-array	Null-ref	M-array	Null-ref	M-array	Null-ref
CAT I critical area								
X	299 m	191 m	329 m	829 m	467 m	1 117 m	610 m	1 360 m
Y	29 m	29 m	20 m	20 m	22 m	22 m	15 m	15 m
CAT I sensitive area								
X	299 m	399 m	279 m	529 m	417 m	717 m	510 m	760 m
Y	29 m	15 m	20 m	20 m	22 m	16 m	15 m	15 m
CAT II/III critical area								
X	299 m	449 m	329 m	829 m	567 m	1 267 m	660 m	1 410 m
Y	29 m	29 m	20 m	20 m	22 m	22 m	15 m	15 m
CAT II/III sensitive area								
X	299 m	449 m	429 m	629 m	517 m	767 m	560 m	1 010 m
Y	29 m	29 m	20 m	20 m	22 m	22 m	15 m	15 m

Table C-2B. Example of glide path critical and sensitive area dimensions for other orientations

Aircraft/vehicle height	Ground vehicle		Medium aircraft		Large aircraft		Very large aircraft	
	$H \leq 6$ m		6 m $< H \leq 14$ m		14 m $< H \leq 20$ m		20 m $< H \leq 25$ m	
Glide path type	M-array	Null-ref	M-array	Null-ref	M-array	Null-ref	M-array	Null-ref
CAT I critical area								
X	298 m	191 m	297 m	829 m	444 m	**1 167 m**	591 m	1 360 m
Y	24 m	15 m	**39 m**	**39 m**	**35 m**	**55 m**	**34 m**	**55 m**
CAT I sensitive area								
X	298 m	394 m	**297 m**	**537 m**	**444 m**	717 m	**541 m**	710 m
Y	24 m	**24 m**	**39 m**	**39 m**	**25 m**	**18 m**	**24 m**	**24 m**
CAT II/III critical area								
X	298 m	443 m	**347 m**	829 m	544 m	1 267 m	**672 m**	1 410 m
Y	24 m	25 m	**39 m**	**39 m**	**35 m**	**55 m**	**34 m**	**55 m**
CAT II/III sensitive area								
X	298 m	445 m	297 m	**829 m**	**528 m**	**817 m**	**610 m**	1 010 m
Y	24 m	24 m	**39 m**	**39 m**	**25 m**	**25 m**	**24 m**	**24 m**

Notes:

1. *X_b = 50 m and applies to both critical and sensitive areas for the large and very large aircraft category only. Otherwise, X_b = 0 m.*

2. *The ground vehicle category also applies to small aircraft. Simulations have approximated these aircraft or large ground vehicles using a rectangular box (4 m high 12 m long 3 m wide). Depending on local conditions, it may be possible to reduce especially Category I critical area dimensions such that taxiing or driving on the taxiway directly in front of the glide path antenna may be allowed.*

3. *Separate tables (C-2A and C-2B) are given for parallel/perpendicular and for other orientations in order to not penalize parallel taxiway operations. To derive worst-case keep-out areas, the largest number among the two tables must be used. Values in Table C-2B ("other orientations") that are larger than the corresponding ones in Table C-2A ("parallel and perpendicular orientations") are highlighted in bold. Perpendicular orientations covered in Table C-2A include only the orientation where the nose of the aircraft is pointing towards the runway. Perpendicular orientations with the tail of the aircraft pointing towards the runway are covered in Table C-2B. Table C-2B also considers aircraft turning towards the runway for line-up at angles of 15, 30, 45, 60 and 75 degrees. Orientations causing the largest keep-out areas (i.e. worst aircraft orientation among all orientations causing out-of-tolerance signals) have been derived based on an A380 using an M-array antenna. Since the number of simulations required to cover all possible orientations for all categories of vehicles over a large area would be excessive, the impact of worst-case orientations on the critical and sensitive areas may need to be verified taking into account the particular taxiway layout.*

4. *Simulations are referenced to the glide path antenna mast using a typical perpendicular distance to the runway centre line of 120 m and a nominal parallel distance from the runway threshold of 300 m. For different antenna-to-runway offsets, the critical and sensitive areas have to be shifted accordingly.*

5. *The edge of the runway closer to the glide path antenna defines the inner limit of the critical area. The farther edge of the runway defines the inner limit of the sensitive area. This sensitive area limit needs to be extended by another 50 m on the opposite side of the runway (starting from the runway centre line) for the large and very large aircraft categories when using a Null-Ref antenna.*

6. *Depending on simulation choices (transition point), the critical area may be larger than the sensitive area and impact associated management procedures.*

7. *In line with the operational logic described in 2.1.9.4 (no protection of the Category I glide path is required below decision height) as well as the observation that in Tables C-1, C-2A and C-2B, the Category I critical area is typically equal or larger than the sensitive area, protecting the Category I sensitive area may not be necessary.*

8. *Boundaries for critical and sensitive areas apply to the entire aircraft (entire fuselage and wings).*

2.1.10 *Reducing localizer bends and areas with insufficient difference in depth of modulation (DDM)*

2.1.10.1 *Introduction.* Owing to site effects at certain locations, it is not always possible to produce, with simple standard ILS installations, localizer courses that are sufficiently free from troublesome bends or irregularities. If this is the case, it is highly preferable to use two radio frequency carriers to provide the standard coverage and signal characteristics. Additional guidance on two radio frequency carrier coverage is provided in 2.7. If standard coverage requirements still cannot be met, reducing radiation in the direction of objects and accepting an increase of the lower vertical coverage boundaries as permitted in Chapter 3, 3.1.3.3.1 may be employed.

2.1.10.2 *Reducing standard localizer coverage.* When using the coverage reduction option defined in Chapter 3, 3.1.3.3.1, care needs to be taken to ensure that the reduced coverage volume is consistent with the minimum altitudes published for the instrument approach procedure. Additionally, normal vectoring operations should not be terminated and a clearance to intercept the localizer should not be issued until within the promulgated coverage area. This is sometimes referred to as the operational service volume.

2.1.10.2.1 *Operational considerations from an air traffic management perspective.* Instrument approach procedures must be designed to take into account any reduction in localizer coverage permitted by the Standard in Chapter 3, 3.1.3.3.1. This can be done either by ensuring that the procedure remains within localizer coverage or by providing alternative means to navigate. Consequently, a significant portion (3.7 km (2 NM) minimum) of the initial segment must be within localizer coverage. Localizer coverage needs to be available sufficiently in advance of the area where controllers usually give the approach or intercept clearance to permit pilots to verify the Morse code identification (IDENT).

2.1.10.2.2 *Operational considerations from a pilot/aircraft perspective.* For aircraft equipped with automatic flight control systems (AFCS), localizer coverage needs to be available prior to the activation of the AFCS intercept mode (manual or automatic flight) and sufficiently in advance of the area where controllers usually give the approach or intercept clearance to permit checking the IDENT signal. When flying manually or when using an AFCS, pilots normally check the IDENT of the ILS facility and then wait to arm the mode enabling localizer intercept turn initiation and capture until after receiving the approach or intercept clearance. Ideally, additional aids (if included in the approach procedure) should permit a determination of the relationship between the aircraft position and the localizer front course line by the pilot.

2.2 ILS airborne receiving equipment

2.2.1 To ensure that the required operational objectives are achieved, it is necessary for the airborne receiving equipment to meet defined performance standards.

Note.— The relevant minimum operational performance standards for ILS receivers are detailed in RTCA DO-195 (1986) and EUROCAE ED-46B (including Amendments Nos. 1 and 2) for the localizer, in RTCA DO-143 (1970) and EUROCAE 1/WG 7/70 for the marker beacon, and in RTCA DO-192 (1986) and EUROCAE ED-47B (including Amendment No. 1) for the glide path receivers.

2.2.2 *Immunity performance of ILS localizer receiving systems to interference from VHF FM broadcast signals*

2.2.2.1 With reference to Note 2 of 3.1.4.2, Chapter 3, the immunity performance defined there must be measured against an agreed measure of degradation of the receiving system’s normal performance, and in the presence of, and under standard conditions for the input wanted signal. This is necessary to ensure that the testing of receiving equipment on the bench can be performed to a repeatable set of conditions and results and to facilitate their subsequent approval. Tests have shown that FM interference signals may affect both course guidance and flag current, and their effects vary depending on the DDM of the wanted signal which is applied. Additional information can be found in ITU Recommendation ITU-R SM.1140, *Test procedures for measuring receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–118 MHz.*

Note.— ITU Recommendation ITU-R SM.1140 can be found in the Manual on Testing of Radio Navigation Aids *(Doc 8071), Volume I.*

2.2.2.2 Commonly agreed methodology and formulae should be used to assess potential incompatibilities to receivers meeting the general interference immunity criteria specified in Chapter 3, 3.1.4. The formulae provide clarification of immunity interference performance of spurious emission (type A1) interference, out-of-band channel (type A2) interference, two-signal and three-signal third order (type B1) interference, and overload/desensitization (type B2) interference. Additional information can be found in ITU Recommendation ITU-R SM.1009-1, *Compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–137 MHz.*

Note.— ITU Recommendation ITU-R SM.1009-1 can be found in Doc 8071, Volume I.

2.2.3 *Localizer and glide path antenna polarization*

2.2.3.1 Over the localizer and glide path frequency bands, respectively, the reception of vertically polarized signals from the forward direction with respect to the localizer and glide path antenna should be at least 10 dB below the reception of horizontally polarized signals from the same direction.

2.3 Alarm conditions for ILS airborne equipment

2.3.1 Ideally, a receiver alarm system such as a visual flag should warn a pilot of any unacceptable malfunctioning conditions which might arise within either the ground or airborne equipments. The extent to which such an ideal may be satisfied is specified below.

2.3.2 The alarm system is actuated by the sum of two modulation depths and, therefore, the removal of the ILS course modulation components from the radiated carrier should result in the actuation of the alarm.

2.3.3 The alarm system should indicate to the pilot and to any other airborne system which may be utilizing the localizer and glide path data, the existence of any of the following conditions:

a) the absence of any RF signal as well as the absence of simultaneous 90 Hz and 150 Hz modulation;

b) the percentage modulation of either the 90 Hz or 150 Hz signal reduction to zero with the other maintained at its normal 20 per cent and 40 per cent modulation respectively for the localizer and glide path;

Note.— It is expected that the localizer alarm occur when either the 90 Hz or 150 Hz modulation is reduced to 10 per cent with the other maintained at its normal 20 per cent. It is expected that the glide path alarm occur when either the 90 Hz or 150 Hz modulation is reduced to 20 per cent with the other maintained at its normal 40 per cent.

2.3.3.1 The alarm indication should be easily discernible and visible under all normal flight deck conditions. If a flag is used, it should be as large as practicable commensurate with the display.

2.4 Guidance for the siting, elevation, adjustment and coverage of glide path equipment

2.4.1 *Lateral placement.* The lateral placement of the glide path antenna system with respect to the runway centre line is normally not less than 120 m (400 ft). In deciding the lateral placement of the glide path antenna, account should be taken of the appropriate provisions of Annex 14 with regard to obstacle clearance surfaces and objects on strips for runways.

2.4.2 *ILS glide path curvature.* In many cases, the ILS glide path is formed as a conic surface originating at the glide path aerial system. Owing to the lateral placement of the origin of this conic surface from the runway centre line, the locus of the glide path in the vertical plane along the runway centre line is a hyperbola. Curvature of the glide path occurs in the threshold region and progressively increases until touchdown. To limit the amount of curvature, the glide path antenna should not be located at an excessive lateral distance from the runway centre line.

2.4.3 *Procedure design.* Chapter 3, 3.1.5.1 provides Standards and Recommended Practices for the glide path angle and the height of the ILS reference datum. The longitudinal position of the glide path antenna with respect to the runway threshold is established in order to provide the selected glide path angle and desired ILS reference datum height for the precision approach procedure designed for that runway. The precision approach procedure design may be modified to meet obstacle clearance requirements or to account for technical siting constraints for the glide path antenna (for example, crossing runways or taxiways). The procedure designer will take into account the acceptable glide path angle, threshold crossing height and runway length available as they relate to the type of aircraft expected to use the precision approach procedure.

2.4.4 *Longitudinal placement.* Assuming that the reflecting surface in the beam forming area can be approximated by a planar surface with appropriate lateral and longitudinal slopes, the required longitudinal position of the glide path antenna is then a function of the ILS reference datum above the runway threshold and of the projection of the glide path reflection plane along the runway centre line . This situation is described pictorially in Figure C-5. In this figure, the line OP is defined by the intersection between the glide path reflection plane and the vertical plane along the runway centre line, and point O is at the same longitudinal distance from the threshold as the glide path antenna. Depending on the height and orientation of the reflection plane, point O may be above or below the runway surface.

For a planar reflecting surface, the longitudinal position of the glide path antenna is then calculated as follows:

$$D = \frac{H + Y}{(\theta) + \tan(\alpha)} \tan$$

where

D = the horizontal distance between O and P (equivalent to the longitudinal distance from the glide path antenna to the runway threshold);

H = the nominal height of the ILS reference datum above the runway threshold;

Y = the vertical height of the runway threshold above P';

θ = the nominal ILS glide path angle;

α = the longitudinal downslope of the glide path reflection plane.

Note.— In the above formula α *is to be taken as positive in the case of a downslope from the antenna towards the threshold.* Y *is taken as positive if the threshold is above the reflection plane intersection line.*

2.4.5 The foregoing guidance material is based on the approximation of the reflecting surface by an appropriately oriented plane. Actual siting characteristics, such as significant lateral slope or an irregular rather than planar reflection surface, may require a more rigorous approach if the design goal for the height of the ILS reference datum is to be closely met. In challenging cases, mathematical modelling predictions of the effects of the siting conditions may be appropriate.

2.4.6 Typically, the glide path has some irregularities. The mean ILS glide path angle can be ascertained only by flight tests; the mean observed position of that part of the glide path between ILS Points A and B being represented as a straight line, and the ILS glide path angle being the angle measured between that straight line and its vertical projection on the horizontal plane.

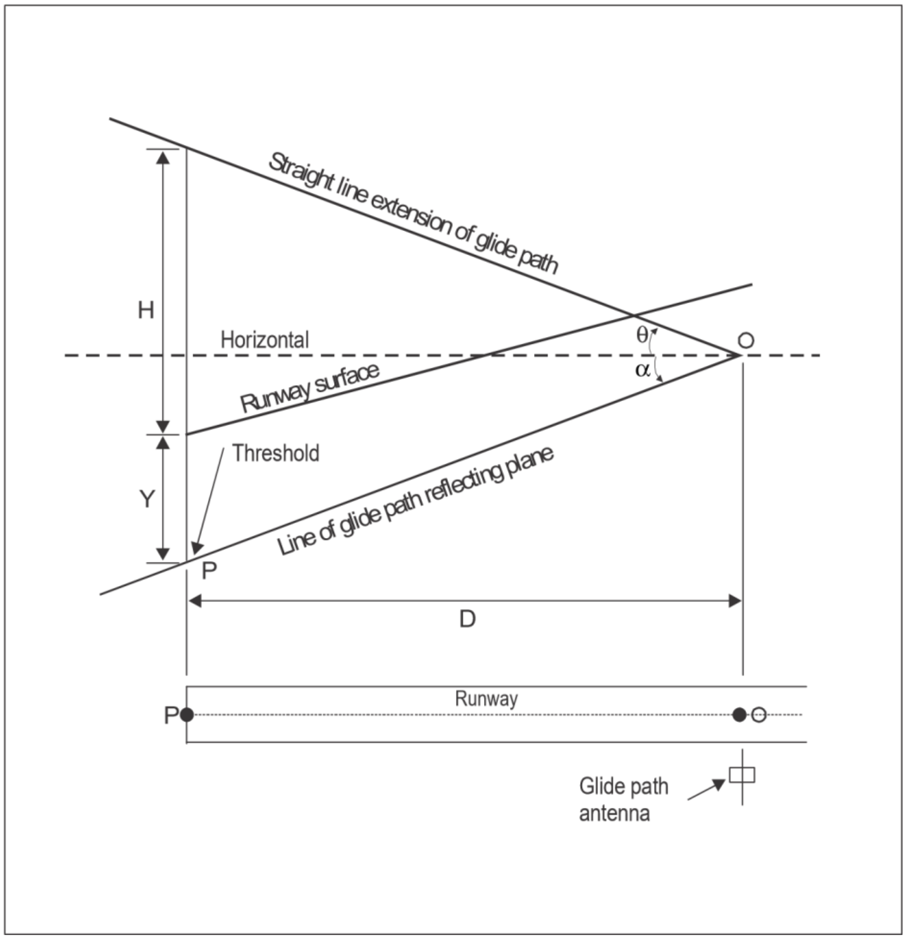


Figure C-5. Glide path siting for sloping runway

2.4.7 It is important to recognize that the effect of glide path irregularities if averaged within the region between the middle marker and the threshold will likely tend to project a reference datum which is actually different from the ILS reference datum. This reference datum, defined here as the achieved ILS reference datum, is considered to be of important operational significance. The achieved ILS reference datum can only be ascertained by flight check, i.e. the mean observed position of that portion of the glide path typically between points 1 830 m (6 000 ft) and 300 m (1 000 ft) from the threshold being represented as a straight line and extended to touchdown. The point at which this extended straight line meets the line drawn vertically through the threshold at the runway centre line is the achieved ILS reference datum.

Note.— Further guidance on the measurement of the glide path angle and the achieved ILS reference datum is given in Doc 8071.

2.4.8 To reduce multipath interference to Category III glide paths and to reduce siting requirements and sensitive areas at these sites, it is desirable that the signals forming the horizontal radiation pattern from the Category III — ILS glide path antenna system be reduced to as low a value as practicable outside the azimuth coverage limits specified in Chapter 3, 3.1.5.3. Another acceptable method is to rotate in azimuth the glide path antennas away from multipath sources thus reducing the amount of radiated signals at specific angles while still maintaining the azimuth coverage limits.

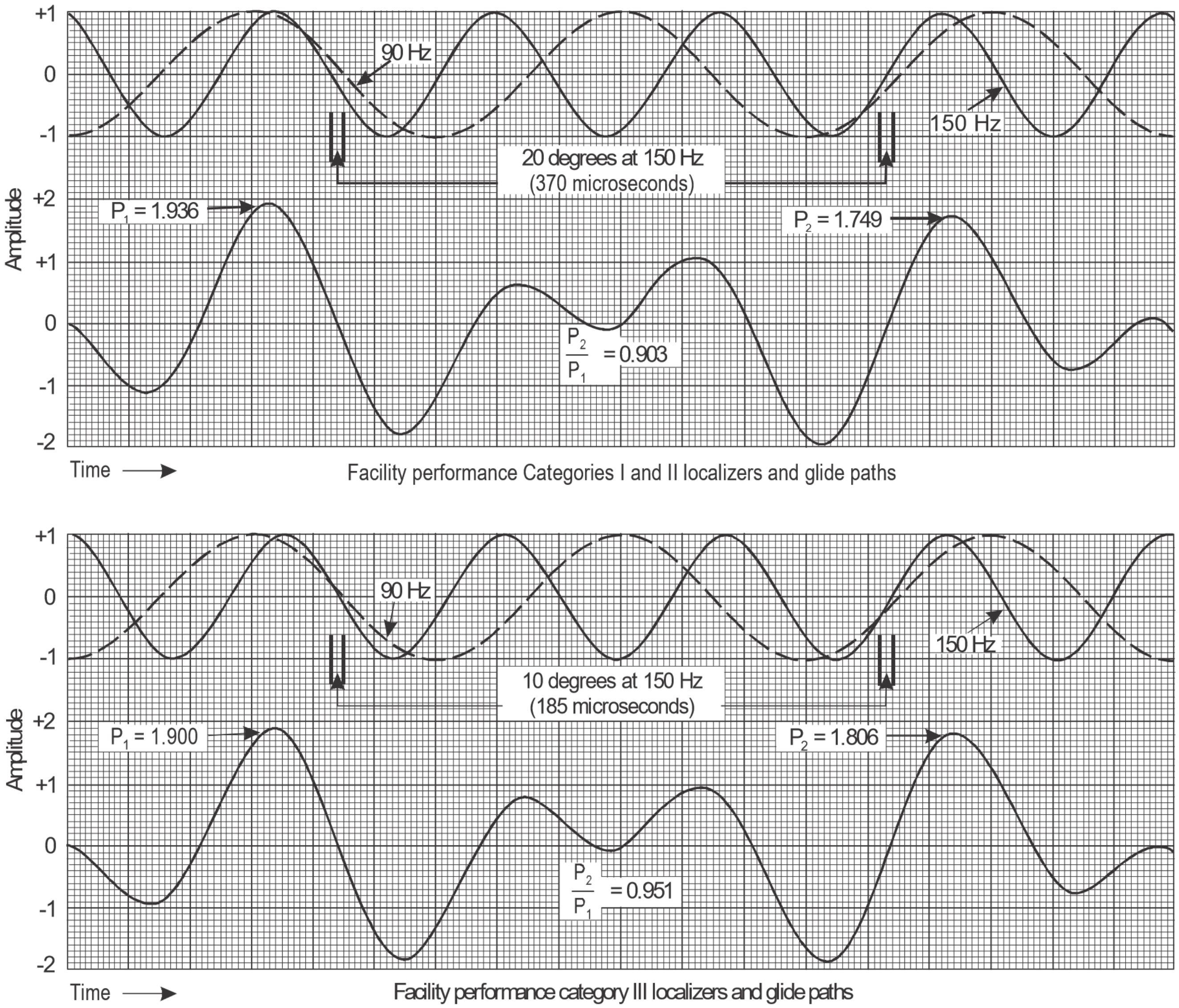
2.4.9 Chapter 3, 3.1.5.3.1 indicates the glide path coverage to be provided to allow satisfactory operation of a typical aircraft installation. The operational procedures promulgated for a facility must be compatible with the lower limit of this coverage. It is usual for descents to be made to the intercept altitude and for the approach to continue at this altitude until a fly-down signal is received. In certain circumstances a cross-check of position may not be available at this point. Automatic flight control systems will normally start the descent whenever a fly-up signal has decreased to less than about 10 microamperes.

2.4.10 The objective is, therefore, to provide a fly-up signal prior to intercepting the glide path. Although under normal conditions, approach procedures will be accomplished in such a way that glide path signals will not be used below 0.45 θ, or beyond 18.5 km (10 NM) from the runway, it is desirable that misleading guidance information should not be radiated in this area. Where procedures are such that the glide path guidance may be used below 0.45 θ, adequate precautions must be taken to guard against the radiation of misleading guidance information below 0.45 θ, under both normal conditions and during a malfunction, thus preventing the final descent being initiated at an incorrect point on the approach. Some precautions which can be employed to guard against the radiation of misleading guidance include the radiation of a supplementary clearance signal such as provided for in Chapter 3, 3.1.5.2.1, the provision of a separate clearance monitor and appropriate ground inspection and setting-up procedures.

2.4.11 To achieve satisfactory monitor protection against below-path out-of-tolerance DDM, depending on the antenna system used, the displacement sensitivity monitor as required in Chapter 3, 3.1.5.7.1 e) may not be adequate to serve also as a clearance monitor. In some systems, e.g. those using multi-element arrays without supplementary clearance, a slight deterioration of certain antenna signals can cause serious degradation of the clearance with no change or only insignificant changes within the glide path sector as seen by the deviation sensitivity monitor. It is important to ensure that monitor alarm is achieved for any or all possible deteriorated antenna and radiated signal conditions, which may lead to a reduction of clearance to 0.175 DDM or less in the below-path clearance coverage.

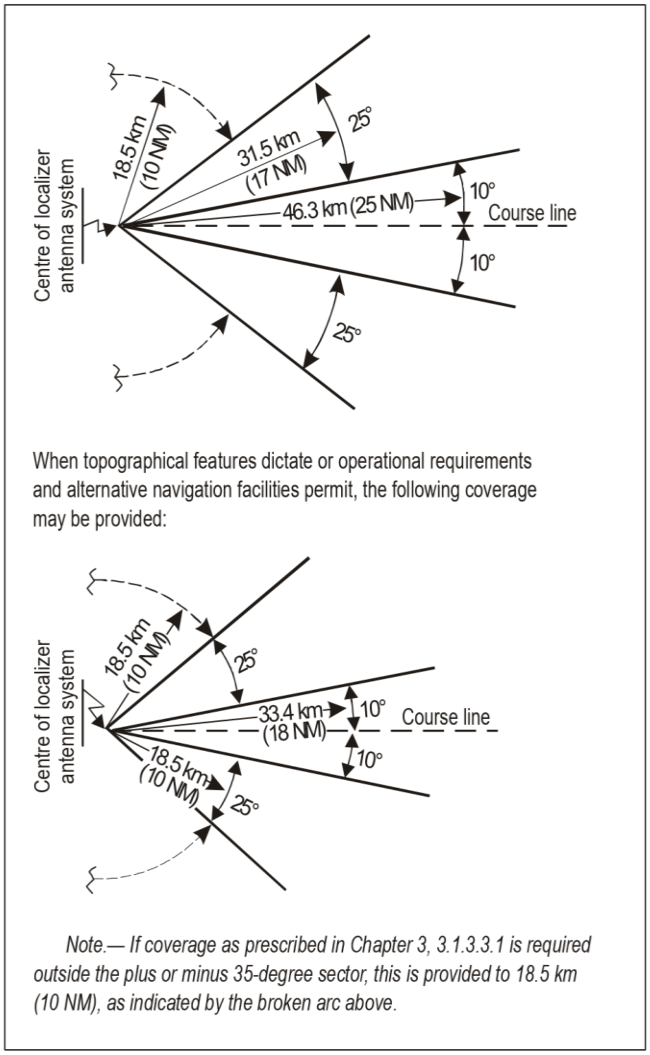
2.5 Diagrams

(Figures C-6 to C-12 illustrate certain of the Standards contained in Chapter 3)



The accompanying graphs illustrate a method that can be used to measure the relative phase relationship between the 90 Hz and 150 Hz tones. The upper portion of each graph shows the individual waveforms and their relationship at the limit of phase differences allowed by Chapter 3, 3.1.3.5.3.3 and 3.1.5.5.3. The lower portion shows the combined waveforms as would be seen on an oscilloscope. By taking the ratio of P_1 and P_2, which gives a value equal to or less than unity, it is possible to determine if the phasing is within tolerance. For Categories I and II ILS the ratio should be greater than 0.903 and for Category III the ratio should be greater than 0.951.

Figure C-6. ILS wave forms illustrating relative audio phasing of the 90 Hz and 150 Hz tones



When topographical features dictate or operational requirements and alternative navigation facilities permit, the following coverage may be provided:

Note.— If coverage as prescribed in Chapter 3, 3.1.3.3.1 is required outside the plus or minus 35-degree sector, this is provided to 18.5 km (10 NM), as indicated by the broken arc above.

Figure C-7A. Localizer coverage with respect to azimuth

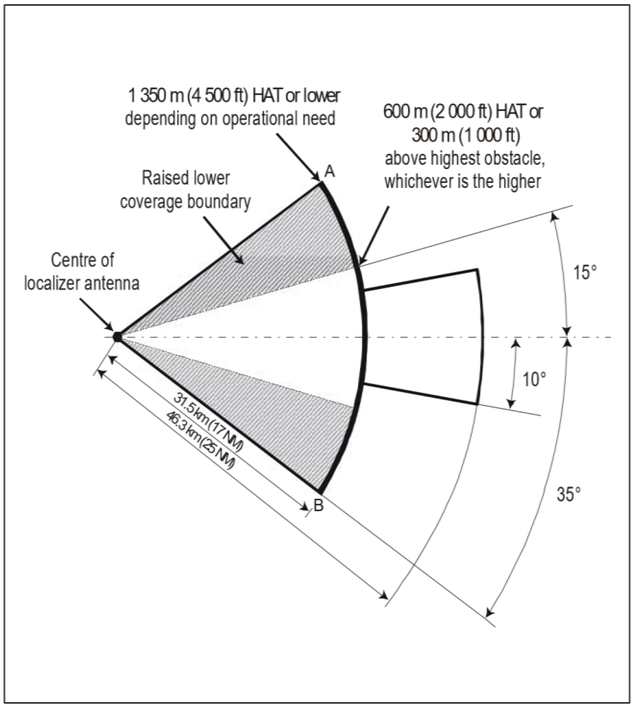
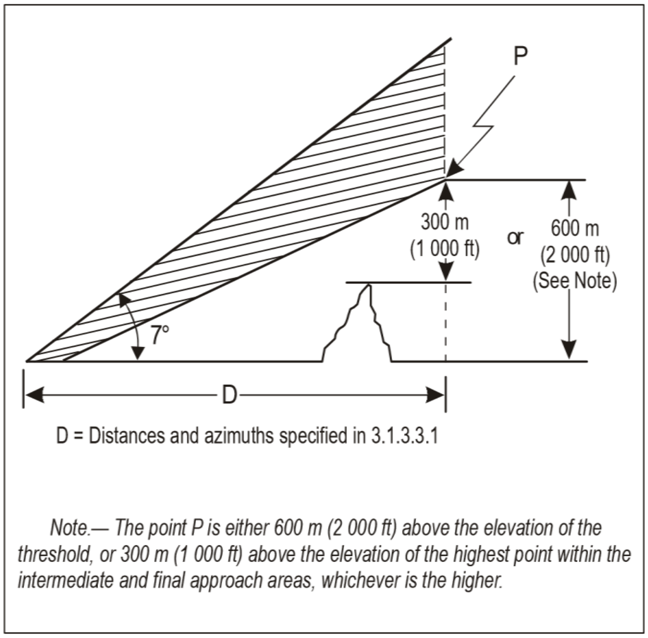


Figure C-7B. Reduced localizer coverage with respect to azimuth



D = Distances and azimuths specified in 3.1.3.3.1

Note.— The point P is either 600 m (2 000 ft) above the elevation of the threshold, or 300 m (1 000 ft) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher.

Figure C-8A. Localizer coverage with respect to elevation

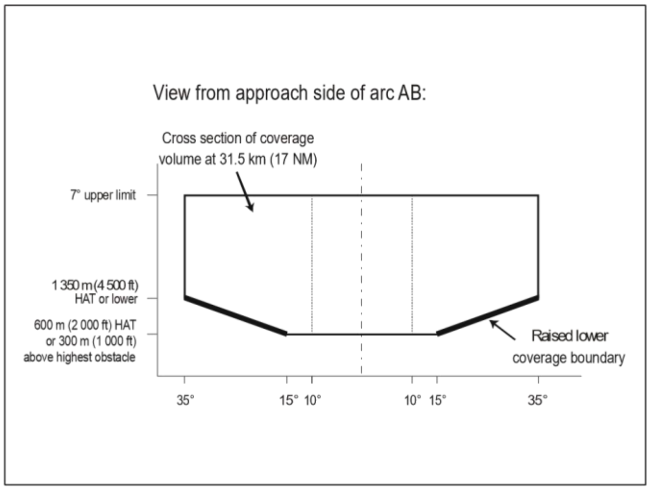
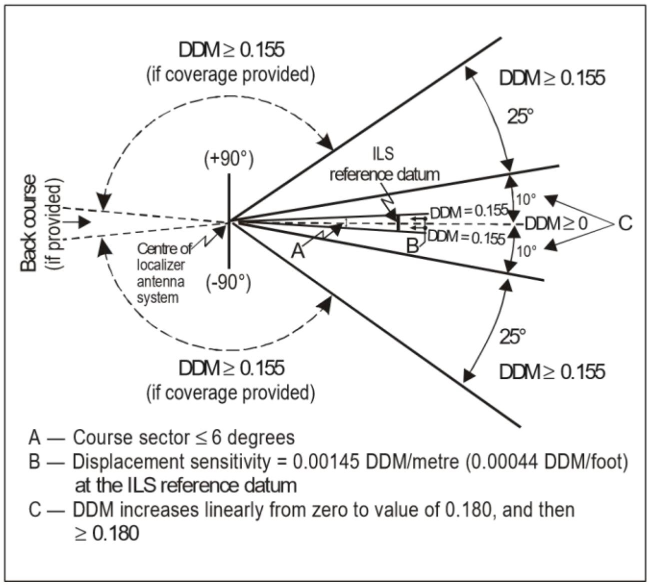
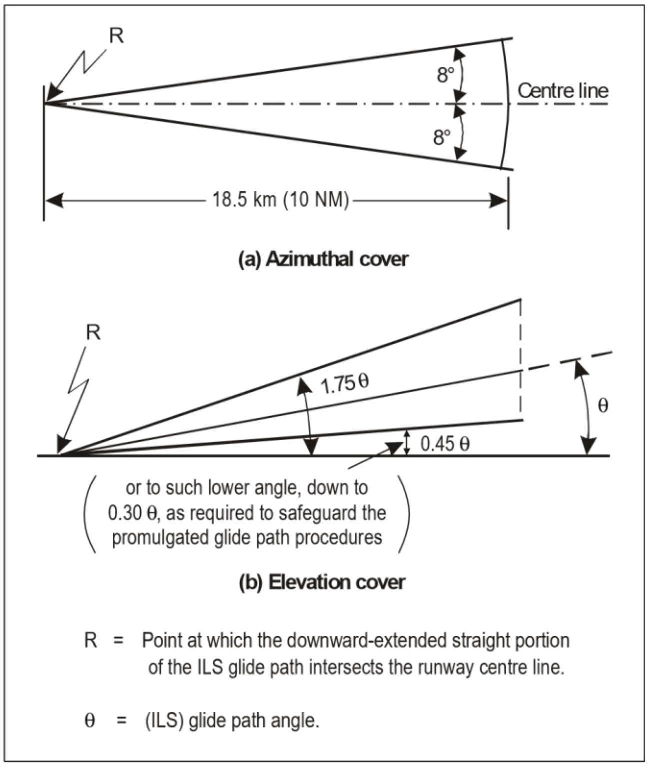


Figure C-8B. Reduced localizer coverage with respect to elevation



A — Course sector ≤ 6 degrees
B — Displacement sensitivity = 0.00145 DDM/metre (0.00044 DDM/foot) at the ILS reference datum
C — DDM increases linearly from zero to value of 0.180, and then ≥ 0.180

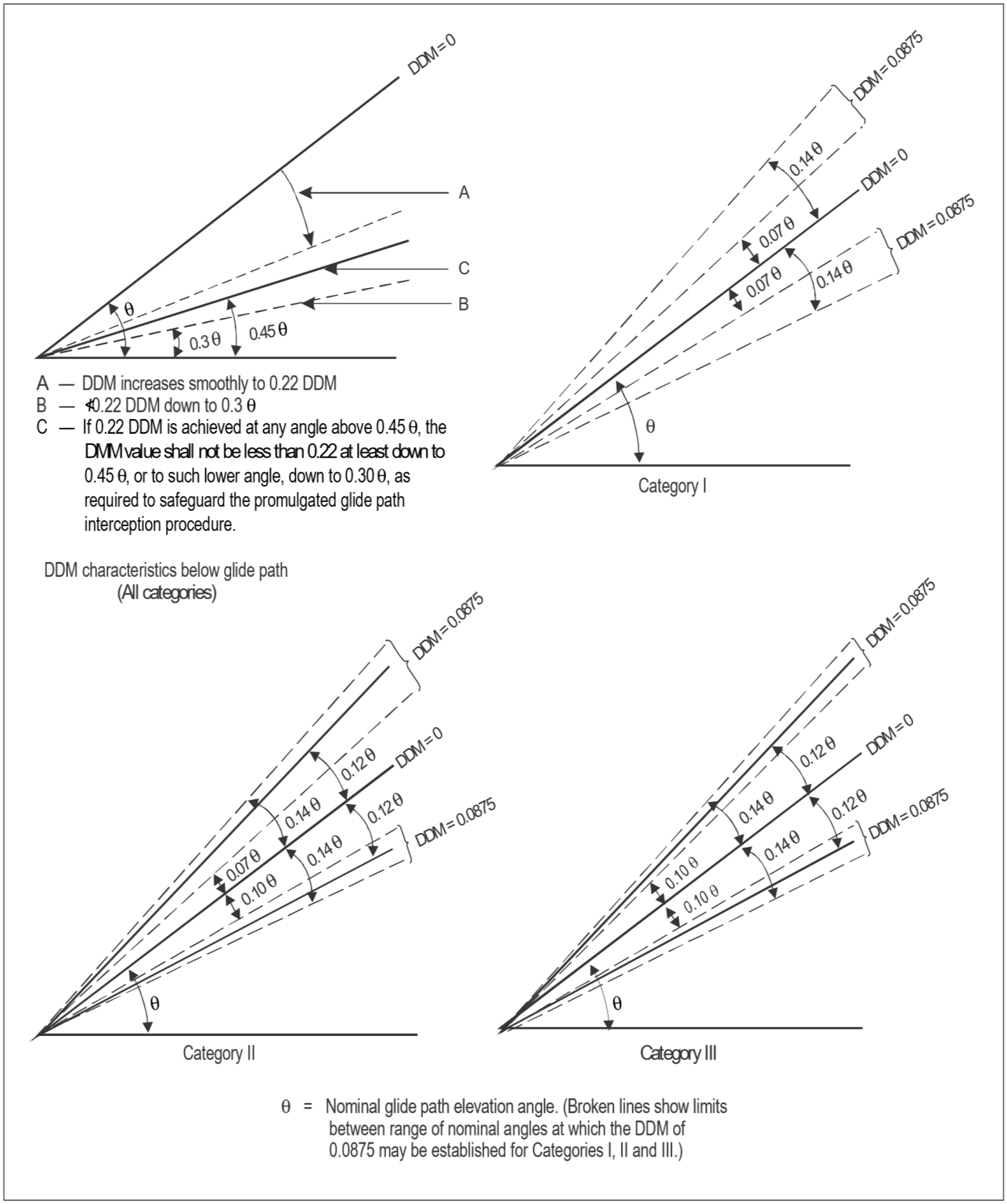
Figure 9. Difference in depth of modulation and displacement sensitivity



R = Point at which the downward-extended straight portion of the ILS glide path intersects the runway centre line.

θ = (ILS) glide path angle.

Figure 10. Glide path coverage

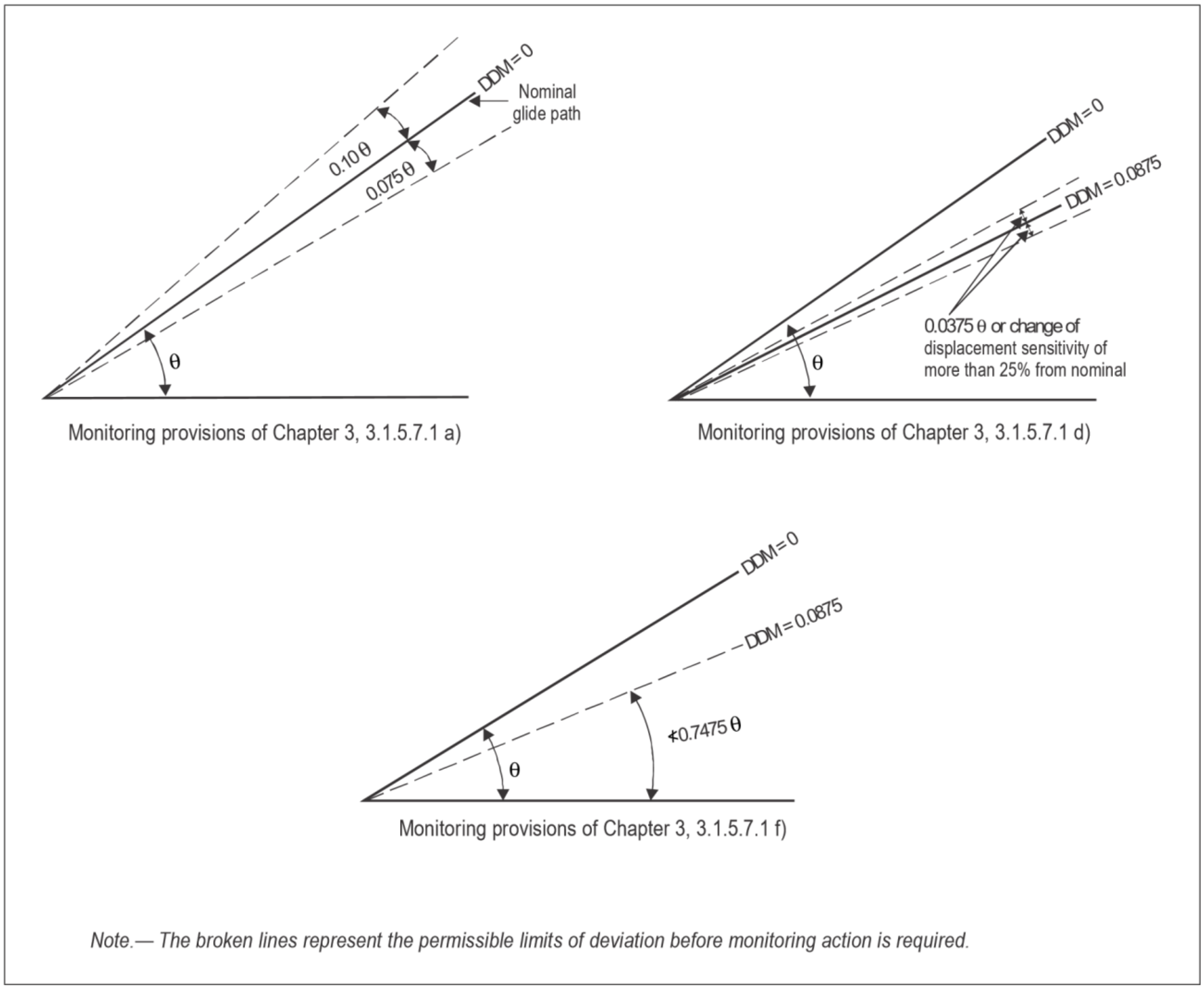


A — DDM increases smoothly to 0.22 DDM
B — ≮0.22 DDM down to 0.3 θ
C — If 0.22 DDM is achieved at any angle above 0.45 θ, the DMM value shall not be less than 0.22 at least down to 0.45 θ, or to such lower angle, down to 0.30 θ, as required to safeguard the promulgated glide path interception procedure.

DDM characteristics below glide path
(All categories)

θ = Nominal glide path elevation angle. (Broken lines show limits between range of nominal angles at which the DDM of 0.0875 may be established for Categories I, II and III.)

Figure C-11. Glide path — difference in depth of modulation



Note.— The broken lines represent the permissible limits of deviation before monitoring action is required.

Figure C-12. Glide path monitoring provisions

2.6 Deployment of ILS frequencies

2.6.1 In using the figures listed in Table C-3, it must be noted that these are related to ensuring freedom from interference to a point at the protection height and at the limit of service distance of the ILS in the direction of the front beam. If there is an operational requirement for back beam use, the criteria would also be applied to a similar point in the back beam direction. Frequency planning will therefore need to take into account the localizer azimuthal alignment. It is to be noted that the criteria must be applied in respect of each localizer installation, in the sense that while of two localizers, the first may not cause interference to the use of the second, nevertheless the second may cause interference to the use of the first.

2.6.2 The figures listed in Table C-3 are based on providing an environment within which the airborne receivers can operate correctly.

2.6.2.1 *ILS localizer receivers*

2.6.2.1.1 In order to protect receivers designed for 50 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

2.6.2.1.2 In order to protect receivers designed for 100 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 7 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

2.6.2.2 *ILS glide path receivers*

2.6.2.2.1 In order to protect receivers designed for 150 kHz spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) a desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired glide path signal, 150 kHz removed from the desired signal, exceeds the desired signal by up to 20 dB;

c) an undesired glide path signal, 300 kHz or further removed from the desired signal, exceeds the desired signal by up to 40 dB.

Table C-3. Required distance separations

	Frequency separation	Minimum separation between second facility and the protection point of the first facility km (NM)		
		List A	List B	List C
Localizer	Co-channel	148 (80)	148 (80)	148 (80)
	50 kHz	—	37 (20)	9 (5)
	100 kHz	65 (35)	9 (5)	0
	150 kHz	—	0	0
	200 kHz	11 (6)	0	0
Glide path	Co-channel	93 (50)	93 (50)	93 (50)
	150 kHz	—	20 (11)	2 (1)
	300 kHz	46 (25)	2 (1)	0
	450 kHz	—	0	0
	600 kHz	9 (5)	0	0

List A refers to the use of localizer receivers designed for 200 kHz channel spacing coupled with glide path receivers designed for 600 kHz channel spacing and applicable only in regions where the density of facilities is low.

List B refers to the use of localizer receivers designed for 100 kHz channel spacing coupled with glide path receivers designed for 300 kHz channel spacing.

List C refers to the use of localizer receivers designed for 50 kHz channel spacing coupled with glide path receivers designed for 150 kHz channel spacing.

Note 1.— The above figures are based on the assumption of protection points for the localizer at 46 km (25 NM) distance and 1 900 m (6 250 ft) height and for the ILS glide path at 18.5 km (10 NM) distance and 760 m (2 500 ft) height.

Note 2.— States, in applying the separations shown in the table, have to recognize the necessity to site the ILS and VOR facilities in a manner which will preclude the possibility of airborne receiver error due to overloading by high unwanted signal levels when the aircraft is in the initial and final approach phases.

Note 3.— States, in applying the separations shown in the table, have to recognize the necessity to site the ILS glide path facilities in a manner which will preclude the possibility of erroneous glide path indications due to reception of adjacent channel signals when the desired signal ceases to radiate for any reason while the aircraft is in the final approach phase.

2.6.2.2.2 In order to protect receivers designed for 300 kHz spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) a desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired glide path signal, 150 kHz removed from the desired signal, does not exceed the desired signal (0 dB signal ratio);

c) an undesired glide path signal, 300 kHz removed from the desired signal, exceeds the desired signal by up to 20 dB;

d) an undesired glide path signal, 450 kHz or further removed from the desired signal, exceeds the desired signal by up to 40 dB.

2.6.3 The calculations are based on the assumption that the protection afforded to the wanted signal against interference from the unwanted signal is 20 dB. This corresponds to a disturbance of not more than 15 microamperes at the limit of the service distance of ILS.

2.6.4 In so far as the wanted and unwanted carriers may produce a heterodyne note, the protection ratio ensures that the instrumentation is not affected. However, in cases where a voice facility is used, the heterodyne note may interfere with this facility.

2.6.5 In general, when international use of ILS systems is confined to the pairings listed in Chapter 3, 3.1.6.1.1, the criteria are such that, provided they are met for the localizer element, the glide path element is automatically covered. At certain congested locations, where it is necessary to make assignments in both the first ten and the second ten sequence pairings, it may be necessary to select certain pairings out of sequence in order to meet the minimum geographical separation in 2.6.6.

Example: Referring to Chapter 3, 3.1.6.1.1, it will be noted that ILS Sequence Number 2 pairs the localizer frequency of 109.9 MHz with glide path frequency 333.8 MHz. Sequence Numbers 12 and 19, however, although providing wide frequency separation from Sequence Number 2 in the case of the localizers, assign frequencies of 334.1 MHz and 333.5 MHz, respectively, for the glide paths, both being first adjacent channels (300 kHz spacing) to the Sequence Number 2 glide path channel. If selection of ILS channels is confined to either the first ten or the second ten pairings, then the minimum glide path frequency separation will be 600 kHz.

2.6.6 *Table of required distance separations* (see Table C-3)

2.6.7 The application of the figures given in Table C-3 will only be correct within the limitations set by the assumptions which include that facilities are essentially non-directional in character, that they have similar radiated powers, that the field strength is approximately proportional to the angle of elevation for angles up to 10 degrees, and that the aircraft antenna is essentially omnidirectional in character. If more precise determination of separation distances is required in areas of frequency congestion, this may be determined for each facility from appropriate propagation curves, taking into account the particular directivity factors, radiated power characteristics and the operational requirements as to coverage. Where reduced separation distances are determined by taking into account directivity, etc., flight measurements at the ILS protection point and at all points on the approach path should be made wherever possible to ensure that a protection ratio of at least 20 dB is achieved in practice.

2.7 Localizers and glide paths achieving coverage with two radio frequency carriers

2.7.1 Localizer and glide path facilities may achieve their coverage requirements by using two radiation field patterns, commonly known as the “course” and “clearance” patterns, transmitted using separate carrier frequencies spaced within the frequency channel. The course field pattern gives accurate course and displacement indications; the clearance field pattern provides displacement indications at angles beyond the limits of the course field pattern . Discrimination between signals is obtained in airborne receivers by the stronger signal capturing the receiver. Effectiveness of capture depends on the type of detector used but, in general, if the ratio of the two signals is of the order of 10 dB or more, the smaller signal does not cause significantly large errors in demodulated output. For optimum performance within the front course sector, the following guidance material should be applied in the operation of two carrier frequency localizer systems.

2.7.2 The localizer should be designed and maintained so that the ratio of the two radiated signals-in-space within the front course sector does not fall below 10 dB. Particular attention should be directed to the vertical lobe structure produced by the two antenna systems which may be different in height and separated in distance, thus resulting in changes in ratio of signal strengths during approach.

2.7.3 Due to the 6 dB allowance for the receiver pass-band filter ripple, localizer receiver response variations can occur as the clearance frequency is displaced from the course frequency. To minimize this effect, particularly for Category III operations, the course-to-clearance signal ratio needs to be increased from 10 dB to 16 dB.

2.7.4 To minimize further the risk of errors if the ratio of the two radiated signals falls below 10 dB within the front course sector, the difference in alignment of the radiation field patterns of the two signals should be kept as minimal as practicable.

2.7.5 Glide paths which employ two carriers are used to form a composite radiation field pattern on the same radio frequency channel. Special configurations of antennas and the distribution of antenna currents and phasing may permit siting of glide path facilities at locations with particular terrain conditions which may otherwise cause difficulty to a singlefrequency system. At such sites, an improvement is obtained by reducing the low angle radiation. The second carrier is employed to provide coverage in the region below the glide path.

2.7.6 *Monitoring dual frequency systems.* The dual frequency monitoring requirements in Chapter 3, 3.1.3.11.2 e) and 3.1.5.7.1 c) specify monitor action for a power output of less than 80 per cent of normal, except that reductions can be accepted to 50 per cent of normal if certain performance requirements are met.

2.7.6.1 Monitoring the course and clearance transmitters for a 20 per cent reduction in power (approximately –1 dB) can be challenging if environmental and other effects such as large ambient temperature variations exist at the site. For example, temperature variations cause normal transmitter power output to vary and coaxial cable insertion losses to change. Even assuming no failure occurs in the transmitting system, the alarm limit occasionally may be exceeded, and this in turn may compromise continuity.

2.7.6.2 The alternative of monitoring at power reductions of up to 50 per cent appears very attractive, but must be used cautiously. Monitoring each transmitter independently at a 50 per cent reduction can allow a large change from the nominal power ratio between the two transmitters if uncorrelated failures occur. This in turn may compromise the capture effect in the receiver, thus increasing structure errors or reducing clearance indications.

2.7.6.3 One solution is to use a monitoring scheme that limits the difference between the power output of the transmitters to approximately 1 dB (i.e. 80 per cent), while allowing both to decrease up to 3 dB (i.e. 50 per cent) if they change together. This method provides a greater tolerance for common mode effects such as cable loss changes due to temperature, and therefore increases continuity of service.

2.8 Integrity and continuity of service — ILS ground equipment

2.8.1 *Introduction*

2.8.1.1 This material is intended to provide clarification of the integrity and continuity of service objectives of ILS localizer and glide path ground equipment and to provide guidance on engineering design and system characteristics of this equipment. Integrity is needed to ensure that an aircraft on approach will have a low probability of receiving false guidance; continuity of service is needed to ensure that an aircraft in the final stages of approach will have a low probability of being deprived of a guidance signal. Integrity and continuity of service are both key safety factors during the critical phase of approach and landing. The integrity and continuity of service must of necessity be known from an operational viewpoint in order to decide the operational application which an ILS could support.

2.8.1.2 It is generally accepted, irrespective of the operational objective, that the average rate of a fatal accident during landing, due to failures or shortcomings in the whole system, comprising the ground equipment, the aircraft and the pilot, should not exceed 1×10^{-7}. This criterion is frequently referred to as the global risk factor.

2.8.1.3 In the case of Category I operations, responsibility for assuring that the above objective is not exceeded is vested more or less completely in the pilot. In Category III operations, the same objective is required but must now be inherent in the whole system. In this context it is of the utmost importance to endeavour to achieve the highest level of integrity and continuity of service of the ground equipment.

2.8.1.4 The requirements for integrity and high continuity of service require highly reliable systems to minimize the probability of failure which may affect any characteristic of the total signal-in-space. It is suggested that States endeavour to achieve reliability with as large a margin as is technically and economically reasonable. Reliability of equipment is governed by basic construction and operating environment. Equipment design should employ the most suitable engineering techniques, materials and components, and rigorous inspection should be applied in manufacture. Equipment should be operated in environmental conditions appropriate to the manufacturers' design criteria.

2.8.2 *Achievement and retention of integrity service levels*

2.8.2.1 An integrity failure can occur if radiation of a signal which is outside specified tolerances is either unrecognized by the monitoring equipment or the control circuits fail to remove the faulty signal. Such a failure might constitute a hazard if it results in a gross error.

2.8.2.2 Clearly not all integrity failures are hazardous in all phases of the approach. For example, during the critical stages of the approach, undetected failures producing gross errors in course width or course line shifts are of special significance whereas an undetected change of modulation depth, or loss of localizer and glide slope clearance and localizer identification would not necessarily produce a hazardous situation. The criterion in assessing which failure modes are relevant must however include all those deleterious fault conditions which are not unquestionably obvious to the automatic flight system or pilot.

2.8.2.3 The highest order of protection is required against the risk of undetected failures in the monitoring and associated control system. This would be achieved by careful design to reduce the probability of such occurrences to a low level and provide fail-safe operations compliant with the Standards of Chapter 3, 3.1.3.11.4 and 3.1.5.7.4, and by carrying out maintenance checks on the monitor system performance at intervals which are determined by a design analysis.

2.8.2.4 A design analysis can be used to calculate the level of integrity of the system in any one landing. The following formula applies to certain types of ILS and provides an example of the determination of system integrity, *I*, from a calculation of the probability of transmission of undetected erroneous radiation, *P*.

(1) $I = 1 - P$

$$P = \frac{T_1 T_2}{\alpha_1 \alpha_2 M_1 M_2} \text{ when } T_1 < T_2$$

where

I = integrity

P = the probability of a concurrent failure in transmitter and monitor systems resulting in erroneous undetected radiation

M_1 = transmitter mean time between failures (MTBF)

M_2 = MTBF of the monitoring and associated control system

$\frac{1}{\alpha_1}$ = ratio of the rate of failure in the transmitter resulting in the radiation of an erroneous signal to the rate of all transmitter failures.

T_1 = period of time (in hours) between transmitter checks

T_2 = period of time (in hours) between checks on the monitoring and associated control system

When $T_1 \geq T_2$ the monitor system check may also be considered a transmitter check. In this case, therefore $T_1 = T_2$ and the formula would be:

(2)

$$P = \frac{T_2^2}{\alpha_1 \alpha_2 M_1 M_2}$$

2.8.2.5 Since the probability of occurrence of an unsafe failure within the monitoring or control equipment is extremely remote, to establish the required integrity level with a high degree of confidence would necessitate an evaluation period many times that needed to establish the equipment MTBF. Such a protracted period is unacceptable and therefore the required integrity level can only be predicted by rigorous design analysis of the equipment.

2.8.2.6 Protection of the integrity of the signal-in-space against degradation which can arise from extraneous radio interference falling within the ILS frequency band or from re-radiation of ILS signals must also be considered. Measures to prevent the latter by critical and sensitive area protection are given in general terms at 2.1.9. With regard to radio interference it may be necessary to confirm periodically that the level of interference does not constitute a hazard.

2.8.2.7 In general, monitoring equipment design is based on the principle of continuously monitoring the radiated signals-in-space at specific points within the coverage volume to ensure their compliance with the Standards specified at Chapter 3, 3.1.3.11 and 3.1.5.7. Although such monitoring provides to some extent an indication that the signal-in-space at all other points in the coverage volume is similarly within tolerance, this is largely inferred. It is essential therefore to carry out rigorous flight and ground inspections at periodic intervals to ensure the integrity of the signal-in-space throughout the coverage volume.

2.8.3 *Achievement and retention of continuity of service levels*

2.8.3.1 A design analysis should be used to predict the MTBF and continuity of service of the ILS equipment. Before assignment of a level of continuity of service and introduction into Category II or III service, however, the mean time between outages (MTBO) of the ILS should be confirmed by evaluation in an operational environment. In this evaluation, an outage is defined as any unanticipated cessation of signal-in-space. This evaluation takes into account the impact of operational factors, i.e. airport environment, inclement weather conditions, power availability, quality and frequency of maintenance. MTBO is related to MTBF, but is not equivalent, as some equipment failures, such as a failure of a transmitter resulting in the immediate transfer to a standby transmitter may not necessarily result in an outage. For continuity of service Level 2, 3 or 4, the evaluation period should be sufficient to determine achievement of the required level with a high degree of confidence. One method to demonstrate that continuity standards are met is the sequential test method. If this method is used, the following considerations apply:

a) the minimum acceptable confidence level is 60 per cent. To achieve the confidence level of 60 per cent, the evaluation period has to be longer than the required MTBO hours as stated in Table C-4. Typically, these minimal evaluation periods for new and subsequent installations are for Level 2, 1 600 operating hours, for Level 3, 3 200 hours and for Level 4, 6 400 hours. To assess the seasonal influence of the environment, a minimal evaluation period of one year is typically required for a new type of installation in a particular environment. It may be possible to reduce this period in cases where the operating environment is well controlled and similar to other proven installations. Where several identical systems are being operated under similar conditions, it may be possible to base the assessment on the cumulative operating hours of all the systems; this will result in a reduced evaluation period.

   Once a higher confidence level is obtained for a type of installation, subsequent installation of the same type of equipment under similar operational and environmental conditions may follow shorter evaluation periods;

b) during the evaluation period, it should be decided for each outage if it is caused by a design failure or if it is caused by a failure of a component due to its normal failure rate. Design failures are, for instance, operating components beyond their specification (overheating, overcurrent, overvoltage, etc. conditions). These design failures should be dealt with such that the operating condition is brought back to the normal operating condition of the component or that the component is replaced with a part suitable for the operating conditions. If the design failure is treated in this way, the evaluation may continue and this outage is not counted, assuming that there is a high probability that this design failure will not occur again. The same applies to outages due to any causes which can be mitigated by permanent changes to the operating conditions.

2.8.3.2 An assigned continuity of service level should not be subject to frequent change. A suitable method to assess the behaviour of a particular installation is to keep the records and calculate the average MTBO over the last five to eight failures of the equipment. This weighs the MTBO for continuity of service purposes to be more relevant to the next approach, rather than computing MTBO over the lifetime of the equipment. If continuity of service deteriorates, the assigned designation should be reduced until improvements in performance can be effected.

2.8.3.3 *Additional detailed guidance.* Several States have published continuity of service policies and procedures. The following documents may be consulted for additional guidance and details:

a) *European Guidance Material on Continuity of Service Evaluation in Support of the Certification of ILS & MLS Ground Systems,* EUR DOC 012; and

b) *Instrument Landing System Continuity of Service Requirements and Procedures*, Order 6750.57, United States Federal Aviation Administration.

2.8.4 The following configuration is an example of a redundant equipment arrangement that is likely to meet the objectives for integrity and continuity of service Levels 3 and 4. The localizer and glide path facilities each consist of two continuously operating transmitters, one connected to the antenna and the standby connected to a dummy load. With these transmitters is associated a monitor system performing the following functions:

a) confirming proper operation within the specified limits of the main transmitter and antenna system by means of majority voting among redundant monitors;

b) confirming operation of the standby equipment.

2.8.4.1 Whenever the monitor system rejects one of the equipments the facility continuity of service level will be reduced because the probability of cessation of signal consequent on failure of other equipment will be increased. This change of performance must be automatically indicated at remote locations.

2.8.4.2 An identical monitoring arrangement to the localizer is used for the glide path facility.

2.8.4.3 To reduce mutual interference between the main and standby transmitters any stray radiation from the latter is at least 50 dB below the carrier level of the main transmitter measured at the antenna system.

2.8.4.4 In the above example, the equipment would include provision to facilitate monitoring system checks at intervals specified by the manufacturer, consequent to the design analysis, to ensure attainment of the required integrity level. Such checks, which can be manual or automatic, provide the means to verify correct operation of the monitoring system including the control circuitry and changeover switching system. The advantage of adopting an automatic monitor integrity test is that no interruption to the operational service provided by the localizer or glide path is necessary. It is important when using this technique to ensure that the total duration of the check cycle is short enough not to exceed the total period specified in Chapter 3, 3.1.3.11.3 or 3.1.5.7.3.

2.8.4.5 Interruption of facility operation due to primary power failures is avoided by the provision of suitable standby supplies, such as batteries or “no-break” generators. Under these conditions, the facility should be capable of continuing in operation over the period when an aircraft may be in the critical stages of the approach. Therefore the standby supply should have adequate capacity to sustain service for at least two minutes.

2.8.4.6 Warnings of failures of critical parts of the system, such as the failure of the primary power supply, must be given at the designated control points.

2.8.4.7 In order to reduce failure of equipment that may be operating near its monitor tolerance limits, it is useful for the monitor system to include provision to generate a pre-alarm warning signal to the designated control point when the monitored parameters reach a limit equal to a value in the order of 75 per cent of the monitor alarm limit.

2.8.4.8 An equipment arrangement similar to that at 2.8.4, but with no transmitter redundancy, would normally be expected to achieve the objectives for continuity of service Level 2.

2.8.5 Guidance relating to localizer far field monitors is given below.

2.8.5.1 Far field monitors are provided to monitor course alignment but may also be used to monitor course sensitivity. A far field monitor operates independently from integral and near field monitors. Its primary purpose is to protect against the risk of erroneous setting-up of the localizer, or faults in the near field or integral monitors. In addition, the far field monitor system will enhance the ability of the combined monitor system to respond to the effects of physical modification of the radiating elements or variations in the ground reflection characteristics. Moreover, multipath effects and runway area disturbances not seen by near field and integral monitors, and some occurrences of radio interferences may be substantially monitored by using a far field monitoring system built around a suitable receiver(s), installed under the approach path.

2.8.5.2 A far field monitor is generally considered essential for Category III operations, while for Category II it is generally considered to be desirable. Also for Category I installations, a far field monitor has proved to be a valuable tool to supplement the conventional monitor system.

2.8.5.3 The signal received by the far field monitor will suffer short-term interference effects caused by aircraft movements on or in the vicinity of the runway and experience has shown that it is not practical to use the far field monitor as an executive monitor. When used as a passive monitor, means must be adopted to minimize such temporary interference effects and to reduce the occurrence of nuisance downgrade indications; some methods of achieving this are covered in 2.8.5.4. The response of the far field monitor to interference effects offers the possibility of indicating to the air traffic control point when temporary disturbance of the localizer signal is present. However, experience has shown that disturbances due to aircraft movements may be present along the runway, including the touchdown zone, and not always be observed at the far field monitor. It must not be assumed, therefore, that a far field monitor can provide comprehensive surveillance of aircraft movements on the runway.

2.8.5.3.1 Additional possible applications of the far field monitor are as follows:

a) it can be a useful maintenance aid to verify course and/or course deviation sensitivity in lieu of a portable far field monitor;

b) it may be used to provide a continuous recording of far field signal performance showing the quality of the far field signal and the extent of signal disturbance.

2.8.5.4 Possible methods of reducing the occurrence of nuisance downgrade indications include:

a) incorporation of a time delay within the system adjustable from 30 to 240 seconds;

b) the use of a validation technique to ensure that only indications not affected by transitory disturbances are transmitted to the control system;

c) use of low pass filtering.

2.8.5.5 A typical far field monitor consists of an antenna, VHF receiver and associated monitoring units which provide indications of DDM, modulation sum, and RF signal level. The receiving antenna is usually of a directional type to minimize unwanted interference and should be at the greatest height compatible with obstacle clearance limits. For course line monitoring, the antenna is usually positioned along the extended runway centre line. Where it is desired to also monitor displacement sensitivity, an additional receiver and monitor are installed with antenna suitably positioned to one side of the extended runway centre line. Some systems utilize a number of spatially separated antennas.

2.9 Localizer and glide path displacement sensitivities

2.9.1 Although certain localizer and glide path alignment and displacement sensitivities are specified in relation to the ILS reference datum, it is not intended to imply that measurement of these parameters must be made at this datum.

2.9.2 Localizer monitor system limits and adjustment and maintenance limits given in Chapter 3, 3.1.3.7 and 3.1.3.11 are stated as percentage changes of displacement sensitivity. This concept, which replaces specifications of angular width in earlier editions, has been introduced because the response of aircraft guidance systems is directly related to displacement sensitivity. It will be noted that angular width is inversely proportional to displacement sensitivity.

2.10 Siting of ILS markers

2.10.1 Considerations of interference between inner and middle markers, and the minimum operationally acceptable time interval between inner and middle marker light indications, will limit the maximum height marked by the inner marker to a height on the ILS glide path of the order of 37 m (120 ft) above threshold for markers sited within present tolerances in Annex 10. A study of the individual site will determine the maximum height which can be marked, noting that with a typical airborne marker receiver a separation period of the order of 3 seconds at an aircraft speed of 140 kt between middle and inner marker light indications is the minimum operationally acceptable time interval.

2.10.2 In the case of ILS installations serving closely spaced parallel runways, e.g. 500 m (1 650 ft) apart, special measures are needed to ensure satisfactory operation of the marker beacons. Some States have found it practical to employ a common outer marker for both ILS installations. However, special provisions, e.g. modified field patterns, are needed in the case of the middle markers if mutual interference is to be avoided, and especially in cases where the thresholds are displaced longitudinally from one another.

2.11 Use of DME and/or other standard radio navigation aids as an alternative to ILS marker beacons

2.11.1 When DME is used as an alternative to ILS marker beacons, the DME should be located on the airport so that the zero range indication will be a point near the runway. If the DME associated with ILS uses a zero range offset, this facility has to be excluded from RNAV solutions.

2.11.1.1 In order to reduce the triangulation error, the DME should be sited to ensure a small angle (e.g. less than 20 degrees) between the approach path and the direction to the DME at the points where the distance information is required.

2.11.1.2 The use of DME as an alternative to the middle marker beacon assumes a DME system accuracy of 0.37 km (0.2 NM) or better and a resolution of the airborne indication such as to allow this accuracy to be attained.

2.11.1.3 While it is not specifically required that DME be frequency paired with the localizer when it is used as an alternative for the outer marker, frequency pairing is preferred wherever DME is used with ILS to simplify pilot operation and to enable aircraft with two ILS receivers to use both receivers on the ILS channel.

2.11.1.4 When the DME is frequency paired with the localizer, the DME transponder identification should be obtained by the "associated" signal from the frequency-paired localizer.

2.11.2 In some locations, the Competent Authority may authorize the use of other means to provide fixes as detailed in the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS) (Doc 8168), such as NDB, VOR or GNSS. This may be useful in particular in locations where aircraft user equipage with DME is low, or if the DME is out of service.

2.12 The use of supplementary sources of orientation guidance in association with ILS

2.12.1 Aircraft beginning an ILS approach may be assisted by guidance information provided by other ground referenced facilities such as VORs, surveillance radar or, where these facilities cannot be provided, by a locator beacon.

2.12.2 When not provided by existing terminal or en-route facilities, a VOR, suitably sited, will provide efficient transition to the ILS. To achieve this purpose the VOR may be sited on the localizer course or at a position some distance from the localizer course provided that a radial will intersect the localizer course at an angle which will allow smooth transitions in the case of auto coupling. The distance between the VOR site and the desired point of interception must be recognized when determining the accuracy of the interception and the airspace available to provide for tracking errors.

2.12.3 Where it is impracticable to provide a suitably sited VOR, a compass locator or an NDB can assist transition to the ILS. The facility should be sited on the localizer course at a suitable distance from the threshold to provide for optimum transition.

2.13 The use of Facility Performance Category I — ILS for automatic approaches and landings in visibility conditions permitting visual monitoring of the operation by the pilot

2.13.1 Facility Performance Category I — ILS installations of suitable quality can be used, in combination with aircraft flight control systems of types not relying solely on the guidance information derived from the ILS sensors, for automatic approaches and automatic landings in visibility conditions permitting visual monitoring of the operation by the pilot.

2.13.2 To assist aircraft operating agencies with the initial appraisal of the suitability of individual ILS installations for such operations, provider States are encouraged to promulgate:

a) the differences in any respect from Chapter 3, 3.1;

b) the extent of compliance with the provisions in Chapter 3, 3.1.3.4 and 3.1.5.4, regarding localizer and glide path beam structure; and

c) the height of the ILS reference datum above the threshold.

2.13.3 To avoid interference which might prevent the completion of an automatic approach and landing, it is necessary that local arrangements be made to protect, to the extent practicable, the ILS critical and sensitive areas.

2.14 ILS classification — supplementary ILS description method with objective to facilitate operational utilization

2.14.1 The classification system given below, in conjunction with the current facility performance categories, is intended to provide a more comprehensive method of describing an ILS.

2.14.2 The ILS classification is defined by using three characters as follows:

a) I, II or III: this character indicates conformance to Facility Performance Category in Chapter 3, 3.1.3 and 3.1.5.

b) A, B, C, T, D or E: this character defines the ILS points to which the localizer structure conforms to the course structure given at Chapter 3, 3.1.3.4.2, except the letter T, which designates the runway threshold. The points are defined in Chapter 3, 3.1.1.

c) 1, 2, 3 or 4: this number indicates the level of integrity and continuity of service given in Table C-4.

Note.— In relation to specific ILS operations it is intended that the level of integrity and continuity of service would typically be associated as follows:

1) Level 2 is the performance objective for ILS equipment used to support low visibility operations when ILS guidance for position information in the landing phase is supplemented by visual cues. This level is a recommended objective for equipment supporting Category I operations;

2) Level 3 is the performance objective for ILS equipment used to support operations which place a high degree of reliance on ILS guidance for positioning through touchdown. This level is a required objective for equipment supporting Category II and IIIA operations; and

3) Level 4 is the performance objective for ILS equipment used to support operations which place a high degree of reliance on ILS guidance throughout touchdown and roll-out. This level basically relates to the needs of the full range of Category III operations.

2.14.3 As an example, a Facility Performance Category II — ILS which meets the localizer course structure criteria appropriate to a Facility Performance Category III — ILS down to ILS point "D" and conforms to the integrity and continuity of service objectives of Level 3 would be described as class II/D/3.

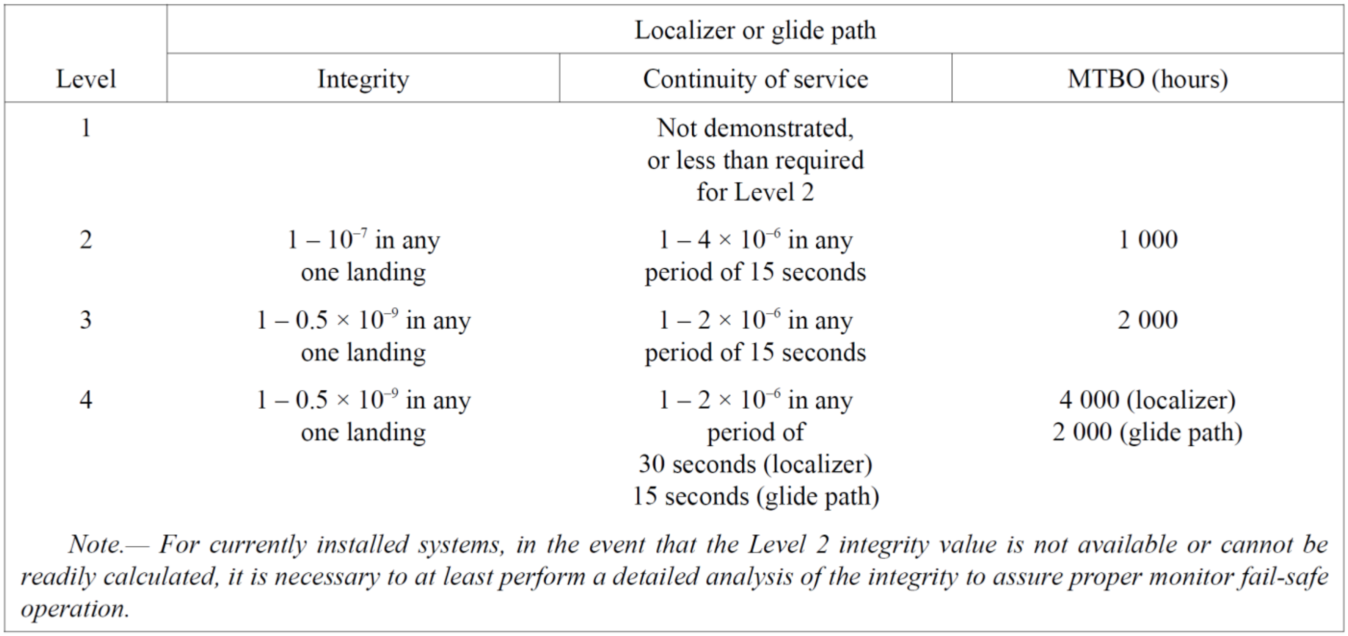
2.14.4 ILS classes are appropriate only to the ground ILS element. Consideration of operational categories must also include additional factors such as operator capability, critical and sensitive area protection, procedural criteria and ancillary aids, such as transmissometers and lights.

2.15 ILS carrier frequency and phase modulation

2.15.1 In addition to the desired 90 Hz and 150 Hz AM modulation of the ILS RF carriers, undesired frequency modulation (FM) and/or phase modulation (PM) may exist. This undesired modulation can cause centring errors in ILS receivers due to slope detection by ripple in the intermediate frequency (IF) filter pass-band.

2.15.2 For this to occur, the translated RF carrier frequency must fall on an IF frequency where the pass-band has a high slope. The slope converts the undesired 90 Hz and 150 Hz frequency changes to AM of the same frequencies. Similarly, any difference in FM deviation between the undesired 90 Hz and 150 Hz components is converted to DDM, which in turn produces an offset in the receiver. The mechanism is identical for PM as for FM, since PM causes a change in frequency equal to the change in phase (radians) multiplied by the modulating frequency.

Table C-4. Integrity and continuity of service objectives



Level	Localizer or glide path		
	Integrity	Continuity of service	MTBO (hours)
1		Not demonstrated, or less than required for Level 2	
2	$1 - 10^{-7}$ in any one landing	$1 - 4 \times 10^{-6}$ in any period of 15 seconds	1 000
3	$1 - 0.5 \times 10^{-9}$ in any one landing	$1 - 2 \times 10^{-6}$ in any period of 15 seconds	2 000
4	$1 - 0.5 \times 10^{-9}$ in any one landing	$1 - 2 \times 10^{-6}$ in any period of 30 seconds (localizer) 15 seconds (glide path)	4 000 (localizer) 2 000 (glide path)

Note.— For currently installed systems, in the event that the Level 2 integrity value is not available or cannot be readily calculated, it is necessary to at least perform a detailed analysis of the integrity to assure proper monitor fail-safe operation.

2.15.3 The effect of the undesired FM and/or PM is summed by vector addition to the desired AM. The detected FM is either in phase or anti-phase with the AM according to whether the pass-band slope at the carrier’s IF is positive or negative. The detected PM is in quadrature with the AM, and may also be positive or negative according to the pass-band slope.

2.15.4 Undesired FM and/or PM from frequencies other than 90 Hz and 150 Hz, but which pass through the 90 Hz and 150 Hz tone filters of the receiver, can also cause changes to the desired 90 Hz and 150 Hz AM modulation of the ILS RF carrier, resulting in a DDM offset error in the receiver. Thus, it is essential that when measuring undesired FM and PM levels, audio band-pass filters with a pass-band at least as wide as that of the tone filters of ILS receivers be used. These filters are typically inserted in commercial modulation meter test equipment between the demodulation and metering circuits, to ensure that only spectral components of interest to ILS applications are measured. To standardize such measurements, the filter characteristics are recommended as shown below:

Frequency (Hz)	*90 Hz band-pass filter attenuation, dB*	*150 Hz band-pass filter attenuation, dB*
≤45	–10	–16
85	–0.5	(no specification)
90	0	–14
95	–0.5	(no specification)
142	(no specification)	–0.5
150	–14	0
158	(no specification)	–0.5
≥300	–16	–10

2.15.5 The preferred maximum limits, as shown below, are derived from ILS receiver centring error limits specified in EUROCAE documents ED-46B and ED-47B, based on the worst-case-to-date observed correlation between undesired modulation levels and centring errors:

Facility type	*90 Hz peak deviation, FM Hz/PM radians (Note 1)*	*150 Hz peak deviation, FM Hz/PM radians (Note 2)*	*Deviation difference, Hz (Note 3)*
Localizer, Cat I	135/1.5	135/0.9	45
Localizer, Cat II	60/0.66	60/0.4	20
Localizer, Cat III	45/0.5	45/0.3	15
Glide path, Cat I	150/1.66	150/1.0	50
Glide path, Cat II or III	90/1.0	90/0.6	30

Note 1.— This column applies to the peak frequency or phase deviation as measured with the 90 Hz tone filter specified in 2.15.4.

Note 2.— This column applies to the peak frequency or phase deviation as measured with the 150 Hz tone filter specified in 2.15.4.

Note 3.— This column applies to the difference in peak frequency deviation between the separate measurements of the undesired 90 Hz FM (or equivalent PM) and the 150 Hz FM (or equivalent PM) obtained with the filters specified in the table in 2.15.4. The equivalent deviation for 90 Hz and 150 Hz measured PM values is calculated by multiplying each peak PM measurement in radians by its corresponding modulating frequency in Hz.

3. Material concerning VOR/DVOR

3.1 Guidance relating to VOR/DVOR equivalent isotropically radiated power (EIRP) and coverage

Note.— Unless specifically mentioned, all guidance material provided below applies to VOR and DVOR signals.

3.1.1 The field strength specified at Chapter 3, 3.3.4.2, is based on the following consideration:

Airborne receiver sensitivity	–117 dBW
Transmission line loss, mismatch loss, antenna polar pattern variation with respect to an isotropic antenna	+7 dB
Power required at antenna	–110 dBW

The power required of minus 110 dBW is obtained at 118 MHz with a power density of minus 107 dBW/m^2; minus 107 dBW/m^2 is equivalent to 90 microvolts per metre, i.e. plus 39 dB referenced to 1 microvolt per metre.

Note.— The power density for the case of an isotropic antenna may be computed in the following manner:

$$P_d = P_a - 10 \log \frac{\lambda^2}{4\pi}$$

where

P_d = *power density in dBW/m^2;*

P_a = *power at receiving point in dBW;*

λ = *wavelength in metres.*

3.1.2 The necessary EIRP to achieve a field strength of 90 microvolts per metre (minus 107 dBW/m^2) is given in Figure C-13. The field strength is directly proportional to the antenna elevation pattern. The actual radiation patterns of the antennas depend on a number of factors such as height of the antenna phase centre above ground level (AGL), surface roughness, terrain form and conductivity of ground and counterpoise. However, to account for lowest EIRP in notches between the lobes of the real elevation antenna pattern, a conservative value has been provided. Whenever more precise system data are available, a more precise estimation of range is permissible. Further guidance may be found in the *Handbook on Radio Frequency Spectrum Requirements for Civil Aviation including statement of approved ICAO policies* (Doc 9718).

3.2 Guidance in respect of siting of VOR

3.2.1 VOR is susceptible to multipath interference from surrounding terrain, buildings, trees and power lines. The effect of this should therefore be considered when selecting a site for a new facility, and when considering the acceptability of proposed developments in the vicinity of established sites. Doppler VOR is more resistant to multipath interference than conventional VOR and may be used to provide acceptable performance on more challenging multipath sites.

Note.— Guidance on siting of VOR is given in documents EUROCAE ED-52 (including Amendment No. 1), United States Federal Aviation Administration Order 6820.10 and ICAO EUR DOC 015 (First Edition).

3.2.2 The impact of wind farm developments on VOR is an increasing problem in many States due to the growth of interest in alternative energy sources. The impact of wind farms on VOR is difficult to assess for several reasons, including:

a) the cumulative effect of a group of turbines may be unacceptable even though the effect of each of the turbines may be acceptable individually;

b) worst-case errors may be experienced when the turbine blades are stationary (due to either high or low wind speeds). The actual error is a function of the orientation of the turbine and position of the turbine blades when stationary;

c) worst-case errors are likely to be experienced at the limit of coverage and at low elevation angles; and

d) it is unlikely that the worst-case errors can be confirmed by flight inspections due to the factors listed above.

3.2.3 Computer simulations can be used to assess the effect of wind farms on VOR using worst-case assumptions, as outlined above.

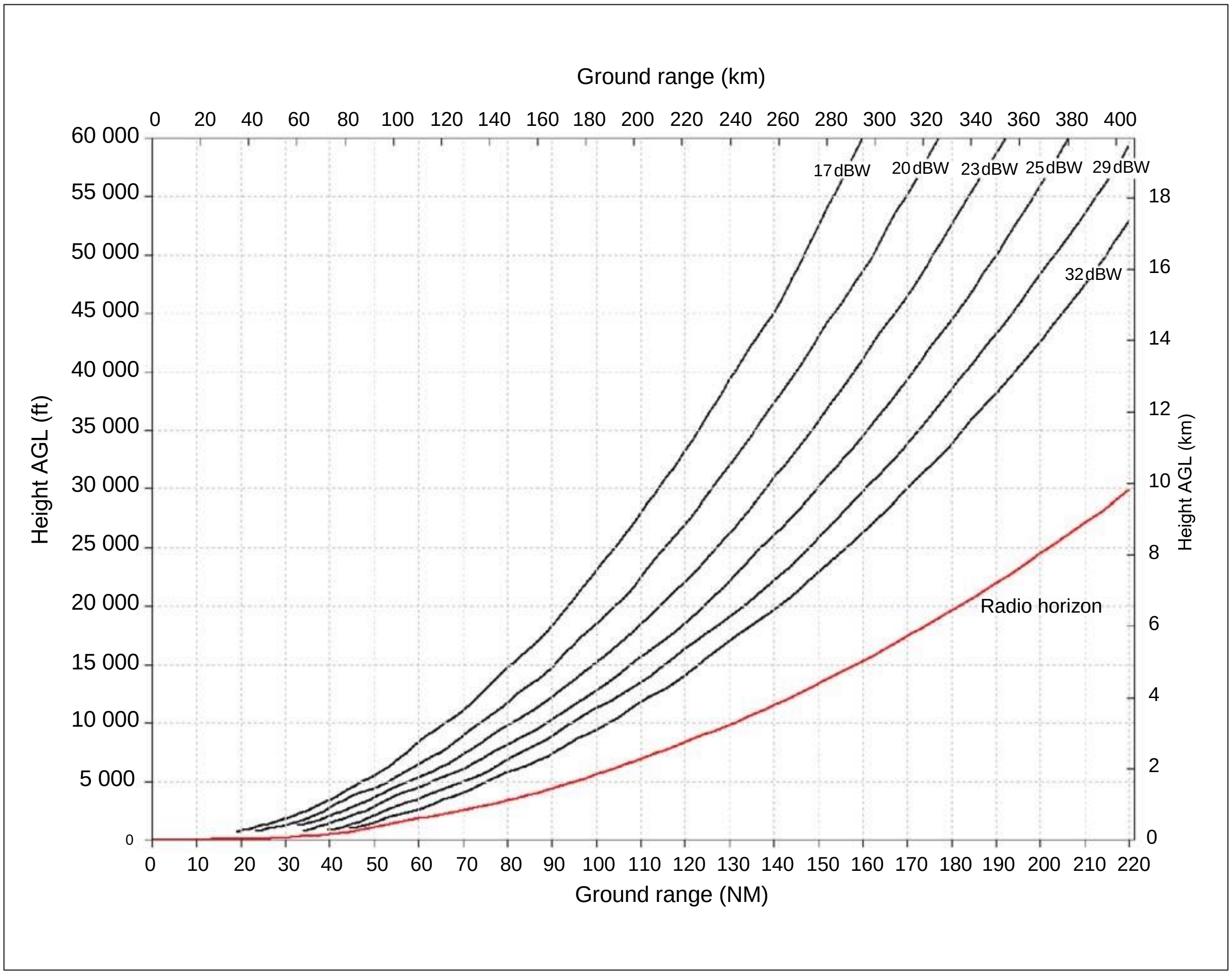


Figure C-13. Necessary EIRP to achieve a field strength of 90 microvolts per metre (−107 dBW/m^2) as a function of height above and distance from the VOR/DVOR

Note 1.— The curves are based on the IF-77 propagation model with a 4/3 Earth radius which has been confirmed by measurements.

Note 2.— The guidance provided assumes that the VOR/DVOR counterpoise height above ground level (AGL) that defines the antenna pattern is at 3 m (10 ft) AGL over flat terrain. Terrain shielding will reduce the achievable range.

Note 3.— The transmitted power required to achieve an EIRP value as shown depends upon transmitting antenna gain and cable losses. As an example, an EIRP of 25 dBW can be achieved by a VOR with an output power of 100 W, a cable loss of 1 dB and an antenna gain of 6 dBi.

3.3 [Reserved]

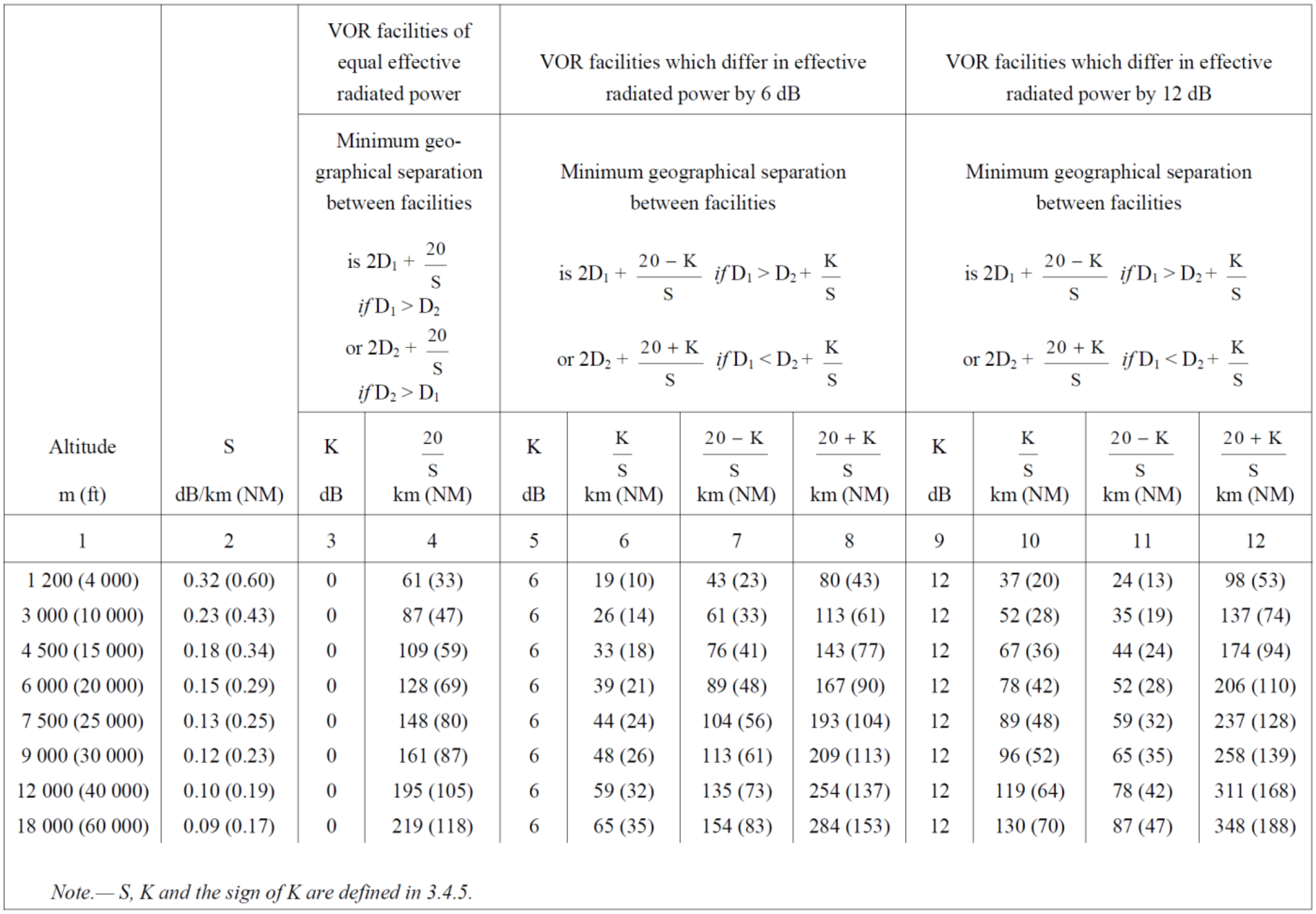
3.4 Criteria for geographical separation of VOR type facilities

3.4.1 In using the figures listed in Table C-5, it must be noted that these are derived from the agreed formulae in respect of specific altitudes. In application of the figures, regional meetings would only afford protection to the extent of the operationally required altitude and distance and, by use of the formulae, criteria can be calculated for any distance or altitude.

3.4.2 The figures listed are calculated on the assumption that the effective adjacent channel rejection of the airborne receiver is better than 60 dB down at the next assignable channel.

3.4.3 The calculations are based on the assumption that the protection against interference afforded to the wanted signal from the unwanted signal is 20 dB, corresponding to a bearing error of less than 1 degree due to the unwanted signal.

Table C-5. Values of geographical separation distances for co-channel operation



		VOR facilities of equal effective radiated power		VOR facilities which differ in effective radiated power by 6 dB				VOR facilities which differ in effective radiated power by 12 dB			
		Minimum geographical separation between facilities is $2D_1 + \frac{20}{S}$ *if* $D_1 > D_2$ or $2D_2 + \frac{20}{S}$ *if* $D_2 > D_1$		Minimum geographical separation between facilities is $2D_1 + \frac{20-K}{S}$ *if* $D_1 > D_2 + \frac{K}{S}$ or $2D_2 + \frac{20+K}{S}$ *if* $D_1 < D_2 + \frac{K}{S}$				Minimum geographical separation between facilities is $2D_1 + \frac{20-K}{S}$ *if* $D_1 > D_2 + \frac{K}{S}$ or $2D_2 + \frac{20+K}{S}$ *if* $D_1 < D_2 + \frac{K}{S}$			
Altitude m (ft)	S dB/km (NM)	K dB	$\frac{20}{S}$ km (NM)	K dB	$\frac{K}{S}$ km (NM)	$\frac{20-K}{S}$ km (NM)	$\frac{20+K}{S}$ km (NM)	K dB	$\frac{K}{S}$ km (NM)	$\frac{20-K}{S}$ km (NM)	$\frac{20+K}{S}$ km (NM)
1	2	3	4	5	6	7	8	9	10	11	12
1 200 (4 000)	0.32 (0.60)	0	61 (33)	6	19 (10)	43 (23)	80 (43)	12	37 (20)	24 (13)	98 (53)
3 000 (10 000)	0.23 (0.43)	0	87 (47)	6	26 (14)	61 (33)	113 (61)	12	52 (28)	35 (19)	137 (74)
4 500 (15 000)	0.18 (0.34)	0	109 (59)	6	33 (18)	76 (41)	143 (77)	12	67 (36)	44 (24)	174 (94)
6 000 (20 000)	0.15 (0.29)	0	128 (69)	6	39 (21)	89 (48)	167 (90)	12	78 (42)	52 (28)	206 (110)
7 500 (25 000)	0.13 (0.25)	0	148 (80)	6	44 (24)	104 (56)	193 (104)	12	89 (48)	59 (32)	237 (128)
9 000 (30 000)	0.12 (0.23)	0	161 (87)	6	48 (26)	113 (61)	209 (113)	12	96 (52)	65 (35)	258 (139)
12 000 (40 000)	0.10 (0.19)	0	195 (105)	6	59 (32)	135 (73)	254 (137)	12	119 (64)	78 (42)	311 (168)
18 000 (60 000)	0.09 (0.17)	0	219 (118)	6	65 (35)	154 (83)	284 (153)	12	130 (70)	87 (47)	348 (188)

Note.— S, K and the sign of K are defined in 3.4.5.

3.4.4 It is recognized that, in the case of adjacent channel operation, there is a small region in the vicinity of a VOR facility, in which interference may be caused to an aircraft using another VOR facility. However, the width of this region is so small that the duration of the interference would be negligible and, in any case, it is probable that the aircraft would change its usage from one facility to the other.

3.4.5 The agreed formulae for calculating the geographical separations are as follows (nautical miles may be substituted for kilometres):

A — *minimum geographical separation (co-channel):*

either $2\,D_1 + \frac{20 - K}{S}$ km

where $D_1 > D_2 + \frac{K}{S}$

or $2\,D_2 + \frac{20 + K}{S}$ km

where $D_1 < D_2 + \frac{K}{S}$

B — *geographical separation (adjacent channel):*

collocation case

$$< \frac{40 - K}{S}$$

non-collocated case

$$> 2D_1 - \frac{40 + K}{S}\ km$$

where $D_1 > D_2 + \frac{K}{S}$

or $2D_2 - \frac{40 - K}{S}\ km$

where $D_1 < D_2 + \frac{K}{S}$

C — *geographical separation (adjacent channel)*
(receivers designed for 100 kHz channel spacing in a 50 kHz channel spacing environment)

If receivers having an effective adjacent channel rejection of no better than 26 dB are used (e.g. a 100 kHz receiver used in a 50 kHz environment), a figure of 6 should be substituted for the figure of 40 in the above adjacent channel formulae. In this instance, the geographical collocation formula should not be used as the protection afforded may be marginal.

This leads to the following formula:

$$> 2D_1 + \frac{6+K}{S}\ km$$

$$\text{where} \qquad D_1 > D_2 + \frac{K}{S}$$

$$or \qquad 2D_2 - \frac{6-K}{S}\ km$$

$$\text{where} \qquad D_1 < D_2 + \frac{K}{S}$$

In the above formulae:

D_1, D_2 = service distances required of the two facilities (km).

K = the ratio (dB) by which the effective radiated power of the facility providing D_1 coverage exceeds that of the facility providing D_2 coverage.

Note.— If the facility providing D_2 is of higher effective radiated power, then "K" will have a negative value.

S = slope of the curve showing field strength against distance for constant altitude (dB/km).

3.4.6 The figures listed in Table C-5 are based on providing an environment within which the airborne receivers can operate correctly.

3.4.6.1 In order to protect VOR receivers designed for 50 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

3.4.6.2 In order to protect VOR receivers designed for 100 kHz channel spacing, minimum separations are chosen in order to provide the following minimum signal ratios within the service volume:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 7 dB;

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

3.4.7 Use of the figures given in 3.4.6 or other figures appropriate to other service distances and altitudes implies recognition of the basic assumptions made in this substitution of an approximate method of calculating separation, and the application of the figures will only be correct within the limitations set by those assumptions. The assumptions include that the change of field strength with distance (Factor "S") at various altitudes of reception is only valid for angles of elevation at the VOR of up to about 5 degrees, but above the radio line of sight. If more precise determination of separation distances is required in areas of frequency congestion, this may be determined for each facility from appropriate propagation curves.

3.4.8 The deployment of 50 kHz channel spacing requires conformity with Chapter 3, 3.3.2.2 and 3.3.5.7 and Annex 10, Volume V, Chapter 4, 4.2.4. Where, due to special circumstances it is essential during the initial conversion period from 100 kHz channel spacing to 50 kHz channel spacing to take account of nearby VOR facilities that do not conform with Chapter 3, 3.3.2.2 and 3.3.5.7 and Annex 10, Volume V, Chapter 4, 4.2.4, greater geographical separation between these and the new facilities utilizing 50 kHz channel spacing will be required to ensure a bearing error of less than one degree due to the unwanted signal. On the assumption that the sideband levels of the 9 960 Hz harmonic of the radiated signal of such facilities do not exceed the following levels:

9960 Hz	0 dB reference
2nd harmonic	–20 dB
3rd harmonic	–30 dB
4th harmonic and above	–40 dB

the separation formulae at 3.4.5 should be applied as follows:

a) where only receivers designed for 50 kHz channel spacing need to be protected, the value of 40 should be replaced by 20 in the formula at B — non-collocated case;

b) where it is necessary to protect receivers designed for 100 kHz channel spacing, the co-channel formula at A — cochannel case, should be applied for the range of altitudes for which protection is required.

3.4.9 When DME/N facilities and VOR facilities are intended to operate in association with each other, as outlined in Chapter 3, 3.5.3.3.4, and have a common service volume, both the co-channel and adjacent channel geographical separation distances required by the DME are satisfied by the separation distances of the VOR as computed in this section, provided the distance between VOR and DME does not exceed 600 m (2 000 ft). A potential interference situation may also occur with the implementation of DME "Y" channels since interference between two DME ground stations spaced 63 MHz apart could occur when transmitting and receiving on the same frequency (e.g. transmissions from channel 17 Y could interfere with reception on channels 80 X and 80 Y). To obviate any ground receiver desensitization due to this interference, a minimum ground separation distance of 18.5 km (10 NM) between facilities is necessary.

3.5 Criteria for geographical separation of VOR/ILS facilities

3.5.1 In using the figures of 3.5.3.1 and 3.5.3.2, it is to be borne in mind that the following assumptions have been made:

a) that the localizer receiver characteristic is as shown in 2.6.2, and the VOR receiver characteristic as shown in 3.4.2;

b) that the protection ratio for the ILS system and the VOR system is 20 dB as in 2.6.4 and 3.4.3, respectively;

c) that the protection point for ILS is at a service distance of 46.25 km (25 NM) measured along the line of use, and at an altitude of 1 900 m (6 250 ft).

Note.— With the advent of highly directional ILS localizer antenna arrays, the most critical protection point will not be along the extended runway centre line. Directive antennas result in critical protection points at maximum distance, either plus or *minus 10 degrees or plus or minus 35 degrees off the runway centre line. Protection of these points should be examined during the frequency assignment process.*

3.5.2 Although international VOR and ILS facilities will not appear on the same frequency, it may occur that an international VOR facility may share temporarily the same frequency as, and on a comparable basis with, a national ILS facility. For this reason, guidance is given as to the geographical separation required not only for a VOR and an ILS facility separated by 50 kHz or 100 kHz, but also for co-channel usage.

3.5.3 Because of the differing characteristics of use of the two equipments, the criteria for minimum geographical separation of VOR/ILS to avoid harmful interference are stated separately for each facility where relevant.

3.5.3.1 *Co-channel case*

a) Protection of the ILS system requires that a VOR having an ERP of 17 dBW (50 W) be at least 148 km (80 NM) from the ILS protection point.

b) On the assumption that a VOR having an ERP of 17 dBW (50 W) is to be protected to a service distance of 46.25 km (25 NM) and an altitude of 3 000 m (10 000 ft), protection of the VOR system requires that the ILS be at least 148 km (80 NM) from the VOR.

c) If protection of the VOR is required to, say, 92.5 km (50 NM) and 6 000 m (20 000 ft), the ILS is to be at least 250 km (135 NM) from the VOR.

3.5.3.2 *Adjacent channel case.* Protection of the VOR system is effectively obtained without geographical separation of the facilities. However, in the case of:

a) a localizer receiver designed for 100 kHz channel spacing and used in an area where navaid assignments are spaced at 100 kHz, the protection of the ILS system requires that a VOR having an ERP of 17 dBW (50 W) be at least 9.3 km (5 NM) from the ILS protection point;

b) a localizer receiver designed for 100 kHz channel spacing and used in an area where assignments are spaced at 50 kHz, the protection of the ILS system requires that a VOR having an ERP of 17 dBW (50 W) be at least 79.6 km (43 NM) from the ILS protection point.

3.5.4 Use of the figures given in 3.5.3 or other figures appropriate to other service distances and altitudes implies recognition of the basic assumptions made in this substitution of an approximate method of calculating separation, and the application of the figures will only be correct within the limitations set by those assumptions. If more precise determination of separation distances is required in areas of frequency congestion, this may be determined for each facility from appropriate propagation curves.

3.5.5 Protection of the ILS system from VOR interference is necessary where a VOR facility is located near an ILS approach path. In such circumstances, to avoid disturbance of the ILS receiver output due to possible cross modulation effects, suitable frequency separation between the ILS and VOR channel frequencies should be used. The frequency separation will be dependent upon the ratio of the VOR and ILS field densities, and the characteristics of the airborne installation.

3.6 Receiving function

3.6.1 *Sensitivity.* After due allowance has been made for aircraft feeder mismatch, attenuation loss and antenna polar diagram variation, the sensitivity of the receiving function should be such as to provide on a high percentage of occasions the accuracy of output specified in 3.6.2, with a signal having a field strength of 90 microvolts per metre or minus 107 dBW/m^2.

3.6.2 *Accuracy.* The error contribution of the airborne installation should not exceed plus or minus 3 degrees with a 95 per cent probability.

Note 1.— The assessment of the error contribution of the receiver will need to take account of:

1) *the tolerance of the modulation components of the ground VOR facility as defined in Chapter 3, 3.3.5;*

2) *variation in signal level and carrier frequency of the ground VOR facility;*

3) *the effects of unwanted VOR and ILS signals.*

Note 2.— The airborne VOR installation is not considered to include any special elements which may be provided for the processing of VOR information in the aircraft and which may introduce errors of their own (e.g. radio magnetic indicator (RMI).).

3.6.3 *Flag alarm operation.* Ideally, the flag alarm should warn a pilot of any unacceptable malfunctioning conditions which might arise within either the ground or airborne equipments. The extent to which such an ideal might be satisfied is specified below.

3.6.3.1 The flag alarm movement is actuated by the sum of two currents which are derived from the 30 Hz and 9 960 Hz elements of the VOR bearing component signal and, therefore, the removal of these elements from the radiated carrier results in the appearance of the flags. Since the VOR ground monitor interrupts the bearing components when any unacceptable condition prevails on the ground, there will be an immediate indication within an aircraft when the system is unusable.

3.6.3.2 The flag alarm movement current is also dependent upon the AGC characteristics of the airborne equipment and any subsequent gain following the receiver's second detector. Thus, if with a correctly adjusted airborne receiver the flag is just out of view when receiving a VOR signal conforming to the modulation characteristics specified in Chapter 3, 3.3.5, the flags will again become visible in the event of a decrease in the receiver's overall gain characteristics.

Note.— Certain types of receivers employ warning indications other than mechanical flags to perform the functions described here.

3.6.4 *VOR receiver susceptibility to VOR and localizer signals*

3.6.4.1 The receiver design should provide correct operation in the following environment:

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;

b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB (during bench testing of the receiver, in this first adjacent channel case, the undesired signal is varied over the frequency range of the combined ground station (plus or minus 9 kHz) and receiver frequency tolerance);

c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB;

d) an undesired signal, 150 kHz or further removed from the desired signal, exceeds the desired signal by up to 50 dB.

Note 1.— It is recognized that not all receivers currently meet requirement b); however, all future equipments are designed to meet this requirement.

Note 2.— In some States, a smaller ground station tolerance is used.

3.6.5 *Immunity performance of VOR receiving systems to interference from VHF FM broadcast signals*

3.6.5.1 With reference to Chapter 3, 3.3.8, the immunity performance defined therein must be measured against an agreed measure of degradation of the receiving system's normal performance, and in the presence of, and under standard conditions for the input wanted signal. This is necessary to ensure that the testing of receiving equipment on the bench can be performed to a repeatable set of conditions and results and to facilitate their subsequent approval. Additional information can be found in ITU Recommendation ITU-R SM.1140, *Test procedures for measuring aeronautical receiver characteristics used for determining compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–118 MHz.*

Note.— Receiver test procedures are also given in the VOR receiver MOPS (RTCA DO-196, and EUROCAE ED-22B).

3.6.5.2 Commonly agreed formulae should be used to assess potential incompatibilities to receivers meeting the general interference immunity criteria specified in Chapter 3, 3.3.8. The formulae provide clarification of immunity interference performance of spurious emission (type A1) interference, out-of-band channel (type A2) interference, two-signal and three-signal third order (type B1) interference, and overload/desensitization (type B2) interference. Additional information can be found in ITU Recommendation ITU-R IS.1009-1, *Compatibility between the sound-broadcasting service in the band of about 87–108 MHz and the aeronautical services in the band 108–137 MHz.*

3.7 VOR system accuracy

Note.— Guidance material on the determination of VOR system performance values is also contained in Annex 11, Attachment A.

3.7.1 *Purpose.* The following guidance material is intended to assist in the use of VOR systems. It is not intended to represent lateral separation standards or minimum obstacle clearances, although it may of course provide a starting point in their determination. The setting of separation standards or minimum obstacle clearances will necessarily take account of many factors not covered by the following material.

3.7.1.1 There is, however, a need to indicate a system use accuracy figure for the guidance of States planning VOR systems.

3.7.2 *Explanation of terms.* The following terms are used with the meanings indicated:

a) *VOR radial signal error.* The difference between the nominal magnetic bearing to a point of measurement from the VOR ground station and the bearing indicated by the VOR signal at that same point. The VOR radial signal error is made up of certain stable elements, such as course displacement error and most site and terrain effect errors, and certain random variable errors. The VOR radial signal error is associated with the ground station only and excludes other error factors, such as airborne equipment errors and pilotage element.

b) *VOR radial variability error.* That part of the VOR radial signal error which can be expected to vary about the essentially constant remainder. The radial variability error is the sum of the variable errors.

c) *VOR radial displacement error.* That part of the VOR radial signal error which is stable and may be considered as fixed for long periods of time.

d) *VOR airborne equipment error.* That error attributable to the inability of the equipment in the aircraft to translate correctly the bearing information contained in the radial signal. This error includes the contributions of the airborne receiver and the instrumentation used to present the information to the pilot.

e) *VOR aggregate error.* The difference between the magnetic bearing to a point of measurement from the VOR ground station and the bearing indicated by airborne VOR equipment of stated accuracy. More simply put, this is the error in the information presented to the pilot, taking into account not only the ground station and propagation path errors, but also the error contributed by the airborne VOR receiver and its instrumentation. The entire VOR radial signal error, both fixed and variable, is used.

f) *VOR pilotage element.* The error in the use of VOR navigation attributable to the fact that the pilot cannot or does not keep the aircraft precisely at the centre of the VOR radial or bearing indicated by the equipment.

g) *VOR system use error.* The square root of the sum of the squares (RSS) of VOR aggregate error and the pilotage element. This combination may be used to determine the probability of an aircraft remaining within specified limits when using VOR.

3.7.3 *Calculation of VOR system use accuracy*

3.7.3.1 The VOR system use accuracy is derived by considering the following error elements:

a) *VOR radial signal error* (Eg). This element consists of the radial displacement error and the radial variability error. It is determined by considering such factors as fixed radial displacement, monitoring, polarization effects, terrain effects and environment changes.

b) *VOR airborne equipment error* (Ea). This element embraces all factors in the airborne VOR system which introduces errors (errors resulting from the use of compass information in some VOR displays are not included).

c) *VOR pilotage element* (Ep). The value taken for this element is that used in PANS-OPS (Doc 8168) for pilot tolerance.

Note.— A measurement error also exists, but in a generalized discussion of errors may be considered to be absorbed in the other error values.

3.7.3.2 Since the errors in a), b), and c), when considered on a system basis (not any one radial) are independent variables, they may be combined on a root-sum-square method (RSS) when the same probability level is given to each element. For the purpose of this material, each element is considered to have a 95 per cent probability.

Therefore, the following formulae are derived:

$$\text{VOR aggregate error} = \sqrt{\text{Eg}^2 + \text{Ea}^2}$$

$$\text{VOR system use error} = \sqrt{\text{Eg}^2 + \text{Ea}^2 + \text{Ep}^2}$$

3.7.3.3 The following examples will derive only the VOR system use error but calculations can also be made to determine VOR aggregate error, if desired. By use of these formulae, the impact on the system of improvement or degradation of one of more error elements can be assessed.

Note.— All figures for VOR radial signal error are related to radials for which no restrictions are published.

3.7.3.4 Subject to the qualifications indicated in 3.7.1, it is considered that a VOR system use accuracy of plus or minus 5 degrees on a 95 per cent probability basis is a suitable figure for use by States planning the application of the VOR system (see, however, 3.7.3.5). This figure corresponds to the following component errors:

VOR radial signal error:

plus or minus 3° (95 per cent probability), a value readily achieved in practice.

VOR airborne equipment error:

plus or minus 3° (95 per cent probability), system characteristics value (see 3.6.2).

VOR pilotage element:

plus or minus 2.5° (95 per cent probability), in accordance with PANS-OPS (see also 3.7.3.8).

3.7.3.5 While the figure of plus or minus 5 degrees on a 95 per cent probability basis is a useful figure based on broad practical experience and used by many States, it must be noted that this figure may be achieved only if the error elements which make it up remain within certain tolerances. It is clear that, if the errors attributable to the VOR system elements are larger than the amounts noted, the resulting VOR system use error will also be larger. Conversely, where any or all of the VOR system error elements are smaller than those used in the above computation, the resulting VOR system use error will also be smaller.

3.7.3.6 The following examples, also derived from practical experience, provide additional planning guidance for States:

A.— *VOR radial signal error:*

plus or minus 3.5° (95 per cent probability), used by some States as the total ground system error.

VOR airborne equipment error:

plus or minus 4.2° (95 per cent probability), recognized in some States as the minimum performance figure for some classes of operations.

VOR pilotage element:

plus or minus 2.5° (95 per cent probability), in accordance with PANS-OPS (see also 3.7.3.8).

Calculated VOR system use accuracy:

plus or minus 6° (95 per cent probability).

B. — *VOR radial signal error:*

plus or minus 1.7° (95 per cent probability), based on extensive flight measurements conducted in one State on a large number of VORs.

VOR airborne equipment error:

plus or minus 2.7° (95 per cent probability), achieved in many airline operations.

VOR pilotage element:

plus or minus 2.5° (95 per cent probability), in accordance with PANS-OPS (see also 3.7.3.8).

Calculated VOR system use accuracy:

plus or minus 4° (95 per cent probability).

3.7.3.7 More realistic application of the VOR system may be achieved by assessing the errors as they actually exist in particular circumstances, rather than by using all-embracing generalizations which may give unduly optimistic or pessimistic results. In individual applications, it may be possible to utilize a system use accuracy value less than plus or minus 5 degrees if one or more of the error elements are smaller than the values used to compute the plus or minus 5 degrees. Conversely, a system use accuracy value greater than plus or minus 5 degrees will be necessary where it is known that radials are of poor quality or significant site errors exist, or for other reasons. However, in addition to this advice a warning is also essential regarding the use of lower values of individual elements in the system (for example, the radial signal error) on the assumption that an overall improvement in system accuracy will occur. There is considerable evidence that this may not be the case in some circumstances and that lower system accuracy values should not be applied without other confirmation (e.g. by radar observation) that an actual improvement in overall performance is being achieved.

3.7.3.8 It is to be noted that in angular systems such as the VOR, the pilotage element error, expressed in angular terms, will be greater as the aircraft nears the point source. Thus, while ground system and airborne error contributions, expressed in angular terms, are for all practical purposes constant at all ranges, it is necessary when considering the overall system use accuracy figures to take into account the larger pilotage element error occurring when the aircraft is near the VOR. However, these larger pilotage element errors do not result in large lateral deviations from course when near the facility.

3.8 Changeover points for VORs

Guidance on the establishment of changeover points on ATS routes defined by VORs is contained in Annex 11, Attachment A.

4. Reserved

5. Specification for 75 MHz marker beacons (en-route)

5.1 Marker beacon antenna arrays

5.1.1 *General.* The following describes types of marker antenna arrays that are frequently used in current practice. These types are the simplest forms meeting normal requirements; in special cases, arrays having a better performance (see Note to 5.1.4) may be required.

5.1.2 *Z marker beacons*

a) *Radiating system.* A radiating system consisting of two horizontal dipole arrays crossed at right angles, each comprising two co-linear half-wave radiating elements with centres spaced approximately a half wavelength apart and mounted one-quarter wavelength above the counterpoise. The currents in the dipoles and their respective elements are adjusted so that:

   1) the current in one set of dipole arrays relative to that in the other set is equal but differs in time phase by 90 degrees;

   2) the currents in the radiating elements of a particular dipole array are equal and in time phase.

b) *Counterpoise.* A square counterpoise with minimum dimensions of 9 m × 9 m, usually elevated about 1.8 m (6 ft) above the ground and, if fabricated from wire mesh, with the dimension of the mesh not exceeding 7.5 cm × 7.5 cm.

5.1.3 *Fan marker beacons for use only at low altitudes (low power fan marker beacons).* A radiating system capable of providing the field strengths indicated in Chapter 3, 3.1.7.3.2.

5.1.4 *Fan marker beacons for general use (high power fan marker beacons)*

a) *Radiating system.* A radiating system consisting of four horizontal co-linear half-wave (approximate) radiating elements mounted approximately one-quarter wavelength above the counterpoise. The current in each of the antenna elements should be in phase and should have a current ratio of 1:3:3:1.

Note.— The current distribution between elements and their height above the counterpoise may be altered to provide patterns for specific operational requirements. Improved vertical patterns for certain operational needs may be achieved by adjusting the height of the dipole arrays above the counterpoise to a value of one-quarter wavelength or greater, but less than a half wavelength.

b) *Counterpoise.* A rectangular counterpoise with minimum dimensions of 6 m × 12 m, usually elevated about 1.8 m (6 ft) above the ground and, if fabricated from wire mesh, with the dimension of the mesh not exceeding 7.5 cm × 7.5 cm.

5.2 Identification coding for fan marker beacons associated with a four-course radio range

5.2.1 Fan marker beacons located on the legs of a four-course radio range do not normally require an identification signal relating to a particular geographic location, but only a signal that will indicate the leg with which they are associated.

5.2.2 In the case of a four-course radio range having not more than one marker on any leg, it is current practice to identify a marker by a single dash if on the leg bearing true north or nearest to north in a clockwise direction (east), and to identify a marker on other legs by two, three or four dashes according to whether the leg with which it is associated is the second, third or fourth leg from north in a clockwise direction. Where more than one fan marker beacon is associated with one leg of a four-course radio range, the marker nearest to the station is identified by dashes only, the next nearest by two dots preceding the dashes, and the third by three dots preceding the dashes, and so on.

Note.— In certain special circumstances, the above coding system may lead to ambiguities due to two markers associated with the legs of different but overlapping radio ranges being geographically close together. In such cases, it is desirable to use a distinctive identification coding with one of the marker beacons.

6. Material concerning NDB

6.1 Guidance material on NDB field strength requirements in latitudes between 30°N and 30°S

6.1.1 In order to obtain a satisfactory service within the rated coverage of an NDB located in latitudes between 30°N and 30°S, a minimum value of field strength of 120 microvolts per metre would be required, except where practical experience in the operation of NDBs over several years has revealed that a minimum field strength of 70 microvolts per metre would be adequate to meet all the operational needs. In some specific areas, field strength values considerably in excess of 120 microvolts per metre would be required. Such areas are:

a) Indonesia and Papua New Guinea, Myanmar, Malay Peninsula, Thailand, Lao People’s Democratic Republic, Democratic Kampuchea, Viet Nam and Northern Australia;

b) Caribbean and northern parts of South America;

c) Central and South Central Africa.

6.1.2 The field strength of 120 microvolts per metre is based upon practical experience to date and is a compromise between what is technically desirable and what it is economically possible to provide.

6.2 Guidance material on meaning and application of rated and effective coverage

6.2.1 *Rated coverage*

6.2.1.1 The rated coverage as defined in Chapter 3, 3.4.1, is a means of designating actual NDB performance, in a measurable way, which is dependent on the frequency, the radiated power, and the conductivity of the path between the NDB and a point on the boundary where the minimum value of field strength is specified.

6.2.1.2 The rated coverage has been found to be a useful means of facilitating regional planning and, in some instances, may be related to effective coverage.

6.2.1.3 The application of rated coverage to frequency planning is governed by the following criteria:

6.2.1.3.1 Frequencies should be deployed having regard to the rated coverage of the NDBs concerned, so that the ratio of the signal strength of any NDB at the boundary of its rated coverage to the total field strength due to co-channel stations and adjacent channel stations (with an appropriate allowance for the selectivity characteristics of a typical airborne receiver) is not less than 15 dB by day.

6.2.1.3.2 The figures set forth in Attachment B to Volume V of Annex 10 should be applied, as appropriate, in determining the allowance to be made for the attenuation of adjacent channel signals.

6.2.1.4 It follows from the application of rated coverage to frequency deployment planning that, unless otherwise specified, protection against harmful interference can only be ensured within the rated coverage of an NDB and, then, only if the radiated power of the NDBs is adjusted to provide within reasonably close limits the field strength required at the limit of the rated coverage. In areas where the density of NDBs is high, any NDB providing a signal at the limit of its rated coverage materially in excess of that agreed in the region concerned will give rise, in general, to harmful interference within the rated coverages of cochannel or adjacent channel NDBs in the area concerned, and will limit the number of NDBs which can be installed in the region within the available spectrum. It is important, therefore, that increases in radiated power beyond that necessary to provide the rated coverage, particularly at night when sky wave propagation may give rise to interference over long distances, should not be made without coordination with the authorities of the other stations likely to be affected (see Chapter 3, 3.4.3).

6.2.1.5 Frequency planning is considerably facilitated if a common value of minimum field strength within the desired coverage is used.

6.2.1.6 Extensive experience has shown that in relatively low noise level areas, such as Europe, the figure of 70 microvolts per metre is satisfactory.

6.2.1.6.1 Experience has also shown that the figure of 120 microvolts per metre is generally satisfactory for higher noise level areas but will be inadequate in areas of very high noise. In such areas, the information given in 6.3 may be used for general guidance.

6.2.2 *Relationship to effective coverage*

6.2.2.1 Rated coverage may have a close correlation to effective coverage under the following conditions:

a) when the minimum field strength within the rated coverage is such that, for most of the time, it exceeds the field strength due to atmospheric and other noise sufficiently to ensure that the latter will not distort the information presented in the aircraft to the extent that it is unusable;

b) when the ratio of the strength of the wanted signal to that of interfering signals exceeds the minimum required value at all points within the coverage, in order to ensure that interfering signals will also not distort the information presented in the aircraft to the extent that it is unusable.

6.2.2.2 Since, normally, the lowest signal within the coverage will occur at its boundary, these conditions imply that at the boundary the field strength should be such that its ratio to atmospheric noise levels would ensure usable indications in the aircraft for most of the time and that, in respect of the boundary value, overall planning should ensure that the ratio of its value to that of interfering signals exceeds the required value for most of the time.

6.2.2.3 Although the value of 70 microvolts per metre used for frequency deployment has been found successful in Europe (i.e. north of 30° latitude) in giving coverage values which closely approximate to effective coverage most of the time, experience is too limited to prove the suitability of the 120 microvolts per metre value for general application in areas of high noise. It is to be expected that rated coverages in high noise based on a boundary value of 120 microvolts per metre will, on many occasions, be substantially greater than the effective coverage achieved. In such areas, in order to secure a better correlation between rated coverage and an average of the achieved effective coverage, it may be advisable to choose a boundary value based more closely on the proportionality of noise in that area to the noise in areas where a boundary value has been satisfactorily established (e.g. Europe), or to determine an appropriate value from a statistical examination of achieved effective coverages in respect of an NDB in the area of known performance.

6.2.2.4 It is important to appreciate, however, that minimum values of field strength based on a simple comparison of noise levels in different areas may be insufficient, because factors such as the frequency of occurrence of noise, its character and effect on the airborne receiver and the nature of the air operation involved may all modify ratios determined in this way.

6.2.2.5 Values of diurnal and seasonal noise in various parts of the world have been published in Report 322 of the former CCIR of the ITU.

6.2.2.5.1 Correlation of these values to actual local conditions and the derivation of required signal-to-noise ratios for effective operational use of ADF equipment is not yet fully established.

6.2.3 *Effective coverage*

6.2.3.1 Effective coverage as defined in Chapter 3, 3.4.1, is the area surrounding an NDB, within which useful information to the operator concerned can be obtained at a particular time. It is, therefore, a measure of NDB performance under prevailing conditions.

6.2.3.2 The effective coverage is limited by the ratio of the strength of the steady (non-fading) signal received from the NDB to the total noise intercepted by the ADF receiver. When this ratio falls below a limiting value, useful bearings cannot be obtained. It should also be noted that the effective coverage of an NDB may in some cases be limited to the range of the usable identification signal.

6.2.3.3 The strength of signal received from the NDB is governed by:

a) the power supplied to the antenna of the NDB;

b) the radiation efficiency of the antenna, which varies according to the height of the antenna and other characteristics of the radiating system;

c) the conductivity of the path between the NDB and the receiver, which may vary considerably as between one site and another, and is always less over land than over seawater;

d) the operating radio frequency.

6.2.3.4 The noise admitted by the receiver depends on:

a) the bandwidth of the receiver;

b) the level of atmospheric noise, which varies according to the geographical area concerned, with the time of day and the season of the year, and which may reach very high levels during local thunderstorms;

c) the level of the interference produced by other radio emissions on the same or on adjacent frequencies, which is governed to a large extent by the NDB density in the area concerned and the effectiveness of regional planning;

d) the level of noise due to electrical noise in the aircraft or to industrial noise (generated by electric motors, etc.), when the coverage of the NDB extends over industrial areas.

6.2.3.4.1 It has to be noted that the effect of noise depends on characteristics of the ADF receiver and the associated equipment, and also on the nature of the noise (e.g. steady noise, impulsive noise).

6.2.3.5 A further factor which limits the effective coverage of an NDB is present at night when interaction occurs between components of the signal which are propagated respectively in the horizontal plane (ground wave propagation) and by reflection from the ionosphere (sky wave propagation). When there is interaction between these components, which arrive at the ADF receiver with a difference of phase, bearing errors are introduced (night effect).

6.2.3.6 It will thus be seen that the effective coverage of an NDB depends on so many factors, some of which are variable, that it is impossible to specify the effective coverage of an NDB in any simple manner. The effective coverage of any NDB, in fact, varies according to the time of day and the season of the year.

6.2.3.6.1 Hence any attempt to specify an effective coverage, which would be obtainable at any time throughout the day or throughout the year, would result either in a figure for coverage which would be so small (since this would be the coverage obtained under the worst conditions of atmospheric noise, etc.) as to give quite a misleading picture of the effectiveness of the NDB, or would involve such high power and costly antenna systems (to provide the required coverage under the worst conditions), that the installation of such an NDB would usually be precluded by considerations of initial and operating costs. No specific formula can be given in determining what rated coverage would be equivalent to a desired effective coverage and the relation must be assessed regionally.

6.2.3.7 Those concerned with the operational aspects of NDB coverage will normally consider requirements in terms of a desired operational coverage and, in regional planning, it will usually be necessary to interpret such requirements in terms of a rated coverage from which may be derived the essential characteristics of the NDB required and which will also define the area to be protected against harmful interference. No specific formula can be given in determining what rated coverage would be equivalent to a desired operational coverage and the relation must be assessed regionally.

6.2.3.8 Some States have recorded data on NDBs and their effective coverage; and collection of similar information would be a practical way of obtaining an assessment of effective coverage in terms of rated coverage of facilities in a given area. This information would also be useful for future regional planning. In order to reduce the number of factors involved in assessing effective coverage, it would be desirable to establish criteria for determining the limit of useful coverage in terms of the reaction of the bearing indicator. The data referred to previously, together with measurements of actual field strength within the coverage of the NDB, would also permit determination of the effectiveness of existing installations and provide a guide to improvements that may be necessary to achieve a desired effective coverage.

6.3 Coverage of NDBs

6.3.1 *Introduction*

6.3.1.1 The following studies have been based on the latest propagation and noise data available to the ITU. They are included in this Attachment as general guidance in respect of NDB planning. Attention is called particularly to the assumptions made.

6.3.1.2 When applying the material, the validity of the assumptions in respect of the particular conditions under consideration should be carefully examined and, in particular, it should be noted that the assumed signal-to-noise ratios require considerable further study before they can be accepted as representative of the ratios limiting useful reception.

6.3.2 *Assumptions*

1. Operating frequency — 300 kHz.
   Reference is made, however, where appropriate, to frequencies of 200 kHz and 400 kHz.

2. a) Average soil conductivity:
   ($\sigma = 10^{-13}$ e.m.u.)

   b) Average seawater conductivity:
   ($\sigma = 4.10^{-11}$ e.m.u.)

3. The level of atmospheric noise (RMS) which is likely to prevail: 1) by day, 2) by night, over land masses, within the belts of latitude mentioned. [The values of expected noise have been derived from Recommendation ITU-R P.372-6 and have been taken as the average noise by day and by night during equinox periods, i.e. the values which are likely to be exceeded 20–25 per cent of the year.]

4. Input powers to the antenna of the NDB of:

   a) 5 kW
   b) 1 kW
   c) 500 W
   d) 100 W
   e) 50 W
   f) 10 W

5. The following average values of radiation efficiencies of antennas, i.e. the ratio of:

$$\left[\frac{\text{Radiated power}}{\text{Input power to antenna}}\right]$$

	Input power efficiency to antenna	*Radiation of antenna*
a)	5 kW	20% (–7 dB)
b)	5 kW	10% (–10 dB)
c)	1 kW	8% (–11 dB)
d)	500 W	5% (–13 dB)
e)	100 W	3% (–15 dB)
f)	50 W	2% (–17 dB)
g)	10 W	1% (–20 dB)
h)	10 W	0.3% (–25 dB)

i) The figure for a) is included because it is possible to realize this efficiency by the use of a more elaborate antenna system than is usually employed.

ii) The figure for h) is included because many low power NDBs use very inefficient antennas.

6. An admittance band of the ADF receiver of 6 kHz.

7. Required ratios of signal-(median) to-noise (RMS) of:

a) 15 dB by day;

b) 15 dB by night.

6.3.3 *Results of studies*

A.— *Minimum field strengths required at the boundary of the rated coverage:*

Latitude	*By day for 15 dB S/N ratio*	*By night for 15 dB S/N ratio*
5°N – 5°S	320 µV/m (+50 dB)	900 µV/m (+59 dB)
5° – 15°N&S	85 µV/m (+39 dB)	700 µV/m (+57 dB)
15° – 25°N&S	40 µV/m (+32 dB)	320 µV/m (+50 dB)
25° – 35°N&S	18★µV/m (+25 dB)	120 µV/m (+42 dB)
>35°N&S	18★µV/m (+25 dB)	50 µV/m (+35 dB)

A star shown against a figure indicates that a higher value of field strength — probably 2 or 3 times the values shown (plus 6 to plus 10 dB) — may be necessary in the presence of high aircraft noise and/or industrial noise.

B.— *Coverage of NDBs (expressed in terms of the radius of a circle, in kilometres, with the NDB at the centre) which may be expected under the assumptions made:*

1) By *day*, over *land*, and for *15 dB S/N ratio* at the boundary of the coverage:

	Input power to antenna			
	(a)	*(b)*	*(c)*	*(d)*
Latitude	*5 kW*	*5 kW*	*1 kW*	*500 W*
5°N – 5°S	320	300	170	120
5° – 15°N&S	510	470	320	250
15° – 25°N&S	>600	600	450	350
25° – 35°N&S	>600★	>600★	600★	500★
>35°N&S	>600★	>600★	>600★	500★

	Input power to antenna			
	(e)	*(f)*	*(g)*	*(h)*
Latitude	*100 W*	*50 W*	*10 W*	*10 W*
5°N – 5°S	50	30	10	<10
5° – 15°N&S	150	90	40	10
15° – 25°N&S	220	160	70	45
25° – 35°N&S	330★	250★	130★	80★
>35°N&S	330★	250★	130★	100★

2) By *night*, over *land*, and for *15 dB S/N ratio* at the boundary of the coverage:

	Input power to antenna			
	(a)	*(b)*	*(c)*	*(d)*
Latitude	*5 kW*	*5 kW*	*1 kW*	*500 W*
5°N – 5°S	190	150	85	50
5° – 15°N&S	210	180	110	70
15° – 25°N&S	320	300	170	120
25° – 35°N&S	390	390	280	200
>35°N&S	390	390	390	310

	Input power to antenna			
	(e)	*(f)*	*(g)*	*(h)*
Latitude	*100 W*	*50 W*	*10 W*	*10 W*
5°N – 5°S	20	<10	<10	<10
5° – 15°N&S	25	15	<10	<10
15° – 25°N&S	50	30	10	<10
25° – 35°N&S	100	70	25	15
>35°N&S	180	120	50	30

6.3.3.1 In all of the above tables, it has to be noted that:

a) the distances are given in kilometres, in accordance with ITU practice;

b) the figures in the final columns, with the heading 10 W, are calculated on the assumption that the low power NDB uses a very inefficient antenna (see 6.3.2, assumption 5 h));

c) a star shown against a figure indicates that the coverage may be limited by aircraft and industrial noises.

6.3.3.2 It has also to be noted that:

a) if a frequency of 200 kHz were used in place of 300 kHz, this would not appreciably affect the coverage of low power short range NDBs, but the coverage of the higher power, longer range beacons (for example, those with a range of 150 km or more) would be increased, as compared with those shown in the tables, by about 20 per cent;

b) if a frequency of 400 kHz were used in place of 300 kHz this would not appreciably affect the coverage of low power short range NDBs, but the coverage of the higher power, longer range beacons (for example, those with a range of 150 km or more) would be decreased, as compared with those shown in the tables, by about 25 per cent;

c) use of an ADF receiver with a narrower band would, other things being equal, provide wider coverage for the same radiated power of the NDB or, for the same coverage, an improved effective signal-to-noise ratio.

For example, if an admittance band of 1 kHz instead of 6 kHz were used, the coverage might be increased by as much as 30 per cent for the same radiated power or, alternatively, the effective signal-to-noise ratio might be increased by as much as 8 dB;

d) if a sector of the coverage of an NDB is over seawater, a greater coverage may be expected within that sector due to:

1) better ground wave propagation over seawater than over land;

2) the noise level, which is highest over land, often drops fairly steeply with increasing distance from the land. It might be assumed, therefore, that the distances shown in the tables could be increased by about 30 per cent by day, and by about 20 per cent by night, when the path is over seawater;

e) if, however, the beacon is sited on an island remote from land masses (for example, in mid-Pacific or mid-Atlantic, but not in the Caribbean), the coverage of the beacon is likely to be much greater, particularly in tropical latitudes, than is indicated in the tables; and in such cases figures for coverage similar to those shown for latitudes more than 35°N and S may be assumed for all latitudes, due to the much lower level of atmospheric noise which prevails in mid-ocean as compared with that experienced over, or in proximity to, land masses.

6.3.4 Limitation of coverage of a beacon at night due to "night effect".

a) The distances, at night, at which the ground wave and sky wave components of the received field are likely to be equal are as follows:

Frequency	*Over land*	*Over sea*
200 kHz	500 km	550 km
300 kHz	390 km	520 km
400 kHz	310 km	500 km

b) The distances, at night, at which the ground wave component of the received field is likely to exceed the sky wave component by 10 dB are as follows:

Frequency	*Over land*	*Over sea*
200 kHz	300 km	320 km
300 kHz	230 km	300 km
400 kHz	200 km	280 km

c) It is, therefore, unlikely that reliable bearings can be obtained, at night, due to interaction of the two components of the received field, at much greater distances than those shown in 6.3.4 b). *These distances are independent of the power of the NDB.*

d) It has to be noted, moreover, that, while with overland paths of good conductivity, night effect will only be serious at somewhat greater distances than those indicated over paths of poor conductivity, night effect may become pronounced at much shorter ranges. This will also depend to some extent upon the characteristics of the radiation system.

6.4 Considerations affecting operations of NDBs

6.4.1 *Depth of modulation*

6.4.1.1 In specifying that the depth of modulation should be maintained as near to 95 per cent as is practicable, it must be noted that, at the frequencies used for NDBs, the small antennas generally in use can affect the effective modulation depth of the NDB system due to attenuation of the sidebands.

6.4.1.2 At this order of frequency, the antennas are normally only a small fraction of a wavelength long; they are therefore highly reactive and tend to have a high Q.

6.4.1.3 The effect is illustrated in Figure C-19, which was compiled from measurements made by one State. The modulating frequency in these measurements was 1 020 Hz. If a lower modulating frequency were used, the effect would be less.

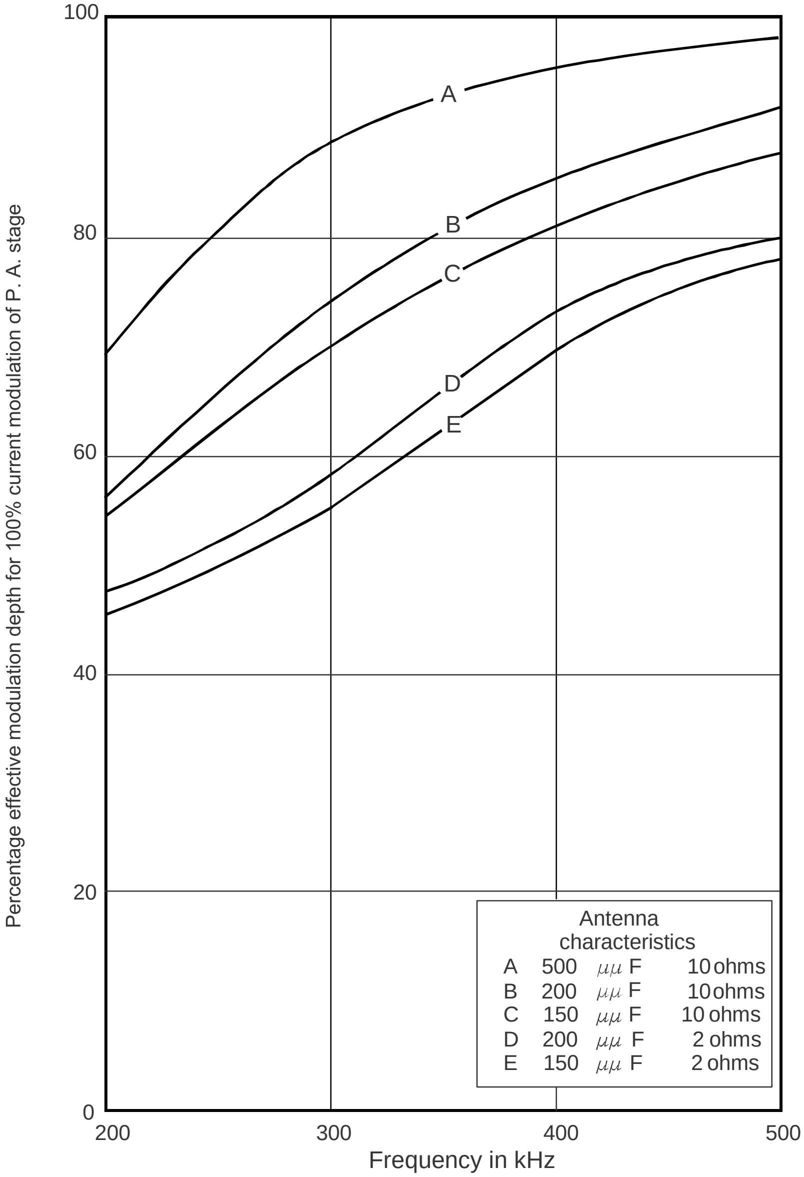
6.4.1.4 In order to reduce the attenuation, attempts should be made to reduce the Q of the antenna. This can be done in two ways, by increasing either its capacity or resistance.

6.4.1.5 Inserting additional resistance in an antenna wastes power, whereas increasing the capacity does not. Additionally, the effect of increasing the capacity is to reduce the voltage across the system and hence to reduce the insulation problems.

6.4.1.6 For these reasons, it is considered desirable to increase antenna capacity by the use of a top load as, for example, in the so-called umbrella top capacity.

6.4.2 *Earth systems*

Frequency planning is done on the assumption that the field strength will be maintained at the correct value. If the earth resistance is high (i.e. an insufficient earth system), not only will the radiation efficiency be low but the power radiated will be sensitive to changes in climatic conditions and other factors affecting the earth loss. In all cases, the earth system needs to be the best possible, taking into account all local circumstances.



Note.— The modulating frequency in these measurements was 1 020 Hz.

Figure C-19. The effect of antenna Q on the depth of modulation of the radiated signal

6.5 Considerations affecting the choice of the modulating frequency for NON/A2A NDBs

Recognition of the fact that modern narrow band ADF receivers have improved selectivity characteristics requires consideration of the fact that, in so far as attenuation of the audio sidebands by these receivers results in a reduction of the effective depth of modulation of the signal, the distance at which satisfactory identification is obtained is consequently reduced. In such circumstances, it is considered that 400 Hz would provide a better identification service than 1 020 Hz. There is some evidence, however, that under conditions of high atmospheric noise, the higher frequency of 1 020 Hz may provide a more easily readable signal.

7. Material concerning DME

7.1 Guidance material concerning both DME/N

7.1.1 *System efficiency*

7.1.1.1 System efficiency is the combined effect of down-link garble, ground transponder dead time, up-link garble, and interrogator signal processor efficiency. Since each of these efficiency components are statistically independent, they can be computed individually and then combined to yield the system efficiency. The effect of a single component is defined as the percentage ratio of valid replies processed by the interrogator in response to its own interrogations assuming all other components are not present. The system efficiency is then the product of the individual components.

7.1.1.2 In computing system efficiency, the number of missing replies as well as the accuracy of the range measurement made with the received replies should be considered. Missing replies may result from signal interference due to garble or from interrogations being received at the transponder during a dead time period. Replies which contain significant errors large enough to be rejected by the interrogator signal processing also should be treated as missing replies when computing the efficiency component.

7.1.1.3 The interference rate due to garble is dependent upon the channel assignment plan, traffic loading, and the ground transponder and interrogator receiver bandwidths. Because the FA mode has a wider receiver bandwidth than the IA mode, it is more susceptible to interference. These factors were accommodated in the DME/P system definition and normally do not require special consideration by the operating authority.

7.1.2 *Down-link garble*

Down-link garble occurs when valid interrogations at the ground transponder are interfered with by coincident interrogations from other aircraft and results in loss of signal or errors in time-of-arrival measurement. This undesired air-toground loading is a function of the number of interrogating aircraft in the vicinity of the serving transponder and the corresponding distribution of interrogation frequencies and signal amplitudes received at the transponder.

Note.— Transponder to transponder garbling is controlled by the channel assignment authorities.

7.1.3 *Up-link garble*

Up-link garble occurs when valid replies at the interrogator are interfered with by other transponders and results in loss of signal or errors in pulse time-of-arrival measurement. The garble can be interference from any transponder whose frequency is within the bandwidth of the interrogator, including those on the same frequency, but with different pulse coding. This undesired ground-to-air loading is a function of the number of transponders in the vicinity of the interrogator and the corresponding distribution of reply frequencies and signal amplitudes received at the interrogator.

7.1.4 *Interrogator processor efficiency*

The interrogator signal processor efficiency is the ratio of the number of replies processed by the interrogator to the number of interrogations in the absence of garble and transponder dead time effects. This efficiency depends on the reply pulse threshold level and the receiver noise level.

7.1.5 *Relationship between aircraft served and transmission rate*

7.1.5.1 Specification of the maximum transponder transmission rate establishes the maximum average transmitter power level. Chapter 3, 3.5.4.1.5.5 recommends that the transponder have a transmission rate capability of 2 700 pulse pairs per second if 100 aircraft are to be served. This represents typical transponder loading arising from 100 aircraft. To determine the actual transmission rate capability that should be accommodated at a given facility during peak traffic conditions requires that the maximum number of interrogators be estimated. To compute the interrogation loading on the transponder, the following should be considered:

a) the number of aircraft that constitutes the peak traffic load;

b) the number of interrogators in use on each aircraft;

c) the distribution of operating modes of the interrogators in use (e.g. search, initial approach, final approach, ground test);

d) the appropriate pulse repetition frequency as given in Chapter 3, 3.5.3.4.

7.1.5.2 Given the interrogation loading which results from the peak traffic as well as the reply efficiency of the transponder in the presence of this load, the resulting reply rate can be computed, thereby establishing the required transmitter capability. This reply rate is the level that, when exceeded, results in a reduction in receiver sensitivity (as specified in Chapter 3, 3.5.4.2.4) in order to maintain the reply rate at or below this maximum level.

7.1.6 *Siting of DME associated with ILS*

7.1.6.1 The DME should, where possible, provide to the pilot an indicated zero range at touchdown in order to satisfy current operational requirements.

7.1.6.2 The optimum site for a DME transponder is dependent upon a number of technical and operational factors. DME/N may be installed with ILS where operational requirements permit.

7.1.6.3 In the case of DME/N, the provision of zero range indication may be achieved by siting the transponder as close as possible to the point at which zero range indication is required. Alternatively, the transponder time delay can be adjusted to permit aircraft interrogators to indicate zero range at a specified distance from the DME antenna. When the indicated DME zero range has a reference other than the DME antenna, consideration should be given to publishing this information.

7.1.6.4 reserved

7.1.6.5 reserved.

7.1.6.6 reserved.

7.1.6.7 The nominal location of the zero range indication provided by a DME/N interrogator needs to be published.

7.1.6.8 In considering DME sites, it is also necessary to take into account technical factors such as runway length, profile, local terrain and transponder antenna height to assure adequate signal levels in the vicinity of the threshold and along the runway, and also to assure the required coverage volume (circular or sector). Care is also to be taken that where distance information is required in the runway region, the selected site is not likely to cause the interrogator to lose track due to excessive rate of change of velocity (i.e. the lateral offset of the DME antenna must be chosen with care).

7.1.7 *Geographical separation criteria*

7.1.7.1 In order to allow consideration of actual antenna designs, equipment characteristics, and service volumes, the signal ratios needed to assure interference-free operation of the various facilities operating on DME channels are provided in 7.1.8 and 7.1.9. Given these ratios, the geographical separations of facilities may be readily evaluated by accounting for power losses over the propagation paths.

7.1.8 *Desired to undesired (D/U) signal ratios at the airborne receiver*

7.1.8.1 Table C-6 indicates the necessary D/U signal ratios needed to protect the desired transponder reply signal at an airborne receiver from the various co-frequency/adjacent frequency, same code/different code, undesired transponder reply signal combinations that may exist. The prerequisite for any calculation using the provided ratios is that the required minimum power density of the desired DME is met throughout the operationally published coverage volume. For initial assignments, the D/U ratios necessary to protect airborne equipment with 6-microsecond decoder rejection should be used. In making an assignment, each facility must be treated as the desired source with the other acting as the undesired. If both satisfy their unique D/U requirement, then the channel assignment may be made.

7.1.8.2 Accordingly, DME channel assignments depend upon the following:

a) *For co-channel assignments:* This condition occurs when both the desired and undesired signals operate on a channel (W, X, Y or Z) that is co-frequency, same code. The D/U signal ratio should be at least 8 dB throughout the service volume.

b) *For co-frequency, different code assignments:* This condition occurs when one facility operates on an X channel with the other on a W channel. A similar Y channel and a Z channel combination also applies.

c) *For first adjacent frequency, same code assignments:* This condition occurs when both the desired and undesired facilities are of W, X, Y or Z type.

d) *For first adjacent frequency, different code assignments:* This condition occurs when one facility operates on an X channel with the other on a W channel, but with a frequency offset of 1 MHz between transponder reply frequencies. A similar Y channel and a Z channel combination also applies.

Table C-6. Protection ratio D/U (dB)

Type of assignment	A	B
Co-frequency:		
Same pulse code	8	8
Different pulse code	8	–42
First adjacent frequency:		
Same pulse code	$-(P_u - 1)$	–42
Different pulse code	$-(P_u + 7)$	–75
Second adjacent frequency:		
Same pulse code	$-(P_u + 19)$	–75
Different pulse code	$-(P_u + 27)$	–75

Note 1.— The D/U ratios in column A protect those DME/N interrogators operating on X or Y channels. Column A applies to decoder rejection of 6 microseconds.

Note 2.— The D/U ratios in column B protect those DME/N interrogators utilizing discrimination in conformance with 3.5.5.3.4.2 and 3.5.5.3.4.3 of Chapter 3 and providing a decoder rejection conforming to 3.5.5.3.5 of Chapter 3.

Note 3.— P_u is the peak effective radiated power of the undesired signal in dBW.

Note 4.— The frequency protection requirement is dependent upon the antenna patterns of the desired and undesired facility and the EIRP of the undesired facility.

Note 5.— In assessing adjacent channel protection, the magnitude of D/U ratio in column A should not exceed the magnitude of the value in column B.

e) *For second adjacent frequency, same or different code assignments:* The second adjacent frequency combinations generally need not be frequency protected.

7.1.9 *Special considerations for DME Y and Z channel assignments*

The channel assignment plan for DME is such that the transponder reply frequency for each Y or Z channel is the same as the interrogation frequency of another DME channel. Where the reply frequency of one DME matches the interrogation frequency of a second DME, the two transponders should be separated by a distance greater than the radio horizon distance between them. The radio horizon distance is calculated taking into account the elevations of the two transponder antennas.

7.1.10 *reserved.*

7.1.11 *reserved.*

7.2 Guidance material concerning DME/N only

7.2.1 *Coverage of DME/N*

7.2.1.1 Whether a particular installation can provide the required frequency, protected coverage volume can be determined by using Figure C-20. The propagation loss for paths without obstructions uses the IF-77 propagation model.

7.2.1.2 Whenever a DME that provides coverage using either a directional or bi-directional DME antenna, the antenna pattern in azimuth and elevation has to be taken into account to achieve the full benefit of the reduced separation requirements outside the antennas main lobe. The actual radiation patterns of the antennas depend on a number of factors, including height of the antenna phase centre, height of the DME counterpoise above ground level (AGL), terrain surface roughness, terrain form, site elevation above mean sea level (MSL), and conductivity of ground and counterpoise. For coverage under difficult terrain and siting conditions, it may be necessary to make appropriate increases in the equivalent isotropically radiated power (EIRP). Conversely, practical experience has shown, that under favourable siting conditions, and under the less pessimistic conditions often found in actual service, satisfactory system operation is achieved with a lower EIRP. However, to account for lowest EIRP in notches between the lobes of the real elevation antenna pattern, the values in Figure C-20 are recommended.

Note.— Further guidance may be found in the Handbook on Radio Frequency Spectrum Requirements for Civil Aviation including statement of approved ICAO policies (*Doc 9718).*

7.2.2 *EIRP of DME/N facilities*

7.2.2.1 The power density figure prescribed in Chapter 3, 3.5.4.1.5.2 is based on the following example:

Airborne receiver sensitivity	–120 dBW
Transmission line loss, mismatch loss, antenna polar pattern variation with respect to an isotropic antenna	+9 dB
Power required at antenna	–111 dBW

Minus 111 dBW at the antenna corresponds to minus 89 dBW/ m^2 at the mid-band frequency.

7.2.2.2 Nominal values of the necessary EIRP to achieve a power density of minus 89 dBW/m^2 are given in Figure C-20. For coverage under difficult terrain and siting conditions it may be necessary to make appropriate increases in the EIRP. Conversely, under favourable siting conditions, the stated power density may be achieved with a lower EIRP.

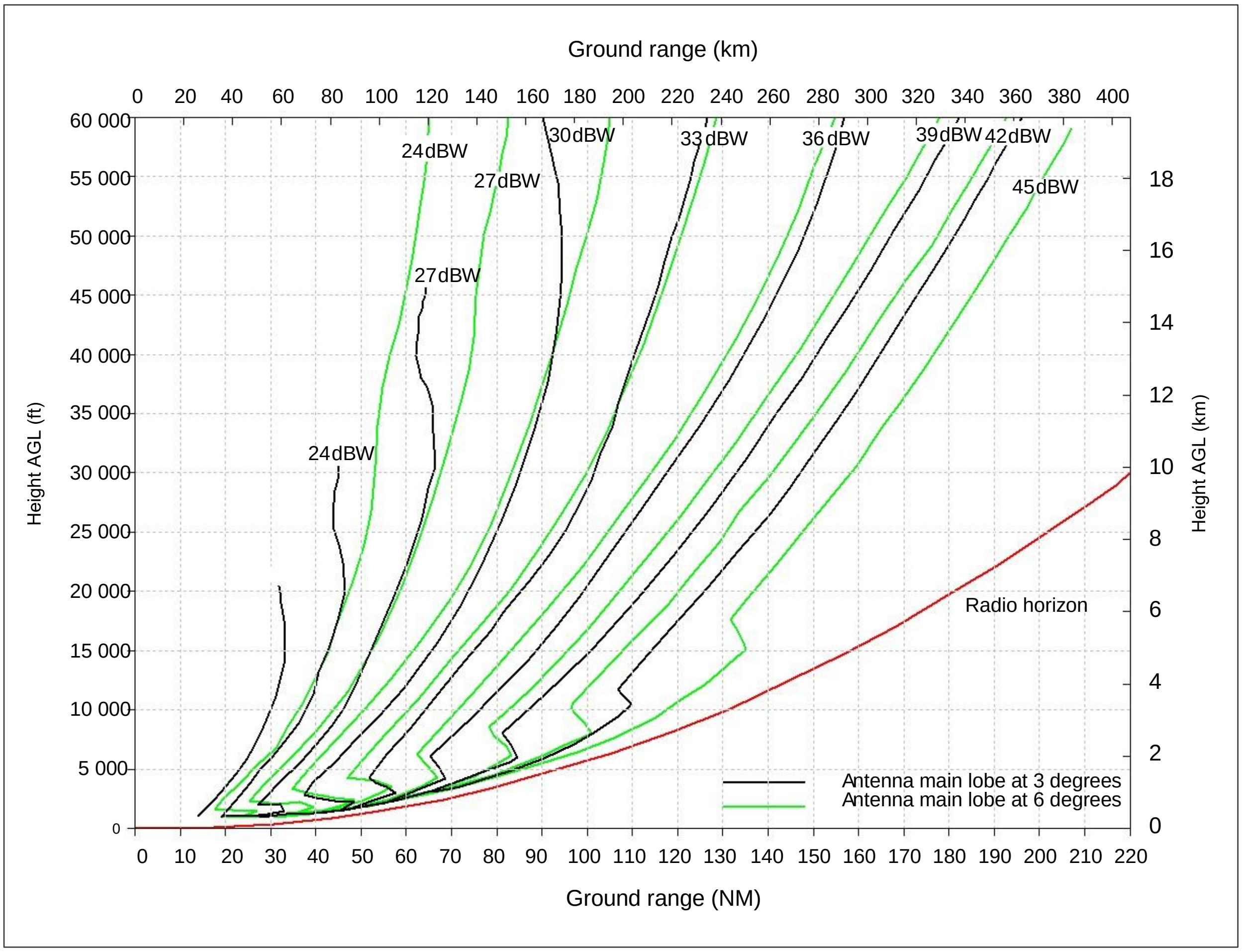


Figure C-20. Necessary EIRP to achieve a power density of –89 dBW/m^2 as a function of height above and distance from the DME

Note 1.— The curves are based on the IF-77 propagation model with a 4/3 Earth radius which has been confirmed by measurements.

Note 2.— The radio horizon in Figure C-20 is for a DME antenna located 5 m (17 ft) AGL over flat terrain. Terrain shielding will reduce the achievable range.

Note 3.— If the antenna is located significantly higher than the assumed reference antenna, the radio horizon and power density will increase.

7.2.3 *DME-DME RNAV*

7.2.3.1 There is an increasing use of DME to support area navigation (RNAV) operations. Although the use of DME to support RNAV operations does not impose any additional technical requirements on the DME system, it does raise some additional issues compared with the traditional use of DME with VOR to support conventional operations. These are examined briefly below.

7.2.3.2 DME/DME positioning is based on the aircraft RNAV system triangulating position from multiple DME ranges from DME facility locations in the aircraft database. The resulting accuracy of the position solution depends on the range to the DMEs and their relative geometry. Some additional measures are therefore necessary to ensure that the DME infrastructure is adequate to support the RNAV operation, i.e. that sufficient DMEs are available and that their location provides adequate geometry to meet the accuracy requirements. For approach and departure procedures, it is also necessary to confirm that there is adequate signal strength and that there are no false locks or unlocks due to multipath. When ensuring there are sufficient DMEs, it is also important to identify any critical DMEs (i.e. those which must be operational for the necessary performance to be assured).

7.2.3.3 Errors in published DME facility locations will result in RNAV position errors. It is therefore important that DME positions are correctly surveyed and that adequate procedures are in place to ensure that the location data are correctly published. For DME facilities collocated with VOR, the DME position should be separately surveyed and published if the separation distance exceeds 30 m (100 ft).

Note.— Specifications concerning data quality and publication of DME location information are contained in PANSAIM (Doc 10066), Appendix 1.

7.2.3.4 When using DME to support RNAV, scanning DME aircraft receivers usually do not check the DME identification. As a consequence, removing the identification of a DME during tests and maintenance operations does not guarantee that the signals will not be used operationally. Maintenance actions that may provide misleading information should be minimized.

Note 1.— Further guidance on flight inspection of DME-DME RNAV procedures is given in Doc 8071.

Note 2.— Further guidance on navigation infrastructure assessment to support RNAV procedures is given in EUROCONTROL-GUID-0114 *(available at http://www.eurocontrol.int) and on the performance-based navigation (PBN) page of the ICAO website at http://www.icao.int/pbn*.

7.3 reserved.

8. Material concerning power supply switch-over times

8.1 Power supply switch-over times for ground-based radio aids used in the vicinity of aerodromes

The power supply switch-over times for radio navigation aids and ground elements of communications systems are dependent on the type of runway and aircraft operations to be supported. Table C-11 indicates representative switch-over times which may be met by power supply systems currently available.

Table C-11. Power supply switch-over times for ground-based radio aids used at aerodromes

Type of runway	Aids requiring power	Maximum switch-over times (seconds)
Instrument approach	SRE	15
	VOR NDB	15
	D/F facility	15
		15
Precision approach, Category I	ILS localizer	10
	ILS glide path	10
	ILS middle marker	10
	ILS outer marker	10
Precision approach, Category II	ILS localizer	0
	ILS glide path	0
	ILS inner marker	1
	ILS middle marker	1
	ILS outer marker	10
Precision approach, Category III	(same as Category II)	

ATTACHMENT D. INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE GNSS STANDARDS AND RECOMMENDED PRACTICES

1. Definitions

Bi-binary. Bi-binary is known as “Manchester Encoding”. It is sometimes referred to as “Differential Manchester Encoding”. Using this system, it is the transition of the edge that determines the bit.

Chip. A single digital bit of the output of a pseudo-random bit sequence.

Gold code. A class of unique codes used by GPS, which exhibit bounded cross-correlation and off-peak auto-correlation values.

Selective availability (SA). A set of techniques for denying the full accuracy and selecting the level of positioning, velocity and time accuracy of GPS available to users of the standard positioning service signal.

Note.— GPS SA was discontinued at midnight on 1 May 2000.

2. General

Standards and Recommended Practices for GNSS contain provisions for the elements identified in Chapter 3, 3.7.2.2. Additional implementation guidance is provided in the *Global Navigation Satellite System (GNSS) Manual* (Doc 9849).

Note.— Except where specifically annotated, GBAS guidance material applies to GRAS.

3. Navigation system performance requirements

3.1 Introduction

3.1.1 Navigation system performance requirements are defined in the *Performance-based Navigation (PBN) Manual* (Doc 9613) for a single aircraft and for the total system which includes the signal-in-space, the airborne equipment and the ability of the aircraft to fly the desired trajectory. These total system requirements were used as a starting point to derive GNSS signal-in-space performance requirements. In the case of GNSS, degraded configurations which may affect multiple aircraft are to be considered. Therefore, certain signal-in-space performance requirements are more stringent to take into account multiple aircraft use of the system.

3.1.2 Two types of approach and landing operations with vertical guidance (APV), APV-I and APV-II, use vertical guidance relative to a glide path, but the facility or navigation system may not satisfy all of the requirements associated with precision approach. These operations combine the lateral performance equal to that of an ILS Category I localizer with different levels of vertical guidance. Both APV-I and APV-II provide access benefits relative to a non-precision approach, and the service that is provided depends on the operational requirements and the SBAS infrastructure. APV-I and APV-II exceed the requirements (lateral and vertical) for current RNAV approaches using barometric altimetry, and the relevant onboard equipment will therefore be suitable for the conduct of barometric VNAV APV and RNAV non-precision approaches.

3.2 Accuracy

3.2.1 GNSS position error is the difference between the estimated position and the actual position. For an estimated position at a specific location, the probability should be at least 95 per cent that the position error is within the accuracy requirement.

3.2.2 Stationary, ground-based systems such as VOR and ILS have relatively repeatable error characteristics, so that performance can be measured for a short period of time (e.g. during flight inspection) and it is assumed that the system accuracy does not change after the test. However, GNSS errors change over time. The orbiting of satellites and the error characteristics of GNSS result in position errors that can change over a period of hours. In addition, the accuracy itself (the error bound with 95 per cent probability) changes due to different satellite geometries. Since it is not possible to continually measure system accuracy, the implementation of GNSS demands increased reliance on analysis and characterization of errors. Assessment based on measurements within a sliding time window is not suitable for GNSS.

3.2.3 The error for many GNSS architectures changes slowly over time, due to filtering in the augmentation systems and in the user receiver. This results in a small number of independent samples in periods of several minutes. This issue is very important for precision approach applications, because it implies that there is a 5 per cent probability that the position error can exceed the required accuracy for an entire approach. However, due to the changing accuracy described in 3.2.2, this probability is usually much lower.

3.2.4 The 95 per cent accuracy requirement is defined to ensure pilot acceptance, since it represents the errors that will typically be experienced. The GNSS accuracy requirement is to be met for the worst-case geometry under which the system is declared to be available. Statistical or probabilistic credit is not taken for the underlying probability of particular ranging signal geometry.

3.2.5 Therefore, GNSS accuracy is specified as a probability for each and every sample, rather than as a percentage of samples in a particular measurement interval. For a large set of independent samples, at least 95 per cent of the samples should be within the accuracy requirements in Chapter 3, Table 3.7.2.4-1. Data is scaled to the worst-case geometry in order to eliminate the variability in system accuracy that is caused by the geometry of the orbiting satellites.

3.2.6 An example of how this concept can be applied is the use of GPS to support performance required for nonprecision approach operations. Assume that the system is intended to support non-precision approaches when the horizontal dilution of precision (HDOP) is less than or equal to 6. To demonstrate this performance, samples should be taken over a long period of time (e.g. 24 hours). The measured position error g for each sample i is denoted g_i. This error is scaled to the worst-case geometry as $6 \times g_i/\mathrm{HDOP}$. Ninety-five per cent of the scaled errors must be less than 220 m for the system to comply with the non-precision accuracy requirement under worst-case geometry conditions. The total number of samples collected must be sufficient for the result to be statistically representative, taking into account the decorrelation time of the errors.

3.2.7 A range of vertical accuracy values is specified for Category I precision approach operations which bounds the different values that may support an equivalent operation to ILS. A number of values have been derived by different groups, using different interpretations of the ILS standards. The lowest value from these derivations was adopted as a conservative value for GNSS; this is the minimum value given for the range. Because this value is conservative, and because GNSS error characteristics are different from ILS, it may be possible to achieve Category I operations using larger values of accuracy within the range. The larger values would result in increased availability for the operation. The maximum value in the range has been proposed as a suitable value, subject to validation.

3.2.7.1 Requirements for position domain accuracy to support precision approach operations below Category I are not defined in the SARPs. GBAS service types intended to support operations with lower than Category I minima are required to meet the SIS accuracy requirements for Category I at a minimum. In addition, specific pseudo-range accuracy requirements apply to support the assessment of adequate performance during aircraft certification. The additional requirements on pseudorange accuracy may be combined with geometry screening to ensure the resulting position domain accuracy is adequate for a given aeroplane design to achieve suitable landing performance. See 7.5.13.

3.2.8 The GPS SPS position error (Chapter 3, 3.7.3.1.1.1) accounts for the contribution of the space and control segment to position errors (satellite clock and ephemeris errors) only; it does not include the contributions of ionospheric and tropospheric delay model errors, errors due to multipath effects, and receiver measurement noise errors (see 4.1.2). These errors are addressed in the receiver standards. The user positioning error at the output of ABAS-capable equipment is mainly driven by the GNSS receiver used.

3.2.8.1 For Basic GNSS receivers, the receiver qualification standards require demonstration of user positioning accuracy in the presence of interference and a model of selective availability (SA) to be less than 100 m (95 per cent of time) horizontally and 156 m (95 per cent of time) vertically. The receiver standards do not require that a Basic GNSS receiver applies the ionospheric correction described in Appendix B, 3.1.2.4.

Note.— The term "Basic GNSS receiver" designates the GNSS avionics that at least meet the requirements for a GPS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-208 as amended by United States Federal Aviation Administration (FAA) TSO-C129A, or EUROCAE ED-72A (or equivalent).

3.2.8.2 Since the discontinuation of SA, the representative user positioning accuracy of GPS has been conservatively estimated to be as shown in Table D-0. The numbers provided assume that the worst two satellites of a nominal 24 GPS satellite constellation are out of service. In addition, a 7 m (1 σ) ionospheric delay model error, a 0.25 m (1 σ) residual tropospheric delay error, and a 0.80 m (1 σ) receiver noise error are assumed. After discontinuation of SA (see section 1.), the dominant pseudo-range error for users of the GPS Standard Positioning Service is the ionospheric error that remains after application of the ionospheric corrections. This error is also highly variable and depends on conditions such as user geomagnetic latitude, level of solar activity (i.e. point of the solar cycle that applies), level of ionospheric activity (i.e. whether there is a magnetic storm, or not), elevation angle of the pseudo-range measurement, season of the year, and time of day. The ionospheric delay model error assumption reflected in Table D-0 is generally conservative; however, conditions can be found under which the assumed 7 m (1 σ) error during solar maximum would be inadequate.

Table D-0. GPS user positioning accuracy

	GPS user positioning accuracy 95% of time, global average
Horizontal position error	33 m (108 ft)
Vertical position error	73 m (240 ft)

3.2.9 SBAS and GBAS receivers will be more accurate, and their accuracy will be characterized in real time by the receiver using standard error models, as described in Chapter 3, 3.5, for SBAS and Chapter 3, 3.6, for GBAS.

Note 1.— The term "SBAS receiver" designates the GNSS avionics that at least meet the requirements for an SBAS receiver as outlined in Annex 10, Volume I and the specifications of RTCA/DO-229D with Change 1 (or equivalent).

Note 2.— The term "GBAS receiver" designates the GNSS avionics that at least meet the requirements for a GBAS receiver as outlined in Annex 10, Volume I and the specifications of the RTCA documents covering the applicable performance types, amended by United States FAA TSO (or equivalent).

3.3 Integrity

3.3.1 Integrity is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight).

3.3.2 To ensure that the position error is acceptable, an alert limit is defined that represents the largest position error allowable for a safe operation. The position error cannot exceed this alert limit without annunciation. This is analogous to ILS in that the system can degrade so that the error is larger than the 95th percentile but within the monitor limit.

3.3.3 The integrity requirement of the navigation system for a single aircraft to support en-route, terminal, initial approach, non-precision approach and departure is assumed to be $1 – 1 \times 10^{-5}$ per hour.

3.3.4 For satellite-based navigation systems, the signal-in-space in the en-route environment simultaneously serves a large number of aircraft over a large area, and the impact of a system integrity failure on the air traffic management system will be greater than with traditional navigation aids. The performance requirements in Chapter 3, Table 3.7.2.4-1, are therefore more demanding.

3.3.5 For APV and precision approach operations, integrity requirements for GNSS signal-in-space requirements of Chapter 3, Table 3.7.2.4-1, were selected to be consistent with ILS requirements.

3.3.6 Alert limits for typical operations are provided in Note 2 to Table 3.7.2.4-1. A range of alert limits is specified for precision approach operations, reflecting potential differences in system design that may affect the operation. In ILS, monitor thresholds for key signal parameters are standardized, and the monitors themselves have very low measurement noise on the parameter that is being monitored. With differential GNSS, some system monitors have comparably large measurement noise uncertainty whose impact must be considered on the intended operation. In all cases, the effect of the alert limit is to restrict the satellite-user geometry to one where the monitor performance (typically in the pseudorange domain) is acceptable when translated into the position domain.

3.3.7 The smallest precision approach vertical alert limit (VAL) value (10 m (33 ft)) was derived based on the monitor performance of ILS as it could affect the glide slope at a nominal decision altitude of 60 m (200 ft) above the runway threshold. By applying this alert limit, the GNSS error, under faulted conditions, can be directly compared to an ILS error under faulted conditions, such that the GNSS errors are less than or equal to the ILS errors. For those faulted conditions with comparably large measurement noise in GNSS, this results in monitor thresholds are more stringent than ILS.

3.3.8 The largest precision approach VAL value (35 m (115 ft)) was derived to ensure obstacle clearance equivalent to ILS for those error conditions which can be modelled as a bias during the final approach, taking into account that the aircraft decision altitude is independently derived from barometric pressure. An assessment has been conducted of the worst-case effect of a latent bias error equal to the alert limit of 35 m (115 ft), concluding that adequate obstacle clearance protection is provided on the approach and missed approach (considering the decision altitude would be reached early or late, using an independent barometric altimeter). It is important to recognize that this assessment only addressed obstacle clearance and is limited to those error conditions which can be modelled as bias errors. Analysis has shown 35 m (115 ft) bias high and low conditions can be tolerated up to the approach speed category (Categories A through D) glide path angle limits in the *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168) without impinging on the ILS obstacle clearance surfaces.

3.3.9 Since the analysis of a 35 m (115 ft) VAL is limited in scope, a system-level safety analysis should be completed before using any value greater than 10 m (33 ft) for a specific system design. The safety analysis should consider obstacle clearance criteria and risk of collision due to navigation error, and the risk of unsafe landing due to navigation error, given the system design characteristics and operational environment (such as the type of aircraft conducting the approach and the supporting airport infrastructure). With respect to the collision risk, it is sufficient to confirm that the assumptions identified in 3.3.8 are valid for the use of a 35 m (115 ft) VAL. With respect to an unsafe landing, the principal mitigation for a navigation error is pilot intervention during the visual segment. Limited operational trials, in conjunction with operational expertise, have indicated that navigation errors of less than 15 m (50 ft) consistently result in acceptable touchdown performance. For errors larger than 15 m (50 ft), there can be a significant increase in the flight crew workload and potentially a significant reduction in the safety margin, particularly for errors that shift the point where the aircraft reaches the decision altitude closer to the runway threshold where the flight crew may attempt to land with an unusually high rate of descent. The hazard severity of this event is major (see the *Safety Management Manual (SMM)* (Doc 9859)). One acceptable means to manage the risks in the visual segment is for the system to comply with the following criteria:

a) the fault-free accuracy is equivalent to ILS. This includes system 95 per cent vertical navigation system error (NSE) less than 4 m (13 ft), and a fault-free system vertical NSE exceeding 10 m (33 ft) with a probability less than 10^{-7} for each location where the operation is to be approved. This assessment is performed over all environmental and operational conditions under which the service is declared available;

b) under system failure conditions, the system design is such that the probability of an error greater than 15 m (50 ft) is lower than 10^{-5}, so that the likelihood of occurrence is remote. The fault conditions to be taken into account are those affecting either the core constellations or the GNSS augmentation under consideration. This probability is to be understood as the combination of the occurrence probability of a given failure with the probability of detection for applicable monitor(s). Typically, the probability of a single fault is large enough that a monitor is required to satisfy this condition.

3.3.10 For GBAS, a technical provision has been made to broadcast the alert limit to aircraft. For SBAS, technical provisions have been made to specify the alert limit through an updatable database (see Attachment C).

3.3.10.1 For GBAS approach service type D (see section 7.1.2.1) additional lower level performance and functional requirements are introduced in order to achieve a total system capable of supporting aircraft landing operations. This service type also supports guided take-off operations.

3.3.11 The approach integrity requirements apply in any one landing and require a fail-safe design. If the specific risk on a given approach is known to exceed this requirement, the operation should not be conducted. One of the objectives of the design process is to identify specific risks that could cause misleading information and to mitigate those risks through redundancy or monitoring to achieve a fail-safe design. For example, the ground system may need redundant correction processors and to be capable of shutting down automatically if that redundancy is not available due to a processor fault.

3.3.12 A unique aspect of GNSS is the time-varying performance caused by changes in the core satellite geometry. A means to account for this variation is included in the SBAS and GBAS protocols through the protection level equations, which provide a means to inhibit use of the system if the specific integrity risk is too high.

3.3.13 GNSS performance can also vary across the service volume as a result of the geometry of visible core constellation satellites. Spatial variations in system performance can further be accentuated when the ground system operates in a degraded mode following the failure of system components such as monitoring stations or communication links. The risk due to spatial variations in system performance should be reflected in the protection level equations, i.e. the broadcast corrections.

3.3.14 GNSS augmentations are also subject to several atmospheric effects, particularly due to the ionosphere. Spatial and temporal variations in the ionosphere can cause local or regional ionospheric delay errors that cannot be corrected within the SBAS or GBAS architectures due to the definition of the message protocols. Such events are rare and their likelihood varies by region, but they are not expected to be negligible. The resulting errors can be of sufficient magnitude to cause misleading information and should be mitigated in the system design through accounting for their effects in the broadcast parameters (e.g. σ_{iono_vert} in GBAS), and monitoring for excessive conditions where the broadcast parameters are not adequate. The likelihood of encountering such events should be considered when developing any system monitor.

3.3.15 Another environmental effect that should be accounted for in the ground system design is the errors due to multipath at the ground reference receivers, which depend on the physical environment of monitoring station antennas as well as on satellite elevations and times in track.

3.3.16 SBAS needs to assure the integrity of its broadcast corrections as required in 3.7.2.4 throughout its coverage area. This requirement also applies outside the intended service area, where user receivers could navigate using either an SBAS navigation solution, if available, or a fault detection and exclusion (FDE) navigation solution. The SBAS contributions to a FDE navigation solution are limited to assuring the integrity of the transmitted corrections. SBAS systems have to comply with all the integrity requirements for all typical operations from En-route to Category I, defined in Table 3.7.2.4-1, in the coverage area when, for a given operation, the horizontal and vertical protection levels are lower than the corresponding alert limits. This is of particular importance for vertically guided operations using SBAS that are not controlled by FAS data block.

3.4 Continuity of service

3.4.1 Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation.

3.4.2 *En-route*

3.4.2.1 For en-route operations, continuity of service relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity throughout the intended operation, assuming that it was available at the start of the operation. The occurrence of navigation system alerts, either due to rare fault-free performance or to failures, constitute continuity failures. Since the durations of these operations are variable, the continuity requirement is specified as a probability on a per-hour basis.

3.4.2.2 The navigation system continuity requirement for a single aircraft is $1 – 1 \times 10^{–4}$ per hour. However, for satellitebased systems, the signal-in-space may serve a large number of aircraft over a large area. The continuity requirements in Chapter 3, Table 3.7.2.4-1, represent reliability requirements for the GNSS signal-in-space, i.e. they derive mean time between outage (MTBO) requirements for the GNSS elements.

3.4.2.3 A range of values is given in Chapter 3, Table 3.7.2.4-1, for the signal-in-space continuity requirement for en-route operations. The lower value is the minimum continuity for which a system is considered to be practical. It is appropriate for areas with low traffic density and airspace complexity. In such areas, the impact of a navigation system failure is limited to a small number of aircraft, and there is, therefore, no need to increase the continuity requirement significantly beyond the single aircraft requirement ($1 – 1 \times 10^{–4}$ per hour). The highest value given (i.e. $1 – 1 \times 10^{–8}$ per hour) is suitable for areas with high traffic density and airspace complexity, where a failure will affect a large number of aircraft. This value is appropriate for navigation systems where there is a high degree of reliance on the system for navigation and possibly for dependent surveillance. The value is sufficiently high for the scenario based on a low probability of a system failure during the life of the system. Intermediate values of continuity (e.g. $1 – 1 \times 10^{–6}$ per hour) are considered to be appropriate for areas of high traffic density and complexity where there is a high degree of reliance on the navigation system but in which mitigation for navigation system failures is possible. Such mitigation may be through the use of alternative navigation means or the use of ATC surveillance and intervention to maintain separation standards. The values of continuity performance are determined by airspace needs to support navigation where GNSS has either replaced the existing navigation aid infrastructure or where no infrastructure previously existed.

3.4.3 *Approach and landing*

3.4.3.1 For approach and landing operations, continuity of service relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity during the approach and landing, given that it was available at the start of the operation. In particular, this means that loss of continuity events that can be predicted and for which NOTAMs have been issued do not have to be taken into account when establishing compliance of a given system design against the SARPs continuity requirement. The occurrence of navigation system alerts, either due to rare fault-free performance or to failures, constitutes a loss of continuity event. In this case, the continuity requirement is stated as a probability for a short exposure time.

3.4.3.2 The continuity requirements for approach and landing operations represent only the allocation of the requirement between the aircraft receiver and the non-aircraft elements of the system. In this case, no increase in the requirement is considered necessary to deal with multiple aircraft use of the system. The continuity value is normally related only to the risk associated with a missed approach and each aircraft can be considered to be independent. However, in some cases, it may be necessary to increase the continuity values since a system failure has to be correlated between both runways (e.g. the use of a common system for approaches to closely-spaced parallel runways).

3.4.3.3 For GNSS-based APV and Category I approaches, missed approach is considered a normal operation, since it occurs whenever the aircraft descends to the decision altitude for the approach and the pilot is unable to continue with visual reference. The continuity requirement for these operations applies to the average risk (over time) of loss of service, normalized to a 15-second exposure time. Therefore, the specific risk of loss of continuity for a given approach could exceed the average requirement without necessarily affecting the safety of the service provided or the approach. A safety assessment performed for one system led to the conclusion that, in the circumstances specified in the assessment, continuing to provide the service was safer than withholding it.

3.4.3.4 For those areas where the system design does not meet the average continuity risk specified in the SARPs, it is still possible to publish procedures. However, specific operational mitigations should be put in place to cope with the reduced continuity expected. For example, flight planning may not be authorized based solely on a GNSS navigation means with such a high average continuity risk.

3.5 Availability

3.5.1 The availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.

3.5.2 When establishing the availability requirements for GNSS, the desired level of service to be supported should be considered. If the satellite navigation service is intended to replace an existing en-route navigation aid infrastructure, the availability of the GNSS should be commensurate with the availability provided by the existing infrastructure. An assessment of the operational impact of a degradation in service should be conducted.

3.5.3 Where GNSS availability is low, it is still possible to use the satellite navigation service by restricting the navigation operating times to those periods when it is predicted to be available. This is possible in the case of GNSS since unavailability due to insufficient satellite geometry is repeatable. Under such restrictions, there remains only a continuity risk associated with the failure of necessary system components between the time the prediction is made and the time the operation is conducted.

3.5.4 *En-route*

3.5.4.1 Specific availability requirements for an area or operation should be based upon:

a) traffic density and complexity;

b) alternate navigation aids;

c) primary/secondary surveillance coverage;

d) air traffic and pilot procedures; and

e) duration of outages.

3.5.4.2 For this reason, the GNSS SARPs specify a range of values for availability requirements. The requirements support GNSS sole-means operations in airspace with various levels of traffic and complexity. The lower end of the range is only sufficient for providing sole means of navigation in a low traffic density and complexity airspace.

3.5.4.3 While augmentations can reduce the dependency of the GNSS on a particular core element, they do not provide usable service without the core elements. The requirement for the availability of a particular augmentation in an area should account for potential degradation in the GNSS core elements (i.e. the minimum constellation of core elements (number and diversity of satellites) that is expected). Operational procedures should be developed in case such a degraded configuration occurs.

3.5.5 *Approach*

3.5.5.1 Specific requirements for an area should be based upon:

a) traffic density and complexity;

b) procedures for filing and conducting an approach to an alternate airport;

c) navigation system to be used for an alternate airport;

d) air traffic and pilot procedures;

e) duration of outages; and

f) geographic extent of outages.

3.5.5.2 When developing operating procedures for GNSS approach systems, the duration of an outage and its impact on the alternate airport should be considered. Although GNSS outages can occur which affect many approaches, the approach service can be restored without any maintenance because of the orbiting of the satellites.

3.5.6 *Determining GNSS availability*

The availability of GNSS is complicated by the movement of satellites relative to a coverage area under consideration and the potentially long time needed to restore a satellite in the event of a failure. Accurately measuring the availability would require many years to allow for a measurement period longer than the MTBF and repair times. The availability of GNSS should be determined through design, analysis and modelling, rather than measurement. The availability model should account for the ionospheric, tropospheric and receiver error models used by the receiver to verify integrity (e.g. HPL, LPL and VPL calculations). The availability specified in Chapter 3, 3.7.2.4, applies to the design availability.

Note.— Additional guidance material pertaining to reliability and availability of radio communications and navigation aids is contained in Attachment F.

4. GNSS core elements

4.1 GPS

Note.— Additional information concerning GPS can be found in the Global Positioning System – Standard Positioning Service – Performance Standard, *September 2008, and Interface Specification (IS)-GPS-200E.*

4.1.1 The performance standard is based upon the assumption that a representative standard positioning service (SPS) receiver is used. A representative receiver has the following characteristics:

a) designed in accordance with IS-GPS-200E;

b) uses a 5-degree masking angle;

c) accomplishes satellite position and geometric range computations in the most current realization of the World Geodetic System 1984 (WGS-84) Earth-Centred, Earth-Fixed (ECEF) coordinate system;

d) generates a position and time solution from data broadcast by all satellites in view;

e) compensates for dynamic Doppler shift effects on nominal SPS ranging signal carrier phase and C/A code measurements;

f) excludes marginal and unhealthy satellites from the position solution;

g) uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and

h) loses track in the event that a GPS satellite stops transmitting a trackable signal.

The time transfer accuracy applies to the data in the broadcast navigation message, which relates GPS SPS time to UTC as maintained by the United States Naval Observatory. A 12-channel receiver will meet performance requirements specified in Chapter 3, 3.7.3.1.1.1 and 3.7.3.1.2. A receiver that is able to track four satellites only (Appendix B, 3.1.3.1.2) will not get the full accuracy and availability performance.

Note.— Conditions indicating that a satellite is "healthy", "marginal" or "unhealthy" can be found in the United States Department of Defense, Global Positioning System – Standard Positioning Service – Performance Standard, *4th Edition, September 2008, Section 2.3.2.*

4.1.2 *Position domain accuracy*. The position domain accuracy is measured with a representative receiver and a measurement interval of 24 hours for any point within the coverage area. The positioning and timing accuracy are for the signal-in-space (SIS) only and do not include such error sources as: ionosphere, troposphere, interference, receiver noise or multipath.

4.1.3 *Range domain accuracy*. The range domain accuracy standard applies to normal operations, which implies that updated navigation data is uplinked to the satellites on a regular basis. Range domain accuracy is conditioned by the satellite indicating a healthy status and transmitting C/A code and does not account for satellite failures outside of the normal operating characteristics. Range domain accuracy limits can be exceeded during satellite failures or anomalies while uploading data to the satellite. The range rate error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The range acceleration error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. Under nominal conditions, all satellites are maintained to the same standards, so it is appropriate for availability modelling purposes to assume that all satellites have a 4-metre RMS SIS user range error (URE). The standards are restricted to range domain errors allocated to space and control segments.

4.1.4 *Availability*. The availability standard applies to normal operations, which implies that updated navigation data is uplinked to the satellites on a regular basis. Availability is the percentage of time over any 24-hour interval that the predicted 95 per cent positioning error (due to space and control segment errors) is less than its threshold, for any point within the coverage area. It is based on a 17-metre horizontal 95 per cent threshold; a 37-metre vertical 95 per cent threshold; using a representative receiver; and operating within the coverage area over any 24-hour interval. The service availability assumes a constellation that meets the criteria in 4.1.4.2.

4.1.4.1 *Relationship to augmentation availability.* The availability of ABAS, GBAS and SBAS does not directly relate to the GPS availability defined in Chapter 3, 3.7.3.1.2. States and operators must evaluate the availability of the augmented system by comparing the augmented performance to the requirements. Availability analysis is based on an assumed satellite constellation and the probability of having a given number of satellites.

4.1.4.2 *Satellite/constellation availability*. Twenty-four operational satellites will be maintained on orbit with 0.95 probability (averaged over any day), where a satellite is defined to be operational if it is capable of, but is not necessarily transmitting, a usable ranging signal. At least 21 satellites in the nominal 24 slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (normalized annually). At least 20 satellites in the nominal 24 slot positions must be set healthy and must be transmitting a navigation signal with 0.99999 probability (normalized annually).

4.1.5 *Reliability*. Reliability is the percentage of time over a specified time interval that the instantaneous SPS SIS URE is maintained within the range error limit, at any given point within the coverage area, for all healthy GPS satellites. The reliability standard is based on a measurement interval of one year and the average of daily values within the coverage area. The worst single point average reliability assumes that the total service failure time of 18 hours will be over that particular point (3 failures each lasting 6 hours).

4.1.6 *Major service failure.* A major service failure is defined to be a condition over a time interval during which a healthy GPS satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the range error limit of 4.42 times the upper bound on the user range accuracy (URA) broadcast by a satellite for longer than the allowable time-to-alert (10 seconds). The probability of 1×10^{-5} in Chapter 3, 3.7.3.1.4 corresponds to a maximum of 3 major service failures for the entire constellation per year assuming a maximum constellation of 32 satellites:

4.1.7 *Continuity*. Continuity for a healthy GPS satellite is the probability that the SPS SIS will continue to be healthy without unscheduled interruption over a specified time interval. Scheduled interruptions which are announced at least 48 hours in advance do not contribute to a loss of continuity.

4.1.8 *Coverage*. The SPS supports the terrestrial coverage area, which is from the surface of the earth up to an altitude of 3 000 km.

4.2 reserved.

4.3 Dilution of precision

Dilution of precision (DOP) factors express how ranging accuracy is scaled by a geometry effect to yield position accuracy. The optimal geometry (i.e. the lowest DOP values) for four satellites is achieved when three satellites are equally spaced on the horizon, at minimum elevation angle, and one satellite is directly overhead. The geometry can be said to "dilute" the range domain accuracy by the DOP factor.

4.4 GNSS antenna and receiver

4.4.1 The antenna specifications in Appendix B, 3.8, do not control the antenna axial ratio except at boresight. Linear polarization should be assumed for the airborne antenna for GEO signals received at low-elevation angles. For instance, if the minimum elevation angle for which a trackable GEO signal needs to be provided is 5 degrees, the antenna should be presumed to be linearly polarized with −2.5 dBil (−5.5 dBic) gain when receiving this signal. This should be taken into account in the GEO link budget in order to ensure that the minimum received RF signal at the antenna port meets the requirements of Chapter 3, 3.7.3.4.4.3.2.

4.4.2 The failures caused by the receiver can have two consequences on navigation system performance which are the interruption of the information provided to the user or the output of misleading information. Neither of these events are accounted for in the signal-in-space requirement.

4.4.3 The nominal error of the GNSS aircraft element is determined by receiver noise, interference, and multipath and tropospheric model residual errors. Specific receiver noise requirements for both the SBAS airborne receiver and the GBAS airborne receiver include the effect of any interference below the protection mask specified in Appendix B, 3.7. The required performance has been demonstrated by receivers that apply narrow correlator spacing or code smoothing techniques.

5. Aircraft-based augmentation system (ABAS)

5.1 ABAS augments and/or integrates the information obtained from GNSS elements with information available on board the aircraft in order to ensure operation according to the values specified in Chapter 3, 3.7.2.4.

5.2 ABAS includes processing schemes that provide:

a) integrity monitoring for the position solution using redundant information (e.g. multiple range measurements). The monitoring scheme generally consists of two functions: fault detection and fault exclusion. The goal of fault detection is to detect the presence of a positioning failure. Upon detection, proper fault exclusion determines and excludes the source of the failure (without necessarily identifying the individual source causing the problem), thereby allowing GNSS navigation to continue without interruption. There are two general classes of integrity monitoring: receiver autonomous integrity monitoring (RAIM), which uses GNSS information exclusively, and aircraft autonomous integrity monitoring (AAIM), which uses information from additional on-board sensors (e.g. barometric altimeter, clock and inertial navigation system (INS));

b) continuity aiding for the position solution using information of alternative sources, such as INS, barometric altimetry and external clocks;

c) availability aiding for the position solution (analogous to the continuity aiding); and

d) accuracy aiding through estimation of remaining errors in determined ranges.

5.3 Non-GNSS information can be integrated with GNSS information in two ways:

a) integrated within the GNSS solution algorithm (an example is the modelling of altimetry data as an additional satellite measurement); and

b) external to the basic GNSS position calculation (an example is a comparison of the altimetry data for consistency with the vertical GNSS solution with a flag raised whenever the comparison fails).

5.4 Each scheme has specific advantages and disadvantages, and it is not possible to present a description of all potential integration options with specific numerical values of the achieved performance. The same applies to the situation when several GNSS elements are combined (e.g. GPS and GLONASS).

6. Satellite-based augmentation system (SBAS)

6.1 An SBAS is made up of three distinct elements:

a) the ground infrastructure;

b) the SBAS satellites; and

c) the SBAS airborne receiver.

6.1.1 The ground infrastructure includes the monitoring and processing stations that receive the data from the navigation satellites and compute integrity, corrections and ranging data which form the SBAS signal-in-space. The SBAS satellites relay the data relayed from the ground infrastructure to the SBAS airborne receivers that determine position and time information using core satellite constellation(s) and SBAS satellites. The SBAS airborne receivers acquire the ranging and correction data and apply these data to determine the integrity and improve the accuracy of the derived position.

6.1.2 The SBAS ground network measures the pseudo-range between the ranging source and an SBAS receiver at the known locations and provides separate corrections for ranging source ephemeris errors, clock errors and ionospheric errors. The user applies a tropospheric delay model.

6.1.3 The ranging source ephemeris error and slow moving clock error are the primary bases for the long-term correction. The ranging source clock error is adjusted for the long-term correction and tropospheric error and is the primary basis for the fast correction. The ionospheric errors among many ranging sources are combined into vertical ionospheric errors at predetermined ionospheric grid points. These errors are the primary bases for ionospheric corrections.

6.2 SBAS coverage area and service areas

6.2.1 It is important to distinguish between the coverage area and service areas for an SBAS. A coverage area typically corresponds to the GEOs footprint areas and comprises one or more service areas. Service areas are declared by SBAS service providers or by the State or group of States managing the SBAS, for the typical operations defined in Table 3.7.2.4-1 (e.g. En-route, APV-I, Category I) where the corresponding accuracy, integrity and continuity requirements are met with a certain availability (e.g. 99 per cent). Some SBAS service providers publish service areas of their systems (e.g. WAAS Performance standard, EGNOS Service Definition Document and AIPs). The service area for En-route may be wider than the service area for APV-I. For the GNSS receiver, the SIS is usable whenever the protection levels are lower than the alert limits for the intended operation (VPL<VAL and HPL<HAL), irrespective of whether or not the GNSS receiver is inside the corresponding service area defined by the SBAS service provider.

6.2.1.1 SBAS systems support operations based on some or all of the SBAS functions defined in Chapter 3, 3.7.3.4.2. These functions can be related to the operations that are supported as follows:

a) *Ranging*: SBAS provides a ranging source for use with other augmentation(s) (ABAS, GBAS or other SBAS);

b) *Satellite status and basic differential corrections*: SBAS provides en-route, terminal, and non-precision approach service. Different operations (e.g. performance-based navigation operations) may be supported in different service areas;

c) *Precise differential corrections*: SBAS provides APV and precision approach service (i.e. APV-I, APV-II and precision approach may be supported in different service areas).

6.2.2 Satellite-based augmentation services are provided by the Wide Area Augmentation System (WAAS) (North America), the European Geostationary Navigation Overlay Service (EGNOS) (Europe and Africa), the Multifunction Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) (Japan) and the GPS-aided Geo-augmented Navigation (GAGAN) (India). The System of Differential Correction and Monitoring (SDCM) (Russia) and other SBAS systems are also under development to provide these services.

6.2.3 An SBAS may provide accurate and reliable service outside the defined service area(s). The ranging, satellite status and basic differential corrections functions are usable throughout the entire coverage area. The performance of these functions may be technically adequate to support en-route, terminal and non-precision approach operations by providing monitoring and integrity data for core satellite constellations and/or SBAS satellites. SBAS mitigates errors which cannot be monitored by its ground network through message Types 27 or 28.

6.2.4 Each State is responsible for approving SBAS-based operations within its airspace. In some cases, States will field SBAS ground infrastructure linked to an SBAS. In other cases, States may simply approve service areas and SBASbased operations using available SBAS signals. In either case, each State is responsible for ensuring that SBAS meets the requirements of Chapter 3, 3.7.2.4, within its airspace, and that appropriate operational status reporting and NOTAMs are provided for its airspace.

6.2.5 Before approving SBAS-based operations, a State must determine that the proposed operations are adequately supported by one or more SBASs. This determination should focus on the practicality of using SBAS signals, taking into account the relative location of the SBAS ground network. This could involve working with the State(s) or organization(s) responsible for operating the SBASs. For an airspace located relatively far from an SBAS ground network, the number of visible satellites for which that SBAS provides status and basic corrections would be reduced. Since SBAS receivers are able to use data from two

SBASs simultaneously, and to use autonomous fault detection and exclusion when necessary, availability may still be sufficient for approval of operations.

6.2.6 Before publishing procedures based on SBAS signals, a State is expected to provide a status monitoring and NOTAM system. To determine the effect of a system element failure on service, a mathematical service volume model is to be used. The State can either obtain the model from the SBAS operator or develop its own model. Using the current and forecast status data of the basic system elements, and the locations where the State has approved operations, the model would identify airspace and airports where service outages are expected, and it could be used to originate NOTAMs. The system element status data (current and forecast) required for the model could be obtained via a bilateral arrangement with the SBAS service provider, or via connection to a real time "broadcast" of the data if the SBAS service provider chooses to provide data in this way.

6.2.7 Participating States or regions will coordinate through ICAO to ensure that SBAS provides seamless global coverage, taking into account that aircraft equipped to use the signal could suffer operational restrictions in the event that a State or region does not approve the use of one or more of the SBAS signals in its airspace. In such an event, the pilot may have to deselect GNSS altogether since the aircraft equipment may not allow deselection of all SBAS or a particular SBAS.

6.2.8 As the SBAS geostationary orbit satellite coverages (footprints) overlap, there will be interface issues among the SBASs. As a minimum, the SBAS airborne receivers must be able to operate within the coverage of any SBAS. It is possible for an SBAS provider to monitor and send integrity and correction data for a geostationary orbit satellite that belongs to another SBAS service provider. This improves availability by adding ranging sources. This improvement does not require any interconnection between SBAS systems and should be accomplished by all SBAS service providers.

6.2.9 Other levels of integration can be implemented using a unique connection between the SBAS networks (e.g. separate satellite communication). In this case, SBASs can exchange either raw satellite measurements from one or more reference stations or processed data (corrections or integrity data) from their master stations. This information can be used to improve system robustness and accuracy through data averaging, or integrity through a cross check mechanism. Availability will also be improved within the service areas, and the technical performance will meet the GNSS SARPs throughout the entire coverage (i.e. monitoring of satellites ephemeris would be improved). Finally, SBAS control and status data could be exchanged to improve system maintenance.

6.3 Integrity

6.3.1 The provisions for integrity are complex, as some attributes are determined within the SBAS ground network and transmitted in the signal-in-space, while other attributes are determined within the SBAS equipment on the aircraft. For the satellite status and basic corrections functions, an error uncertainty for the ephemeris and clock corrections is determined by the SBAS ground network. This uncertainty is modelled by the variance of a zero-mean, normal distribution that describes the user differential range error (UDRE) for each ranging source after application of fast and long-term corrections and excluding atmospheric effects and receiver errors.

6.3.2 For the precise differential function, an error uncertainty for the ionospheric correction is determined. This uncertainty is modelled by the variance of a zero-mean, normal distribution that describes the L1 residual user ionospheric range error (UIRE) for each ranging source after application of ionospheric corrections. This variance is determined from an ionospheric model using the broadcast grid ionospheric vertical error (GIVE).

6.3.3 There is a finite probability that an SBAS receiver would not receive an SBAS message. In order to continue navigation in that case, the SBAS broadcasts degradation parameters in the signal-in-space. These parameters are used in a number of mathematical models that characterize the additional residual error from both basic and precise differential corrections induced by using old but active data. These models are used to modify the UDRE variance and the UIRE variance as appropriate.

6.3.4 The individual error uncertainties described above are used by the receiver to compute an error model of the navigation solution. This is done by projecting the pseudo-range error models to the position domain. The horizontal protection level (HPL) provides a bound on the horizontal position error with a probability derived from the integrity requirement. Similarly, the vertical protection level (VPL) provides a bound on the vertical position. If the computed HPL exceeds the horizontal alert limit (HAL) for a particular operation, SBAS integrity is not adequate to support that operation. The same is true for precision approach and APV operations, if the VPL exceeds the vertical alert limit (VAL).

6.3.5 One of the most challenging tasks for an SBAS provider is to determine UDRE and GIVE variances so that the protection level integrity requirements are met without having an impact on availability. The performance of an individual SBAS depends on the network configuration, geographical extent and density, the type and quality of measurements used and the algorithms used to process the data. General methods for determining the model variance are described in section 14.

6.3.6 *Residual clock and ephemeris error (σ_{UDRE}).* The residual clock error is well characterized by a zero-mean, normal distribution since there are many receivers that contribute to this error. The residual ephemeris error depends upon the user location. For the precise differential function, the SBAS provider will ensure that the residual error for all users within a defined service area is reflected in the σ_{UDRE}. For the basic differential function, the residual ephemeris error should be evaluated and may be determined to be negligible.

6.3.7 *Vertical ionospheric error (σ_{GIVE}).* The residual ionospheric error is well represented by a zero-mean, normal distribution since there are many receivers that contribute to the ionospheric estimate. Errors come from the measurement noise, the ionospheric model and the spatial decorrelation of the ionosphere. The position error caused by ionospheric error is mitigated by the positive correlation of the ionosphere itself. In addition, the residual ionospheric error distribution has truncated tails, i.e. the ionosphere cannot create a negative delay, and has a maximum delay.

6.3.8 *Aircraft element errors*. The combined multipath and receiver contribution is bounded as described in section 14. This error can be divided into multipath and receiver contribution as defined in Appendix B, 3.6.5.5.1, and the standard model for multipath may be used. The receiver contribution can be taken from the accuracy requirement (Appendix B, 3.5.8.2 and 3.5.8.4.1) and extrapolated to typical signal conditions. Specifically, the aircraft can be assumed to have $\sigma^2_{\mathrm{air}} = \sigma^2_{\mathrm{receiver}} + \sigma^2_{\mathrm{multipath}}$, where it is assumed that $\sigma_{\mathrm{receiver}}$ is defined by the $\mathrm{RMS}_{\mathrm{pr\_air}}$ specified for GBAS Airborne Accuracy Designator A equipment, and $\sigma_{\mathrm{multipath}}$ is defined in Appendix B, 3.6.5.5.1. The aircraft contribution to multipath includes the effects of reflections from the aircraft itself. Multipath errors resulting from reflections from other objects are not included. If experience indicates that these errors are not negligible, they must be accounted for operationally.

6.3.9 *Tropospheric error*. The receiver must use a model to correct for tropospheric effects. The residual error of the model is constrained by the maximum bias and variance defined in Appendix B, 3.5.8.4.2 and 3.5.8.4.3. The effects of this mean must be accounted for by the ground subsystem. The airborne user applies a specified model for the residual tropospheric error (σ_{tropo}).

6.4 RF characteristics

6.4.1 *Minimum GEO signal power level*. The minimum aircraft equipment (e.g. RTCA/DO-229D with Change 1) is required to operate with a minimum signal strength of –164 dBW at the antenna port in the presence of non-RNSS interference (Appendix B, 3.7) and an aggregate RNSS noise density of –173 dBm/Hz. In the presence of interference, receivers may not have reliable tracking performance for a signal strength at the antenna port below –164 dBW (e.g. with GEO satellites placed in orbit prior to 2014). A GEO that delivers a signal power below –164 dBW at the receiving antenna port at 5-degree elevation on the ground can be used to ensure signal tracking in a service area contained in a coverage area defined by a minimum elevation angle that is greater than 5 degrees (e.g. 10 degrees). In this case, advantage is taken from the gain characteristic of the standard antenna to perform a trade-off between the GEO signal power and the size of the service area in which a trackable signal needs to be ensured. When planning for the introduction of new operations based on SBAS, States are expected to conduct an assessment of the signal power level as compared to the level interference from RNSS and non-RNSS sources. If the outcome of this analysis indicates that the level of interference is adequate to operate, then operations can be authorized.

6.4.2 *SBAS network time.* SBAS network time is a time reference maintained by SBAS for the purpose of defining corrections. When using corrections, the user's solution for time is relative to the SBAS network time rather than core satellite constellation system time. If corrections are not applied, the position solution will be relative to a composite core satellite constellation/SBAS network time depending on the satellites used and the resulting accuracy will be affected by the difference among them.

6.4.3 *SBAS convolutional encoding.* Information on the convolutional coding and decoding of SBAS messages can be found in RTCA/DO-229D with Change 1, Appendix A.

6.4.4 *Message timing.* The users' convolutional decoders will introduce a fixed delay that depends on their respective algorithms (usually 5 constraint lengths, or 35 bits), for which they must compensate to determine SBAS network time (SNT) from the received signal.

6.4.5 S*BAS signal characteristics*. Differences between the relative phase and group delay characteristics of SBAS signals, as compared to GPS signals, can create a relative range bias error in the receiver tracking algorithms. The SBAS service provider is expected to account for this error, as it affects receivers with tracking characteristics within the tracking constraints in 8.11. For GEOs for which the on-board RF filter characteristics have been published in RTCA/DO-229D with Change 1, Appendix T, the SBAS service providers are expected to ensure that the UDREs bound the residual errors including the maximum range bias errors specified in RTCA/DO-229D with Change 1. For other GEOs, the SBAS service providers are expected to work with equipment manufacturers in order to determine, through analysis, the maximum range bias errors that can be expected from existing receivers when they process these specific GEOs. This effect can be minimized by ensuring that the GEOs have a wide bandwidth and small group delay across the pass-band.

6.4.6 *SBAS pseudo-random noise (PRN) codes.* Receivers compliant with RTCA DO-229D with Change 1 and earlier versions only search for PRN codes in the range 120 to 138 only (out of the full 120 to 158 range in Table B-23), and therefore will not acquire and track SBAS signals identified by a PRN code in the range 139 to 158. Receivers compliant with DO-229E and subsequent versions can acquire and track SBAS signals identified by all PRN codes in Table B-23.

6.5 SBAS data characteristics

6.5.1 *SBAS messages.* Due to the limited bandwidth, SBAS data is encoded in messages that are designed to minimize the required data throughput. RTCA/DO-229D with Change 1, Appendix A, provides detailed specifications for SBAS messages.

6.5.2 *Data broadcast intervals.* The maximum broadcast intervals between SBAS messages are specified in Appendix B, Table B-54. These intervals are such that a user entering the SBAS service broadcast area is able to output a corrected position along with SBAS-provided integrity information in a reasonable time. For en-route, terminal and NPA operations, all needed data will be received within 2 minutes, whereas for precision approach operations, it will take a maximum of 5 minutes. The maximum intervals between broadcasts do not warrant a particular level of accuracy performance as defined in Chapter 3, Table 3.7.2.4-1. In order to ensure a given accuracy performance, each service provider will adopt a set of broadcast intervals taking into account different parameters such as the type of constellations (e.g. GPS with SA, GPS without SA) or the ionospheric activity.

6.5.3 *Time-to-alert.* Figure D-2 provides explanatory material for the allocation of the total time-to-alert defined in Chapter 3, Table 3.7.2.4-1. The time-to-alert requirements in Appendix B, 3.5.7.3.1, 3.5.7.4.1 and 3.5.7.5.1 (corresponding to the GNSS satellite status, basic differential correction and precise differential correction functions, respectively) include both the ground and space allocations shown in Figure D-2.

6.5.4 *Tropospheric function.* Because tropospheric refraction is a local phenomenon, users will compute their own tropospheric delay corrections. A tropospheric delay estimate for precision approach is described in RTCA/DO-229D with Change 1, although other models can be used.

6.5.5 *Multipath considerations.* Multipath is one of the largest contributors to positioning errors for SBAS affecting both ground and airborne elements. For SBAS ground elements, emphasis should be placed on reducing or mitigating the effects of multipath as much as possible so that the signal-in-space uncertainties will be small. Many mitigation techniques have been studied from both theoretical and experimental perspectives. The best approach for implementing SBAS reference stations with minimal multipath errors is to:

a) ensure that an antenna with multipath reduction features is chosen;

b) consider the use of ground plane techniques;

c) ensure that the antenna is placed in a location with low multipath effects; and

d) use multipath-reducing receiver hardware and processing techniques.

6.5.6 *reserved.*

6.6 SBAS final approach segment (FAS) data block

6.6.1 The SBAS final approach segment (FAS) data block for a particular approach procedure is as shown in Appendix B, 3.5.8.4.2.6.1 and Table B-57A. It is the same as the GBAS FAS data block defined in Appendix B, section 3.6.4.5.1 and Table B-66, with the following exceptions. The SBAS FAS data block also contains the HAL and VAL to be used for the approach procedure as described in 6.3.4. SBAS user equipment interprets certain fields differently from GBAS user equipment.

6.6.2 FAS data blocks for SBAS and some GBAS approaches are held within a common on-board database supporting both SBAS and GBAS. Within this database, channel assignments must be unique for each approach and coordinated with civil authorities. States are responsible for providing the FAS data for incorporation into the database.

6.6.3 An example of the coding of FAS data block for SBAS is provided in Table D-1. This example illustrates the coding of the various application parameters, including the cyclic redundancy check (CRC). The engineering values for the message parameters in the table illustrate the message coding process.

Table D-1. Example of an SBAS FAS data block

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	CODING RULES (*Note 5*)	PROCEDURE DESIGN VALUES PROVIDED	FAS DB VALUE USED	BINARY DEFINITION	BINARY REPRESENTATION (*Note 1*)	HEXADECIMAL REPRESENTATION
Operation Type	4	[0..15]	1	0 : Straight-in approach procedure 1..15 : Spare	Straight-In	0	$m_4..m_1$	0000	08
SBAS service provider ID	4	[0..15]	1	0 : WAAS 1 : EGNOS 2 : MSAS 3 : GAGAN 4 : SDCM 5..13 : Spare 14 : GBAS only 15 : Any SBAS provider	EGNOS	1	$m_8..m_5$	0001	
Airport ID	32	$\alpha_1\alpha_2\alpha_3\alpha_4$	-	α_1, α_2, α_3 = [0..9, A..Z] α4 = [<space>,0..9, A..Z] D_{OUT} =ASCII value & 3F	LFBO	LFBO	$m_{40}..m_{33}$ $m_{32}..m_{25}$ $m_{24}..m_{17}$ $m_{16}..m_9$	'L' **00** 001100 'F' **00** 000110 'B' **00** 000010 'O' **00** 001111 (*Note 2*)	F0 40 60 30
Runway number	6	[01..36]	1	-	14	14	$m_{46}..m_{41}$	001110	72
Runway letter	2	[0..3]	1	0 : No letter 1 : Right (R) 2 : Centre (C) 3 : Left (L)	R	1	m_{48} m_{47}	01	
Approach performance designator	3	[0..7]	1	Not used by SBAS	0 (default value)	0	$m_{51}..m_{49}$	000	0B
Route indicator	5	α	-	α =[<space>, A..Z] $\alpha \neq$ I and $\alpha \neq$ O	Z	Z	$m_{56}..m_{52}$	11010	
Reference path data selector	8	[0..48]	-	Not used by SBAS	0 (default value)	0	$m_{64}..m_{57}$	00000000	00
Reference path identifier	32	$\alpha_1\alpha_2\alpha_3\alpha_4$	-	α_1 =[E,M,W] α_2,α_3=[0..9] α_4 = [<space>,A,B, D..K,M..Q, S..Z] D_{OUT} =ASCII value & 3F	E14A	E14A	$m_{96}..m_{89}$ $m_{88}..m_{81}$ $m_{80}..m_{73}$ $m_{72}..m_{65}$	E' **00** 000101 '1' **00** 110001 '4' **00** 110100 'A' **00** 000001 (*Note 2*)	80 2C 8C A0
LTP/FTP latitude	32	[-90.0°.. 90.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 N : D_{OUT} S : Two's complement (D_{OUT})	D_{IN} = 43°38'38.8103" N	D_{CONV1} = 43°38'38.8105" N D_{CONV2} = 157118.8105 sec D_{OUT} = 314 237 621	$m_{128}..m_{121}$ $m_{120}..m_{113}$ $m_{112}..m_{105}$ $m_{104}..m_{97}$	00010010 10111010 11100010 10110101	AD 47 5D 48
LTP/FTP longitude	32	[-180.0°.. 180.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 E : D_{OUT} W : Two's complement (D_{OUT})	D_{IN} = 001°20'45.3591" E	D_{CONV1} = 001°20'45.3590" E D_{CONV2} = 4845.359 sec D_{OUT} = 9 690 718	$m_{160}..m_{153}$ $m_{152}..m_{145}$ $m_{144}..m_{137}$ $m_{136}..m_{129}$	00000000 10010011 11011110 01011110	7A 7B C9 00
LTP/FTP height	16	[-512.. 6041.5]	0.1m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = (D_{IN} + 512) x 10	D_{IN} = 148.74m	D_{CONV} = 148.7 D_{OUT} = 6 607	$m_{176}..m_{169}$ $m_{168}..m_{161}$	00011001 11001111	F3 98
ΔFPAP latitude	24	[-1.0°..1.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 + : D_{OUT} - : Two's complement (D_{OUT})	D_{IN} = -0°01'37.8973"	D_{CONV1} = -00°01'37.8975" D_{CONV2} = -97.8975" D_{OUT} = Two's complement (195795) D_{OUT} = 16 581 421	$m_{200}..m_{193}$ $m_{192}..m_{185}$ $m_{184}..m_{177}$	11111101 00000011 00101101	B4 C0 BF

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	CODING RULES (*Note 5*)	PROCEDURE DESIGN VALUES PROVIDED	FAS DB VALUE USED	BINARY DEFINITION	BINARY REPRESENTATION (*Note 1*)	HEXADECIMAL REPRESENTATION
ΔFPAP longitude	24	[-1.0°..1.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 + : D_{OUT} - : Two's complement (D_{OUT})	D_{IN} = 0°01'41.9329"	D_{CONV1} = 0°01'41.9330" D_{CONV2} = 101.9330" D_{OUT} = 203 866	$m_{224}..m_{217}$ $m_{216}..m_{209}$ $m_{208}..m_{201}$	00000011 00011100 01011010	5A 38 C0
Approach TCH	15	[0..1638.35m] [0..3276.7ft]	0.05m 0.1ft	D_{CONV} = round (D_{IN}, resolution) m : D_{OUT} = D_{IN} x 20 ft : D_{OUT} = D_{IN} x 10	D_{IN} = 15.00m	D_{CONV} = 15.00m D_{OUT} = 300	$m_{239}..m_{233}$ $m_{232}..m_{225}$	0000001 00101100	34 81
Approach TCH units selector	1	[0,1]	-	0 : feet 1 : metres	m	1	m_{240}	1	
Glide path angle (GPA)	16	[0..90.00°]	0.01°	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = D_{IN} x 100	D_{IN} = 3.00°	D_{CONV} = 3.00° D_{OUT} = 300	$m_{256}..m_{249}$ $m_{248}..m_{241}$	00000001 00101100	34 80
Course width	8	[80.00m.. 143.75m]	0.25m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = (D_{CONV} - 80) x 4	D_{IN} = 105.00m	D_{CONV} = 105.00m D_{OUT} = 100	$m_{264}..m_{257}$	01100100	26
ΔLength offset	8	[0..2032m]	8m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = (integer division of D_{CONV} by 8) + 1 D_{OUT} = 255 : not provided value	D_{IN} = 284.86m	D_{CONV} = 288m D_{OUT} = 36	$m_{272}..m_{265}$	00100100	24
Horizontal alert limit (HAL)	8	[0..50.8m]	0.2m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = D_{IN} * 5	D_{IN} = 40.0m	D_{CONV} = 40.0m D_{OUT} = 200	$m_{280}..m_{273}$	11001000	13
Vertical alert limit (VAL)	8	[0..50.8m]	0.2m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = Value * 5 D_{OUT} = 0 : vertical deviations cannot be used	D_{IN} = 50.0m	D_{CONV} = 50.0m D_{OUT} = 250	$m_{288}..m_{281}$	11111010	5F
Final approach segment CRC	32	[0..2^{32}-1]		D_{OUT} = remainder (P(x) / Q(x))	-	-	$r_{32}..r_{25}$ $r_{24}..r_{17}$ $r_{16}..r_{9}$ $r_{8}..r_{1}$	10101110 11000011 01100100 10001111	75 C3 26 F1 (*Note 4*)

Notes.

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted to the CRC calculator.*
2. *The two most significant bits of each byte are set to 0 (see bold characters).*
3. *The rounding methodology is provided in the PANS-OPS (Doc 8168) Volume II.*
4. *The FAS CRC value is displayed in the order $r_{25}..r_{32}$, $r_{17}..r_{24}$, $r_{9}..r_{16}$, $r_{1}..r_{8}$ where r_i is th i^{th} coefficient of the remainder R(x) as defined in Appendix B, 3.9 .*
5. *D_{IN} : raw data value, D_{CONV} : converted data value according to coding rules, D_{OUT} : coded data value.*

7. Ground-based augmentation system (GBAS) and ground-based regional augmentation system (GRAS)

Note.— In this section, except where specifically annotated, reference to approach with vertical guidance (APV) means APV-I and APV-II.

7.1 System description

7.1.1 GBAS consists of ground and aircraft elements. A GBAS ground subsystem typically includes a single active VDB transmitter and broadcast antenna, referred to as a broadcast station, and multiple reference receivers. A GBAS ground subsystem may include multiple VDB transmitters and antennas that share a single common GBAS identification (GBAS ID) and frequency as well as broadcast identical data. The GBAS ground subsystem can support all the aircraft subsystems within its service volume providing the aircraft with approach data, corrections and integrity information for GNSS satellites in view. GBAS ground and aircraft elements are classified according to the types of service they support (as defined in section 7.1.2).

7.1.2 GBAS systems may provide two types of services: approach services and the GBAS positioning service. The approach service provides deviation guidance for FASs within the approach service volume. The GBAS positioning service provides horizontal position information to support RNAV operations within the positioning service volume. The two types of services are also distinguished by different performance requirements associated with the particular operations supported (see Table 3.7.2.4-1) including different integrity requirements as discussed in 7.5.1.

7.1.2.1 GBAS approach services are further differentiated into multiple types referred to as GBAS approach service types (GAST). A GAST is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used in concert in order to provide approach guidance with quantifiable performance. Four types of approach service, GAST A, GAST B, GAST C and GAST D are currently defined. GAST A, B and C are intended to support typical APV I, APV II and Category I operations, respectively. GAST D has been introduced to support landing and guided take-off operations in lower visibility conditions including Category III operations. Note that provisions for a separate service type to support Category II operations, but not Category I nor Category III, have not been made. Since equipment supporting GAST D will function the same when supporting Category II minima as when supporting Category III minima, GAST D provides one means of supporting Category II operations. Category II operations may potentially be supported using GAST C in conjunction with an appropriate aeroplane level integration. A relevant analogy is the authorization in at least one State of lower than Category I minima based on guidance from a facility performance Category I ILS used in conjunction with a head-up display (HUD). Requirements for the approval of Category II operations using GBAS will be defined by the airworthiness and operational approval authorities within States.

7.1.2.1.1 A GBAS ground subsystem may support multiple service types simultaneously. There are two types of ground subsystems, those that support multiple types of approach service and those that do not. Equipment designed in compliance with earlier versions of these SARPs may only support a single type of approach service, GAST C. Equipment designed in compliance with these SARPs may or may not support multiple types of service on one or more runway ends. The type of services supported for each approach are indicated in the approach performance designation field in a FAS data block within the Type 4 message. The GBAS continuity/integrity designator (GCID) parameter in the Type 2 message indicates whether a GBAS ground subsystem is currently supporting multiple types of approach service. Airborne equipment that can support multiple service types will first check the GCID to determine if the ground segment supports multiple types of service. If it does, the equipment will then check the approach performance designator (APD) field of the selected FAS data block within the Type 4 message to determine which types of service are supported by the ground segment for the approach selected (using the channel selection scheme described in section 7.7 below). The airborne equipment will then determine which approach service to select based on APD, the current status of GCID and the airborne equipment type. Operators should understand that the available operations may be restricted by many factors including pilot qualifications or temporary ANSP limitations which are not reflected in the APD value. Therefore, APD should not be interpreted as an indication of the availability of any operational use, only as an indication of the service types that are supported for the given runway.

7.1.2.1.2 GBAS airborne equipment may attempt to automatically select the highest type of service supported by both the airborne equipment and the ground segment for the selected approach (as indicated in APD). If the desired type of service is not available, the airborne equipment may select the next lower available type of service and annunciate this appropriately. Therefore, during a GBAS operation, there is the selected service type (SST) and the active service type (AST). The SST is the service type that the airborne equipment would use if it were available, and can be no higher than the highest type of service offered by the ground segment for the selected approach. The AST is the service type that the airborne equipment is actually using at a particular time. The AST may differ from the SST if the SST is unavailable for some reason. The airborne equipment annunciates both the SST and AST so that proper action (e.g. annunciations) may be taken in the context of the airborne integration and operational procedures.

7.1.2.1.3 Service providers should give consideration to what service type or types are actually required for each runway given the planned operations and encode the availability of the appropriate service types in the APD field of the associated FAS block.

7.1.2.1.4 When the ground subsystem is no longer capable of meeting FAST D requirements there are several options, depending upon which requirements are not met. If the ground subsystem cannot meet all of the FAST D integrity requirements (Appendix B, 3.6.7.1.2.1.1.2, 3.6.7.1.2.1.1.3, and 3.6.7.1.2.2.1.1, 3.6.7.3.2) FAST D needs to be removed within the time-to-alert defined in Appendix B, 3.6.7.1.2.1.1.3. If it is still capable of meeting FAST C integrity requirements, the ground subsystem should only remove FAST D and continue to broadcast in FAST C mode. The procedure for removing FAST D includes two options for reflecting this in the corrections (Appendix B, 3.6.7.3.2.1).

7.1.2.1.4.1 When downgrading from FAST D to C, the GCID in the Type 2 message (Appendix B, 3.6.7.2.3.2) also needs to change. A FAST D ground subsystem normally broadcasts a GCID of 2, indicating it supports FAST C and FAST D.
When the ground subsystem can no longer support FAST D, but can still support FAST C, the GCID should change to 1. Note that it is assumed here that a FAST D ground subsystem would downgrade to FAST C only, and not to FAST A or B.

7.1.2.1.4.2 Another condition that could result in the ground subsystem no longer being capable of supporting FAST D would be a failure such that FAST D continuity (Appendix B, 3.6.7.1.3.1 and 3.6.7.1.3.2) cannot be met (e.g. failure of redundant components). If FAST D integrity requirements are still met, the ground subsystem is not required to remove the corrections in the Type 11 messages. However, the GCID needs to change to 1. Communicating the change in GCID nominally would take 10 seconds, as the minimum update rate for Type 2 messages is 10 seconds. It may take as long as one minute. A change in FAST should be reflected in the next scheduled broadcast of the Type 2 message. In addition, changes to GCID are ignored by the airborne equipment when the aircraft is in the final stages of the approach. Therefore, GCID changes only affect the FAST for aircraft outside of the final stages of the approach.

7.1.3 A significant distinguishing feature for GBAS ground subsystem configurations is whether additional ephemeris error position bound parameters are broadcast. This feature is required for the positioning service, but is optional for some approach services. If the additional ephemeris error position bound parameters are not broadcast, the ground subsystem is responsible for assuring the integrity of ranging source ephemeris data without reliance on the aircraft calculating and applying the ephemeris bound as discussed in 7.5.9.

7.1.4 *GBAS configurations.* There are multiple configurations possible of GBAS ground subsystems conforming to the GNSS Standards, examples of such configurations are:

a) a configuration that supports GAST C only;

b) a configuration that supports GAST A, GAST B, GAST C, and also broadcasts the additional ephemeris error position bound parameters;

c) a configuration that supports only GAST C and GAST D, and the GBAS positioning service, while also broadcasting the ephemeris error position bound parameters referred to in b); and

d) a configuration that supports only GAST A and the GBAS positioning service, and is used within a GRAS.

7.1.4.1 *GBAS facility classification (GFC).* A GBAS ground subsystem is classified according to key configuration options. A GFC is composed of the following elements:

a) facility approach service type (FAST);

b) ranging source types;

c) facility coverage; and

d) polarization.

7.1.4.1.1 *Facility approach service type (FAST).* The FAST is a collection of letters from A to D indicating the service types that are supported by the ground subsystem. For example, FAST C denotes a ground subsystem that meets all the performance and functional requirements necessary to support GAST C. As another example, a FAST ACD designates a ground subsystem that meets the performance and functional requirements necessary to support service types A, C and D.

Note.— The facility classification scheme for GBAS includes an indication of which Service Types the ground subsystem can support. This means the ground subsystem meets all the performance requirements and functional requirements such that a compatible airborne user can apply the information from the ground subsystem and have quantifiable performance at the output of the processing. It does not necessarily mean that the ground subsystem supports all service types on every runway end. Which GBAS approach service types are supported on a given runway end is indicated in the Type 4 message and is included as part of the approach facility designation defined in section 7.1.4.2.

7.1.4.1.2 *Ranging source types*: The ranging source type designation indicates what ranging sources are augmented by the ground subsystem. The coding for this parameter is as follows:

G1 - GPS
G2 - SBAS
G3 - reserved
G4 - Reserved for Galileo
G5+ - Reserved for future ranging sources

7.1.4.1.3 *Facility coverage*: The facility coverage designation indicates positioning service capability and maximum use distance. The facility coverage is coded as 0 for ground facilities that do not provide the positioning service. For other cases, the facility coverage indicates the radius of D_{max} expressed in nautical miles.

Note.— The service volume for specific approaches is defined as part of the approach facility designations defined in section 7.1.4.2.

7.1.4.1.4 *Polarization*: The polarization designation indicates the polarization of the VHF data broadcast (VDB) signal. E indicates elliptical polarization and H indicates horizontal polarization.

7.1.4.1.5 *GBAS facility classification examples*. The facility classification for a specific facility is specified by a concatenated series of codes for the elements described in sections 7.1.4.1 through 7.1.4.1.4. The general form of the facility classification is:

GFC = Facility Approach Service Type/Ranging Source Type /Facility Coverage/Polarization.

For example, a facility with the designation of GFC – C/G1/50/H, denotes a ground subsystem that meets all the performance and functional requirements necessary to support service type C on at least one approach, using GPS ranges only, with the GBAS positioning service available to a radius of 50 NM from the GBAS reference position and a VDB that broadcasts in Horizontal polarization only. Similarly, GFC – CD/G1G2G3G4/0/E denotes a ground subsystem that supports at least one approach with a service type of C and D, provides corrections for GPS, SBAS, satellites does not support the positioning service and broadcasts on elliptical polarization.

7.1.4.2 *Approach facility designations*. A GBAS ground subsystem may support many approaches to different runway ends at the same airport or even runways at adjacent airports. It is even possible that a GBAS will support multiple approaches to the same runway end with different types of service (intended, for example, to support different operational minima). Each approach provided by the ground system may have unique characteristics and in some sense may appear to the user to be a separate facility. Therefore, in addition to the GBAS facility classification, a system for classifying or designating the unique characteristics of each individual approach path is needed. For this purpose, a system of approach facility designations is defined. Figure D-4 illustrates the relationship between GBAS facility classifications and approach facility designations. The classification is intended to be used for pre-flight planning and published in the AIP.

7.1.4.2.1 *Approach facility designation elements*. Each approach supported by a GBAS can be characterized by an approach facility designation (AFD). The AFD is composed of the following elements:

GBAS identification:	Indicates the GBAS facility identifier that supports the approach (4-character GBAS ID).
Approach identifier:	This is the approach identifier associated with the approach in the message Type 4 data block. It is 4 characters and must be unique for each approach within radio range of the GBAS facility.
Channel number:	This is the channel number associated with the approach selection. It is a 5 digit channel number between 20001 and 39999.
Approach service volume:	Associated with each published approach, indicates the service volume either by a numerical value in feet corresponding to the minimum decision height (DH) or by the GBAS points as defined below (i.e. GBAS Points A, B, C, T, D, E, or S).
Supported service types:	Designates the GBAS service types (A-D) that are supported for the approach by the ground subsystem. This field can never be given a value greater than the facility approach service type for the GBAS ground subsystem that supports the approach.

The GBAS points A, B, C, T, D and E define the same locations relative to the runway as the ILS Points in Attachment C, Figure C-1 used to define the ILS localizer course and glide path bend amplitude limits. Point S is a new point defining the stop end of the runway. For GBAS, the points are used to indicate the location along the nominal approach and/or along the runway for which GBAS performance for the supported service type(s) has been verified. When a decision height is used instead to define the approach service volume, the service volume is provided to a height of half the DH as defined in Chapter 3, 3.7.3.5.3.1. The choice of coding using a DH or GBAS points depends upon the intended operational use of the runway. For example, if the approach identifier corresponds to a Category I instrument approach procedure from which automatic landings are authorized, the approach service volume element is intended to indicate at what point along the runway the performance has been verified. The point definitions are given below:

GBAS Point "A". A point on a GBAS final approach segment measured along the extended runway centre line in the approach direction a distance of 7.5 km (4 NM) from the threshold.

GBAS Point "B". A point on the GBAS final approach segment measured along the extended runway centre line in the approach direction a distance of 1 050 m (3 500 ft) from the threshold.

GBAS Point "C". A point through which the downward extended straight portion of the nominal GBAS final approach segment passes at a height of 30 m (100 ft) above the horizontal plane containing the threshold.

GBAS Point "D". A point 3.7 m (12 ft) above the runway centre line and 900 m (3 000 ft) from the threshold in the direction of the GNSS azimuth reference point (GARP).

GBAS Point "E". A point 3.7 m (12 ft) above the runway centre line and 600 m (2 000 ft) from the stop end of the runway in the direction of the threshold.

GBAS Point "S". A point 3.7 m (12 ft) above the runway centre line at the stop end of the runway.

GBAS reference datum (Point "T"). A point at a height specified by TCH located above the intersection of the runway centre line and the threshold.

7.1.4.2.2 Approach facility designation examples

The approach facility designation consists of the concatenation of the parameters defined in section 7.1.4.2.1 as: GBAS ID/approach ID/ranging sources/approach service volume/required service type. An example application of this concept to a particular approach at the US Washington, DC Ronald Reagan International Airport is:

"KDCA/XDCA/21279/150/CD"

where:

KDCA − indicates the approach is supported by the GBAS installation at DCA
XDCA − indicates the approach ident (echoed to the pilot on approach selection) for this specific approach is "XDCA"
21279 − is the 5-digit channel number used to select the approach
150 − indicates the GBAS coverage has been verified to be sufficient to support a DH as low as 150 ft.
CD − indicates that GBAS approach service types C and D are supported by the ground subsystem for the approach

Another example application of this concept to a particular approach at Boeing Field is:

"KBFI/GBFI/35789/S/C"

where:

KBFI − indicates the approach is supported by the GBAS installation at BFI (with GBAS Station identifier KBFI)
GBFI − indicates the approach ident (echoed to the pilot on approach selection) for this specific approach is "GBFI"
35789 − is the 5-digit channel number used to select the approach.
S − indicates the GBAS service volume extends along the approach and the length of the runway surface (i.e. 12 ft above the runway to the stop end).
C − indicates that GBAS approach service type C is supported by the ground subsystem for this FAS.

7.1.4.3 *GBAS airborne equipment classification (GAEC)*

7.1.4.3.1 GBAS airborne equipment may or may not support multiple types of approach service that could be offered by a specific ground subsystem. The GBAS airborne equipment classifications (GAEC) specifies which subsets of potentially available services types the airborne equipment can support. The GAEC includes the following elements:

Airborne approach service type (AAST): The AAST designation is a series of letters in the range from A to D indicating which GASTs are supported by the airborne equipment. For example, AAST C denotes airborne equipment that supports only GAST C. Similarly, AAST ABCD indicates the airborne equipment can support GASTs A, B, C & D.

Note.— For airborne equipment, designating only the highest GBAS approach service type supported is insufficient as not all airborne equipment is required to support all service types. For example, a particular type of airborne equipment may be classified as AAST CD, meaning the airborne equipment supports GAST C and D (but not A or B).

Ranging source types: This field indicates which ranging sources can be used by the airborne equipment. The coding is the same as for the ground facility classification (see section 7.1.4.1.2)

7.1.4.3.2 *Multiple service type capable equipment*. Ground and airborne equipment designed and developed in accordance with previous versions of these SARPs (Amendment 80) and RTCA DO-253A will only support GAST C. The current version of the Standards has been designed such that legacy GBAS airborne equipment will still operate correctly when a ground subsystem supports multiple types of service. Also, airborne equipment which can support multiple types of service will operate correctly when operating with a ground subsystem that supports only GAST C.

7.1.4.3.3 *GBAS airborne equipment classification examples*. GBAS airborne equipment classifications consist of a concatenated series of codes for the parameters defined in 7.1.4.3. The general form of the GAEC is:

GAEC = (airborne approach service type)/(ranging source type)

For example:

GAEC of C/G1 - denotes airborne equipment that supports only GAST C and uses only GPS ranges.

Similarly:

GAEC of ABC/G1G4 - denotes airborne equipment that supports all GASTs except GAST D and can use both GPS and Galileo ranging sources.

GAEC of ABC/G1G3 - denotes airborne equipment that supports all GASTs except GAST D and can use both GPS and GLONASS ranging sources.

Finally:

GAEC – CD/G1G2G3G4 - denotes airborne equipment that supports GASTs C and D and uses GPS, SBAS, GLONASS and Galileo ranging sources.

7.1.5 *GRAS configurations.* From a user perspective, a GRAS ground subsystem consists of one or more GBAS ground subsystems (as described in 7.1.1 through 7.1.4), each with a unique GBAS identification, providing the positioning service and one or more approach service types where required. By using multiple GBAS broadcast stations, and by broadcasting the Type 101 message, GRAS is able to support en-route operations via the GBAS positioning service, while also supporting terminal, departure, and operations supported by GAST A or B over a larger coverage region than that typically supported by GBAS. In some GRAS applications, the corrections broadcast in the Type 101 message may be computed using data obtained from a network of reference receivers distributed in the coverage region.

7.1.6 *VDB transmission path diversity.* All broadcast stations of a GBAS ground subsystem broadcast identical data with the same GBAS identification on a common frequency. The airborne receiver need not and cannot distinguish between messages received from different broadcast stations of the same GBAS ground subsystem. When within coverage of two such broadcast stations, the receiver will receive and process duplicate copies of messages in different time division multiple access (TDMA) time slots.

7.1.7 Interoperability of the GBAS ground and aircraft elements compatible with RTCA/DO-253() is addressed in Appendix B, 3.6.8.1. GBAS receivers compliant with RTCA/DO-253A will not be compatible with GRAS ground subsystems broadcasting Type 101 messages. However, GRAS and GBAS receivers compliant with RTCA/DO-310 GRAS MOPS, will be compatible with GBAS ground subsystems. SARPs-compliant GBAS receivers may not be able to decode the FAS data correctly for GAST A transmitted from GBAS ground subsystems (i.e. a FAS data block with APD coded as “0”). These receivers will apply the FASLAL and FASVAL as if the active service type is GAST C. ANSPs should be cognizant of this fact and relevant operational restrictions may have to be applied to ensure the safety of the operation. For GBAS ground subsystems providing GAST D, APD in the FAS data blocks may be coded as values of 1 or 2 (Appendix B, 3.6.4.5.1). SARPs compliant GBAS receivers developed in accordance with SARPs prior to Amendment 91 may not be able to use FAS data blocks with APD equal to 2 or above.

7.1.8 The GBAS VDB transmits with either horizontal or elliptical polarization (GBAS/H or GBAS/E). This allows service providers to tailor the broadcast to their operational requirements and user community.

7.1.9 The majority of aircraft will be equipped with a horizontally-polarized VDB receiving antenna, which can be used to receive the VDB from both GBAS/H and GBAS/E equipment. A subset of aircraft will be equipped with a verticallypolarized antenna due to installation limitations or economic considerations. These aircraft are not compatible with GBAS/H equipment and are, therefore, limited to GBAS-based operations supported by GBAS/E.

7.1.10 GBAS service providers must publish the signal polarization (GBAS/H or GBAS/E), for each GBAS facility in the aeronautical information publication (AIP). Aircraft operators that use vertically polarized receiving antenna will have to take this information into account when managing flight operations, including flight planning and contingency procedures.

7.1.11 *Availability considerations for GBAS*. A single GBAS ground subsystem may provide multiple types of service to multiple users and service for multiple runway ends simultaneously. These different types of service may have different availability and consequently one type of service may be available when another is not. Furthermore, as some elements of GBAS are optional (e.g. augmentation of multiple constellations or use of SBAS ranging sources), the capabilities of different users will vary. For this reason, it is not practical for the service provider to predict if a given user will find a specific service type to be available at any given time. All that can be known by the service provider is the status of the ground subsystem and satellite constellation. An assessment can be made as to whether the ground subsystem is meeting the allocated requirements for some target service type and further, the availability of service can be predicted based on an assumed level of performance and a nominal user. The definition of the nominal user includes which elements of GNSS are used (core satellite systems, SBAS ranges etc.) and within that, which subset of satellites are used in the position solution. For GBAS supporting GAST D this is further complicated by the fact that certain parameters (e.g. geometry screening thresholds) may be adjusted by the airframe designer to ensure adequate landing performance given the characteristics of the specific aircraft type. ANSPs and air space designers should be cognizant of the fact that availability of service for GNSS augmentation systems in general is less predictable than conventional navigation aids. Variations in user capabilities will result in times where service may be available to some users and unavailable to others.

7.2 RF characteristics

7.2.1 *Frequency coordination*

7.2.1.1 *Performance factors*

7.2.1.1.1 The geographical separation between a candidate GBAS station, a candidate VOR station and existing VOR or GBAS installations must consider the following factors:

a) the service volume, minimum field strength and effective isotropically radiated power (EIRP) of the candidate GBAS including the GBAS positioning service, if provided. The minimum requirements for service volume and field strength are found in Chapter 3, 3.7.3.5.3 and 3.7.3.5.4.4, respectively. The EIRP is determined from these requirements;

b) the coverage and service volume, minimum field strength and EIRP of the surrounding VOR and GBAS stations including the GBAS positioning service, if provided. Specifications for coverage and field strength for VOR are found in Chapter 3, 3.3, and respective guidance material is provided in Attachment C;

c) the performance of VDB receivers, including co-channel and adjacent channel rejection, and immunity to desensitization and intermodulation products from FM broadcast signals. These requirements are found in Appendix B, 3.6.8.2.2;

d) the performance of VOR receivers, including co-channel and adjacent channel rejection of VDB signals. Since existing VOR receivers were not specifically designed to reject VDB transmissions, desired-to-undesired (D/U) signal ratios for co-channel and adjacent channel rejection of the VDB were determined empirically. Table D-2 summarizes the assumed signal ratios based upon empirical performance of numerous VOR receivers designed for 50 kHz channel spacing;

e) for areas/regions of frequency congestion, a precise determination of separation may be required using the appropriate criteria;

Table D-2. Assumed $[D/U]_{required}$ signal ratios to protect VOR from GBAS VDB

Frequency offset	$[D/U]_{required}$ ratio to protect VOR receivers (dB)
Co-channel	26
$\| f_{VOR} – f_{VDB} \| = 25$ kHz	0
$\| f_{VOR} – f_{VDB} \| = 50$ kHz	–34
$\| f_{VOR} – f_{VDB} \| = 75$ kHz	–46
$\| f_{VOR} – f_{VDB} \| = 100$ kHz	–65

f) that between GBAS installations RPDS and RSDS numbers are assigned only once on a given frequency within radio range of a particular GBAS ground subsystem. The requirement is found in Appendix B, 3.6.4.3.1;

g) that between GBAS installations within radio range of a particular GBAS ground subsystem the reference path identifier is assigned to be unique. The requirement is found in Appendix B, 3.6.4.5.1; and

h) the four-character GBAS ID to differentiate between GBAS ground subsystems. The GBAS ID is normally identical to the location indicator at the nearest aerodrome. The requirement is found in Appendix B, 3.6.3.4.1; and

i) *Slot assignment*. The relative assignment of slots to a GBAS ground subsystem can impact performance in instances where messages in multiple slots need to be received by the airborne subsystem prior to processing. This will occur when using linked messages and/or for a GAST D ground subsystem where correction data is contained in both the Type 1 and Type 11 messages. In these cases slot assignments for all MT 1 and 11 should be adjacent to avoid unnecessary latency and complexity of design. Non-adjacent assignments may, depending on the design of the ground subsystem, result in a lack of time for the ground subsystem to process fault detections, render some slot combinations unusable and thus result in lower efficiency of spectrum use.

7.2.1.1.2 Nominal link budgets for VDB are shown in Table D-3. The first example in Table D-3 assumes a user receiver height of 3 000 m (10 000 ft) MSL and a transmit antenna designed to suppress ground illumination in order to limit the fading losses to a maximum of 10 dB at VDB coverage edge. In the case of GBAS/E equipment, the 10 dB also includes any effects of signal loss due to interference between the horizontal and vertical components. The second example in Table D-3 provides a link budget for longer range positioning service. It is for a user receiver height sufficient to maintain radio line-of-sight with a multi-path limiting transmitting antenna. No margin is given in Table D-3 for fading as it is assumed that the receiver is at low elevation angles of radiation and generally free from significant null for the distances shown in the table (greater than 50 NM). In practice, installations will experience a fade margin that will be dependent on many parameters including aircraft altitude, distance from transmit antenna, antenna type/design and ground reflectors.

7.2.1.2 *FM immunity*

7.2.1.2.1 Once a candidate frequency is identified for which the GBAS and VOR separation criteria are satisfied, compatibility with FM transmissions must be determined. This is to be accomplished using the methodology applied when determining FM compatibility with VOR. If FM broadcast violates this criterion, an alternative candidate frequency has to be considered.

7.2.1.2.2 The desensitization is not applied for FM carriers above 107.7 MHz and VDB channels at 108.050 MHz because the off-channel component of such high-level emissions from FM stations above 107.7 MHz will interfere with GBAS VDB operations on 108.025 and 108.050 MHz, hence those assignments will be precluded except for special assignments in geographic areas where the number of FM broadcast stations in operation is small and would unlikely generate interference in the VDB receiver.

7.2.1.2.3 The FM intermodulation immunity requirements are not applied to a VDB channel operating below 108.1 MHz, hence assignments below 108.1 MHz will be precluded except for special assignments in geographic areas where the number of FM broadcast stations in operation is small and would unlikely generate intermodulation products in the VDB receiver.

7.2.1.3 *Geographic separation methodologies*

7.2.1.3.1 The methodologies below may be used to determine the required GBAS-to-GBAS and GBAS-to-VOR geographical separation. They rely on preserving the minimum desired-to-undesired signal ratio. $[D/U]_{required}$ is defined as the signal ratio intended to protect the desired signal from co-channel or adjacent channel interference from an undesired transmission. $[D/U]_{required}$ values required for protection of a GBAS receiver from undesired GBAS or VOR signals are defined in Appendix B, 3.6.8.2.2.5 and 3.6.8.2.2.6. $[D/U]_{required}$ values intended for protection of a VOR receiver from GBAS VDB transmissions as shown in Table D-2 are not defined in SARPs and represent the assumed values based on test results.

7.2.1.3.2 Geographic separation is constrained by preserving $[D/U]_{required}$ at the edge of the desired signal coverage where the desired signal power is derived from the minimum field strength requirements in Chapter 3. This desired signal level, converted to dBm, is denoted $P_{D,min}$. The allowed signal power of the undesired signal ($P_{U,allowed}$) is:

$$P_{Uallowed}(dBm) = (P_{D,min}\ (dBm) - [D/U]_{required}\ (dB))$$

The undesired signal power P_U converted to dBm is:

$$P_U(dBm) = (Tx_U\ (dBm) - L\ (dB))$$

where

Tx_U is the effective radiated power of the undesired transmitter; and

L is the transmission loss of the undesired transmitter, including free-space path loss, atmospheric and ground effects. This loss depends upon the distance between the undesired transmitter and the edge of the desired signal coverage.

To ensure $D/U_{required}$ is satisfied, $P_u \leq D_{Uallowed}$. The constraint for assigning a channel is therefore:

$$L(dB) \geq ([D/U]_{required}\ (dB) + Tx_U(dBm) - P_{D,min}\ (dBm))$$

7.2.1.3.3 The transmission loss can be obtained from standard propagation models published in ITU-R Recommendation P.528-2 or from free-space attenuation until the radio horizon and then a constant 0.5 dB/NM attenuation factor. These two methodologies result in slightly different geographical separation for co-channel and first adjacent channels, and identical separation as soon as the second adjacent channel is considered. The free-space propagation approximation is applied in this guidance material.

7.2.1.4 *Example of GBAS/GBAS geographical separation criteria*

7.2.1.4.1 For GBAS VDB co-channel transmissions assigned to the same time slot, the parameters for horizontal polarization are:

D/U = 26 dB (Appendix B, 3.6.8.2.2.5.1);

$P_{D,min}$ = –72 dBm (equivalent to 215 microvolts per metre, Chapter 3, 3.7.3.5.4.4); and

Tx_U = 47 dBm (example link budget, Table D-3);

so

$$L \geq (47 + 26 - (-72)) = 145 \text{ dB}.$$

7.2.1.4.2 The geographic separation for co-channel, co-slot GBAS VDB assignments is obtained by determining the distance at which the transmission loss equals 145 dB for receiver altitude of 3 000 m (10 000 ft) above that of the GBAS VDB transmitter antenna. This distance is 318 km (172 NM) using the free-space attenuation approximation and assuming a negligible transmitter antenna height. The minimum required geographical separation can then be determined by adding this distance to the nominal distance between the edge of VDB coverage and the GBAS transmitter 43 km (23 NM). This results in a co-channel, co-slot reuse distance of 361 km (195 NM).

7.2.1.5 *Guidelines on GBAS/GBAS geographical separation criteria*. Using the methodology described above, typical geographic separation criteria can be defined for GBAS to GBAS and GBAS to VOR. The resulting GBAS/GBAS minimum required geographical separation criteria are summarized in Table D-4.

Note.— Geographical separation criteria between the GBAS transmitters providing the GBAS positioning service are under development. A conservative value corresponding to the radiohorizon may be used as an interim value for separation between co-frequency, adjacent time slot transmitters to ensure time slots do not overlap.

7.2.1.6 *Guidelines on GBAS/VOR geographical separation criteria.* The GBAS/VOR minimum geographical separation criteria are summarized in Table D-5 based upon the same methodology and the nominal VOR coverage volumes in Attachment C.

Table D-3. Nominal VDB link budget

VDB link elements For approach service	Vertical component at coverage edge	Horizontal component at coverage edge
Required receiver sensitivity (dBm)	–87	–87
Maximum aircraft implementation loss (dB)	11	15
Power level after aircraft antenna (dBm)	–76	–72
Operating margin (dB)	3	3
Fade margin (dB)	10	10
Free space path loss (dB) at 43 km (23 NM)	106	106
Nominal effective isotropically radiated power (EIRP) (dBm)	43	47

For longer range and low radiation angle associated with positioning service	Vertical component	Horizontal component
Required receiver sensitivity (dBm)	–87	–87
Maximum aircraft implementation loss (dB)	11	15
Power level after aircraft antenna (dBm)	–76	–72
Operating margin (dB)	3	3
Fade margin (dB)	0	0

Nominal EIRP (dBm)

Range (km (NM))	Free space loss (dB)	EIRP (dBm)	EIRP (W)	EIRP (dBm)	EIRP (W)
93 (50)	113	39.9	10	43.9	25
185 (100)	119	45.9	39	49.9	98
278 (150)	122	49.4	87	53.4	219
390 (200)	125	51.9	155	55.9	389

Notes.—

1 It is possible, with an appropriately sited multipath limiting VDB transmitting antenna with an effective radiated power sufficient to meet the field strength requirements for approach service and considering local topographical limitations, to also satisfy the field strength requirements such that positioning service can be supported at the ranges in this table.

2. Actual aircraft implementation loss (including antenna gain, mismatch loss, cable loss, etc.) and actual receiver sensitivity may be balanced to achieve the expected link budget. For example, if the aircraft implementation loss for the horizontal component is 19 dB, the receiver sensitivity must exceed the minimum requirement and achieve -91 dBm to satisfy the nominal link budget.

3. The long-range performance estimates may generally be optimistic with the assumption of no fade margin, i.e., link budget performance will generally not be as good as these estimates indicate.

Note 1.— When determining the geographical separation between VOR and GBAS, VOR as the desired signal is generally the constraining case due to the greater protected altitude of the VOR coverage region.

Note 2.— Reduced geographical separation requirements can be P obtained using standard propagation models defined in ITU-R Recommendation P.528-2.

7.2.2 The geographical separation criteria for GBAS/ILS and GBAS/VHF communications are under development.

7.2.3 *Compatibility with ILS.* Considerations for assignment of VDB channels include the frequency separation between the ILS and the VDB, the distance separation between the ILS coverage area and the VDB, the VDB and ILS field strengths, and the VDB and ILS localizer receiver sensitivity. Until compatibility criteria are developed for GBAS VDB and ILS, VDB can generally not be assigned to channels below 112.025 MHz (i.e. a minimum frequency separation of 75 kHz from the highest assignable ILS localizer frequency).

7.2.3.1 *Inter-airport compatibility*. The minimum geographical separation based on a minimum frequency separation of 75 kHz between ILS localizer and GBAS ground station deployed at different airports is 3 NM between the undesired transmitter antenna location and the edges of the coverage of the desired service that are assumed to be at minimum signal power. Smaller necessary separation distance values may be obtained by taking into account additional information such as the actual desired service field strength and actual undesired service transmit antenna radiation patterns.

Note.— The coverage of the ILS localizer is standardized in Chapter 3, section 3.1.3.3 and the GBAS service volume is standardized in Chapter 3, section 3.7.3.5.3, respectively.

7.2.3.2 *Same-airport compatibility*. To analyse the constraints for the deployment of a GBAS ground station at the same airport as ILS, it is necessary to consider ILS and VDB compatibility in detail taking into account information such as the actual desired service field strength and actual undesired service transmit antenna radiation patterns. For GBAS equipment with transmitter power such that the maximum field strength of 0.879 volts per metre (-27 dBW/m^2) for the horizontally polarized signal component is not exceeded in the ILS coverage volume, the 16th channel (and beyond) will be below -100.5 dBm in a 25 kHz bandwidth at a distance of 80 m from the VDB transmitter, including allowance for a +5 dB increase due to constructive multipath. This -100.5 dBm in a 25 kHz bandwidth translates to a signal-to-noise ratio of 21.5 dB (above the assumed minimum signal-to-noise ratio of 20 dB) for a -79 dBm localizer signal which corresponds to an ILS localizer field strength of 90 microvolts per metre (minus 107 dBW/m^2).

Note.— When deploying GBAS and ILS at the same airport, it is recommended to also analyse the impact of the GBAS VDB transmission on the ILS localizer monitor. Interference may be avoided by installing an appropriate filter.

7.2.4 *Compatibility with VHF communications*. For GBAS VDB assignments above 116.400 MHz, it is necessary to consider VHF communications and GBAS VDB compatibility. Considerations for assignment of these VDB channels include the frequency separation between the VHF communication and the VDB, the distance separation between the transmitters and coverage areas, the field strengths, the polarization of the VDB signal, and the VDB and VHF communication receiver sensitivity. Both aircraft and ground VHF communication equipment are to be considered. For GBAS/E equipment with a transmitter maximum power of up to 150 W (100 W for horizontal 64th channel (and beyond) will be below –112 dBm in a 25 kHz bandwidth at a distance of 80 m from the VDB transmitter including an allowance of +5 dB increase due to constructive multipath. For GBAS/H equipment with a transmitter maximum power of 100 W, the 32nd channel (and beyond) will be below –112 dBm in a 25 kHz bandwidth at a distance of 80 m from the VDB transmitter including an allowance of +5 dB increase due to constructive multipath, and a 10 dB polarization isolation. It must be noted that due to differences in the GBAS VDB and VDL transmitter masks, separate analysis must be performed to ensure VDL does not interfere with the GBAS VDB.

Table D-4. Typical GBAS/GBAS frequency assignment criteria

Channel of undesired VDB in the same time slots	Path loss (dB)	Minimum required geographical separation for Tx_U = 47 dBm and $P_{D,min}$ = –72 dBm in km (NM)
Cochannel	145	361 (195)
1st adjacent channel (±25 kHz)	101	67 (36)
2nd adjacent channel (±50 kHz)	76	44 (24)
3rd adjacent channel (±75 kHz)	73	No restriction
4th adjacent channel (±100 kHz)	73	No restriction

Note 1.— No geographic transmitter restrictions are expected between co-frequency, adjacent time slots provided the undesired VDB transmitting antenna is located at least 80 m from areas where the desired signal is at minimum field strength.

Note 2.— The PD,min of -72 dBm is the output from an ideal isotropic antenna.

Table D-5. Minimum required geographical separation for a VOR coverage (12 000 m (40 000 ft) level)

Channel of undesired GBAS VDB	Path loss (dB)	VOR coverage radius		
		342 km (185 NM)	300 km (162 NM)	167 km (90 NM)
Co-channel	152	892 km (481 NM)	850 km (458 NM)	717 km (386 NM)
$\mid f_{Desired} - f_{Undesired} \mid$ = 25 kHz	126	774 km (418 NM)	732 km (395 NM)	599 km (323 NM)
$\mid f_{Desired} - f_{Undesired} \mid$ = 50 kHz	92	351 km (189 NM)	309 km (166 NM)	176 km (94 NM)
$\mid f_{Desired} - f_{Undesired} \mid$ = 75 kHz	80	344 km (186 NM)	302 km (163 NM)	169 km (91 NM)
$\mid f_{Desired} - f_{Undesired} \mid$ = 100 kHz	61	No restriction	No restriction	No restriction

Note.— Calculations are based on reference frequency of 112 MHz and assume GBAS Tx_U = 47 dBm and VOR $P_{D,min}$ = –79 dBm.

7.2.5 For a GBAS ground subsystem that only transmits a horizontally-polarized signal, the requirement to achieve the power associated with the minimum sensitivity is directly satisfied through the field strength requirement. For a GBAS ground subsystem that transmits an elliptically-polarized component, the ideal phase offset between HPOL and VPOL components is 90 degrees. In order to ensure that an appropriate received power is maintained throughout the GBAS service volume during normal aircraft manoeuvres, transmitting equipment should be designed to radiate HPOL and VPOL signal components with an RF phase offset of 90 degrees. This phase offset should be consistent over time and environmental conditions. Deviations from the nominal 90 degrees must be accounted for in the system design and link budget, so that any fading due to polarization loss does not jeopardize the minimum receiver sensitivity. System qualification and flight inspection procedures will take into account an allowable variation in phase offset consistent with maintaining the appropriate signal level throughout the GBAS service volume. One method of ensuring both horizontal and vertical field strength is to use a single VDB antenna that transmits an elliptically-polarized signal, and flight inspect the effective field strength of the vertical and horizontal signals in the service volume.

7.3 Service volume

7.3.1 The minimum GBAS service volume to support approach services is depicted in Figure D-5. Where practical, it is operationally advantageous to provide valid guidance along the visual segment of an approach. The lateral approach service volume may be different (larger) than the vertical approach service volume. When the additional ephemeris error position bound parameters are broadcast, differential corrections may only be used within the Maximum Use Distance (D_{max}) defined in the Type 2 message. It is also allowable for D_{max} to extend beyond an approach service volume. Reasons why this may be desirable include providing pilots with situational awareness and GBAS status information prior to intercepting the approach procedure, and improving GBAS course capture at the limits of the service volume. In such cases, the potential for reduced protection level, ephemeris bound, and VDB continuity outside the approach service volume should be considered especially when broadcasting large or unlimited values of D_{max}.

7.3.1.1 If a GBAS installation supports multiple approach service volumes, use of a single omnidirectional data broadcast covering all intended service volumes should be considered to limit complexity, if geographically feasible.

7.3.1.2 In addition, autoland or guided take-off may be used at facilities or runways not intended to support or not currently supporting Category II or III operations using GBAS. Even in Category I or better visual conditions, use of an approved autoland system with GAST C can aid pilots in achieving stabilized approaches and reliable touchdown performance, for Category II or III training, to exercise the airborne system to ensure suitable performance, and for maintenance checks. Use of this capability may also provide pilot workload relief. Similarly, use of an approved guided takeoff system will also provide operational benefits. Autoland and guided take-off service volume requirements are contained in Chapter 3, 3.7.3.5.3.2. VDB reception on the runway surface is significantly affected by the transmit antenna design and its installed height as well as the geography of the airport. Service along all runways at an airport using a single VDB antenna/transmitter location may be difficult. However, where practical, service to support autoland and guided take-off operations should be provided at suitable runways supporting any precision approach. The approach service volume element of the approach facility designation allows this information to be contained in the AIP (refer to 7.1.4.2.1). A useful autoland capability may be achievable for some aircraft even when the requirements of Chapter 3, 3.7.3.5.3.2 are not entirely met. Similarly, some aircraft may not be able to conduct automatic landings with only the minimum service volume provided. For approaches with a FAS data path not aligned with the runway centre line, autoland service volume is not required.

7.3.2 An increased signal power (-62.5 dBm) from 36 ft and above, compared to the minimum requirement set for the GBAS service volume at 12 ft above the ground (-72 dBm), is required above the runway surface to accommodate various implementations of airborne VDB antenna. Indeed, VDB antenna height and aircraft implementation loss might not be suitable to meet adequate continuity for autoland under Category III conditions and guided take-off if:

a) aircraft VDB antenna height located above 12 ft may induce more than the expected 15 dB aircraft implementation loss; and

b) aircraft VDB antenna height located below 12 ft may receive a signal power that is below the minimum required value of -72 dBm.

7.3.2.1 To mitigate a lack of adequate VDB link budget, actual aircraft implementation loss (including type of antenna and location of antenna on the fuselage, antenna gain, mismatch loss, cable loss, etc.) and actual receiver sensitivity may be balanced to achieve the expected link budget. The need for additional operational mitigations might be identified and implemented during the aircraft approval process in case of potential loss of VDB along the flight path. It is common practice that a verification flight test is performed by a candidate operator to perform autoland under Category III conditions on a given runway.

7.3.2.2 It is not practical to measure the signal strength at 36 ft. Therefore, two example means of verification are identified below:

- Simplified analysis method: Measure the signal at 12 ft and estimate the signal strength at 36 ft using mathematical tools;
- Complex analysis method: Model the airport configuration and simulate, using a mathematical tool, the signal strength at 12 ft and 36 ft.

Note 1.— There exists an upper limit in the autoland service volume above the runway surface set at 100 ft.

Note 2.— Verification of minimum signal strength at 36 ft is sufficient to ensure compliance above 36 ft.

7.3.2.3 Simplified analysis method.

In order to apply this method, it is assumed the following:

- o VDB transmitters are installed above a planar ground with line-of-sight to runways in the desired GBAS service volume as mentioned in 7.12.3.

- The analysis methodology consists of:
  - o Ground subsystem manufacturers and/or service providers perform a generic (non-airport specific) analysis to show that signal strength requirements at both 12 ft and 36 ft can be met based on distance from and height of the VDB antenna at their specific location. Studies have shown that signal strength will increase from the signal strength measured at 12 ft in various airport configurations. When verifying compliance for a specific installation, an acceptable means of compliance is to measure the signal strength at 12 ft and estimate the signal strength by using the following formula:

To estimate the power $P_{hd\mathrm{Bm}}$ (in dBm) at a height h (in metres) from the power at a height h_0 (in metres), one can use the following expression:

$$\mathrm{P}_{h\mathrm{dBm}} = P_{h_0\mathrm{dBm}} + 20\log\left(\sin\left(\frac{2\pi h h_a}{\lambda d}\right)\right) - 20\log\left(\sin\left(\frac{2\pi h_0 h_a}{\lambda d}\right)\right)$$

where

- d is the distance to the transmitter antenna in metres
- h_a is the height of the transmitter antenna phase centre in metres
- $\lambda = c / f$ is the wavelength in metres
- f is the frequency in Hertz
- c is the speed of light

For $h < \frac{\lambda d}{8h_a}$, the previous formulation can be approximated with an error smaller than 1dB as follows:

$$\mathrm{P}_{h\mathrm{dBm}} = P_{h_0\mathrm{dBm}} + 20\log\left(\frac{h}{h_0}\right)$$

Alternatively, converting heights in feet and considering, $h_0^{\mathrm{ft}} = 12$ ft, the previous expressions become:

$$\mathrm{P}_{h\mathrm{dBm}} = P_{h_0\mathrm{dBm}} + 20\log\left(\sin\left(\frac{0.584 h^{\mathrm{ft}} h_a^{\mathrm{ft}}}{\lambda d}\right)\right) - 20\log\left(\sin\left(\frac{7 h_a^{\mathrm{ft}}}{\lambda d}\right)\right)$$

and

$$\mathrm{P}_{h\mathrm{dBm}} = P_{h_0\mathrm{dBm}} + 20\log\left(h^{\mathrm{ft}}\right) - 21.58\mathrm{dB}$$

The applicability of the above-mentioned formula at different heights above the runway surface may vary with the distance between the VDB transmitter and the intended path on the runway surface and the VDB transmitter antenna height. Some siting constraints may be needed to verify the minimum signal strength is met in the service volume above the runway surface.

7.3.2.4 Complex analysis method.

This method assumes that:

- Airport configuration is so complex that “noise like multipath” (multipath reflections from buildings or aircraft standing or moving) cannot be easily accounted for and must be addressed in the analysis;

and/or

- Line-of-sight between the VDB antenna and runway cannot be maintained.

The analysis methodology consists of:

- The airport configuration includes relevant surfaces such as buildings and metallic fences, and topology of the ground surface is modeled with their electromagnetic characteristics. Radiation pattern of the VDB transmitter antenna is also modeled.
- Signal powers at 12 ft and 36 ft are estimated by simulating radio propagation. One of the acceptable means of the simulation is the ray-tracing method based on geometric optics. Such simulation is available with commercially available software with an intuitive human-machine interface to the airport modeling.
- Effects of small-scale (less than 5-10 wavelengths) structures limit the accuracy of simulation by the ray-tracing method. Therefore, an additional margin to represent such effects may need to be added to the simulation results.
- The signal power at 12 ft is measured and compared with the simulated one. If the measured and simulated signal powers at 12 ft match well, the simulation can be regarded as being able to model the signal powers at different heights over the runway.
- The simulated signal power and the minimum requirement at 36 ft are compared to verify the compliance of the VDB coverage over the runway.

7.3.3 The service volume required to support the GBAS positioning service is dependent upon the specific operations intended. The optimal service volume for this service is intended to be omnidirectional in order to support operations using the GBAS positioning service that are performed outside of the approach service volume. Each State is responsible for defining a service volume for the GBAS positioning service and ensuring that the requirements of Chapter 3, 3.7.2.4 are satisfied. When making this determination, the characteristics of the fault-free GNSS receiver should be considered, including the reversion to ABAS-based integrity in the event of loss of GBAS positioning service.

7.3.4 The limit on the use of the GBAS positioning service information is given by the Maximum Use Distance (D_{max}). D_{max} however does not delineate the coverage area where field strength requirements specified in Chapter 3, 3.7.3.5.4.4 are necessarily met nor matches this area. Accordingly, operations based on the GBAS positioning service can be predicated only in the service volume(s) (where performance requirements are met) within the D_{max} range.

7.3.5 As the desired service volume of a GBAS positioning service may be greater than that which can be provided by a single GBAS broadcast station, a network of GBAS broadcast stations can be used to provide the service. These stations can broadcast on a single frequency and use different time slots (8 available) in neighbouring stations to avoid interference or they can broadcast on different frequencies. Figure D-5A details how the use of different time slots will allow a single frequency to be used without interference subject to guard time considerations noted under Table B-59. For a network based on different VHF frequencies, guidance material in 7.17 should be considered.

7.4 Data structure

A bit scrambler/descrambler is shown in Figure D-6.

Note.— Additional information on the data structure of the VHF data broadcast is given in RTCA/DO-246E, GNSS Based Precision Approach Local Area Augmentation System (LAAS) — Signal-in-Space Interface Control Document (ICD).

7.5 Integrity

7.5.1 Different levels of integrity are specified for precision approach operations and operations based on the GBAS positioning service. The signal-in-space integrity risk for approach services is 2×10^{-7} per approach. GBAS ground subsystems that are also intended to support other operations through the use of the GBAS positioning service have to also meet the signalin-space integrity risk requirement specified for terminal area operations, which is 1×10^{-7}/hour (Chapter 3, Table 3.7.2.4-1). Therefore additional measures are necessary to support these more stringent requirements for positioning service. The signalin-space integrity risk is allocated between the ground subsystem integrity risk and the protection level integrity risk. The ground subsystem integrity risk allocation covers failures in the ground subsystem as well as core constellation and SBAS failures such as signal quality failures and ephemeris failures. For GAST A, B, and C the protection level integrity risk allocation covers rare fault-free position domain performance risks and the case of failures in one of the reference receiver measurements. In both cases the protection level equations ensure that the effects of the satellite geometry used by an aircraft fault-free receiver are taken into account. This is described in more detail in the following paragraphs. For GAST D, the position domain integrity is delegated to the aircraft and a FAST D ground subsystem provides additional data and ranging source monitoring for aircraft using this service type.

7.5.1.1 Additional integrity requirements apply for GAST D, which is intended to support precision approach and automatic landing in low visibility conditions with minima less than Category I. The same requirements for bounding the position solution within a protection level that is compared to an alert limit apply, for all error sources except single ground reference receiver faults and errors induced by ionospheric anomalies. Single ground reference receiver faults are mitigated as described in 7.5.11. The responsibility for some errors induced by anomalous ionospheric conditions has been allocated to the airborne equipment. Mitigation of errors due to ionospheric anomalies is described in 7.5.6.1.6. Additional monitoring requirements and design assurance requirements are needed to allow a FAST D GBAS ground subsystem to provide a service that can provide equivalent safety to Category III ILS operations. Some additional monitoring requirements are allocated to the ground subsystem (see 7.5.6.1 to 7.5.6.1.7) and some are allocated to the airborne equipment. The additional monitoring performance requirements for the ground subsystem can be found in Appendix B, 3.6.7.3.3.

7.5.1.2 The ground subsystem integrity risk requirement for GAST D (Appendix B, section 3.6.7.1.2.1.1.3) limits the probability of a ground subsystem failure resulting in the transmission of erroneous data during a minimum exposure time of “any one landing.” Typically the critical period of exposure to failures for vertical guidance in Category III operations is taken to be the period between the Category I Decision Height (200 ft) and the threshold (50 ft height). This is nominally 15 seconds, depending upon the aircraft approach speed. The critical period of exposure to failures for lateral guidance in Category III operations is taken to be the period between the Category I Decision Height and completion of the roll-out, which occurs when the aircraft decelerates to a safe taxi speed (typically less than 30 knots). This is nominally 30 seconds, again depending upon the aircraft approach speed and rate of deceleration. The term “any one landing” is used to emphasize that the time period where faults could occur extends prior to the critical period of exposure. The reason for this is that the fault may develop slowly over time; it could occur earlier in the landing phase and become a hazard during the critical period of exposure.

7.5.1.3 The critical period of exposure to failure for lateral guidance during a guided take-off in low visibility conditions is nominally 60 seconds. Erroneous or loss of guidance during a guided take-off being less critical than for Category III landings, it does not introduce any changes to the ground subsystem integrity requirements.

7.5.2 The GBAS ground subsystem defines a corrected pseudo-range error uncertainty for the error relative to the GBAS reference point (σ_{pr_gnd}) and the errors resulting from vertical (σ_{tropo}) and horizontal (σ_{iono}) spatial decorrelation. These uncertainties are modelled by the variances of zero-mean, normal distributions which describe these errors for each ranging source.

7.5.3 The individual error uncertainties described above are used by the receiver to compute an error model of the navigation solution. This is done by projecting the pseudo-range error models to the position domain. General methods for determining that the model variance is adequate to guarantee the protection level integrity risk are described in section 14. The lateral protection level (LPL) provides a bound on the lateral position error with a probability derived from the integrity requirement. Similarly, the vertical protection level (VPL) provides a bound on the vertical position. For approach services, if the computed LPL exceeds the lateral alert limit (LAL) or the VPL exceeds the vertical alert limit (VAL), integrity is not adequate to support the selected service type . For the positioning service the alert limits are not defined in the standards, with only the horizontal protection level and ephemeris error position bounds required to be computed and applied. The alert limits will be determined based on the operation being conducted. The aircraft will apply the computed protection level and ephemeris bounds by verifying they are smaller than the alert limits. Two protection levels are defined, one to address the condition when all reference receivers are fault-free (H_0 – Normal Measurement Conditions), and one to address the condition when one of the reference receivers contains failed measurements (H_1 – Faulted Measurement Conditions). Additionally an ephemeris error position bound provides a bound on the position error due to failures in ranging source ephemeris. For approach services, a lateral ephemeris error bound (LEB) and a vertical ephemeris error bound (VEB) are defined. For the positioning service a horizontal ephemeris error bound (HEB) is defined.

7.5.3.1 The GBAS signal-in-space integrity risk (Appendix B, 3.6.7.1.2.1.1) is defined as the probability that the ground subsystem provides information which when processed by a fault-free receiver, using any combination of GBAS data allowed by the protocols for data application (Appendix B, 3.6.5), results in an out-of-tolerance lateral or vertical relative position error without annunciation for a period longer than the maximum time-to-alert. An out-of-tolerance lateral or vertical relative position error is defined as an error that exceeds the GBAS approach services protection level and, if additional data block 1 is broadcast, the ephemeris error position bound. Hence it is the responsibility of the ground subsystem to provide a consistent set of data including the differential corrections, and all parameters that are used by the protocols for data application (e.g, σ_{pr_gnd} and the B values as defined in the Type 1 message), so that the protection levels bound the position error with the required integrity risk. This error bounding process must be valid for any set of satellites that the user might be using. To ensure the computed protection levels actually bound the error with the required probability, it may in some cases be necessary to inflate or otherwise manipulate one or more of the parameters that are used by the protocols for data application. For example, to address the impact of anomalous ionospheric effects one strategy that has been used is to inflate σ_{pr_gnd} and $\sigma_{vert\_iono\_gradient}$ to ensure that airborne equipment that complies with the protocols for data application will be adequately protected.

7.5.4 *Ground system contribution to corrected pseudo-range error (σ_{pr_gnd})*. Error sources that contribute to this error include receiver noise, multipath, and errors in the calibration of the antenna phase centre. Receiver noise has a zero-mean, normally distributed error, while the multipath and antenna phase centre calibration can result in a small mean error.

7.5.5 *Residual tropospheric errors*. Tropospheric parameters are broadcast in Type 2 messages to model the effects of the troposphere, when the aircraft is at a different height than the GBAS reference point. This error can be well-characterized by a zero-mean, normal distribution.

7.5.6 *Residual ionospheric errors*. An ionospheric parameter is broadcast in Type 2 messages to model the effects of the ionosphere between the GBAS reference point and the aircraft. This error can be well-characterized by a zero-mean, normal distribution during nominal conditions.

7.5.6.1 *Ionospheric anomalies*. Small scale structures in the ionosphere can result in non-differentially corrected errors in the GBAS position. Such phenomena are typically associated with solar storm activity and may be characterized by steep gradients in the ionospheric delay over a relatively short distance (e.g. a few tens of kilometres). The errors that may be induced by these phenomena result when the airborne receiver and ground subsystem are receiving satellite signals that have different propagation delays. Also, since GBAS uses code-carrier smoothing with a relatively long time constant, biases build up in these filters that are a function of the rate of change of ionospheric delay. If the ground subsystem and airborne receivers experience significantly different delays and rates of change of the ionospheric delays, the biases that build up in these filters will not match and will not be cancelled by the differential processing.

7.5.6.1.1 *Ionospheric anomaly mitigation*. Ionospheric anomalies can produce position errors which are significant (i.e. tens of metres) in the context of approach operations. To mitigate these errors, different strategies are used depending on the GBAS approach service type.

7.5.6.1.2 *Ionospheric anomaly mitigation for GAST A, B and C*. For GAST A, B or C, the ground subsystem is responsible for mitigating the potential impact of ionospheric anomalies. This may be handled through various monitoring schemes (e.g. far-field monitors or integration with a wide area ground network supporting SBAS) which detect the presence of ionosphere anomalies and deny service if the resulting user position errors would be unacceptable. One means to deny service is to inflate some combination of the broadcast integrity parameters: σ_{pr_gnd}, $\sigma_{vert\_iono\_gradient}$, the ephemeris decorrelation parameter (P), the ephemeris missed detection parameters $K_{md\_e,GPS}$ and $K_{md\_e\_,GLONASS}$ such that any geometry that could be used by an airborne user will not be subjected to intolerably large errors (given the intended operational use). This inflation scheme could also be used without the complexity of monitoring the ionosphere during operations by assuming ionosphere anomalies are present. In this case, a model of the possible ionosphere conditions that could occur is used to determine the proper values of the broadcast integrity parameters. Since the extremes of ionosphere conditions vary significantly through the world, the model is location dependent. Such an inflation scheme results in a reduction in availability because it inflates the values even when anomalies are not present.

7.5.6.1.3 *Ionospheric anomaly mitigation for GAST D*. Requirements for monitoring and geometry screening in the airborne equipment have been introduced for GAST D to mitigate the potential impact of ionospheric anomalies. The airborne monitoring consists of monitoring the code-carrier divergence continuously in order to detect large gradients in the ionosphere. In addition, the airborne equipment will screen geometries to ensure that an unacceptably large amplification of residual pseudo-range errors (i.e. errors that may exist after airborne monitoring has been applied) will not occur. Another factor which is useful for the mitigation of errors induced by ionospheric anomalies is the use of the 30-second carrier smoothed pseudo-ranges in a position solution. (The shorter time constant smoothing is inherently less susceptible to filter bias mismatch errors.) Finally, GAST D includes parameters: $K_{md\_e\_D,GLONASS}$, $K_{md\_e\_D,GPS}$, P_D and $\sigma_{vert\_iono\_gradient\_D}$, which are intended to be used in place of the parameters $K_{md\_e,GLONASS}$, $K_{md\_e,GPS}$, P, and $\sigma_{vert\_iono\_gradient}$, respectively, when the active service type is GAST D. This is done so that if the ground subsystem employs inflation of the parameters $K_{md\_e\_,GLONASS}$, $K_{md\_e,GPS}$, P and $\sigma_{vert\_iono\_gradient}$ to mitigate the effects of ionospheric anomalies for GAST A, B or C, the GAST D user can be provided with non-inflated parameters for use in GAST D where airborne monitoring is employed to address the ionospheric anomaly errors. This enables GAST D service to have improved availability.

7.5.6.1.4 *Bounding of ionospheric anomaly errors*. As stated above, ionospheric anomalies may be addressed by inflating one or more of the parameters: σ_{pr_gnd}, $\sigma_{vert\_iono\_gradient}$, the ephemeris decorrelation parameter (P), the ephemeris missed detection parameters $K_{md\_e,GPS}$ and $K_{md\_e,GLONASS}$. The ground subsystem is responsible for providing values in these parameters such that the error is appropriately bounded by the VPL and HPL computations at the output of a fault free receiver. In GAST D, responsibility for mitigation of errors due to anomalous ionospheric conditions has been divided between the airborne subsystem and the ground subsystem. Although GAST D still requires the protection levels to bound the errors (as described in 7.5.3.1), they are not required to bound the errors that result from an anomalous ionospheric event as is the case for GAST C. Hence, the protection levels as computed with PD, $K_{md\_e\_D,GLONASS}$, $K_{md\_e\_D,GPS}$, and $\sigma_{vert\_iono\_gradient\_D}$ must bound the error for all error sources as discussed in 3.6.7.1.2.1.1.2 except for the errors due to anomalous ionospheric conditions. The protections level computations must bound the nominal ionospheric errors.

7.5.6.1.5 *Dual solution ionospheric gradient monitoring*. Another component of the airborne mitigation of errors induced by ionospheric anomalies is by the use of dual position solutions computed simultaneously with two different carrier smoothing time constants (see 7.19.3). This dual solution computation has two purposes. Firstly, taking the difference of two corrected pseudo-range measurements as detection statistics allows the filter build-up errors on each satellite, due to large differences in ionospheric gradients between the ground measurements and airborne measurements, to be directly observable. Hence a threshold can be applied to these detection statistics in order to detect a large portion of the ionospheric anomalies. The second application of the dual solutions is to compute a bound for the 30-second smoothed position (excluding the impact of ionospheric anomalies). The data provided by the ground segment allows a protection level bound to be computed for the 100-second solution. By adding the direct observation of the magnitude of the difference between the 30-second smoothed position and the 100-second smoothed position, to the protection level computation, a protection level is obtained, which is guaranteed to bound the 30-second position solution with the required $1x10^{-7}$/approach. This allows airborne equipment, with an active service type of D to provide equivalent bounding performance, as required for approaches to Category I minima even though the 30-second solution is used to develop the guidance.

7.5.6.1.6 *Requirements for FAST D ground subsystems to support mitigation of errors caused by ionospheric anomalies*. Although much of the responsibility for mitigation of ionospheric errors is allocated to the airborne segment, there is a requirement for FAST D ground subsystems that is necessary to support mitigation of such effects. Appendix B, 3.6.7.3.4 specifies that the ground subsystem is responsible for ensuring mitigation of ionospheric spatial delay gradients. The ground subsystem ensures that the value of the maximum corrected pseudo-range error (E_{IG}) computed from the Type 2 data does not exceed 2.75 metres at all LTPs associated with runways that support GAST D procedures. One option available to the manufacturer is to restrict the distance between the GBAS reference point and the LTP.

7.5.6.1.7 *Ionospheric anomaly threat models used for GAST D validation*. As discussed above, the mitigation of errors that could be induced by ionospheric anomalies is accomplished through a combination of airborne and ground system monitoring. The effectiveness of the required monitoring has been demonstrated through simulation and analysis and the maximum errors at the output of the monitoring have been shown to be consistent with airworthiness certification criteria for a range of anomalies described below. This range of anomalies is described in terms of a "standard threat space" consisting of an ionospheric anomaly model which defines physical attributes of the ionospheric anomaly. The model described in 7.5.6.1.7.1 is a conservative rendition of the model developed for the continental United States. This model has been shown to bound the ionospheric threat evaluated in several other mid-latitude regions, relative to the magnetic equator. Recent data collected in some low-latitude regions, relative to the magnetic equator, has shown ionospheric conditions associated with local ionospheric density depletion ("plasma bubbles") that exceed this threat model. Research has resulted, for example, in a reference low-latitude threat model for the Asia-Pacific Region by a dedicated Ionospheric Studies Task Force (APAC ISTF). The threat models define an ionospheric environment for which the standardized monitoring is known to produce acceptable performance on a per-pseudo-range basis. Each service provider should evaluate whether the standard threat space model described below is appropriate for the ionospheric characteristics in the region where GBAS is intended to support GAST D service. This evaluation should always be performed, regardless of the latitudes involved. If a service provider determines that the ionospheric behaviour is not adequately characterized by this threat model (e.g. for a region of uniquely severe ionospheric behaviour), that service provider must take appropriate action to ensure the users will not be subjected to ionospheric anomalies with characteristics outside the range of the standard threat space. The service provider may elect to:

1. alter the characteristics of its ground subsystem; and/or

2. introduce additional monitoring (internal or external to the GBAS); and/or

3. introduce other operational mitigations that limit users' exposure to the extreme ionospheric conditions.

Potential ground subsystem changes which could achieve this risk reduction include tighter siting constraints (see 7.5.6.1.6) and improved ground subsystem monitoring performance (Appendix B, 3.6.7.3.4). Another mitigation strategy is monitoring of space weather (external to the GBAS system) in conjunction with operational limitations on the use of the system during predicted periods of severely anomalous ionospheric activity. Combinations of these strategies may be used to ensure that the GAST D user is not subjected to ionospheric anomalies outside the standard threat space.

7.5.6.1.7.1 *Ionosphere anomaly model: moving wedge*. This models a severe ionospheric spatial gradient as a moving wedge of constant, linear change in slant ionosphere delay, as shown in Figure D-7. The key parameters of this model are the gradient slope (g) in mm/km, the width (w) of the wedge in km, the amplitude of the change in delay (D) in m, and the speed (v) at which the wedge moves relative to a fixed point on the ground. These values are assumed to remain (approximately) constant over the period in which this wedge affects the satellites tracked by a single aircraft completing a GAST D approach. While the width of the wedge is small, the "length" of the wedge in the East-North coordinate frame (i.e. how far the "ionospheric front" containing the wedge extends) is not constrained.

In this model, the upper bound on g is dependent on wedge speed as specified in Table D-5A. This value is not dependent on satellite elevation angle. Because g is expressed in terms of slant delay, no "obliquity" correction from zenith delay is needed. The width w can vary from 25 to 200 km. The maximum value of D is 50 m. Note that, to make the model consistent, D must equal the product of slope g and width w. In cases where slope and width each fall within their allowed ranges, but their product

D exceeds the 50-metre bound, that combination of slope and width is not a valid point within the threat model. For example, both g = 400 mm/km and *w* = 200 km are individually allowed, but their product equals 80 metres. Since this violates the constraint on *D*, a wedge with g = 400 mm/km and *w* = 200 km is not included in this threat model.

Note.— In the GAST D validation, it was assumed that each simulated wedge model is applied to the two ranging sources that produced the worst-case position errors. However, the numbers of wedges and impacted ranging sources depend on the ionospheric characteristics in the region where GBAS is intended to support GAST D service.

Table D-5A. Upper bound on gradient slope

Propagation speed (v)	Upper bound on gradient slope (g)
$v < 750$ m/s	500 mm/km
$750 \leq v < 1500$ m/s	100 mm/km

7.5.6.1.8 *Ionosphere gradient mitigation validation*

7.5.6.1.8.1 Because the mitigation responsibility for spatial ionosphere gradients is shared between the airborne and ground subsystems, this section includes guidance for modeling the critical airborne components (e.g. aircraft motion and monitoring) which will enable a ground manufacturer to validate the mitigation of spatial ionosphere gradients from a total system perspective. The validation can take into account the combination of ground and airborne monitors for the detection of gradients. When accounting for the combination of monitors, the correlation or independence between the monitors needs to be considered. Monitor performance should also consider the effective time between independent samples of each monitor's test statistic. Modeling of the ionosphere monitoring should include re admittance criteria for an excluded satellite, as appropriate per the ground subsystem design and DO-253D.

7.5.6.1.8.2 This section also includes test scenario guidance to help ensure all possible airborne position, ground reference point, approach direction, and gradient direction orientations are considered during validation.

7.5.6.1.8.3 Airborne monitor implementation

Validation may account for the following airborne monitors:

a) airborne code carrier divergence filtering as described in 2.3.6.11 of DO-253D;

b) differential RAIM used for satellite addition as described in 2.3.9.6.1 of DO-253D; and

c) dual solution pseudo-range ionospheric gradient monitoring as described in 2.3.9.7 of DO-253D.

7.5.6.1.8.3.1 In assessing the probability of missed detection, the contribution of all noise sources to the test statistic used for the airborne code carrier divergence monitor, excluding the effects of the ionosphere, can be assumed to have a normal distribution with a zero mean and a standard deviation of 0.002412 m/s.

7.5.6.1.8.3.2 In assessing the probability of missed detection, the contribution of all noise sources to the test statistic used for the dual solution pseudo-range ionospheric gradient monitor can be assumed to have a normal distribution with a zero mean and a standard deviation of 0.1741 m.

7.5.6.1.8.3.3 Note that the prior probability of the gradient that can be utilized during validation of 3.6.7.3.4 applies for these airborne monitors as well.

7.5.6.1.8.4 *Modeling airborne positioning and speed*

The airborne speed and position can be modeled working backward from the threshold crossing time using the following four values:

a) speed at landing;

b) amount of time at landing speed;

c) deceleration rate; and

d) speed at start of deceleration.

7.5.6.1.8.4.1 Figure D-8 illustrates how these four values are used to define a speed profile and Table D-5B shows the values that define the family of curves to be used in determination of GAST D broadcast parameters for a specific IGM design.

Table D-5B. Airborne speed profile from initial position to LTP

Landing ground speed (knots)	Time at landing speed (seconds)	Deceleration rate (knots/s)	Ground speed at start of deceleration (knots)
161	50	1.1	290
148	50	1.1	277
135	50	1.1	264

Note.— Modeling aircraft altitude is not necessary.

7.5.6.1.8.4.2 Figure D-9 shows the approach speed profiles based on the values in Table D-5B in terms of ground speed versus time until the aircraft reaches the landing threshold point.

7.5.6.1.8.5 *Gradient, airborne position, ground reference point, and approach direction considerations*

7.5.6.1.8.5.1 Figure D-10 illustrates the basic anomalous ionospheric scenarios (A-D) that constitute a threat. For a given ground station installation, the ground manufacturer should demonstrate valid mitigation for any ionosphere gradient/airborne/approach orientations corresponding to that particular installation.

7.5.6.1.8.5.2 Validation test scenarios should also address the timing component for each orientation. For example, for a given scenario, an approach should be executed at least at one minute intervals.

7.5.7 *Aircraft receiver contribution to corrected pseudo-range error*. The receiver contribution is bounded as described in section 14. The maximum contribution, used for analysis by the GBAS provider, can be taken from the accuracy requirement, where it is assumed that $\sigma_{receiver}$ equals RMS_{pr_air} for GBAS Airborne Accuracy Designator A equipment.

7.5.8 *Airframe multipath error*. The error contribution from airframe multipath is defined in Appendix B, 3.6.5.5.1. Multipath errors resulting from reflections from other objects are not included. If experience indicates that these errors are not negligible, they must be accounted for operationally or through inflation of the parameters broadcast by the ground (e.g. σ_{pr_gnd}).

7.5.9 *Ephemeris error uncertainty*. Pseudo-range errors resulting from ephemeris errors (defined as a discrepancy between the true satellite position and the satellite position determined from the broadcast data) are spatially decorrelated and will therefore be different for receivers in different locations. When users are relatively close to the GBAS reference point, the residual differential error due to ephemeris errors will be small and both the corrections and uncertainty parameters σ_{pr_gnd} sent by the ground subsystem will be valid to correct the raw measurements and compute the protection levels. For users further away from the GBAS reference point, protection against ephemeris failures can be ensured in two different ways:

a) the ground subsystem does not transmit the additional ephemeris error position bound parameters. In this case, the ground subsystem is responsible for assuring integrity in case of satellite ephemeris failures without reliance on the aircraft calculating and applying the ephemeris bound. This may impose a restriction on the distance between the GBAS reference point and the decision altitude/height depending upon the ground subsystem means of detecting ranging source ephemeris failures. One means of detection is to use satellite integrity information broadcast by
SBAS; or

b) the ground subsystem transmits the additional ephemeris error position bound parameters which enable the airborne receiver to compute an ephemeris error bound. These parameters are: coefficients used in the ephemeris error position bound equations ($K_{md\_e\_()}$, where the subscript () means either "GPS", "POS, GPS"), and the ephemeris decorrelation parameters (P). The ephemeris decorrelation parameter (P) in the Type 1 or Type 101 message characterizes the residual error as a function of distance between the GBAS reference point and the aircraft. The value of P is expressed in m/m. The values of P are determined by the ground subsystem for each satellite. One of the main factors influencing the values of P is the ground subsystem monitor design. The quality of the ground monitor will be characterized by the smallest ephemeris error that it can detect. The relationship between the P parameter and the smallest detectable error ε_{ephdet} for a particular satellite, i, can be approximated by $P_i = \varepsilon_{ephdet} / R_i$ where R_i is the smallest of the predicted ranges from the ground subsystem reference receiver antenna(s) for the period of validity of P_i. Since R_i varies with time, the P parameters values are time dependent as well. However, it is not a requirement for the ground subsystem to dynamically vary P. Static P parameters can be sent if they properly ensure integrity. In this latter case, the availability would be slightly degraded. Generally, as ε_{ephdet} becomes smaller, overall GBAS availability improves.

7.5.10 *Ephemeris error/failure monitoring*. There are several types of monitoring approaches for detecting ephemeris errors/failures. They include:

a) *Long baseline*. This requires the ground subsystem to use receivers separated by large distances to detect ephemeris errors that are not observable by a single receiver. Longer baselines translate to better performance in smallest detectable error;

b) *SBAS*. Since SBAS augmentation provides monitoring of satellite performance, including ephemeris data, integrity information broadcast by SBAS can be used as an indication of ephemeris validity. SBAS uses ground subsystem receivers installed over very long baselines, therefore this provides optimum performance for ephemeris monitoring and thus makes small errors detectable;

c) *Ephemeris data monitoring*. This approach involves comparing the broadcast ephemeris over consecutive satellite
orbits. This monitoring assumes that the only threat of failure is due to a failure in the ephemeris upload from the constellation ground control network so that the ephemeris is inconsistent with previously broadcast ephemeris; and

d) *Delta-V (change in velocity) monitoring.* This monitoring covers the cases of uncommanded satellite manoeuvres
out of view with unchanged ephemeris.

7.5.10.1 The monitor design (for example, its smallest detectable error) is to be based upon the integrity risk requirements and the failure model the monitor is intended to protect against. A bound on the GPS ephemeris failure rate can be determined from the reliability requirements defined in Chapter 3, 3.7.3.1.3, since such an ephemeris error would constitute a major service failure.

7.5.10.2 reserved.

7.5.11 *Ground reference receiver faults.* A typical GBAS ground subsystem processes measurements from 2 to 4 reference receivers installed in the immediate vicinity of the reference point. For GAST A, B, C and D, the aircraft receiver is protected against a large error or fault condition in a single reference receiver by computing a protection level based on the B parameters from the Type 1 or Type 101 message and comparing that protection level to the alert limit. Ground subsystem compliance with the GAST A, B, C and D integrity risk (Appendix B, 3.6.7.1.2.2.1) is demonstrated taking into account the protocols required of the airborne subsystem (Appendix B, 3.6.5.5.1.2) and explicit monitoring required in the airborne subsystem. Alternative system architectures with sufficiently high redundancy in reference receiver measurements may employ processing algorithms capable of identifying a large error or fault in one of the receivers. This may apply for a GRAS network with receivers distributed over a wide area and with sufficient density of ionospheric pierce points to separate receiver errors from ionospheric effects. The integrity can then be achieved using only the protection levels for normal measurement conditions (VPL_{H0} and LPL_{H0}), with appropriate values for K_{ffmd} and σ_{pr_gnd}. This can be achieved using the Type 101 message with the B parameters excluded.

7.5.11.1 *GAST D ground reference receiver faults.* For GAST D, there is an additional standardized monitor implemented in the airborne receiver used to maintain the single reference receiver faulted measurement condition integrity regardless of the satellite geometry used in the aircraft. The aircraft receiver computes a position error estimate based on the B parameters and compares that error estimate directly to a threshold set as low as possible consistent with acceptable continuity risk. Although the monitor is mechanized in the airborne subsystem, the ground subsystem must meet specific requirements for the monitor to provide the required protection. The integrity performance depends on the assumed a priori failure rate (Appendix B, 3.6.7.1.2.2.1.2) and the probability of missed detection of the monitor. The a priori rate of a single reference receiver providing faulted measurements is required to be less than 1×10^{-5} per 150 seconds. The rate per individual receiver is dependent upon the number of reference receivers in the ground subsystem. For example, with four reference receivers the rate per receiver would be required to be less than 2.5×10^{-6} per 150 seconds. This a priori rate is achieved through a combination of receiver design requirements and proper reference receiver siting and operational constraints. Because conditions during system operation vary, ground subsystems may monitor receiver outputs to verify continued compliance with the requirement. The integrity performance also depends on the probability of missed detection (P_{md}) performance of the monitor implemented in the airborne equipment. The P_{md} performance of this monitor in turn depends on the characteristics of the errors that confound the observability of a reference failure. This is also true for the existing protection level integrity risk equations associated with faulted measurement conditions. The ground subsystem is required to broadcast integrity parameters that bound the errors such that a normal distribution can sufficiently characterize the errors and the P_{md} can be estimated (Appendix B, 3.6.7.1.2.2.1.1 and 3.6.7.2.2.4.1).

7.5.11.2 *GAST D ground reference receiver fault magnitude bounding.* Because the airborne subsystem implements the monitor as defined in the MOPS, it is possible to compute the size of the largest error that can result from the failure of a single reference receiver with a probability of greater than 1×10^{-9}. The calculated maximum size of the error will depend on the assumed a priori failure rate (Appendix B, 3.6.7.1.2.2.1.1) and the probability of missed detection of the monitor. The monitor P_{md} is dependent on the monitor threshold which is computed by the airborne equipment as a function of the geometry and the error distribution associated with the H_1 hypothesis.

7.5.12 *Range domain monitoring requirements for GAST D.* To support equivalent safety of Category II/III operations, requirements beyond the basic “signal-in-space” requirements defined for GAST A, B and C are necessary. These requirements include performance requirements for monitors implemented to detect pseudo-range errors. Two requirements apply to the post monitoring error in the corrected pseudo-range due to specific ranging source failures (Appendix B, 3.6.7.3.3.2 and 3.6.7.3.3.3). In both cases, the requirement applies to the probability of missed detection as a function of the size of an error due to the failure in the 30-second smoothed pseudo-range after the correction is applied.

1) The first requirement constrains the P_{md} performance of the specified ranging source failures without regard for the a priori probability of the ranging source failure. The bound for a ground subsystem’s monitor performance defined in Appendix B, 3.6.7.3.3.2 is illustrated in Figure D-11. GAEC-D equipment will use the 30-second differential corrections to form the position solution used for deviation guidance. The limits of the constraint region define the minimum P_{md} that the ground subsystem must ensure for any single ranging source failure condition.

Note.— The example compliant P_{md} in Figure D-11 is based on a hypothetical monitor with a threshold set to 0.8 m and monitor noise of 0.123 m. The curve is for illustration purposes only and does not represent the performance of any specific monitor design.

2) The second requirement constrains the conditional probability of the P_{md} performance of the specified ranging source given the a-priori failure probability for the specific ranging source failure. The conditional probability bound, $P_{md} \times P_{apriori}$, for a ground subsystem's monitor performance defined in Appendix B, 3.6.7.3.3.3 is illustrated in Figure D-12. The prior probability of each ranging source failure (Papriori), used to evaluate compliance, should be the same value that is used in the analysis to show compliance with the bounding requirements for FAST C and D (see 7.5.3.1).

7.5.12.1 *Verification of ground subsystem compliance with range domain monitoring requirements*

Verifying that a ground system design complies with the monitor requirements provided in Appendix B, 3.6.7.3.3.2 and 3.6.7.3.3.3 is achieved by a combination of testing and analysis. The requirements take the form of a constraint on the probability of missed detection as a function of the size of an error in the corrected pseudo-range. The general process that may be used to verify that a specific monitor, included as part of a ground subsystem design, meets the specified performance is as follows:

- Identify the threat space for each fault mode to be considered. (The requirements in Appendix B, 3.6.7.3.3 apply to four specific fault modes). These fault modes (i.e. the threat space), which may be used for evaluating compliance with a ground subsystem design, are provided in 7.5.12.1.3.1 through 7.5.12.1.3.4. These fault modes and fault combinations constitute the threat space. These threat space definitions represent what at least one State has found acceptable as an assumed threat space for each fault mode.

- Identify the airborne configuration space. The airborne system requirements introduce constraints on the design and performance of airborne equipment. These constraints define the range of critical airborne parameters of the configuration space for each fault mode and/or monitor that must be protected by the ground subsystem. For example, the bandwidth and correlator spacing of a compliant airborne receiver will conform to the requirements in sections 8.11.4 through 8.11.7.1. These are two of the critical parameters of the airborne configuration space for the satellite signal deformation fault mode. A critical airborne parameter directly influences how each point in the threat space translates to an error in the differentially corrected pseudo-range.

- An error analysis is done considering the specific monitor design under consideration given the full range of fault characteristics that comprise the threat space. For each characterized fault, the error that would be induced in the corrected pseudo-range (using the 30-second smoothed pseudo-ranges and pseudo-range corrections) is computed given the full range of critical airborne parameters that comprise the airborne configuration space.

- When assessing the compliance of a ground subsystem design, the performance is characterized by relevant statistical measures. Any monitor is subject to noise and therefore the performance may be characterized by the false detection rate and the missed detection probability. Both of these performance metrics are specified in the ground requirements in Appendix B by means of a not-to-exceed constraint. The missed detection probability performance is constrained by the requirements in Appendix B, 3.6.7.3.3.2 and 3.6.7.3.3.3. The false detection rate performance is constrained by the continuity requirements given in Appendix B, 3.6.7.1.3.2. It should be understood that the ground subsystem must meet all requirements in the Standards. It is possible that the performance of individual monitors may be further constrained by other requirements, such as the ground subsystem integrity risk requirement in Appendix B, 3.6.7.1.2.1.1.1. Ground station accuracy performance may have an impact on airborne and ground monitor performance. In the validation of requirement feasibility a GAD C4 performance was assumed to account for instance for single reference receiver faults. Use of lower performance categories may have an availability or continuity impact and should be investigated in the design process.

7.5.12.1.1 *Compliance of ground subsystem monitoring with continuity requirements.* The compliance with the false detection rate (continuity) may be established based on collected real data combined with analysis and/or simulation. The required number of truly independent samples should be sufficient to adequately characterize the cumulative distribution function (CDF) of the monitor discriminator, which is compared to the threshold set for the monitor. The fault free noise CDF must be such that for the threshold set in the monitor the false detection probability is smaller than that required to support continuity. An allocation of the continuity to each monitor must be done with consideration given to the overall specified probability of false detection (Appendix B, 3.6.7.1.3.2). The achieved probability of false detection is determined by extrapolation of the observed trends in the measured CDF. Additionally, detection events in the ground system may be logged and if, over time, the false detection rates are not maintained at the required levels, thresholds may be adjusted as the result of a maintenance action to correct the problem.

7.5.12.1.2 *Compliance of ground subsystem monitoring with integrity requirements.* The compliance with the missed detection probability (integrity risk) is typically established based on simulation and analysis. (Given the low allowed probability of observing actual faults, collection of enough real data to establish that the probability is met with any statistical significance is impossible.) The threat space for the fault mode is divided into discrete intervals across the relevant parameters that define the fault behavior. The total space of potential faults is represented by a multidimensional grid of discrete points that span the threat space. The airborne configuration space is also discretized i.e. represented by a multidimensional grid of discrete (critical parameter) points. A simulation is used to compute the expected pseudo-range error performance for each point in the threat space, each possible airborne configuration and the ground receiver function with the monitors. The worst-case error in the corrected pseudo-range is computed as a function of the discriminator value for the monitor addressing the threat (assuming no noise at this point). This also makes it possible to determine the discriminator value as a function of the worst-case error in the corrected pseudo-range (the inverse mapping). The missed detection probability is obtained by superimposing noise based on a conservative noise model (using an over bound of the CDF that was generated by the real data), on the discriminator determined from the worst-case differential range. This can be done either analytically or by simulation. The mapping from discriminator to worst-case error in the corrected pseudo-range and the noise levels applied may have further dependencies (for instance satellite elevation), and the established missed detection probability is therefore also a function of a set of parameters that constitute the detection parameter space which is divided into discrete intervals as well, i.e. represented by a multidimensional grid of discrete (detection parameter) points. The final missed detection probability is obtained by searching for the worst case when evaluating all the grid points in the detection parameter space.

7.5.12.1.3 *Threat space and relevant airborne configuration space for each fault mode*

7.5.12.1.3.1 *Code carrier divergence threat*

7.5.12.1.3.1.1 The code carrier divergence threat is a fault condition in a GPS satellite that causes the code and carrier of the broadcast signal to diverge excessively.

7.5.12.1.3.1.2 A code carrier divergence fault may cause a differential ranging error in one or both of the following cases: (1) the aircraft and ground filter designs are not identical, and (2) the aircraft and ground filters start at different times. Both of these cases can result in a difference between the transient responses of the filters in the presence of a CCD event.
The critical airborne parameters are:

— The time of initialization of the airborne smoothing filter relative to the fault onset.

— The smoothing filter type (fixed time constant 30 seconds or adjustable time constant equal to time from initialization up to 30 seconds and thereafter fixed).

— The carrier code divergence rate monitoring required in airborne system for GAST D and the associated fault reaction.

— The time period from initialization of the airborne smoothing filter to the incorporation of the measurement in the position solution.

7.5.12.1.3.2 *Excessive acceleration threat*

The excessive acceleration threat is a fault condition in a GPS satellite that causes the carrier (and code in unison) of the broadcast signal to accelerate excessively. The threat space is one-dimensional and corresponds to all possible accelerations including ramps and steps.

7.5.12.1.3.3 *Ephemeris error threat*

The ephemeris error threat is a fault condition that causes the broadcast ephemeris parameters to yield excessive satellite position errors perpendicular to the ground subsystem's line of sight to the satellite. The resultant differential range error is the satellite position error (true compared to broadcast ephemeris) multiplied by the distance between ground subsystem and airborne and scaled by the inverted distance to the satellite. It is bounded by the product of the P parameter (see 7.5.9) and the distance between the user and the ground subsystem. The critical airborne parameter for the ephemeris error threat is therefore the distance between the user and the ground subsystem.Satellite ephemeris faults are categorized into two types, A and B, based upon whether or not the fault is associated with a satellite manoeuvre. There are two subclasses of the type A fault, A1 and A2.

7.5.12.1.3.3.1 *Ephemeris error threat type B*

7.5.12.1.3.3.1.1 The type B threat occurs when the broadcast ephemeris data is anomalous, but no satellite manoeuvre is involved.

7.5.12.1.3.3.1.2 The GBAS ground subsystem can monitor against such faults by comparing current and prior ephemerides. One example of a type B fault: no manoeuvre occurs, an incorrect upload is sent to a satellite, and the satellite subsequently broadcasts an erroneous ephemeris.

7.5.12.1.3.3.2 *Ephemeris error threat type A1*

7.5.12.1.3.3.2.1 The type A1 threat occurs when the broadcast ephemeris data is anomalous following an announced and intentional satellite manoeuvre.

7.5.12.1.3.3.2.2 Prior ephemerides are of limited use in the detection of type A1 failures because of the intervening manoeuvre. The GBAS ground subsystem will need to monitor ranging data directly as part of ephemeris validation. One example of a type A1 fault: a satellite is set unhealthy, a manoeuvre is executed, an incorrect upload is sent to the satellite, the satellite is reset to healthy and subsequently broadcasts an erroneous ephemeris.

7.5.12.1.3.3.3 *Ephemeris error threat type A2*

7.5.12.1.3.3.3.1 The type A2 threat occurs when the broadcast ephemeris data is anomalous following an unannounced or unintentional satellite manoeuvre.

7.5.12.1.3.3.3.2 Prior ephemerides are of limited use in the detection of type A2 failures because of the intervening manoeuvre. The GBAS ground subsystem will need to monitor ranging data directly as part of ephemeris validation. One example of a type A2 fault: a satellite is set healthy, an intentional manoeuvre or unintentional thruster firing occurs, and the satellite continues to broadcast the pre-manoeuvre (now erroneous) ephemeris.

7.5.12.1.3.4 *Signal deformation threat*

7.5.12.1.3.4.1 The signal deformation threat is a fault condition in the GPS satellite that causes the broadcast C/A code to be distorted so that the correlation peaks used for tracking in the airborne system and the ground system are deformed. The extent of the deformation depends on the receiver bandwidth and the resulting tracking error depends on where the correlator points used for code tracking are located (along the correlator peak).

7.5.12.1.3.4.2 The signal deformation monitoring threat space is defined in section 8. There are three fault types A, B, C.

7.5.12.1.3.4.3 Most satellites naturally show some degree of correlator peak deformation and these are referred to as natural (correlator measurement) biases. These natural biases may vary over time.

7.5.12.1.3.4.4 A fault condition (onset) will appear as a step in the raw (unfiltered) code measurement both in the airborne system and in the ground. If both system had exactly the same front end (RF and IF filtering, sampling method), correlator type and correlator spacing the error would be the same in ground and air and no differential error would occur. But typically that is not the case.

7.5.12.1.3.4.5 The step is filtered by the smoothing algorithm in the ground and in the airborne systems and the steady state differential error will gradually manifest itself in a 60 – 90 second time frame when using corrections from message Type 11 (or 200 – 300 seconds for message Type 1).

7.5.12.1.3.4.6 If a fault (A, B or C) occurs in a satellite it will take about 60 – 90 seconds before the steady state for the error and the monitor discriminator is reached. In essence the fault onset starts a race between the increasing differential error and the monitor discriminator as it moves towards the threshold. This is referred to as the transient state. If the range error reaches the limit that must be protected while the discriminator is not yet past the threshold with sufficient margin to guarantee the required detection probability, the requirement is not met. Both the steady state and the transient state performance must be evaluated.

7.5.12.1.3.4.7 The critical airborne parameters for the signal deformation threat are:

- The time period from initialization of the airborne smoothing filter to incorporation of the measurement in the position solution.
- The parameters that have constraints defined in the GAST D standard (Attachment B) including:
    - Correlator type Early-Late (EL) or Double Delta (DD)
    - Correlator spacing
    - GPS signal bandwidth (from reception at antenna through RF, IF, and A/D conversion)
- Group delay (from reception at antenna through RF, IF, and A/D conversion).

7.5.12.1.3.4.8 Apart from the discrete choice of EL versus DD the configuration space is two-dimensional (correlator spacing and bandwidth). The filters implemented in the airborne system may be of different types (Butterworth, Chebychev, Elliptical, etc.). The group-delay constraints will exclude some of these filters. However the possible variation in receiver design introduces additional dimensions that the ground subsystem manufacturer must consider. The filter types are part of the configuration space to be considered.

7.5.13 *Ground subsystem requirements and airworthiness performance assessment.* Airworthiness certification of autoland systems, for use in Category II/III operations, requires an assessment of landing performance under fault-free and faulted conditions. More information, describing how the technical standards can be used to support an assessment, may be found in RTCA document DO-253D, “Minimum Operational Performance Requirements for Airborne Equipment using the Local Area Augmentation System” Appendix J”.

7.5.14 *GBAS signal-in-space time-to-alert.* The GBAS signal-in-space time-to-alert (SIS TTA) is defined below within the context of GBAS based upon the TTA definition in Chapter 3, section 3.7.1. The GBAS SIS TTA is the maximum allowable time elapsed from the onset of an out-of-tolerance condition at the output of the fault-free aircraft GBAS receiver until the aircraft GBAS receiver annunciates the alert. This time is a never-to-be-exceeded limit and is intended to protect the aircraft against prolonged periods of guidance outside the lateral or vertical alert limits.

7.5.14.1 There are two allocations made to support the GBAS SIS TTA in the Standards.

1) The first allocation, the ground subsystem TTA for SIS requirements, limits the time it takes the ground subsystem to provide an indication that it has detected an out-of-tolerance situation considering the output of a fault-free GBAS receiver. The indication to the aircraft element is either: a) to broadcast Type 1 (and Type 11 if broadcast) or Type 101 messages indicating the condition (in accordance with Appendix B, 3.6.7.3.2.1), or b) terminate all VDB transmissions. The ground subsystem is allocated 3 seconds to take either action.

For airborne receivers using GAST C, at least one Type 1 message signaling the out-of-tolerance condition must be received by a fault-free airborne receiver within the message time out to meet the SIS TTA. For airborne receivers using GAST D at least one of each (Type 1 and Type 11) message with the same applicable modified z-count (and the same set of satellites) must be received by a fault-free airborne receiver within the message time out to meet the SIS TTA. Because shutting down the VDB may result in an exposure time longer than the SIS TTA for satellite faults, this option is recommended only under conditions where the VDB transmission does not meet its associated performance requirements (reference Appendix B, 3.6.7.3.1.1.).

In addition, for ground subsystems that support GAST D monitoring performance requirements, the ground subsystem is allocated only 1.5 seconds to detect a condition producing out-of-tolerance errors in 30-second corrected pseudo-ranges and to either exclude the ranging source measurements from the broadcast or mark them as invalid. This time-to-detect and broadcast is similar in definition, but not equivalent in function to the ground subsystem TTA, as an out-of-tolerance condition in a single ranging source does not necessarily lead to out-oftolerance guidance information.

2) The second allocation for the GBAS signal-in-space time-to-alert provides for the possible temporary loss of message reception. Airborne equipment operating with GAST C active will generate an alert if a Type 1 message is not received within 3.5 seconds when on the final stages of approach. When the airborne equipment is below 200 ft height above the runway threshold (HAT), airborne equipment operating with GAST D active will generate an alert or change the active service type if a set of Type 1 and Type 11 messages with the same modified z-count are not received within 1.5 seconds. Note that these time-outs will also dictate the achieved signal-in-space time-to-alert when the ground subsystem ceases VDB transmissions instead of broadcasting messages as an alert to the airborne equipment.

Requirements on how quickly the receiver outputs must be invalidated (so annunciating an alert), as well as additional conditions requiring the outputs to be indicated as invalid, are contained in RTCA DO-253D. For example, there is a requirement for the aircraft GBAS receiver position determination function to use the most recently received message content and reflect the message content in its outputs within 400 ms. The SIS TTA is defined by start and stop events at the same point in the aircraft. Any processing that is common to generating outputs under both normal conditions and alert conditions will not change the achieved SIS TTA. That is, this common period acts like a lag to both the start event and end event and does not affect the total exposure time to the aircraft. Within the GBAS receiver, the outputs under both of these conditions must meet the same latency requirement, so large differences are not expected. SIS TTA will differ from ground subsystem TTA by a value equal to the difference between receiver processing time and receiver time to invalidate outputs.

7.5.14.2 Table D-5C summarizes the time periods that contribute to the GBAS SIS TTA and the range of achieved TTA that can be expected.

7.5.14.3 Figure D-13 illustrates the nominal case with no missed messages and Figure D-14 illustrates the effect of missed messages for GAST D below 200 ft. Above 200 ft, the situation is similar, but the aircraft has a longer missed message allocation, as described above.

7.5.14.3.1 Figure D-14 illustrates the effect on the SIS TTA due to missed messages (upper half) and VDB termination (lower half) using the example of GAST D requirements below 200 ft. The upper time-line shows just two messages being missed, but the third is received, so operations can continue, unless the third message is indicating a fault condition that results in an alert from the receiver. The lower time-line shows the effect of the VDB terminating. The aircraft receiver invalidates its outputs after three messages are missed. The SIS TTA combines the ground TTA and the missed message allocation (See Table D-5B), but it is now displaced by the aircraft receiver processing time. Above 200 ft, the situation is similar, but the aircraft has a longer allocation, as described in RTCA DO-253D.

7.5.14.3.2 For SIS integrity, the diagram indicates that the SIS TTA starting point is where the fault-free airborne receiver outputs out-of-tolerance data. The SIS TTA end event is also at the output of the airborne receiver.

7.5.14.3.3 The start event of the ground subsystem's time-to-alert or time-to-detect and broadcast is the last bit of the first message (Type 1 and Type 11 message pair for GAST D) including the out-of-tolerance data. For ground equipment failures or termination of the VDB signal, this is the first message the ground subsystem broadcasts containing correction, integrity or path information that does not conform to the applicable integrity requirement (e.g. SIS integrity, ground subsystem integrity). For satellite failures, the requirements are out-of-tolerance once differential pseudo-range errors exceed the performance metrics detailed within a certain requirement (e.g. Ranging Source Monitoring). Their end event is the last bit of the first message (message pair for GAST D) removing the out-of-tolerance data or flagging it invalid.

7.5.14.3.4 It should be noted that, while the Figure D-13 indicates that the SIS and ground subsystem TTAs reference different start and end points in time, an ANSP may assume that they are the same. A ground subsystem should be evaluated and certified with no credit or penalty for airborne receiver variations due to a specific, approved aircraft implementation. From the ground subsystem perspective, all received messages are assumed to be instantaneously applied or acted upon by the airborne receiver. This effectively results in equivalent SIS and ground subsystem TTA reference points from the ground subsystem's point of view.

7.5.15 *Ground subsystem integrity risk for GAST D.* Appendix B, 3.6.7.1.2.1.1.3 specifies a new ground subsystem integrity requirement relating to fail-safe design criteria. This integrity method will ensure that failures within the ground subsystem that might affect the stations functions and result in erroneous information are extremely improbable. The intent of this requirement is to specify the allowable risk that the ground subsystem would internally generate and cause erroneous information to be broadcast. Other requirements specify the required performance of the ground subsystem with respect to detection and mitigation of faults originating outside the ground subsystem (such as ranging source failures). This requirement relates to the probability that the ground subsystem fails to meet the intended function. The intended function for GBAS is defined in Chapter 3, 3.7.3.5.2. The functions listed in that section and their associated performance requirements characterize the intended function of the system.

Table D-5C. Contributions to signal-in-space time-to-alert

Integrity risk requirements and service types	Ground subsystem TTA *[Note 1]*	Message time-out in aircraft *[Note 5]*	Signal-in-space TTA (nominal) *[Note 6]*	Signal-in-space TTA (maximum) *[Note 7]*
App B, 3.6.7.1.2.1.1.1 and 3.6.7.1.2.2.1 (GAST A,B,C)	3.0 s *[Note 2]*	3.5 s	3.0 s	6.0 s
App B, 3.6.7.1.2.1.1.2 and 3.6.7.1.2.2.1 (GAST D)	3.0 s *[Notes 2 and 8]*	3.5 s (above 200 ft HAT) 1.5 s (below 200 ft HAT)	3.0 s 3.0 s	6.0 s 4.0 s
App. B, 3.6.7.1.2.1.1.3 (GAST D)	1.5 s	3.5 s (above 200 ft HAT) 1.5 s (below 200 ft HAT)	1.5 s 1.5 s	4.5 s*[Note3]* 2.5 s*[Note3]*
App. B, 3.6.7.3.3 (GAST D)	1.5 s *[Note 9]*	3.5 s (above 200 ft HAT) 1.5 s (below 200 ft HAT)	1.5 s 1.5 s	4.5 s*[Note4]* 2.5 s*[Note4]*

Note 1.— These ground subsystem TTA requirements apply to a ground subsystem transmitting Type 1 messages. Ground subsystems transmitting Type 101 messages have a 5.5 s TTA as standardized in Appendix B, 3.6.7.1.2.1.2.1.2.

Note 2.— These times apply to excluding all ranging sources, marking all ranging sources as invalid in message Type 1 or the cessation of VDB transmission. When a single ranging source is marked invalid or excluded, it may or may not cause the aircraft receiver to generate an alert, depending on the role of that ranging source in the aircraft's position solution.

Note 3.— This design requirement applies to the integrity of internal ground subsystem functions (excluding single reference receiver failures). This includes the ground subsystem ranging source monitoring capability. The table illustrates the exposure time for ground equipment failures that result in the transmission of non-compliant information and that are enunciated to the aircraft using the VDB transmission.

Note 4.— These requirements apply to the integrity monitoring for GNSS ranging sources. When a single ranging source is marked invalid or excluded, it may or may not cause the aircraft receiver to generate an alert, depending on the role of that ranging source in the aircraft's position solution. The times listed in the table assume the ranging source was critical to determining the position solution.

Note 5.— The missed message time-out allocation starts with the last received message and not with the first missed message, so is 0.5 s longer than time added to the SIS time-to-alert.

Note 6.— If transmissions continue and there are no missed messages, the "nominal" column is relevant. This value includes the maximum ground subsystem contribution.

Note 7.— The maximum SIS TTA includes the maximum ground subsystem contribution and the possible temporary loss of message reception. When VDB transmissions cease, the maximum SIS TTA is relevant. This time is computed by adding the ground subsystem TTA and the airborne message time out minus 0.5 s (see Note 5).

Note 8.— Although these sections are related to FAST D and the maximum TTA values are larger than those historically associated with Category II/III operations, the TTA values in this line are not relevant for integrity to support Category II/III. These TTA values apply to the bounding conditions (see 7.5.3.1) and therefore are related to the total risk of fault-free error sources and faults exceeding the protection levels. For GAST D, the effects of malfunctions are addressed by the additional requirements in Appendix B, 3.6.7.1.2.1.1.3, Appendix B, 3.6.7.3.3 and additional airborne requirements as provided in RTCA DO-253D, for example the reference receiver fault monitor. These additional requirements are more constraining and enforce a shorter TTA that is appropriate for Category II/III operations. The existence of the longer TTA values in this line should not be interpreted to imply that errors near or exceeding the alert limit for up to these longer exposure times can occur with a probability greater than 1 x 10^{-9} in any landing.

Note 9.— This is "time to detect and broadcast"; the other ground system requirements apply in addition.

7.5.15.1 *Verification of compliance with subsystem integrity risk for GAST D.* Verification that a ground subsystem meets the integrity risk requirements of Appendix B, 3.6.7.1.2.1.1.3 would typically be accomplished through a combination of analysis and appropriate safety-related design practices/processes. The overall process must ensure that failures within the ground subsystem that might affect the stations intended functions and result in erroneous information are extremely improbable. All ground subsystem component failure conditions must be shown to be sufficiently mitigated through either direct monitoring or through use of an acceptable design assurance development process (such as RTCA/DO-178 and RTCA/DO-254). The methodology should provide assurance of mitigation of component (HW, SW) failures. The integrity method of design assurance, applied in conjunction with fail-safe design concepts and other assurance actions (such as those in SAE ARP 4754) to detect and remove systematic errors in the design, provides safety assurance of the GAST D ground system. Some States have used safety assurance guidance from ICAO's *Safety Management Manual (SMM)* (Doc 9859).

7.6 Continuity of service

7.6.1 *GBAS continuity /integrity designator.* The GBAS continuity/integrity designator (GCID) provides an indication of the current capability of GBAS ground subsystems. The ground subsystem meets the performance and functional requirements of GAST A, B or C when GCID is set to 1. The ground subsystem meets the performance and functional requirements of GAST A, B, C and D when GCID is set to 2. GCID of 3 and 4 are intended to support future operations with an associated service type that has requirements that are more stringent than GAST D. The GCID is intended to be an indication of ground subsystem status to be used when an aircraft selects an approach. It is not intended to replace or supplement an instantaneous integrity indication communicated in a Type 1 or Type 101 message. GCID does not provide any indication of the ground subsystem capability to support the GBAS positioning service.

7.6.2 *Ground subsystem continuity of service.* GBAS ground subsystems are required to meet the continuity of service specified in Appendix B to Chapter 3, 3.6.7.1.3 in order to support GAST A, B and C. GBAS ground subsystems that are also intended to support other operations through the use of the GBAS positioning service should support the minimum continuity required for terminal area operations, which is 1–10^{-4}/hour (Chapter 3, Table 3.7.2.4-1). When the GAST A, B or C required continuity (1–8 × 10^{-6}/15 seconds) is converted to a per hour value it does not meet the 1–10^{-4}/hour minimum continuity requirement. Therefore, additional measures are necessary to meet the continuity required for other operations. One method of showing compliance with this requirement is to assume that airborne implementation uses both GBAS and ABAS to provide redundancy and that ABAS provides sufficient accuracy for the intended operation.

7.6.2.1 *Ground subsystem continuity of service for GAST D.* A ground segment that supports GAST D must meet the SIS continuity requirement (1-8.0 x 10^{-6}/15 seconds) for a GAST A, B and C system but must also meet the continuity requirements specific to GAST D as defined in Appendix B, 3.6.7.1.3.2. The ground subsystem continuity is defined by two requirements. One is the continuity of the ground subsystem that includes failures of all components necessary for the VDB broadcast, including the reference receivers. It also includes loss of service due to integrity failures in the ground subsystem that result in alerts and monitor false alerts. The other allocation is the continuity associated with monitor fault-free detections. The reason for defining the ranging source monitor detections as a separate requirement is because the VDB broadcast portion includes all failures that result in the loss of the SIS, whereas the monitor contribution is related only to exclusion of individual satellites from the broadcast corrections. This does not necessarily result in a loss of the SIS by the airborne receiver. The requirement is defined on a per ranging source basis so that the ground design does not need to account for the actual number of satellites in view or the number considered critical to the user for a specific approach. It is the responsibility of the airborne user to demonstrate the overall continuity achieved when considering the contribution of the satellites and the airborne monitors.

7.7 GBAS channel selection

7.7.1 Channel numbers are used in GBAS to facilitate an interface between aircraft equipment and the signal-in-space that is consistent with interfaces for ILS and MLS. The cockpit integration and crew interface for GBAS may be based on entry of the 5-digit channel number. An interface based on approach selection through a flight management function similar to current practice with ILS is also possible. The GBAS channel number may be stored in an on-board navigation database as part of a named approach. The approach may be selected by name and the channel number can automatically be provided to the equipment that must select the appropriate GBAS approach data from the broadcast data. Similarly, the use of the GBAS positioning service may be based on the selection of a 5-digit channel number. This facilitates conducting operations other than the approaches defined by the FAS data. To facilitate frequency tuning, the GBAS channel numbers for neighbouring GBAS ground subsystems supporting positioning service may be provided in the Type 2 message additional data block 2.

7.7.2 A channel number in the range from 20 001 to 39 999 is assigned when the FAS data are broadcast in the Type 4 message. A channel number in the range from 40 000 to 99 999 is assigned when the FAS data associated with a GAST A service type are obtained from the on-board database.

7.7.3 Every FAS data block uplinked in a Type 4 message will be associated with a single 5-digit channel number regardless of whether or not the approach is supported by multiple approach service types. For approaches that are supported by multiple approach service types, the approach performance designator field in the Type 4 message is used to indicate the most demanding approach service type supported by the ground subsystem for any specific approach.

7.8 Reference path data selector and reference station data selector

A mapping scheme provides a unique assignment of a channel number to each GBAS approach. The channel number consists of five numeric characters in the range 20 001 to 39 999. The channel number enables the GBAS airborne subsystem to tune to the correct frequency and select the final approach segment (FAS) data block that defines the desired approach. The correct FAS data block is selected by the reference path data selector (RPDS), which is included as part of the FAS definition data in a Type 4 message. Table D-6 shows examples of the relationship between the channel number, frequency and RPDS. The same mapping scheme applies to selection of the positioning service through the reference station data selector (RSDS). The RSDS is broadcast in the Type 2 message and allows the selection of a unique GBAS ground subsystem that provides the positioning service. For GBAS ground subsystems that do not provide the positioning service and broadcast the additional ephemeris data, the RSDS is coded with a value of 255. All RPDS and RSDS broadcast by a ground subsystem must be unique on the broadcast frequency within radio range of the signal. The RSDS value must not be the same as any of the broadcast RPDS values.

7.9 Assignment of RPDS and RSDS by service provider

RPDS and RSDS assignments are to be controlled to avoid duplicate use of channel numbers within the protection region for the data broadcast frequency. Therefore, the GBAS service provider has to ensure that an RPDS and RSDS are assigned only once on a given frequency within radio range of a particular GBAS ground subsystem. Assignments of RPDS and RSDS are to be managed along with assignments of frequency and time slots for the VHF data broadcast.

Table D-6. Channel assignment examples

Channel number (N)	Frequency in MHz (F)	Reference path data selector (RPDS) or Reference station data selector (RSDS)
20 001	108.025	0
20 002	108.05	0
20 003	108.075	0
….	….	….
20 397	117.925	0
20 398	117.95	0
20 412 (Note)	108.025	1
20 413	108.05	1
….	….	….

Note.— Channels between 20 398 and 20 412 are not assignable because the channel algorithm maps them to frequencies outside the range of 108.025 MHz and 117.950 MHz. A similar "gap" in the channel assignments occurs at each RPDS transition.

7.10 GBAS identification

The GBAS identification (ID) is used to uniquely identify a GBAS ground subsystem broadcasting on a given frequency within the VDB coverage of the GBAS. The aircraft will navigate using data broadcast from one or more GBAS broadcast stations of a single GBAS ground subsystem (as identified by a common GBAS identification).

7.11 Final approach segment (FAS) path

7.11.1 FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). These parameters are determined from data provided in a FAS data block within a Type 4 message or in the on-board database. The relationship between these parameters and the FAS path is illustrated in Figure D-15.

7.11.1.1 FAS data blocks for SBAS and some GBAS approaches are held within a common onboard database supporting both SBAS and GBAS. States are responsible for providing the FAS data to support APV procedures when the Type 4 message is not broadcast. These data comprise the parameters contained within the FAS block, the RSDS, and associated broadcast frequency. The FAS block for a particular approach procedure is described in Appendix B, 3.6.4.5.1 and Table B-66.

7.11.2 *FAS path definition*

7.11.2.1 *Lateral orientation*. The LTP/FTP is typically at or near the runway threshold. However, to satisfy operational needs or physical constraints, the LTP/FTP may not be at the threshold. The FPAP is used in conjunction with the LTP/FTP to define the lateral reference plane for the approach. For a straight-in approach aligned with the runway, the FPAP will be at or beyond the stop end of the runway. The FPAP is not placed before the stop end of the runway.

7.11.2.2 *ΔLength offset*. The Δlength offset defines the distance from the end of the runway to the FPAP. This parameter is provided to enable the aircraft equipment to compute the distance to the end of the runway. If the Δlength offset is not set to appropriately indicate the end of the runway relative to the FPAP, the service provider should ensure the parameter is coded as "not provided".

7.11.2.3 *Vertical orientation*. Local vertical for the approach is defined as normal to the WGS-84 ellipsoid at the LTP/FTP and may differ significantly from the local gravity vector. The local level plane for the approach is defined as a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). The datum crossing point (DCP) is a point at a height defined by TCH above the LTP/FTP. The FAS path is defined as a line with an angle (defined by the GPA) relative to the local level plane passing through the DCP. The GPIP is the point where the final approach path intercepts the local level plane. The GPIP may actually be above or below the runway surface depending on the curvature of the runway.

7.11.3 *"ILS look-alike" deviation computations*. For compatibility with existing aircraft designs, it is desirable for aircraft equipment to output guidance information in the form of deviations relative to a desired flight path defined by the FAS path. The Type 4 message includes parameters that support the computation of deviations that are consistent with typical ILS installations.

7.11.3.1 *Lateral deviation definition*. Figure D-15 illustrates the relationship between the FPAP and the origin of the lateral angular deviations. The course width parameter and FPAP are used to define the origin and sensitivity of the lateral deviations. By adjusting the location of the FPAP and the value of the course width, the course width and sensitivity of a GBAS can be set to the desired values. They may be set to match the course width and sensitivity of an existing ILS or MLS. This may be necessary, for example, for compatibility with existing visual landing aids.

7.11.3.1.1 *Lateral deviation reference*. The lateral deviation reference plane is the plane that includes the LTP/FTP, FPAP and a vector normal to the WGS-84 ellipsoid at the LTP/FTP. The rectilinear lateral deviation is the distance of the computed aircraft position from the lateral deviation reference plane. The angular lateral deviation is a corresponding angular displacement referenced to the GNSS azimuth reference point (GARP). The GARP is defined to be beyond the FPAP along the procedure centre line by a fixed offset value of 305 m (1 000 ft).

7.11.3.1.2 *Lateral displacement sensitivity*. The lateral displacement sensitivity is determined by the aircraft equipment from the course width provided in the FAS data block. The service provider is responsible for setting the course width parameter to a value that results in the appropriate angle for full scale deflection (i.e. 0.155 DDM or 150 µA) taking into account any operational constraints.

7.11.3.2 *Vertical deviations*. Vertical deviations are computed by the aircraft equipment with respect to a GBAS elevation reference point (GERP). The GERP may be at the GPIP or laterally offset from the GPIP by a fixed GERP offset value of 150 m. Use of the offset GERP allows the glide path deviations to produce the same hyperbolic effects that are normal characteristics of ILS and MLS (below 200 ft). The decision to offset the GERP or not is made by the aircraft equipment in accordance with requirements driven by compatibility with existing aircraft systems. Service providers should be aware that users may compute vertical deviations using a GERP which is placed at either location. Sensitivity of vertical deviations is set automatically in the aircraft equipment as a function of the GPA. The specified relationship between GPA and the full scale deflection (FSD) of the vertical deviation sensitivity is: FSD = 0.25*GPA. The value 0.25 is the same as for MLS (Attachment G, 7.4.1.2) and differs slightly from the nominal value of 0.24 recommended for ILS (Chapter 3, section 3.1.5.6.2). However, the value specified is well within the tolerances recommended for ILS (0.2 to 0.28). Therefore the resulting sensitivity is equivalent to the glide path displacement sensitivity provided by a typical ILS.

7.11.4 *Approaches not aligned with the runway*. Some operations may require the definition of a FAS path that is not aligned with the runway centre line as illustrated in Figure D-16. For approaches not aligned with the runway, the LTP/FTP may or may not lie on the extended runway centre line. For this type of approach Δlength offset is not meaningful and should be set to "not provided".

7.11.5 *SBAS service provider.* A common format is used for FAS data blocks to be used by both GBAS and SBAS. The SBAS service provider ID field identifies which SBAS system(s) may be used by an aircraft that is using the FAS data during an approach. The GBAS service provider may inhibit use of the FAS data in conjunction with any SBAS service. For precision approaches based on GBAS this field is not used, and it can be ignored by aircraft GBAS equipment.

7.11.6 *Approach identifier*. The service provider is responsible for assigning the approach identifier for each approach. The approach identification should be unique within a large geographical area. Approach identifications for multiple runways at a given aerodrome should be chosen to reduce the potential for confusion and misidentification. The approach identification should appear on the published charts that describe the approach. The first letter of the approach identifier is used in the authentication protocols for GBAS. Ground stations that support the authentication protocols must encode the first character of the identifier for all approaches supported from the set of letters {A X Z J C V P T} as described in Appendix B, section 3.6.7.4.1.4. This enables airborne equipment (that supports the authentication protocols) to determine which slots are assigned to the ground station and therefore to subsequently ignore reception of data broadcast in slots not assigned to the selected ground station. For ground stations that do not support the authentication protocols, the first character of the approach identifier may be assigned any character except those in the set {A X Z J C V P T}.

7.12 Airport siting considerations

7.12.1 The installation of a GBAS ground subsystem involves special considerations in choosing prospective sites for the reference receiver antennas and the VDB antenna(s). In planning antenna siting, Annex 14 obstacle limitation requirements must be met.

7.12.2 *Locating reference receiver antennas*. The site should be selected in an area free of obstructions, so as to permit the reception of satellite signals at elevation angles as low as possible. In general, anything masking GNSS satellites at elevation angles higher than 5 degrees will degrade system availability.

7.12.2.1 The antennas for the reference receivers should be designed and sited to limit multipath signals that interfere with the desired signal. Mounting antennas close to a ground plane reduces long-delay multipath resulting from reflections below the antenna. Mounting height should be sufficient to prevent the antenna being covered by snow, or being interfered with by maintenance personnel or ground traffic. The antenna should be sited so that any metal structures, such as air vents, pipes and other antennas are outside the near-field effects of the antenna.

7.12.2.2 Besides the magnitude of the multipath error at each reference receiver antenna location, the degree of correlation must also be considered. Reference receiver antennas should be located in places that provide independent multipath environments.

7.12.2.3 The installation of each antenna should include a mounting that will not flex in winds or under ice loads. Reference receiver antennas should be located in an area where access is controlled. Traffic may contribute to error due to multipath or obstruct view of satellites from the antennas.

7.12.3 *Locating the VDB antenna*. The VDB antenna must be located to comply with the minimum and maximum field strength requirements within the service volume(s) as defined in Chapter 3, 3.7.3.5.4.4. Compliance with the minimum field strength for approach services can generally be met if the VDB antenna is located so that an unobstructed line-of-sight exists from the antenna to any point within the service volume for each supported FAS. Consideration should also be given to ensuring the minimum transmitter-to-receiver separation so that the maximum field strength is not exceeded. For the nominal link budget, typically, an 80 m separation is required to avoid exceedance of the maximum field strength requirement. Though it is desirable to apply the separation criteria to any location where an aircraft may operate (including taxiways, ramp areas and gates), it is only necessary to meet the maximum field strength in the service volume(s) (see 3.7.3.5.3 for service volume definitions). If the minimum separation cannot be met for all operating aircraft (including taxiways, ramp areas and gates) it must be ensured that the airborne receiver is protected from burn-out in accordance with the RTCA/DO-253 D MOPS. This typically requires a minimum separation of 20 m from the VDB antenna to the aircraft antenna. In order to provide the required coverage for multiple FASs at a given airport, and in order to allow flexibility in VDB antenna siting, the actual coverage around the transmitter antenna may need to be considerably larger than that required for a single FAS. The ability to provide this coverage is dependent on the VDB antenna location with respect to the runway and the height of the VDB antenna. Generally speaking, increased antenna height may be needed to provide adequate signal strength to users at low altitudes, but may also result in unacceptable multipath nulls within the desired coverage. A suitable antenna height trade-off must be made based on analysis, to ensure the signal strength requirements are met within the entire coverage. Consideration should also be given to the effect of terrain features and buildings on the multipath environment.

7.12.3.1 In order to ensure that the maximum field strength requirements defined in Chapter 3, 3.7.3.5.4.4 are not violated, VDB transmitters should not be located any closer than 80 m to where aircraft are approved to operate based on published procedures using GBAS or ILS guidance information. This applies to aircraft on final approach, departure, and on runways. The 80-metre separation applies to the slant range distance between VDB transmit antennas and the aircraft antenna position. For aircraft on the runway the maximum deviation from the centre line can be assumed to be 19 m. In regions prior to runway thresholds, the maximum lateral course angular deviation from the extended centre line on final approach is plus and minus one sixth of the full course width, which is nominally 210 m (±105 m (±350 ft)) at threshold. The origin of the lateral course should be assumed to be the GBAS GARP, or the ILS localizer, as appropriate. The maximum vertical deviation is one half of the full scale deflection from the glide path, where full scale deflection is calculated as ±0.25 times the glide path angle. The origin of the glide path should be assumed to be the GPIP. See 7.11.3 for further guidance on lateral and vertical course width deviation sensitivity.

7.12.4 *Use of multiple transmit antennas to improve VDB coverage.* For some GBAS installations, constraints on antenna location, local terrain or obstacles may result in ground multipath and/or signal blockage that make it difficult to provide the specified field strength at all points within the service volume. Some GBAS ground facilities may make use of one or more additional antenna systems, sited to provide signal path diversity such that collectively they meet the service volume requirements.

7.12.4.1 Whenever multiple antenna systems are used, the antenna sequence and message scheduling must be arranged to provide broadcasts at all points within the service volume that adhere to the specified minimum and maximum data broadcast rates, considering the receiver's ability to adapt to transmission-to-transmission variations in signal strength in a given slot. Exceedance of the signal power variation requirement in Appendix B, 3.6.8.2.2.3 is acceptable for limited areas within the service volume, provided it can be shown based on receiver behaviour as described, for example in RTCA DO253D and the assumptions listed below, that the resulting performance is acceptable.

7.12.4.1.2 Message transmission and reception rate requirements, and time-to-alert requirements prevent Type 1 and Type 11 messages from being alternated between antennas in the same slot from frame to frame. Only Type 2 and 4 messages (and Type 3 messages as a filler message) are candidates for being alternated. Continuity is maintained as long as a Type 2 message is received at least once per minute. The receiver does not verify repeated reception of Type 4 messages during the final stages of an approach.

7.12.4.1.3 While the signal power variation requirement in Appendix B, 3.6.8.2.2.3 applies on the input port of the receiver, the situation for a specific site has to be assessed in the field strength domain. Therefore, the potential variation in aircraft antenna gain must be taken into account. If the area where the signal power variation requirement may be exceeded is so large that it may take one minute or more for an approaching aircraft to pass through it, it may be necessary to address the potential message loss from a probabilistic point of view. In these cases the multiple VDB antenna set-up should be limited so that in case alternation of messages in the same slot from frame to frame is applied, the alternating pattern should only involve two transmitter antennas, with a scheduled burst in every frame, and the transmission should alternate between the antennas every frame, in order to resemble the situation for which the receiver has been tested. This is necessary in order to be able to make assumptions on receiver message failure rates (MFR).

7.12.4.1.4 When analysing the probability of lost messages, the following basic assumptions apply:

1. If all received signal levels are between the receiver minimum design input power (S_{min}) and maximum design input power (S_{max}), and they are within 40 dB of each other, then the analysis can assume 10^{-3} message failure rate (MFR).
2. If all received signals are below S_{min}, then the analysis must assume a MFR of 100 per cent.
3. If any signal exceeds S_{max} it must be assumed that reception in all slots in that frame and any number of subsequent frames is adversely affected (not only those where S_{max} is exceeded), as no receiver recovery time is specified for these conditions.

Furthermore, in the case of a dual antenna set-up with messages alternating in each frame, the following assumptions can be made:

4. If one signal is below S_{min} ($S_{min} - \Delta$) and the second signal is within 40 dB (i.e., $S_{min} - \Delta + 40$ dB or less), then the analysis must assume that the MFR for the signal below Smin is 100 per cent and the MFR for the stronger signal is 10^{-3}.
5. If both signals are within S_{min} to S_{max}, but the variation between the signals is greater than 40 dB, then the analysis must assume a MFR of 60 per cent.
6. If one signal is below S_{min} ($S_{min} - \Delta$) and the second is above S_{min}, and exceeds 40 dB variation ($S_{min} - \Delta + 40$ dB $+ \varepsilon$ or more), then the analysis must assume that the MFR for the signal below S_{min} is 100 per cent and the MFR for the stronger signal is 60 per cent.

7.12.4.1.5 The resulting probability of no Type 2 messages being received for a duration of one minute should be assessed against the applicable continuity requirement.

Note.— The analysis may have to consider up to 15 dB variation for the aircraft VDB antenna gain variation depending upon the scenario, such that the 40 dB power variation ⩽ SIS power variation + up to 15 dB aircraft antenna gain variation.

To avoid receiver processing issues concerning lost or duplicated messages, all transmissions of the Type 1, Type 11 or Type 101 message, or linked pairs of Type 1, Type 11 or Type 101 messages for a given measurement type within a single frame need to provide identical data content.

7.12.4.2 One example of the use of multiple antennas is a facility with two antennas installed at the same location but at different heights above the ground plane. The heights of the antennas are chosen so that the pattern from one antenna fills the nulls in the pattern of the other antenna that result from reflections from the ground plane. The GBAS ground subsystem alternates broadcasts between the two antennas, using one, two or three assigned slots of each frame for each antenna. Type 1, Type 11 or Type 101 messages as appropriate for the service type supported are broadcast once per frame, per antenna. This allows for reception of one or two Type 1, Type 11 or Type 101 messages per frame, depending on whether the user is located within the null of one of the antenna patterns. Type 2 and 4 messages are broadcast from the first antenna in one frame, then from the second antenna in the next frame. This allows for reception of one each of the Type 2 and 4 messages per one or two frames, depending on the user location.

7.13 Definition of lateral and vertical alert limits

7.13.1 The lateral and vertical alert limits when the active service type is C or D are computed as defined in Appendix B, Tables B-68 and B-69. In these computations the parameters D and H have the meaning shown in Figure D-17.

7.13.2 The vertical alert limit when the active service type is C or D is scaled from a height of 60 m (200 ft) above the LTP/FTP. For a procedure designed with a decision height of more than 60 m (200 ft), the VAL at that decision height will be larger than the broadcast FASVAL.

7.13.3 The lateral and vertical alert limits for procedures supported by GAST A service type associated with channel numbers 40 001 to 99 999 are computed in the same manner as SBAS as given in 6.6.

7.14 Monitoring and maintenance actions

7.14.1 Specific monitoring requirements or built-in tests may be necessary in addition to the monitors defined in Appendix B, 3.6.7.3 and should be determined by individual States. Since the VDB signal is critical to the operation of the GBAS broadcast station, any failure of the VDB to successfully transmit a usable signal within the assigned slots and over the entire service volume is to be corrected as soon as possible. Therefore, it is recommended that the following conditions be used as a guide for implementing a VDB monitor:

a) *Power.* A significant drop in power is to be detected within an appropriate time period.

b) *Loss of message type.* The failure to transmit any scheduled message type(s). This could be based on the failure to transmit a unique message type in succession, or a combination of different message types.

c) *Loss of all message types.* The failure to transmit any message type for an appropriate time period will be detected.

The appropriate time periods for these monitors depend on the FAST and on whether a back-up transmitter is provided. Where a back-up transmitter is provided, the objective is to switch to the back-up transmitter quickly enough to avoid an alert being generated in the airborne equipment. This means that the appropriate time periods are a maximum of 3 seconds for FAST C and a maximum of 1.5 seconds for FAST D ground systems in order to be consistent with the aircraft equipment message loss requirements. If longer periods than this are implemented, the changeover to the back-up transmitter will cause an alert and must therefore be considered to be a continuity failure. If no back-up transmitter is provided, the time periods for these monitors are not critical.

7.14.2 Upon detection of a failure, and in the absence of a back-up transmitter, termination of the VDB service should be considered if the signal cannot be used reliably within the service volume to the extent that aircraft operations could be significantly impacted. Appropriate actions in operational procedures are to be considered to mitigate the event of the signal being removed from service. These would include dispatching maintenance specialists to service the GBAS VDB or special ATC procedures. Additionally, maintenance actions should be taken when possible for all built-in test failures to prevent loss of GBAS service.

7.14.3 The use of a back-up transmitter also applies to the VDB monitoring requirements defined in Appendix B, 3.6.7.3.1. The time to switch over to the back-up needs to be taken into account while remaining compliant with the time to detect and terminate transmissions defined in Appendix B, 3.6.7.3.1.1 and 3.6.7.3.1.2.

7.15 Examples of VDB messages

7.15.1 Examples of the coding of VDB messages are provided in Tables D-7 through D-10A. The examples illustrate the coding of the various application parameters, including the cyclic redundancy check (CRC) and forward error correction (FEC) parameters, and the results of bit scrambling and D8PSK symbol coding. The engineering values for the message parameters in these tables illustrate the message coding process, but are not necessarily representative of realistic values.

7.15.2 Table D-7 provides an example of a Type 1 VDB message. The additional message flag field is coded to indicate that this is the first of two Type 1 messages to be broadcast within the same frame. This is done for illustration purposes; a second Type 1 message is not typically required, except to allow broadcast of more ranging source corrections than can be accommodated in a single message.

7.15.3 Table D-7A provides an example of a Type 101 VDB message. The additional message flag field is coded to indicate that this is the first of two Type 101 messages to be broadcast within the same frame. This is done for illustration purposes; a second Type 101 message is not typically required, except to allow broadcast of more ranging source corrections than can be accommodated in a single message.

7.15.4 Table D-8 provides examples of a Type 1 VDB message and a Type 2 VDB message coded within a single burst (i.e. two messages to be broadcast within a single transmission slot). The additional message flag field of the Type 1 message is coded to indicate that it is the second of two Type 1 messages to be broadcast within the same frame. The Type 2 message includes additional data block 1. Table D-8A provides an example of Type 1 and Type 2 messages with additional data blocks 1 and 2.

7.15.4.1 Table D-8B provides an example of Type 2 messages with additional data blocks 1, 3 and 4 coded within a single burst with a Type 3 message that is used to fill the rest of the time slot.

7.15.5 Table D-9 provides an example of a Type 4 message containing two FAS data blocks.

7.15.6 Table D-10 provides an example of a Type 5 message. In this example, source availability durations common to all approaches are provided for two ranging sources. Additionally, source availability durations for two individual approaches are provided: the first approach has two impacted ranging sources and the second approach has one impacted ranging source.

7.15.7 Table D-10A provides an example of a Type 11 message.

7.16 GBAS survey accuracy

The standards for the survey accuracy for NAVAIDs are contained in Annex 14 — *Aerodromes*. In addition, the *Manual of the World Geodetic System 1984 (WGS-84)* (Doc 9674) provides guidance on the establishment of a network of survey control stations at each aerodrome and how to use the network to establish WGS-84 coordinates. Until specific requirements are developed for GBAS, the Annex 14 survey accuracy requirements for NAVAIDs located at the aerodrome apply to GBAS. The recommendation contained in Appendix B to Chapter 3, 3.6.7.2.3.4, for the survey accuracy of the GBAS reference point is intended to further reduce the error in the WGS-84 position calculated by an airborne user of the GBAS positioning service to a value smaller than that established by the requirements of Appendix B to Chapter 3, 3.6.7.2.4.1 and 3.6.7.2.4.2, in the GBAS standards and to enhance survey accuracy compared to that specified in Annex 14. The integrity of all aeronautical data used for GBAS is to be consistent with the integrity requirements in Chapter 3, Table 3.7.2.4-1.

7.17 Type 2 message additional data blocks

7.17.1 The Type 2 message contains data related to the GBAS facility such as the GBAS reference point location, the GBAS continuity and integrity designator (GCID) and other pertinent configuration information. A method for adding new data to the

Type 2 message has been devised to allow GBAS to evolve to support additional service types. The method is through the definition of new additional data blocks that are appended to the Type 2 message. In the future, more additional data blocks may be defined. Data blocks 2 through 255 have variable length and may be appended to the message after additional data block 1 in any order.

7.17.2 Type 2 message additional data block 1 contains information related to spatial decorrelation of errors and information needed to support selection of the GBAS positioning service (when provided by a given ground station).

7.17.3 Type 2 message additional data block 2 data may be used in GRAS to enable the GRAS airborne subsystem to switch between GBAS broadcast stations, particularly if the GBAS broadcast stations utilize different frequencies. Additional data block 2 identifies the channel numbers and locations of the GBAS broadcast station currently being received and other adjacent or nearby GBAS broadcast stations.

7.17.4 Type 2 message additional data block 3 contains information necessary to support GAST D. All FAST D ground subsystems are required to transmit a Type 2 message with additional data block 3 properly populated so that the bounding requirements are met.

7.17.5 Type 2 message additional data block 4 contains information necessary for a ground station that supports the authentication protocols. It includes a single parameter which indicates which slots are assigned to the ground station for VDB transmissions. Airborne equipment that supports the authentication protocols will not use data unless it is transmitted in the slots indicated by the slot group definition field in the MT 2 ADB 4.

Table D-7. Example of a Type 1 VDB message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	E	100
Transmission length (bits)	17	0 to 1 824 bits	1 bit	536	000 0000 1000 0110 00
Training sequence FEC	5	—	—	—	0000 1
APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 1 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	61	0011 1101
Message (Type 1 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	1st of pair	01
Number of measurements	5	0 to 18	1	4	0 0100
Measurement type	3	0 to 7	1	C/A L1	000

Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m	1 × 10^{-4}	0001 0100
Ephemeris CRC	16	—	—	—	0000 0000 0000 0000
Source availability duration	8	0 to 2 540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	2	0000 0010
Issue of data (IOD)	8	0 to 255	1	255	1111 1111
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.0 m	0000 0000 0110 0100
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	0.98 m	0011 0001
B_1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B_2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B_3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Issue of data (IOD)	8	0 to 255	1	126	0111 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	–1.0 m	1111 1111 1001 1100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	+0.2 m/s	0000 0000 1100 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	0.34 m	0001 0001
B_1	8	±6.35 m	0.05 m	+0.20 m	0000 0100
B_2	8	±6.35 m	0.05 m	+0.30 m	0000 0110
B_3	8	±6.35 m	0.05 m	–0.50 m	1111 0110
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 3					
Ranging source ID	8	1 to 255	1	12	0000 1100
Issue of data (IOD)	8	0 to 255	1	222	1101 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.11 m	0000 0000 0110 1111
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	1.02 m	0011 0011
B_1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B_2	8	±6.35 m	0.05 m	+0.25 m	0000 0101
B_3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 4					
Ranging source ID	8	1 to 255	1	23	0001 0111
Issue of data (IOD)	8	0 to 255	1	80	0101 0000
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	–2.41 m	1111 1111 0000 1111
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.96 m/s	1111 1100 0100 0000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	0.16 m	0000 1000
B_1	8	±6.35 m	0.05 m	+0.20 m	0000 0100
B_2	8	±6.35 m	0.05 m	+0.30 m	0000 0110
B_3	8	±6.35 m	0.05 m	–0.50 m	1111 0110
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block CRC	32	—	—	—	1100 0010 1111 0011 0000 1011 1100 1010

APPLICATION FEC	48	—	—	—	0110 0011 1110 1001 1110 0000 1110 1101 0010 1001 0111 0101
Input to the bit scrambling (Note 2)	0 46 10 10 55 30 CA 10 80 BC 17 C2 20 28 00 00 FF 40 FF 26 00 1C FF 8C 40 C0 DF 01 20 7E 39 FF 13 00 88 20 60 6F 01 30 7B F6 00 1C FF CC 40 A0 DF 01 E8 0A F0 FF 02 3F 10 20 60 6F 01 53 D0 CF 43 AE 94 B7 07 97 C6				
Output from the bit scrambling (Note 3)	0 60 27 98 1F 2F D2 3B 5F 26 C2 1B 12 F4 46 D0 09 81 B6 25 1C 18 D0 7C 2A 7F B9 55 A8 B0 27 17 3A 60 EB 5F 1B 3B A5 FE 0A E1 43 D7 FA D7 B3 7A 65 D8 4E D7 79 D2 E1 AD 95 E6 6D 67 12 B3 EA 4F 1A 51 B6 1C 81 F2 31				
Fill bits	0 to 2	—	—	0	
Power ramp-down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	00000035 11204546 31650100 12707716 71645524 74035772 26234621 45311123 22460075 52232477 16617052 04750422 07724363 40733535 05120746 45741125 22545252 73171513 51047466 13171745 10622642 17157064 67345046 36541025 07135576 55745512 222				
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5 π/4 radians), relative to the phase of the first symbol*.

Table D-7A. Example of a Type 101 VDB message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3			E	100
Transmission length (bits)	17	0 to 1824 bits	1 bit	416	00000000110100000
Training sequence FEC	5				11011
APPLICATION DATA MESSAGE BLO CK					
Message Block (Type 101 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8101	1	101	0110 0101
Message length	8	10 to 222 bytes	1 byte	46	0010 1110
Message (Type 101 example)					
Modified Z-count	14	0 to 1199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	1st of pair	01
Number of measurements	5	0 to 18	1	4	0 0100
Measurement type	3	0 to 7	1	C/A L1	000

Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10^{-3}m/m	5 × 10^{-6}m/m	0.115 × 10^{-3}m/m	0001 0111
Ephemeris CRC	16			0	0000 0000 0000 0000
Source availability duration	8	0 to 2540 s	10 s	Not provided	1111 1111
Number of B parameters	1	0 to 1	1	0	0
Spare	7			0	000 0000
Measurement Block 1					
Ranging source ID	8	1 to 255	1	2	0000 0010
Issue of data (IOD)	8	0 to 255	1	255	1111 1111
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+3.56 m	0000 0001 0110 0100
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.011 m/s	1111 1111 1111 0101
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	9.8 m	0011 0001
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Issue of data (IOD)	8	0 to 255	1	126	0111 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	-1.0 m	1111 1111 1001 1100
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	+0.002 m/s	0000 0000 0000 0010
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	3.4 m	0001 0001
Measurement Block 3					
Ranging source ID	8	1 to 255	1	12	0000 1100
Issue of data (IOD)	8	0 to 255	1	222	1101 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+4.11 m	0000 0001 1001 1011
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.029 m/s	1111 1111 1110 0011
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	10.2 m	0011 0011
Measurement Block 4					
Ranging source ID	8	1 to 255	1	23	0001 0111
Issue of data (IOD)	8	0 to 255	1	80	0101 0000
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	-2.41 m	1111 1111 0000 1111
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.096 m/s	1111 1111 1010 0000
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	1.6 m	0000 1000
Message Block CRC	32				1000 1000 1001 1111 0111 1000 0000 0100
APPLICATION FEC	48				1100 1100 1110 0110 1111 0110 1100 1110 1101 0110 0110 0010
Input to the bit scrambling (Note 2)	0 41 60 1B 55 73 A4 A8 A6 74 17 C2 20 E8 00 00 FF 00 40 FF 26 80 AF FF 8C 20 7E 39 FF 40 00 88 30 7B D9 80 C7 FF CC E8 0A F0 FF 05 FF 10 20 1E F9 11 46 6B 73 6F 67 33				
Output from the bit scrambling (Note 3)	0 67 57 93 1F 6C BC 83 79 EE C2 1B 1 2 34 46 D0 09 C1 09 FC 3A 84 80 0F E6 9F 18 6D 77 8E 1E 60 19 1B BA FF BC AB 68 26 7B E7 BC CE FA 0B D3 C4 43 C8 E0 B6 FA 42 84 A1				
Fill bits	0 to 2			0	
Power ramp-down	9				000 000 000

D8PSK Symbols (Note 4)	00000035 11204546 31650105 06345463 57026113 51374661 15123376 12066670 44776307 04225000 02735027 73373152 13230100 04706272 74137202 47724524 12715704 15442724 01101677 44571303 66447212 222

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-8. Example of Type 1 and Type 2 VDB messages in a single burst

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	E	10 0
Transmission length (bits)	17	0 to 1 824 bits	1 bit	544	000 0000 1000 1000 00
Training sequence FEC	5	—	—	—	0000 0
APPLICATION DATA					
Message Block 1 (Type 1 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 1 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	2nd of pair	11
Number of measurements	5	0 to 18	1	1	0 0001
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m	0 (SBAS)	0000 0000
Ephemeris CRC	16	—	—	0	0000 0000 0000 0000
Source availability duration	8	0 to 2 540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	122	0111 1010
Issue of data (IOD)	8	0 to 255	1	2	0000 0010
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.0 m	0000 0000 0110 0100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000

σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	1.96 m	0110 0010
B_1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B_2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B_3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B_4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block 1 CRC	32	—	—	—	1011 0101 1101 0000 1011 1100 0101 0010
Message Block 2 (Type 2 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	34	0010 0010
Message (Type 2 example)					
GBAS reference receivers	2	2 to 4	1	3	01
Ground accuracy designator letter	2	—	—	B	01
Spare	1	—	—	0	0
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
GBAS continuity/integrity designator	3	0 to 7	1	1	001
Local magnetic variation	11	±180°	0.25°	58° E	000 1110 1000
Spare	5	—	—	0	0000 0
$\sigma_{vert\_iono\_gradient}$	8	0 to 25.5 × 10^{-6} m/m	0.1 × 10^{-6} m/m	0	0000 0000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 to 255	1	20	0001 0100
Latitude	32	±90.0°	0.0005 arcsec	45°40’32’’ N	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	±180.0°	0.0005 arcsec	93°25’13’’W	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference Station Data Selector	8	0 to 48	1	5	0000 0101
Maximum Use Distance (D_{max})	8	2 to 510 km	2 km	50 km	0001 1001
$K_{md\_e\_POS,GPS}$	8	0 to 12.75	0.05	6	0111 1000
$K_{md\_e,GPS}$	8	0 to 12.75	0.05	5	0110 0100
$K_{md\_e\_POS,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
$K_{md\_e,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
Message Block 2 CRC	32	—	—	—	0101 1101 0111 0110 0010 0011 0001 1110
Application FEC	48				1110 1000 0100 0101 0011 1011 0011 1011 0100 0001 0101 0010
Input to the bit scrambling (Note 2)	0 41 10 00 55 30 CA 10 8 0 38 17 C3 80 00 00 00 FF 5E 40 26 00 1C FF 46 40 C0 DF 01 4A 3D 0B AD 55 30 CA 10 40 44 A4 17 00 00 9F 80 28 00 88 59 C8 0D 51 17 EB E5 3A 80 A0 98 1E 26 00 00 78 C4 6E BA 4A 82 DC DC A2 17				
Output from the bit scrambling (Note 3)	0 67 27 88 1F 2F D2 3B 5F A2 C2 1A B2 DC 46 D0 09 9F 09 25 1C 18 D0 B6 2A 7F B9 55 C2 F3 15 45 7C 50 A9 6F 3B 10 00 D9 71 17 DC 4B 2D 1B 7B 83 72 D4 F7 CA 62 C8 D9 12 25 5E 13 2E 13 E0 42 44 37 45 68 29 5A B9 55 65				
Fill bits	0 to 2	—	—	1	0
Power ramp-down	9	—	—	—	000 000 000

D8PSK Symbols (Note 4)	00000035 11204546 31650105 67443352 35201160 30501336 62023576 12066670 74007653 30010255 31031274 26172772 76236442 41177201 35131033 33421734 42751235 60342057 66270254 17431214 03421036 70316613 46567433 66547730 34732201 40607506 014444

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example fill bits are not scrambled.*
4. *This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of 5 $\pi/4$ radians), relative to the phase of the first symbol.*

Table D-8A. Example of Type 1 and Type 2 VDB messages with additional data blocks 1 and 2

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3			E	100
Transmission length (bits)	17	0 to 1824 bits	1 bit	592	00000001001010000
Training sequence FEC	5				10110
APPLICATION DATA					
Message Block 1 (Type 1 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 1 example)					
Modified Z-count	14	0 to 1199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	2nd of pair	11
Number of measurements	5	0 to 18	1	1	0 0001
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m	0 (SBAS)	0000 0000
Ephemeris CRC	16			0	0000 0000 0000 0000
Source availability duration	8	0 to 2540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	122	0111 1010
Issue of data (IOD)	8	0 to 255	1	2	0000 0010
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+2.09 m	0000 0000 1101 0001
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.2 m/s	1111 1111 0011 1000
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m	1.96 m	0110 0010

B1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B3	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block 1 CRC	32				00110010 10100100 11001011 00110000
Message Block 2 (Type 2 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	40	0010 1000
Message (Type 2 example)					
GBAS reference receivers	2	2 to 4	1	3	01
Ground accuracy designator letter	2			B	01
Spare	1			0	0
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
GBAS continuity/integrity designator	3	0 to 7	1	1	001
Local magnetic variation	11	±180°	0.25°	58° E	000 1110 1000
Spare	5			0	0000 0
$\sigma_{vert\_iono\_gradient}$	8	0 to 25.5 × 10^{-6}m/m	0.1 × 10^{-6}m/m	0	0000 0000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 to 255	1	20	0001 0100
Latitude	32	±90.0°	0.0005 arcsec	45°40'32" N	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	±180.0°	0.0005 arcsec	93°25'13" W	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference Station Data Selector	8	0 to 48	1	5	0000 0101
Maximum Use Distance (Dmax)	8	2 to 510 km	2 km	50 km	0001 1001
$K_{md\_e\_POS,GPS}$	8	0 to 12.75	0.05	6	0111 1000
$K_{md\_e,GPS}$	8	0 to 12.75	0.05	5	0110 0100
$K_{md\_e\_POS,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
$K_{md\_e,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
Additional Data Blocks					
Additional Data Block Length	8	2 to 255	1	6	0000 0110
Additional Data Block Number	8	2 to 255	1	2	0000 0010
Additional Data Block 2					
Channel Number	16	20001 to 39999	1	25001	0110 0001 1010 1001
ΔLatitude	8	±25.4°	0.2°	5.2	0001 1010
ΔLongitude	8	±25.4°	0.2°	–3.4	1110 1111

Message Block 2 CRC	32				11100000 01110010 00011101 00100100
Application FEC	48				1110 0010 0101 1100 0000 1111 1010 1011 0011 0100 0100 0000
Input to the bit scrambling (Note 2)		0 42 90 0D 55 7 3 A4 A8 80 38 17 C3 80 00 00 00 FF 5E 40 8B 00 1C FF 46 40 C0 DF 01 0C D3 25 4C 55 73 A4 A8 40 14 A4 17 00 00 9F 80 28 00 88 59 C8 0D 51 17 EB E5 3A 80 A0 98 1E 26 00 00 60 40 95 86 58 F7 24 B8 4E 07 02 2C D5 F0 3A 47			
Output from the bit scrambling (Note 3)		0 64 A7 85 1F 6 C BC 83 5F A2 C2 1A B2 DC 46 D0 09 9F 09 88 1C 18 D0 B6 2A 7F B9 55 84 1D 3B A4 7C 13 C7 D7 3B 40 00 D9 71 17 DC 4B 2D 1B 7B 83 72 D4 F7 CA 62 C8 D9 12 25 5E 13 2E 13 E0 5A C0 CC 79 7A 5C A2 DD B9 75 B6 95 64 52 78 3F			
Fill bits	0 to 2			1	0
Power ramp-down	9				000 000 000
D8PSK Symbols (Note 4)		00000035 11204546 31650107 56336574 60137224 74145772 26467132 56422234 30443700 05565722 06506741 73647332 27242654 63345227 31575333 33421734 42751235 60342057 66270254 17431214 03421036 70316613 46567433 62077121 37275607 55315167 17135031 34423411 274444			

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-8B. Example of a Type 2 message containing data blocks 1, 3 and 4 and a Type 3 message to fill the remainder of the slot

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15	—	—	—	000 0000 0000 0000
Synchronization and ambiguity resolution	48	—	—	—	0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier	3	—	—	E	100
Transmission length	17	0 to 1824 bits	1 bit	1704	0 0000 0110 1010 1000
Training sequence FEC	5	—	—	—	01000
APPLICATION DATA					
Message Block 1 (Type 2 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	000010 000101 001100 001100

Message type identifier	8	1 to 101	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	43	0010 1011
Message (Type 2 example)					
GBAS reference receivers	2	2 to 4	1	4	10
Ground accuracy designator letter	2	—	—	C	10
Spare	1	—	—	—	0
GBAS continuity/integrity designator	3	0 to 7	1	2	010
Local magnetic variation	11	±180°	0.25°	E58.0°	000 1110 1000
Reserved	5	—	zero	—	0000 0
$\sigma_{vert\_iono\_gradient}$	8	0 to 25.5 x 10^{-6} m/m	0.1 x 10^{-6} m/m	4 x 10^{-6}	0010 1000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 to 255	1	20	0001 0100
Latitude	32	±90.0°	0.0005 arcsec	N45° 40' 32" (+164432")	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	±180.0°	0.0005 arcsec	W93° 25' 13" (-336313")	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference station data selector	8	0 to 48	1	5	0000 0101
Maximum use distance (D_{max})	8	2 to 510 km	2 km	50 km	0001 1001
$K_{md\_e\_POS,GPS}$	8	0 to 12.75	0.05	6	0111 1000
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
$K_{md\_e,GPS}$	8	0 to 12.75	0.05	5	0110 0100
$K_{md\_e\_POS,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000

$K_{md\_e,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
Additional Data Block 4					
Additional data block length	8	3	1 byte	3	0000 0011
Additional data block number	8	4	1	4	0000 0100
Slot group definition	8	—	—	E+F	0011 0000
Additional Data Block 3					
Additional Data Block Length	8	6	1 byte	6	0000 0110
Additional Data Block Number	8	3	1	3	0000 0011
$K_{md\_e\_D,GPS}$	8	0 to 12.75	0.05	5.55	0110 1111
$K_{md\_e\_D,GLONASS}$	8	0 to 12.75	0.05	0	0000 0000
$\sigma_{vert\_iono\_gradient\_D}$	8	0 – 25.5 x 10^{-6} m/m	0.1 x 10^{-6} m/m	4 x 10^{-6}	0010 1000
Y_{EIG}	5	0 to 3.0 m	0.1	1	0 1010
M_{EIG}	3	0 to 0.7 m/km	0.1	0.3	011
Message Block 1 CRC	32	—	—	—	0011 1100 1110 0001 1000 0100 1011 1011
Message Block 2 (Type 3 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	000010 000101 001100 001100
Message type identifier	8	1 to 101	1	3	0000 0011
Message length	8	N/A	1 byte	164	1010 0100
Message (Type 3 example)					
Filler	1232	—	—	—	1010 1010 …... 1010 1010
Message Block 2 CRC	32	—	—	—	0110 1101 1011 1001 1110 0100 1110 0100
Application FEC	48	—	—	—	1111 0110 0011 0100 1101 1001 1110 0010 1110 0011 1111 1101

Input to the bit scrambling (Note 2)	0 45 58 02 55 30 CA 10 40 D4 52 17 00 14 9 F 80 28 00 88 59 C8 0D 51 17 EB E5 3A 80 A0 98 1E 26 00 00 C0 20 0C 60 C0 F6 00 14 56 DD 21 87 3C 55 30 CA 10 C0 25 55 27 27 9D B6 BF C7 47 9B 2C				
Output from the bit scrambling (Note 3)	0 63 6F 8A 1F 2F D2 3B 9F 4E 87 CE 32 C8 D9 50 DE C1 C1 5A D4 09 7E E7 81 5A 5C D4 28 56 00 CE 29 60 A3 5F 77 34 64 38 71 03 15 16 24 9C CF 8F 8A 13 B6 1D AC 78 B6 C7 D0 93 58 5D 46 B5 6F D5 0C AA 77 FE D3 30 A2 27 E1 EC E4 F7 17 2D AD F4 0B 29 82 04 6 1 96 E4 50 E9 58 F A B8 C0 38 99 C7 BB 6C 3D 09 CA 7B 7E C2 CF 60 8D 18 75 B9 2B C5 FC 94 C8 57 79 5 2 C5 5F 6A B2 F F DF 33 4D DD 74 B5 28 2A 06 01 91 9B A4 43 E9 63 05 1D 95 B4 54 29 56 05 51 95 5B AA BC 00 36 66 2E EE 0F 0E 72 71 21 25 E5 EB 14 FD A8 CB F8 83 38 62 39 1E 3A 4E 3E 8E 30 71 D9 24 BA 17 C1 AC 9B F7 BC D3 C8 A3 78 1D 39 B5 C4 2B 69 FD 04 CA 68 81 07 9A 1E 33 C1 86 6F 86 78 98 87 95				
Fill bits	0 to 2	—	—	2	00
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Power ramp-down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	00000035 11204546 31650102 46331130 13067746 52652552 60712455 15066026 22433136 20007526 34111714 74536644 75444673 47266102 52635407 12243401 11561037 01237127 60553360 64340421 37024663 76701711 41435042 46314343 14302740 43711436 70511643 01271030 13504154 47365114 45511504 12200201 40164744 00021467 34131754 52554125 73741336 24044706 62272634 50547410 75654505 73645775 05153625 27427624 71315376 42507750 01000470 73036771 61401006 63561510 31143140 01422617 26364743 33357073 46405563 35412370 11472764 14014631 72320522 11576761 26127747 24352562 32277467 01242252 66037246 31604613 72367522 27243731 56617534 16114672 47000774 37674402 66002316 56521466 56347666 6				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-9. Example of a Type 4 message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				010 0011 1110 1111 1100 0110 0011 1011 0000 0011 1100 1000 0
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	D	01 1
Transmission length (bits)	17	0 to 1 824 bits	1 bit	784	000 0000 1100 0100 00
Training sequence FEC	5	—	—	—	0000 0

APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 4 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	CMJ	0000 1100 1101 0010 1010 0000
Message type identifier	8	1 to 8	1	4	0000 0100
Message length	8	10 to 222 bytes	1 byte	92	0101 1100
Message (Type 4 example)					
FAS Data Set 1					
Data set length	8	2 to 212	1 byte	41	0010 1001
FAS Data Block 1					
Operation type	4	0 to 15	1	0	0000
SBAS service provider	4	0 to 15	1	15	1111
Airport ID	32	—	—	LFBO	0000 1100 0000 0110 0000 0010 0000 1111
Runway number	6	1 to 36	1	15	00 1111
Runway letter	2	—	—	R	01
Approach performance designator	3	0 to 7	1	CAT 1	001
Route indicator	5	—	—	C	0001 1
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE1)
Reference path data selector (RPDS)	8	0 to 48	1	3	0000 0011
Reference path identifier	32	—	—	GTBS	0000 0111 0001 0100 0000 0010 0001 0011
LTP/FTP latitude	32	±90.0°	0.0005 arcsec	43.6441075°N	0001 0010 1011 1010 1110 0010 1000 0110
LTP/FTP longitude	32	±180.0°	0.0005 arcsec	1.345940°E	0000 0000 1001 0011 1101 1110 1001 0000
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m	197.3	0001 1011 1011 0101
ΔFPAP latitude	24	±1°	0.0005 arcsec	–0.025145°	1111 1101 0011 1100 1100 1100
ΔFPAP longitude	24	±1°	0.0005 arcsec	0.026175°	0000 0010 1110 0000 0010 1100
Approach threshold crossing height (TCH)	15	0 to 1638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)	17.05 m	000 0001 0101 0101
Approach TCH units selector	1	0 = ft; 1 = m	—	metres	1
Glide path angle (GPA)	16	0 to 90°	0.01°	3°	0000 0001 0010 1100
Course width	8	80.0 to 143.75 m	0.25 m	105	0110 0100
ΔLength offset	8	0 to 2 032 m	8 m	0	0000 0000
FAS Data Block 1 CRC	32	—	—	—	1010 0010 1010 0101 1010 1000 0100 1101
FASVAL/Approach status	8	0 to 25.4	0.1 m	10	0110 0100
FASLAL/Approach status	8	0 to 50.8	0.2 m	40	1100 1000
FAS Data Set 2					
Data set length	8	2 to 212	1 byte	41	0010 1001
FAS Data Block 2					
Operation type	4	0 to 15	1	0	0000
SBAS service provider	4	0 to 15	1	01	0001

Airport ID	32	—	—	LFBO	0000 1100 0000 0110 0000 0010 0000 1111
Runway number	6	1 to 36	1	33	10 0001
Runway letter	2	—	—	R	01
Approach performance designator	3	0 to 7	1	CAT 1	001
Route indicator	5	—	—	A	0000 1
Reference path data selector (RPDS)	8	0 to 48	1	21	0001 0101
Reference path identifier	32	—	—	GTN	0000 0111 0001 0100 0000 1110 0010 0000
LTP/FTP latitude	32	±90.0°	0.0005 arcsec	43.6156350°N	0001 0010 1011 0111 1100 0001 1011 1100
LTP/FTP longitude	32	±180.0°	0.0005 arcsec	1.3802350°E	0000 0000 1001 0111 1010 0011 0001 1100
LTP/FTP height	16	–512.0 to 6041.5 m	0.1 m	200.2 m	0001 1011 1101 0010
ΔFPAP latitude	24	±1°	0.0005 arcsec	0.02172375°	0000 0010 0110 0010 1111 1011
ΔFPAP longitude	24	±1°	0.0005 arcsec	–0.0226050°	1111 1101 1000 0100 0011 1100
Approach threshold crossing height (TCH)	15	0 to 1638.35 m (0 to 3276.7 ft)	0.05 m (0.1 ft)	15.25 m	000 0001 0011 0001
Approach TCH units selector	1	0 = ft; 1 = m	—	metres	1
Glide path angle (GPA)	16	0 to 90°	0.01°	3.01°	0000 0001 0010 1101
Course width	8	80.0 to 143.75 m	0.25 m	105	0110 0100
ΔLength offset	8	0 to 2 032 m	8 m	0	0000 0000
FAS data block 2 CRC	32	—	—	—	1010 1111 0100 1101 1010 0000 1101 0111
FASVAL/Approach status	8	0 to 25.4	0.1 m	10	0110 0100
FASLAL /Approach status	8	0 to 50.8	0.2 m	40	1100 1000
Message Block CRC	32	—	—	—	0101 0111 0000 0011 1111 1110 1001 1011
APPLICATION FEC	48	—	—	—	0001 1011 1001 0001 0010 1010 1011 1100 0010 0101 1000 0101
Input to the bit scrambling	1 82 30 00 55 05 4B 30 20 3A 94 0F F0 40 60 30 F2 98 C0 C8 40 28 E0 61 47 5D 48 09 7B C9 00 AD D8 33 3C BF 34 07 40 AA				
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE1)
(Note 2)	81 34 80 26 00 B2 15 A5 45 26 13 94 08 F0 40 60 30 86 90 A8 04 70 28 E0 3D 83 ED 48 38 C5 E9 00 4B D8 DF 46 40 3C 21 BF 8C 81 B4 80 26 00 EB 05 B2 F5 26 13 D9 7F C0 EA A1 A4 3D 54 89 D8				
Output from the bit scrambling (Note 3)	1 A4 07 88 1F 1A 53 1B FF A0 41 D6 C2 9C 26 E0 04 59 89CB 5C 2C CF 91 2D E2 2E 5D F3 07 1E 45 F1 53 5F C0 4F 53 E4 64 F0 2 3 C3 ED 05 A9 E6 7F FF FF B5 49 81 DD A3 F2 B5 40 9D A0 17 90 12 60 64 7C CF E3 BE A0 1E 72 FF 61 6E E4 02 44 D9 1E D2 FD 63 D1 12 C3 5A 00 0E F8 89 FE 4C 12 0C 78 4F 9D 55 08 16 F6				
Fill bits	0 to 2	—	—	1	0
Power ramp down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	0000003511204546316504322300771662170713052556673176724345377776157763461661570543615214576405133401677 5214231304443061301150266774341755603276241630527536540015247051420322575333462555437707605652760631444 624316310135372225012076040752643510345771407777041566527360012232400740203144336275444				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example, fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians), relative to the phase of the first symbol.*

Table D-10. Example of a Type 5 message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	D	01 1
Transmission length (bits)	17	0 to 1 824 bits	1 bit	272	000 0000 0100 0100 00
Training sequence FEC	5	—	—	—	0001 1
APPLICATION DATA MESSAGE BLOCK					
Message Block (Type 5 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	CMJ	0000 1100 1101 0010 1010 0000
Message type identifier	8	1 to 8	1	5	0000 0101
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 5 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Spare	2	—	—	—	00
Number of impacted sources (N)	8	0 to 31	1	2	0000 0010
First impacted source					
Ranging source ID	8	1 to 255	1	4	0000 0100
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	50 s	0000 101
Second impacted source					
Ranging source ID	8	1 to 255	1	3	0000 0011
Source availability sense	1	—	—	Will start	1
Source availability duration	7	0 to 1 270 s	10 s	200 s	0010 100
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)

Number of obstructed approaches (	A) 8	0 to 255	1	2	0000 0010
First obstructed approach					
Reference path data selector (RPDS	) 8	0 to 48	1	21	0001 0101
Number of impacted sources for first obstructed approach (N_A)	8	1 to 31	1	2	0000 0010
First impacted ranging source of first obstructed approach					
Ranging source ID	8	1 to 255	1	12	0000 1100
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	250 s	0011 001
Second impacted ranging source of first obstructed approach					
Ranging source ID	8	1 to 255	1	14	0000 1110
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	1 000 s	1100 100
Second obstructed approach					
Reference path data selector (RPDS	) 8	0 to 48	1	14	0000 1110
Number of impacted sources for second obstructed approach (N_A)	8	1 to 31	1	1	0000 0001
First impacted ranging source of second obstructed approach					
Ranging source ID	8	1 to 255	1	12	0000 1100
Source availability sense	1	—	—	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	220 s	0010 110
Message Block CRC	32	—	—	—	1101 1011 0010 1111 0001 0010 0000 1001

APPLICATION FEC	48	—	—	—	0011 1110 1011 1010 0001 1110 0101 0110 1100 1011 0101 1011
Input to the bit scrambling (Note 2)	182 20 18 55 05 4 B 30 A0 38 17 C0 40 20 50 C0 94 40 A8 40 30 4C 70 13 70 80 30 34 90 48 F4 DB DA D3 6A 78 5D 7C				
Output from the bit scrambling	1 A4 17 90 1F 1A 53 1B 7F A2 C2 19 72 FC 16 10 62 81 E1 43 2C 48 5F E3 1A 3F 56 60 18 86 EA 33 F3 B3 09 07 26 28				
Fill bits	0 to 2	—	—	0	
Power ramp-down	9				000 000 000
D8PSK Symbols (Note 3)	000000351120454631650432205666055106760241612447736346322070010322400660133212416623116364377711017311574302323445146644444				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *Symbols are represented by their differential phase with respect to the first symbol of the message, in units of π/4 (e.g. a value of 5 represents a phase of 5/4 radians) relative to the first symbol.*

Table D-10A. Example of a Type 11 VDB message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	—	—	E	100
Transmission length (bits)	17	0 to 1 824 bits	1 bit	440	0 0000 0001 1011 1000
Training sequence FEC	5	—	—	-	0 1011
APPLICATION DATA MESSAGE BLOCK					
Message Block 1 (Type 11 message)					
Message Block Header					
Message block identifier	8	—	—	Normal	1010 1010
GBAS ID	24	—	—	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 101	1	11	0000 1011

Message length	8	10 to 222 bytes	1 byte	49	0011 0001
Message (Type 11 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	0	00
Number of measurements	5	0 to 18	1	5	0 0101
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P$_D$)	8	0 to 1.275 $\times 10^{-3}$m/m	5×10^{-6}m/m	1×10^{-4}	0001 0100
Measurement Block 1					
Ranging source ID	8	1 to 255	1	12	0000 1100
Pseudo-range correction (PRC$_{30}$)	16	±327.67 m	0.01 m	+1.04 m	0000 0000 0110 1000
Range rate correction (RRC$_{30}$)	16	±32.767 m	0.001 m/s	–0.18 m/s	1111 1111 0100 1100
$\sigma_{pr\_gnd,D}$	8	0 to 5.08 m	0.02 m	0.96 m	0011 0000
$\sigma_{pr\_gnd,30}$	8	0 to 5.08 m	0.02 m	1.00 m	0011 0010
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Pseudo-range correction (PRC$_{30}$)	16	±327.67 m	0.01 m	–1.08 m	1111 1111 1001 0100
Range rate correction (RRC$_{30}$)	16	±32.767 m	0.001 m/s	+0.18 m/s	0000 0000 1011 0100
$\sigma_{pr\_gnd,D}$	8	0 to 5.08 m	0.02 m	0.24 m	0000 1100
$\sigma_{pr\_gnd,30}$	8	0 to 5.08 m	0.02 m	0.6 m	0001 1110
Measurement Block 3					
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Ranging source ID	8	1 to 255	1	2	0000 0010
Pseudo-range correction (PRC$_{30}$)	16	±327.67 m	0.01 m	+1.2 m	0000 0000 0111 1000
Range rate correction (RRC$_{30}$)	16	±32.767 m	0.001 m/s	0.3 m/s	0000 0001 0010 1100

$\sigma_{pr\_gnd,D}$	8	0 to 5.08 m	0.02 m	0.64 m	0010 0000
$\sigma_{pr\_gnd,30}$	8	0 to 5.08 m	0.02 m	0.74 m	0010 0101
Measurement Block 4					
Ranging source ID	8	1 to 255	1	23	0001 0111
Pseudo-range correction (PRC_{30})	16	±327.67 m	0.01 m	–2.64 m	1111 1110 1111 1000
Range rate correction (RRC_{30})	16	±32.767 m	0.001 m/s	–0.51 m/s	1111 1110 0000 0010
$\sigma_{pr\_gnd,D}$	8	0 to 5.08 m	0.02 m	0.08 m	0000 0100
$\sigma_{pr\_gnd,30}$	8	0 to 5.08 m	0.02 m	0.14 m	0000 0111
Measurement Block 5					
Ranging source ID	8	1 to 255	1	122	0111 1010
Pseudo-range correction (PRC_{30})	16	±327.67 m	0.01 m	+0.8 m	0000 0000 0101 0000
Range rate correction (RRC_{30})	16	±32.767 m	0.001 m/s	–0.25 m/s	1111 1111 0000 0110
$\sigma_{pr\_gnd,D}$	8	0 to 5.08 m	0.02 m	0.92 m	0010 1110
$\sigma_{pr\_gnd,30}$	8	0 to 5.08 m	0.02 m	1.08 m	0011 0110
Message Block CRC	32	—	—	—	0010 1111 0000 0101 1101 1001 0000 1100
APPLICATION FEC	48	—	—	—	1001 0011 1110 0111 1101 1100 0100 0001 0100 0101 1011 1110
Input to the bit scrambling (Note 2)	0 47 60 1A 55 30 CA 10 D0 8C 17 C0 A0 28 30 16 00 32 FF 0C 4C 20 29 FF 2D 00 30 78 40 1E 00 34 80 04 A4 E8 1F 7 F 40 7F 20 E0 5E 0A 00 60 FF 74 6C 30 9B A0 F4 7D A2 82 3B E7 C 9				
Output from the bit scrambling (Note 3)	0 61 57 92 1F 2F D2 3B 0F 16 C2 19 92 F4 76 C6 F6 F3 B6 0F 50 24 06 0F 47 BF 56 2C C8 D0 1E DC A9 64 C7 97 64 2B E4 B1 51 F7 1D C1 05 7B 0C AE D6 E9 3D 7D 7D 50 41 10 BE 21 C4				
Fill bits	0 to 2	—	—	0	
Power ramp-down	9	—	—	—	000 000 000
D8PSK Symbols (Note 4)	00000035 11204546 31650101 42701130 13067746 60457114 40234621 31760262 76357705 07725551 13760416 17615700 43341354 25047116 53736646 34577501 64015223 34742121 71757170 16162053 65544366 41033007 777				

Notes.—

1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.*
2. *This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.*
3. *In this example fill bits are not scrambled.*
4. *This field represents the phase, in units of π/4 (e.g. a value of 5 represents a phase of 5 π/4 radians), relative to the phase of the first symbol.*

7.18 Type 101 message

Type 101 message is an alternative to Type 1 message developed to fit the specific needs of GRAS systems. The primary difference in the contents and application of these two message types is two-fold: (a) Type 101 message has a larger available range for σpr_gnd values and (b) ground subsystem time-to-alert is larger for a system broadcasting Type 101 messages. The first condition would typically occur in a system where a broadcast station covers a large area, such that decorrelation errors increase the upper limit of the pseudo-range correction errors. The second condition may be typical for systems where a central master station processes data from multiple receivers dispersed over a large area.

7.19 Airborne processing for GBAS approach service types

Note.— In order to ensure the required performance and functional objectives for GAST D are achieved, it is necessary for the airborne equipment to meet defined performance and functional standards. The relevant minimum operational performance standards (MOPS) are detailed in RTCA DO-253D.

7.19.1 *Differential position solution for the GBAS positioning service.* The position solution used to provide position, velocity and time outputs is based on 100-second smoothed pseudo-ranges corrected with corrections obtained from message Type 1 or message Type 101.

7.19.2 *Differential position solution for approach service GAST A, B and C.* When the active approach service type is A, B or C, the position solution used to generate deviations is based on 100 second smoothed pseudo-ranges corrected with corrections obtained from message Type 1 or message Type 101. The projection matrix, S, used to compute the position solution (Appendix B, 3.6.5.5.1.1.2) is computed based on σ_i computed using $\sigma_{pr\_gnd}[i]$ from message Type 1 or message Type 101 and $\sigma_{iono,i}$ based on $\sigma_{vert\_iono\_gradient}$ from message Type 2.

7.19.3 *Differential position solutions for approach service GAST D.* When GAST D is the active approach service type, the airborne equipment will compute two different position solutions, one based on 30-second smoothed pseudo-ranges and the other based on 100-second smoothed pseudo-ranges. The following characterizes the standard processing required by the MOPS:

a) the position solution used to develop deviations is based on 30-second smoothed pseudo-ranges corrected with corrections obtained from message Type 11;

b) the projection matrix, S, used for both position solutions is computed based on $\sigma_{w,i}$ computed using $\sigma_{pr\_gnd\_30s}$ from message Type 11 and $\sigma_{iono,i}$ based on $\sigma_{vert\_iono\_gradient\_D}$ from message Type 2 Additional Data Block 3;

c) a second position solution is computed using the projection matrix from b) and the 100-second smoothed pseudoranges corrected with corrections obtained from message Type 1; and

d) both position solutions are based on the same set of satellites as used for the position solution defined in a) above.

Additional information regarding the intended use of these dual position solutions is given in 7.5.6.1 of this attachment.

7.20 Type 11 message

A Type 11 message is required for FAST D ground subsystems. The Type 11 message contains differential corrections derived from pseudo-range data that has been carrier smoothed with a time constant of 30 seconds. The Type 11 message also includes alternative parameters for integrity bounding and for optimal weighting of measurements. Additional information regarding the standard processing of parameters in the Type 11 message is given in 7.19.

7.21 Slot occupancy

The slot occupancy requirement in Appendix B, 3.6.7.4.1.3 is for ground subsystems that support authentication. The slot occupancy is the length of a burst divided by the length of a single time slot. In more detail and expressed in number of bits:

slot occupancy = (88 bits + up to 1 776 bits application data + 57 to 59 bits for application FEC, fill bits and ramp down) / 1 968.75 bits

The numerator in the formula sums all bits that are included in a single burst of the ground subsystem. These are the first 88 bits from ramp up to training sequence FEC, up to 1 776 application data bits, 48 application FEC bits, 0 to 2 fill bits and 9 bits for ramp down. For the denominator 1 968.75 bits are the calculated number of bits that can be transmitted in 62.5 ms (Appendix B, 3.6.3.1) using the data rate of 31 500 bits/s (Appendix B, 3.6.2.5).

8. Signal quality monitor (SQM) design

8.1 The objective of the signal quality monitor (SQM) is to detect satellite signal anomalies in order to prevent aircraft receivers from using misleading information (MI). MI is an undetected aircraft pseudo-range differential error greater than the maximum error (MERR) that can be tolerated. For GAST D equipment, additional requirements are in place to assure detection before the differential pseudo-range error reaches a specified value (see Appendix B, 3.6.7.3.3). These large pseudo-range errors are due to C/A code correlation peak distortion caused by satellite payload failures. If the reference receiver used to create the differential corrections and the aircraft receiver have different measurement mechanizations (i.e. receiver bandwidth and tracking loop correlator spacing), the signal distortion affects them differently. The SQM must protect the aircraft receiver in cases when mechanizations are not similar. SQM performance is further defined by the probability of detecting a satellite failure and the probability of incorrectly annunciating a satellite failure.

8.2 The signal effects that might cause a GBAS or SBAS to output MI can be categorized into three different effects on the correlation function as follows:

a) *Dead zones:* If the correlation function loses its peak, the receiver’s discriminator function will include a flat spot or dead zone. If the reference receiver and aircraft receiver settle in different portions of this dead zone, MI can result.

b) *False peaks:* If the reference receiver and aircraft receiver lock to different peaks, MI could exist.

c) *Distortions:* If the correlation peak is misshapen, an aircraft that uses a correlator spacing other than the one used by the reference receivers may experience MI.

8.3 The threat model proposed for use in assessment of SQM has three parts that can create the three correlation peak pathologies listed above.

8.4 Threat Model A consists of the normal C/A code signal except that all the positive chips have a falling edge that leads or lags relative to the correct end-time for that chip. This threat model is associated with a failure in the navigation data unit (NDU), the digital partition of a GPS satellite.

8.4.1 Threat Model A for GPS has a single parameter Δ, which is the lead ($\Delta < 0$) or lag ($\Delta > 0$) expressed in fractions of a chip. The range for this parameter is $-0.12 \leq \Delta \leq 0.12$.

8.4.2 Within this range, threat Model A generates the dead zones described above. (Waveforms with lead need not be tested, because their correlation functions are simply advances of the correlation functions for lag; hence, the MI threat is identical.)

8.5 Threat Model B introduces amplitude modulation and models degradations in the analog section of the GPS satellite. More specifically, it consists of the output from a second order system when the nominal C/A code baseband signal is the input. Threat Model B assumes that the degraded satellite subsystem can be described as a linear system dominated by a pair of complex conjugate poles. These poles are located at $\sigma \pm j2\pi f_d$, where σ is the damping factor in 10^6 nepers/second and f_d is the resonant frequency with units of 10^6 cycles/second.

8.5.1 The unit step response of a second order system is given by:

$$e(t) = \begin{cases} 0 & t \leq 0 \\ 1 - \exp(-\sigma t)\left[\cos\omega_d t + \dfrac{\sigma}{\omega_d}\sin\omega_d t\right] & t \geq 0 \end{cases}$$

where $\omega_d = 2\pi f_d$.

8.5.2 Threat Model B for GPS corresponding to second order anomalies uses the following ranges for the parameters Δ, f_d and σ:

$$\Delta = 0;\ 4 \leq f_d \leq 17;\ \text{and}\ 0.8 \leq \sigma \leq 8.8.$$

8.5.3 Within these parameter ranges, threat Model B generates distortions of the correlation peak as well as false peaks.

8.6 Threat Model C introduces both lead/lag and amplitude modulation. Specifically, it consists of outputs from a second order system when the C/A code signal at the input suffers from lead or lag. This waveform is a combination of the two effects described above.

8.6.1 Threat Model C for GPS includes parameters Δ, f_d and σ with the following ranges:

$$-0.12 \leq \Delta \leq 0.12;\ 7.3 \leq f_d \leq 13;\ \text{and}\ 0.8 \leq \sigma \leq 8.8.$$

8.6.2 Within these parameter ranges, threat Model C generates dead zones, distortions of the correlation peak and false peaks.

8.7 Unlike GPS, the SBAS signal is commissioned and controlled by the service provider. Moreover, the service provider also monitors the quality of the signal from the SBAS. To this end, the threat model will be specified and published by the service provider for each SBAS satellite. The SBAS SQM will be designed to protect all avionics that comply with Table D-12. Publication of the threat model is required for those cases where a service provider chooses to allow the SBAS ranging signal from a neighbouring service provider to be used for precision approach by SBAS or GBAS. In these cases, the service provider will monitor the SBAS ranging signal from the neighbouring satellite.

8.8 In order to analyse the performance of a particular monitor design, the monitor limit must be defined and set to protect individual satellite pseudo-range error relative to the protection level, with an allocation of the ground subsystem integrity risk. The maximum tolerable error (denoted as MERR) for each ranging source *i* can be defined in GBAS as:

$$\text{MERR} = K_{\text{ffmd}}\sigma_{\text{pr\_gnd},i}\ \text{and}$$

$$\text{MERR}=K_{V,PA}\sqrt{\sigma^2_{i,\text{UDRE}} + \min\{\sigma^2_{i,\text{UIRE}}\}}$$

for SBAS APV and precision approach where min $\sigma_{i,UIRE}$ is the minimum possible value for any user. MERR is evaluated at the output of a fault-free user receiver and varies with satellite elevation angle and ground subsystem performance.

8.9 The SQM is designed to limit the UDRE to values below the MERR in the case of a satellite anomaly. Typically, the SQM measures various correlation peak values and generates spacing and ratio metrics that characterize correlation peak distortion. Figure D-18 illustrates typical points at the top of a fault-free, unfiltered correlation peak.

8.9.1 A correlator pair is used for tracking. All other correlator values are measured with respect to this tracking pair.

8.9.2 Two types of test metrics are formed: early-minus-late metrics (D) that are indicative of tracking errors caused by peak distortion, and amplitude ratio metrics (R) that measure slope and are indicative of peak flatness or close-in, multiple peaks.

8.9.3 It is necessary that the SQM has a precorrelation bandwidth that is sufficiently wide to measure the narrow spacing metrics, so as not to cause significant peak distortion itself and not to mask the anomalies caused by the satellite failure. Typically, the SQM receiver must have a precorrelation bandwidth of at least 16 MHz for GPS.

8.9.4 The test metrics are smoothed using low-pass digital filters. The time constant of these filters are to be shorter than those used jointly (and standardized at 100 seconds) by the reference receivers for deriving differential corrections and by the aircraft receiver for smoothing pseudo-range measurements (using carrier smoothing). The smooth metrics are then compared to thresholds. If any one of the thresholds is exceeded, an alarm is generated for that satellite.

8.9.5 The thresholds used to derive performance are defined as minimum detectable errors (MDEs) and minimum detectable ratios (MDRs). Fault-free false detection probability and missed detection probability are used to derive MDEs and MDRs. The noise in metrics (D) and (R), as denoted $\sigma_{D,test}$ and $\sigma_{R,test}$ below, is dominated by multipath errors. Note that the metric test can also have a mean value (μ_{test}) caused by SQM receiver filter distortion. Threshold tests must also account for the mean values.

8.9.6 The MDE and MDR values used in the SQM performance simulations are calculated based on the following equations:

$$MDE = (K_{ffd} + K_{md})\,\sigma_{D,test} \text{ and}$$
$$MDR = (K_{ffd} + K_{md})\,\sigma_{R,test}$$

where

K_{ffd} = 5.26 is a typical fault-free detection multiplier representing a false detection probability of 1.5×10^{-7} per test;

K_{md} = 3.09	is a typical missed detection multiplier representing a missed detection probability of 10^{-3} per test;
$\sigma_{D,test}$	is the standard deviation of measured values of difference test metric D; and
$\sigma_{R,test}$	is the standard deviation of measured values of ratio test metric R.

8.9.7 If multiple independent SQM receivers are used to detect the failures, the sigma values can be reduced by the square root of the number of independent monitors.

8.9.8 A failure is declared if

$$|\,D,test - \mu_{D,test}\,| \geq MDE \text{ or}$$
$$|\,R,test - \mu_{R,test}\,| \geq MDR$$

for any of the tests performed, where $\mu_{X,test}$ is the mean value of the test X that accounts for fault-free SQM receiver filter distortion, as well as correlation peak distortion peculiar to the specific C/A code PRN. (Not all C/A code correlation peaks have the same slope. In a simulation environment, however, this PRN distortion can be ignored, and a perfect correlation peak can be used, except for simulated filter distortion.)

8.10 The standard deviations of the test statistics, $\sigma_{D,test}$ and $\sigma_{R,test}$ can be determined via data collection on a multicorrelator receiver in the expected operating environment. The data collection receiver utilizes a single tracking pair of correlators and additional correlation function measurement points which are slaved to this tracking pair, as illustrated in Figure D-18. Data is collected and smoothed for all available measurement points in order to compute the metrics. The standard deviation of these metrics define $\sigma_{D,test}$. It is also possible to compute these one sigma test statistics if a multipath model of the installation environment is available.

8.10.1 The resulting $\sigma_{D,test}$ is highly dependent on the multipath environment in which the data are collected. The deviation due to multipath can be an order of magnitude greater than that which would result from noise even at minimum carrier-to-noise level. This aspect illustrates the importance of the antenna design and siting criteria which are the primary factors in determining the level of multipath that will enter the receiver. Reducing multipath will significantly decrease the resulting MDEs and thus improve the SQM capabilities.

8.10.2 Mean values $\mu_{D,test}$ and $\mu_{R,test}$, on the other hand, are determined in a relatively error-free environment, such as through the use of GPS. These mean values model the nominal SQM receiver's filter distortion of the autocorrelation peak, including the effects of distortion due to adjacent minor autocorrelation peaks. The mean values can differ for the various PRNs based on these properties.

8.10.3 The presence of nominal signal deformation biases may cause the distribution of the monitor detectors to have non-zero mean. These biases can be observed by averaging measurements taken from a real-world data collection. Note that the nominal biases may depend on elevation and they typically change slowly over time.

8.11 In order for the ground monitor to protect users against the different threat models described above, it is necessary to assume that aircraft receivers have specific characteristics. If no such constraints were assumed, the complexity of the ground monitor would be unnecessarily high. Evolution in the technology may lead to improved detection capability in the aircraft receiver and may alleviate the current constraints.

8.11.1 For double-delta correlators, the aircraft receiver tracks the strongest correlation peak over the full code sequence for every ranging source used in the navigation solution.

8.11.2 For double-delta correlators, the precorrelation filter rolls off by at least 30 dB per octave in the transition band. For GBAS receivers, the resulting attenuation in the stop band is required to be greater than or equal to 50 dB (relative to the peak gain in the pass band).

8.11.3 The following parameters are used to describe the tracking performance specific to each type of satellite:

a) the instantaneous correlator spacing is defined as the spacing between a particular set of early and late samples of the correlation function;

b) the average correlator spacing is defined as a one-second average of the instantaneous correlator spacing. The average applies over any one-second time frame;

c) the discriminator Δ is based upon an average of early-minus-late samples with spacings inside the specified range, or is of the type $\Delta = 2\Delta_{d1} - \Delta_{2d1}$, with both d_1 and $2d_1$ in the specified range. Either a coherent or non-coherent discriminator is used;

d) the differential group delay applies to the entire aircraft system prior to the correlator, including the antenna. The differential group delay is defined as:

$$\left|\frac{d\phi}{d\omega}(f_c) - \frac{d\phi}{d\omega}(f)\right|$$

where

f_c is the precorrelation band pass filter centre frequency;

f is any frequency within the 3dB bandwidth of the precorrelation filter;

φ is the combined phase response of precorrelation band pass filter and antenna; and

ω is equal to $2\pi f$.

8.11.4 For aircraft receivers using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11, except as noted below.

8.11.4.1 For GBAS airborne equipment using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay (including the contribution of the antenna) are within the ranges defined in Table D-11, except that the region 1 minimum bandwidth will increase to 4 MHz and the average correlator spacing is reduced to an average of 0.21 chips or instantaneous of 0.235 chips.

8.11.4.2 For GBAS airborne equipment class D (GAEC D) receivers using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11, regions 2, 3 or 4 only. In addition, in region 2 the range of average correlator spacing is 0.045 – 0.12 chips, and the instantaneous correlator spacing is 0.04 – 0.15 chips.

8.11.4.3 For SBAS airborne equipment using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay (including the contribution of the antenna) are within the ranges of the first three regions defined in Table D-11.

8.11.5 For aircraft receivers using early-late correlators and tracking GLONASS satellites, the precorrelation bandwidth of the installation, the correlator spacing, and the differential group delay are within the ranges as defined in Table D-12.

8.11.5.1 For GBAS airborne equipment class D (GAEC D) aircraft receivers using early-late correlators and tracking GLONASS satellites, the precorrelation bandwidth of the installation, the correlator spacing, and the differential group delay are within the ranges as defined in Table D-12, regions 2 and 3 only. In addition, in region 2 the range of average correlator spacing is 0.05 – 0.1 chips, and the instantaneous correlator spacing is 0.045 – 0.11 chips.

8.11.6 For aircraft receivers using double-delta correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Tables D-13A and D-13B.

8.11.6.1 For GBAS airborne equipment class D (GAEC D) receivers using double-delta correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-13, regions 2 and 3 only.

8.11.7 For aircraft receivers using the early-late or double-delta correlators and tracking SBAS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-14.

8.11.7.1 For GBAS airborne equipment class D (GAEC D) receivers using the early-late or double-delta correlators and tracking SBAS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-14, region 2 only. In addition, for GAEC D receivers using early-late correlators and tracking SBAS satellites, the average correlator spacing is 0.045 – 0.12 chips, and the instantaneous correlator spacing is 0.04 – 0.15 chips.

9. Status monitoring and notam

9.1 System status

9.1.1 Degradation of GBAS usually has local effects and affects mainly approach operations. System degradation of GBAS is to be distributed as approach-related information.

9.1.2 Degradation of core satellite constellation(s) or SBAS usually has not only local effects, but additional consequences for a wider area, and may directly affect en-route operations. System degradation of these elements is to be distributed as area-related information. An example is a satellite failure.

9.1.3 Degradation of GRAS may have local effects and/or wide area effects. Therefore, if the degradation has only local effects, GRAS system degradation information is to be distributed in accordance with 9.1.1. If the degradation has wide area effects, GRAS system degradation information is to be distributed in accordance with 9.1.2.

9.1.4 Information is to be distributed to indicate the inability of GNSS to support a defined operation. For example, GPS/SBAS may not support a precision approach operation on a particular approach. This information can be generated automatically or manually based upon models of system performance.

Table D-11. GPS tracking constraints for early-late correlators

Region	3dB precorrelation bandwidth, BW	Average correlator spacing (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	2 < BW ≤ 7 MHz	0.045 – 1.1	0.04 – 1.2	≤ 600 ns
2	7 < BW ≤ 16 MHz	0.045 – 0.21	0.04 – 0.235	≤ 150 ns
3	16 < BW ≤ 20 MHz	0.045 – 0.12	0.04 – 0.15	≤ 150 ns
4	20 < BW ≤ 24 MHz	0.08 – 0.12	0.07 – 0.13	≤ 150 ns

Table D-12.reserved.

Table D-13A. GPS tracking constraints for GRAS and SBAS airborne receivers with double-delta correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing (X) (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	(–50 × X) + 12 < BW ≤ 7 MHz 4 < BW ≤ 7 MHz	0.1 – 0.16 0.16– 0.6	0.09 – 0.18 0.14– 0.65	≤ 600 ns
2	(–50 × X) + 12 < BW ≤ (40 × X) + 11.2 MHz	0.045 – 0.07	0.04 – 0.077	≤ 150 ns
	(–50 × X) + 12 < BW ≤ 14 MHz	0.07 – 0.1	0.062 – 0.11	
	7 < BW ≤ 14 MHz	0.1 – 0.24	0.09 – 0.26	
3	14 < BW (133.33 × X) + 2.667 MHz	0.07 – 0.24	0.06 – 0.26	≤ 150 ns

Table D-13B. GPS tracking constraints for GBAS airborne receivers with double-delta correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing range (X) (chips)	Instantaneous correlator spacing range (chips)	Differential group delay
1	(–50 × X) + 12 < BW ≤ 7 MHz 4 < BW ≤ 7 MHz	0.1 – 0.16 0.16 – 0.6	0.09 – 0.18 0.14 – 0.65	≤ 600 ns
2	(–50 × X) + 12 < BW ≤ (133.33 × X) + 2.667 MHz	0.07 – 0.085	0.063 – 0.094	≤ 150 ns
	(–50 × X) + 12 < BW ≤ 14 MHz	0.085 – 0.1	0.077 – 0.11	
	7 < BW ≤ 14 MHz	0.1 – 0.24	0.09 – 0.26	
3	14 < BW ≤ 16 MHz 14 < BW ≤ (133.33 × X) + 2.667 MHz	0.1 – 0.24 0.085 – 0.1	0.09 – 0.26 0.077 – 0.11	≤ 150 ns

Table D-14. SBAS ranging function tracking constraints

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	2 < BW ≤ 7 MHz	0.045 – 1.1	0.04 – 1.2	≤ 600 ns
2	7 < BW ≤ 20 MHz	0.045 – 1.1	0.04 – 1.2	≤ 150 ns

9.2 Information on type of degradation

The following information is to be distributed:

a) non-availability of service;

b) downgrade of service, if applicable; and

c) time and expected duration of degradation.

9.3 Timing of notification

For scheduled events, notification should be given to the NOTAM authority at least 72 hours prior to the event. For unscheduled events, notification to the NOTAM authority should be given within 15 minutes. Notification should be given for events of 15-minute, or longer, duration.

10. Interference

10.1 Potential for interference

Satellite radio navigation systems such as GPS feature relatively weak received signal power, meaning that an interference signal could cause loss of service. In order to maintain service, it will be necessary to ensure that the maximum interference levels specified in the SARPs are not exceeded.

10.2 In-band interference sources

A potential source of in-band harmful interference is Fixed Service operation in certain States. There is a primary allocation to the fixed service for point-to-point microwave links in certain States in the frequency band used by GPS.

10.3 Out-of-band interference sources

Potential sources of out-of-band interference include harmonics and spurious emissions of aeronautical VHF and UHF transmitters. Out-of-band noise, discrete spurious products and intermodulation products from radio and TV broadcasts can also cause interference problems.

10.4 Aircraft generated sources

10.4.1 The potential for harmful interference to GPS on an aircraft depends on the type of aircraft, its size and the transmitting equipment installed. The GNSS antenna location should take into account the possibility of onboard interference (mainly SATCOM).

10.4.2 GNSS receivers that are used on board aircraft with SATCOM equipment must have a higher interference threshold in the frequency range between 1 610 MHz and 1 626.5 MHz than receivers on board aircraft without SATCOM equipment. Therefore, specifications for the interference threshold discriminate between both cases.

Note.— Limits for radiated SATCOM aircraft earth stations are given in Annex 10, Volume III, Part I, Chapter 4, 4.2.3.5.

10.4.3 The principal mitigation techniques for on-board interference include shielding, filtering, receiver design techniques, and, especially on larger aircraft, physical separation of antennas, transmitters and cabling. Receiver design techniques include the use of adaptive filters and interference cancellation techniques that mitigate against narrow in-band interference. Antenna design techniques include adaptive null steering antennas that reduce the antenna gain in the direction of interference sources without reducing the signal power from satellites.

10.5 Integrity in the presence of interference

The requirement that SBAS and GBAS receivers do not output misleading information in the presence of interference is intended to prevent the output of misleading information under unintentional interference scenarios that could arise. It is not intended to specifically address intentional interference. While it is impossible to completely verify this requirement through testing, an acceptable means of compliance can be found in the appropriate receiver Minimum Operational Performance Standards published by RTCA and EUROCAE.

11. Recording of GNSS parameters

11.1 In order to be able to conduct post-incident/accident investigations (Chapter 2, 2.1.4.2 and 2.1.4.3), it is necessary to record GNSS information both for the augmentation system and for the appropriate GNSS core system constellation used for the operation. The parameters to be recorded are dependent on the type of operation, augmentation system and core elements used. All parameters available to users within a given service area should be recorded at representative locations in the service area.

11.2 The objective is not to provide independent assurance that the GNSS is functioning correctly, nor is it to provide another level of system monitoring for anomalous performance or input data for a NOTAM process. The recording system need not be independent of the GNSS service and may be delegated to other States or entities. In order to enable future reconstruction of position, velocity and time indications provided by specific GNSS configurations, it is recommended to log data continuously, generally at a 1 Hz rate.

11.3 For GNSS core systems the following monitored items should be recorded for all satellites in view:

a) observed satellite carrier-to-noise density (C/N_0);

b) observed satellite raw pseudo-range code and carrier phase measurements;

c) broadcast satellite navigation messages, for all satellites in view; and

d) relevant recording receiver status information.

11.4 For SBAS the following monitored items should be recorded for all geostationary satellites in view in addition to the GNSS core system monitored items listed above:

a) observed geostationary satellite carrier-to-noise density (C/N_0);

b) observed geostationary satellite raw pseudo-range code and carrier phase measurements;

c) broadcast SBAS data messages; and

d) relevant receiver status information.

11.5 For GBAS the following monitored items should be recorded in addition to the GNSS core system and SBAS monitored items listed above (where appropriate):

a) VDB power level;

b) VDB status information; and

c) broadcast GBAS data messages.

12. GNSS performance assessment

12.1 GNSS performance assessment is a periodic offline activity that may be performed by a State or delegated entity, aiming to verify that GNSS performance parameters conform to the relevant Annex 10 Standards. This activity can be done for the core constellation, the augmentation system or a combination of both.

Note.— Additional guidance material on GNSS performance assessment is provided in the Global Navigation Satellite System (GNSS) Manual *(Doc 9849).*

12.2 The data described in section 11 may also support GNSS performance assessment .

13. GNSS and database

Note.— Provisions relating to aeronautical data are contained in Annex 11, Chapter 2, and Annex 15, Chapter 3.

13.1 The database is to be current with respect to the effective AIRAC cycle, which generally means that a current database be loaded into the system approximately every 28 days. Operating with out-of-date navigation databases has to be avoided.

13.2 In certain situations, operations using an expired database can be conducted safely by implementing a process and/or using procedures to ensure that the required data is correct. These processes and/or procedures need prior approval by the State.

13.2.1 These procedures should be based on one of the following methods:

a) require the crew to check, prior to the operation, critical database information against current published information. (This method increases workload and would not be practical for all applications.); or

b) waive the requirement for a current database and frequent checks by the crew of the database information. This waiver can only be applied to very specific cases where aircraft are operated in a strictly limited geographical area and where that area is controlled by a single regulatory agency or multiple agencies that coordinate this process; or

c) use another approved method that ensures an equivalent level of safety.

14. Modelling of residual errors

14.1 Application of the integrity requirements for SBAS and GBAS requires that a model distribution be used to characterize the error characteristics in the pseudo-range. The HPL/LPL and VPL models (see 7.5.3) are constructed based on models of the individual error components (in the pseudo-range domain) that are independent, zero-mean, normal distributions. The relationship between this model and the true error distribution must be defined.

14.2 One method of ensuring that the protection level risk requirements are met is to define the model variance (σ^2), such that the cumulative error distribution satisfies the conditions:

$$\int_{y}^{\infty} f(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \left(\frac{y}{\sigma}\right) \geq 0 \text{ and}$$

$$\int_{-\infty}^{-y} f(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \left(\frac{y}{\sigma}\right) \geq 0 \text{ and}$$

where

$f(x)$ = probability density function of the residual aircraft pseudo-range error component; and

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_{x}^{\infty} e^{-\frac{t^2}{2}} dt.$$

14.3 This method can be directly applied when the error components have zero-mean, symmetrical and unimodal probability density functions. This is the case for the receiver contribution to corrected pseudo-range error, since the aircraft element is not subjected to low-frequency residual multipath errors.

14.4 This method can be extended to address non-zero-mean, residual errors by inflating the model variance to compensate for the possible effect of the mean in the position domain.

14.5 Verification of the pseudo-range error models must consider a number of factors including:

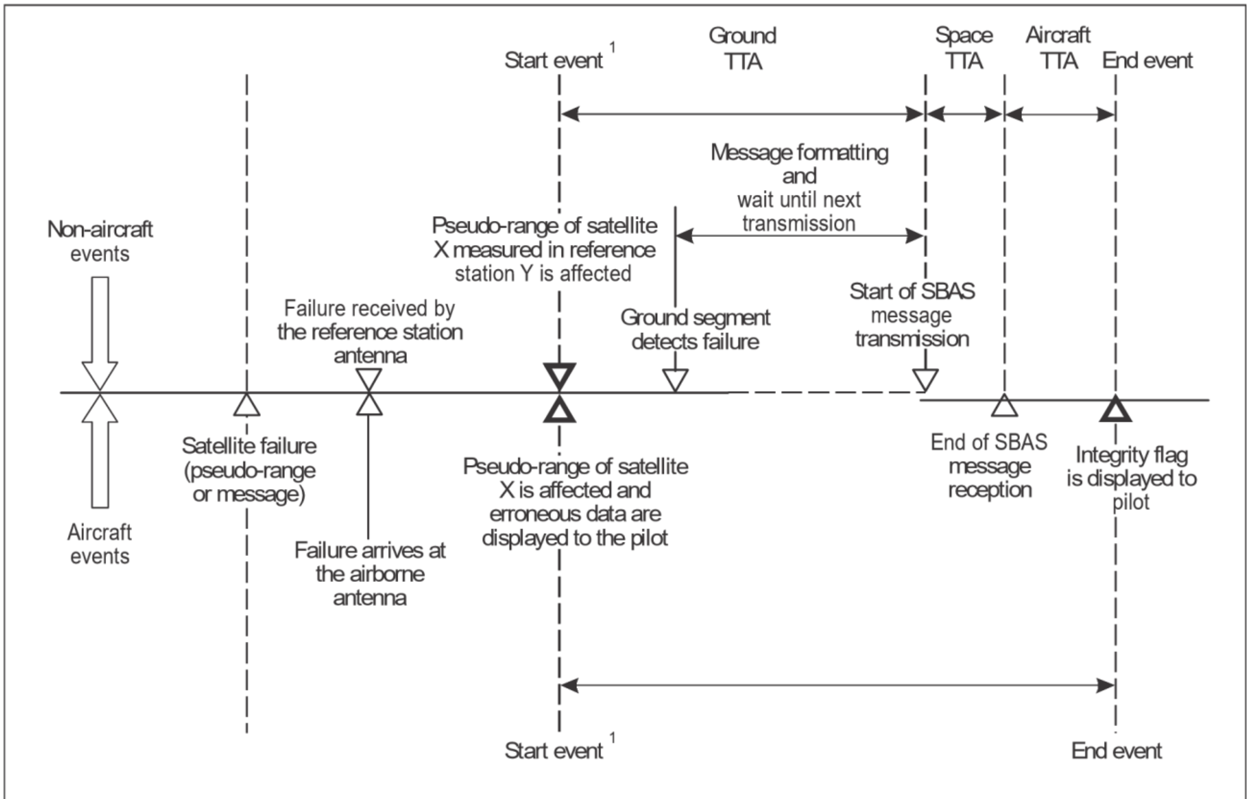
a) the nature of the error components;

b) the sample size required for confidence in the data collection and estimation of each distribution;

c) the correlation time of the errors; and

d) the sensitivity of each distribution to geographic location and time.

Figure D-1. ***Reserved***



1. Both events are considered as simultaneous. This is not strictly the case because of difference of performance between specific receivers. There is a slight difference due to receiver processing between the time the pseudo-range measurement is affected and the erroneous data are displayed. For practical reasons, this is not reflected in this diagram.

Figure D-2. SBAS time-to-alert

Figure D-3. reserved

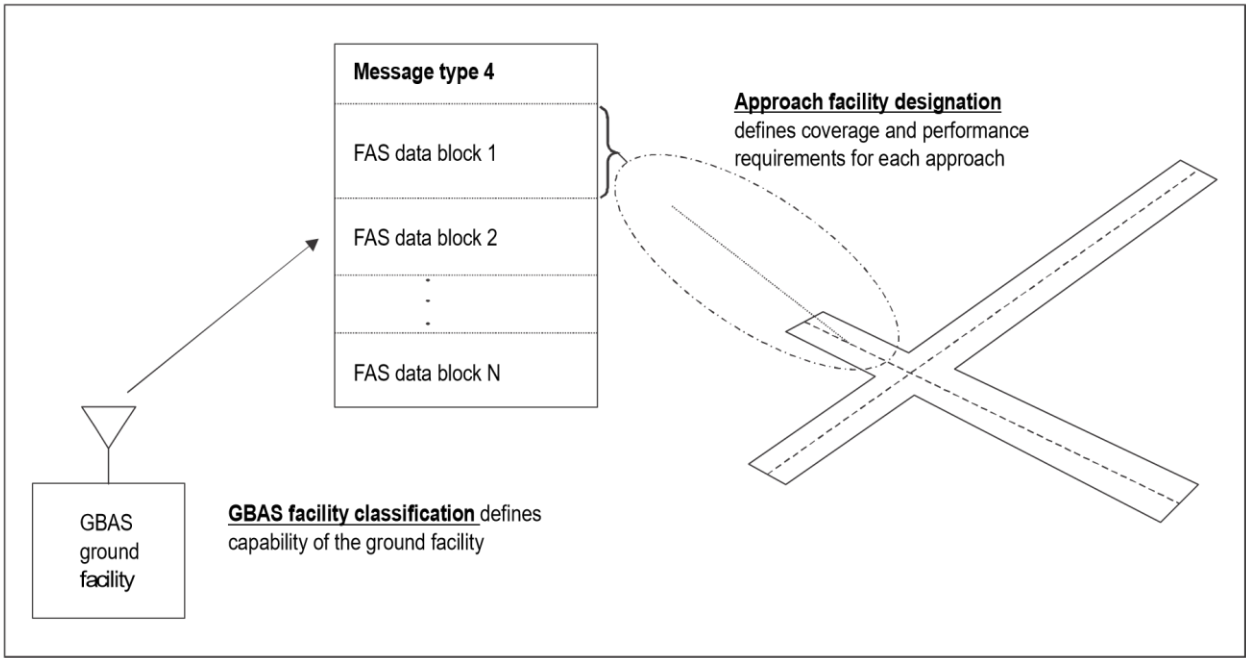
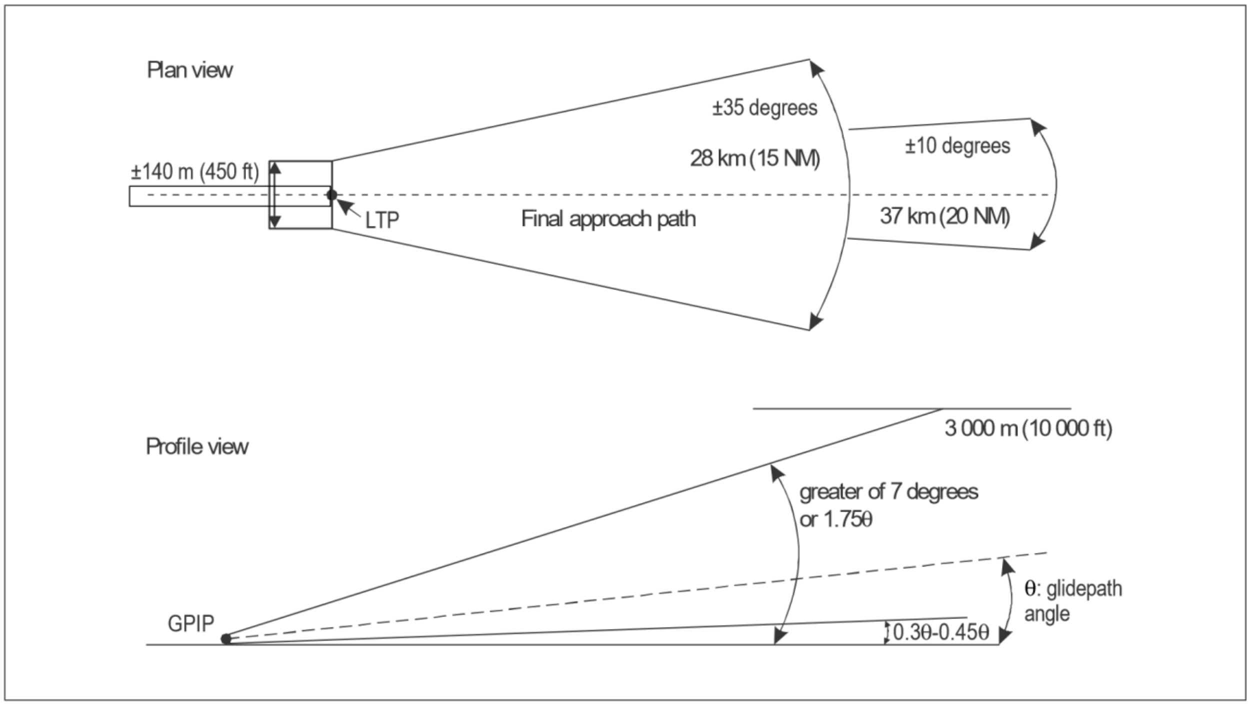


Figure D-4 Relationship between GBAS facility classification and approach facility designation



GPIP — glide path intersection point
LTP — landing threshold point

Figure D-5. Minimum GBAS service volume

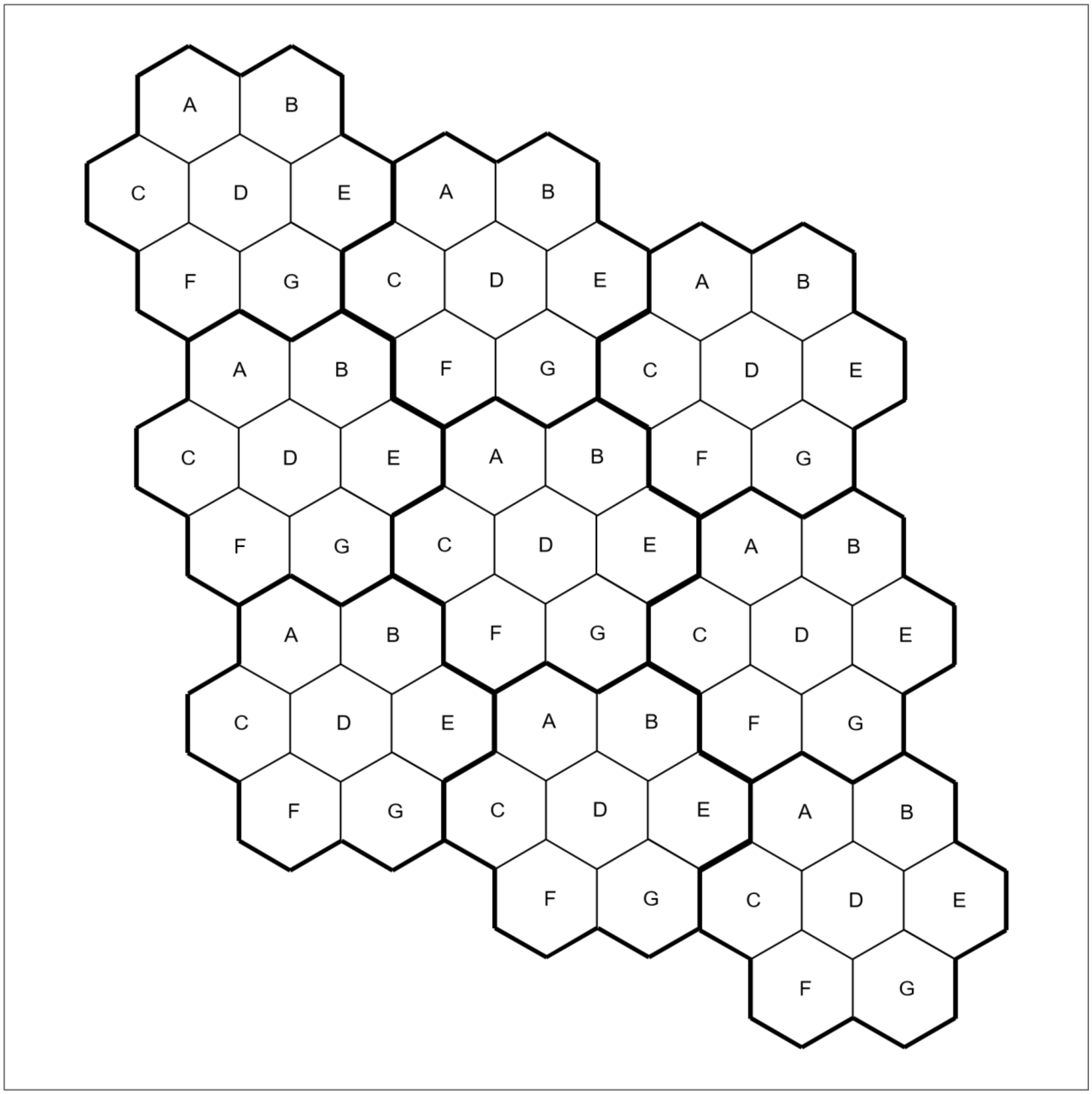


Figure D-5A. Single frequency GRAS VHF networking using multiple time slots

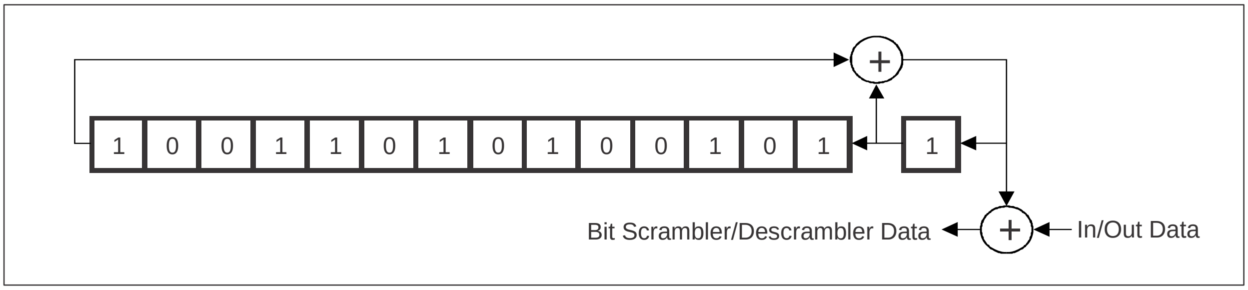


Figure D-6. Bit scrambler/descrambler

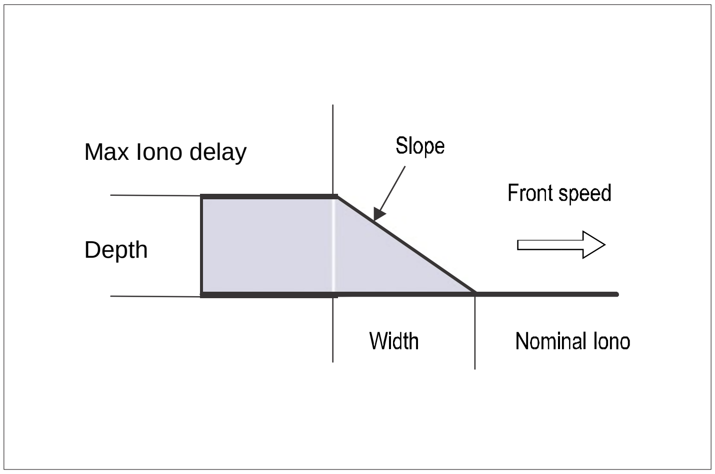


Figure D-7. Moving wedge ionospheric anomaly model

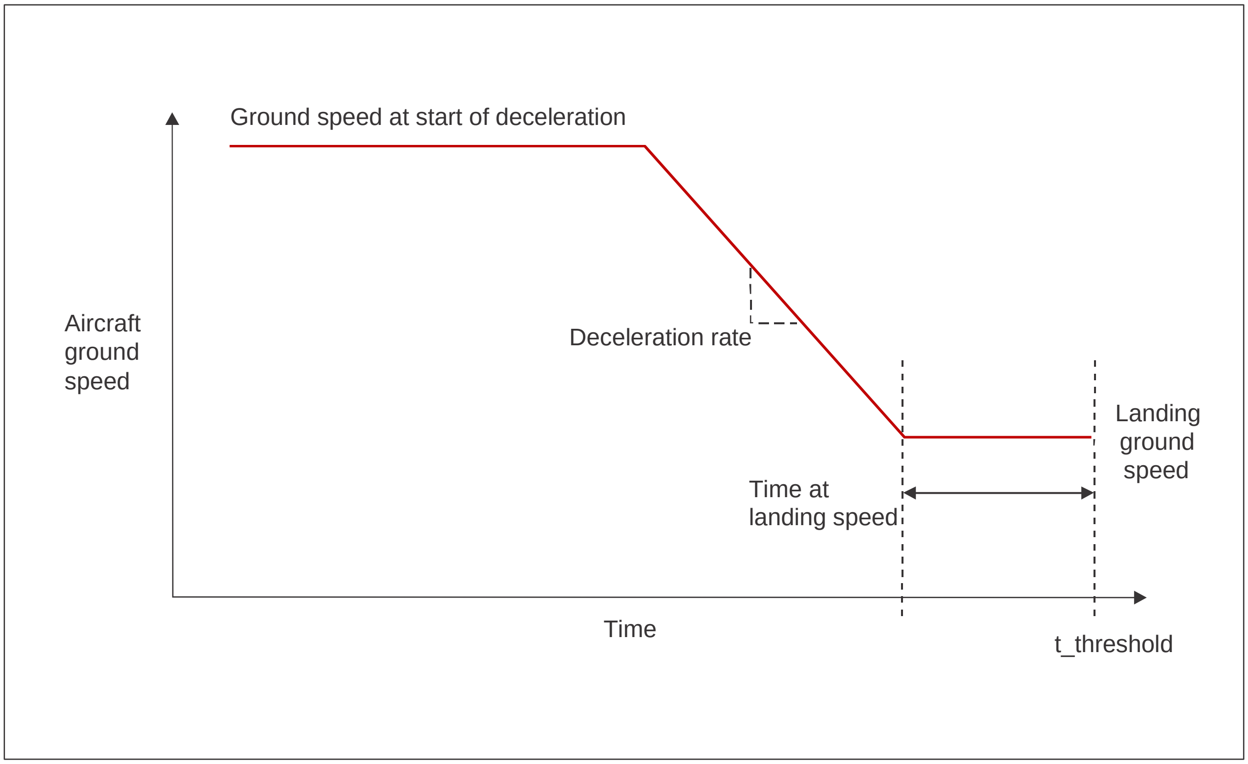


Figure D-8. Aircraft speed profile model

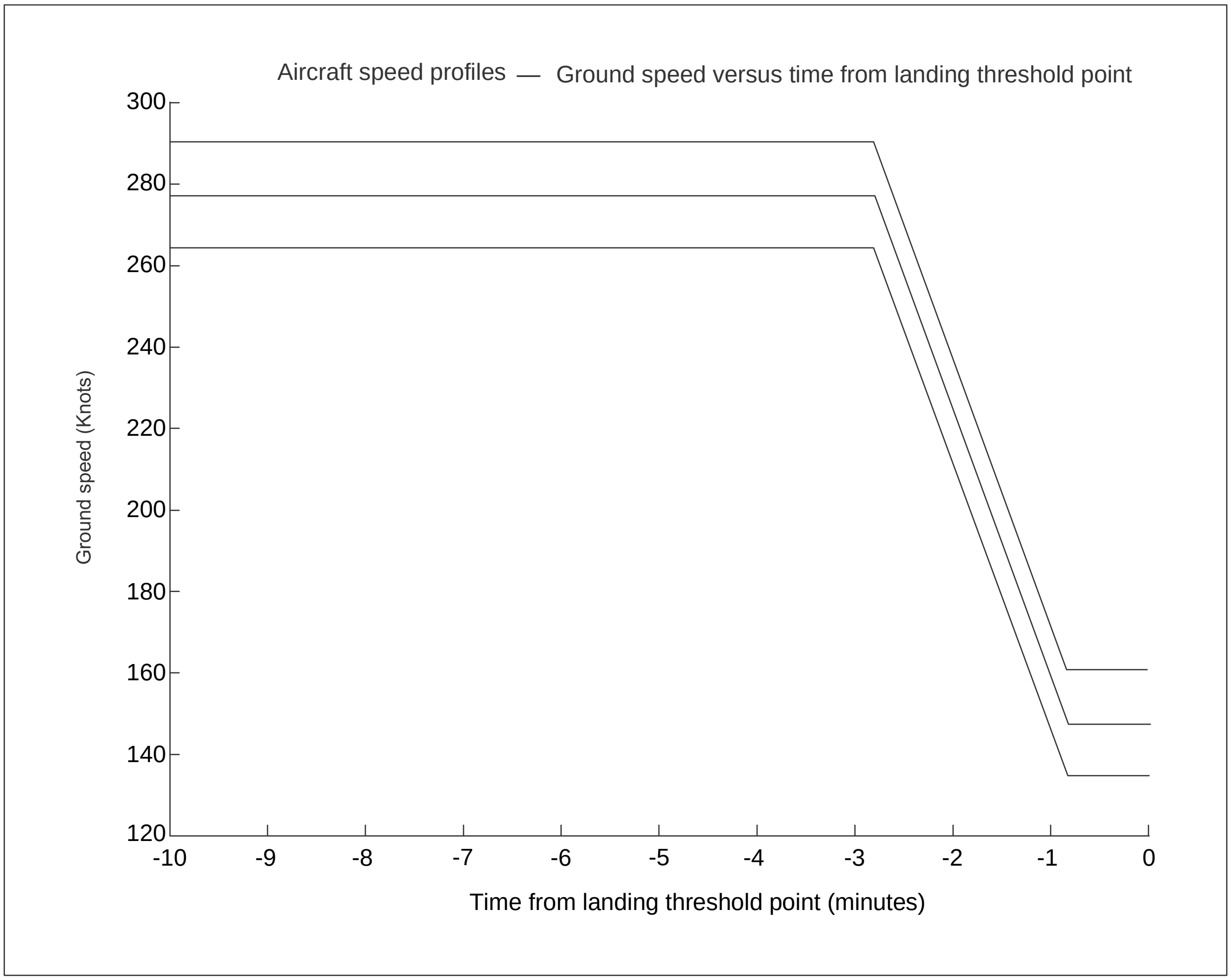


Figure D-9. Family of aircraft speed profiles

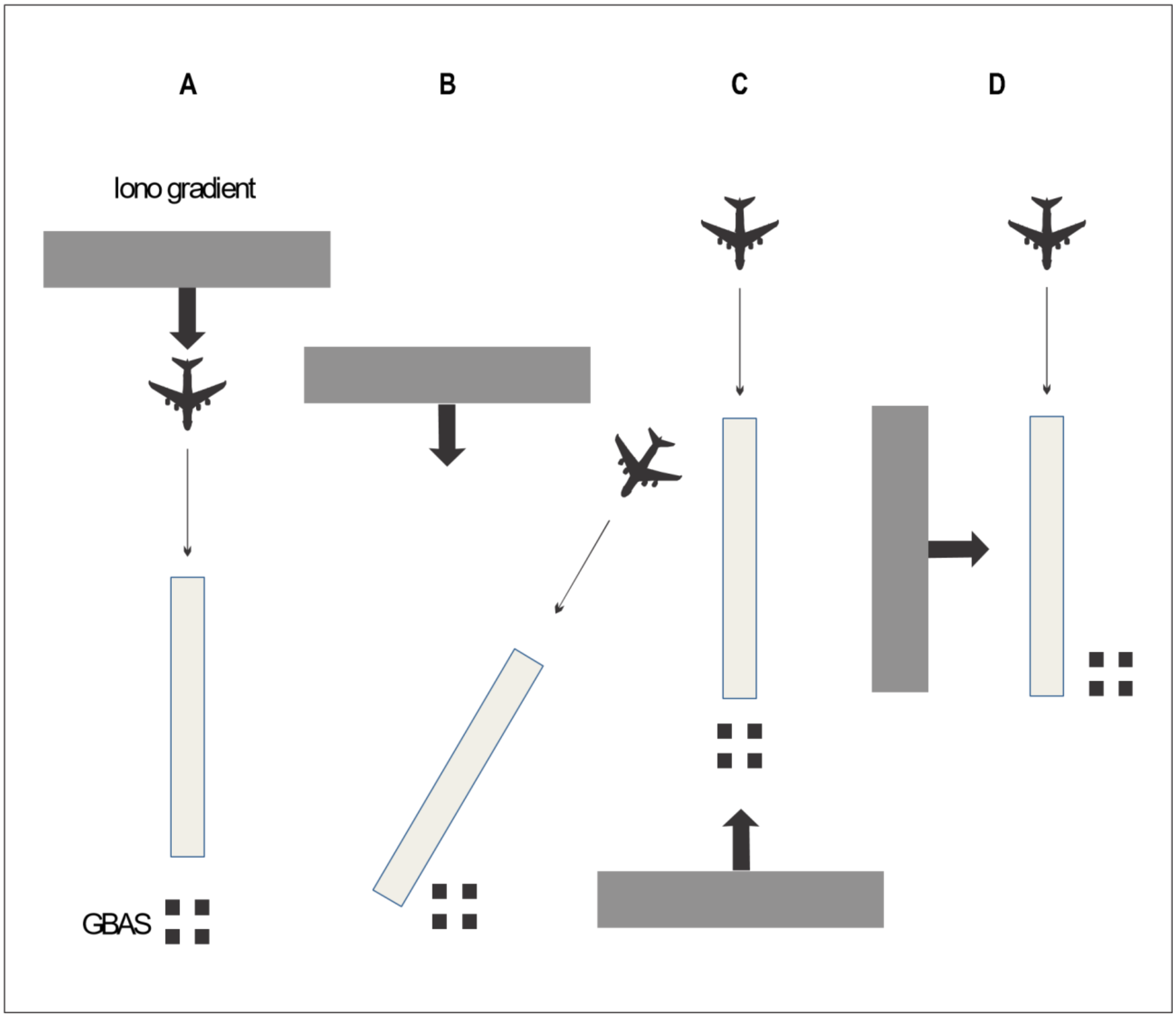


Figure D-10. Ionospheric gradient air/ground/approach orientations

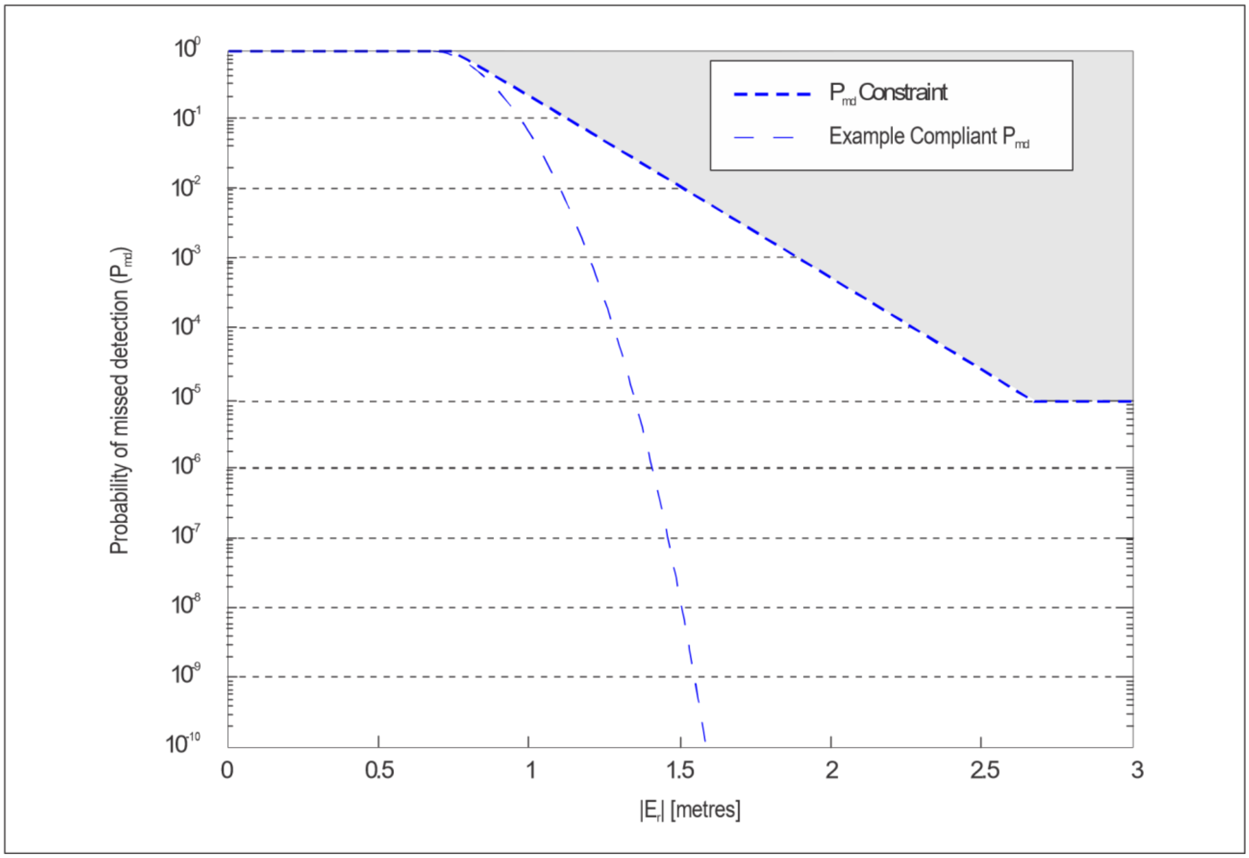
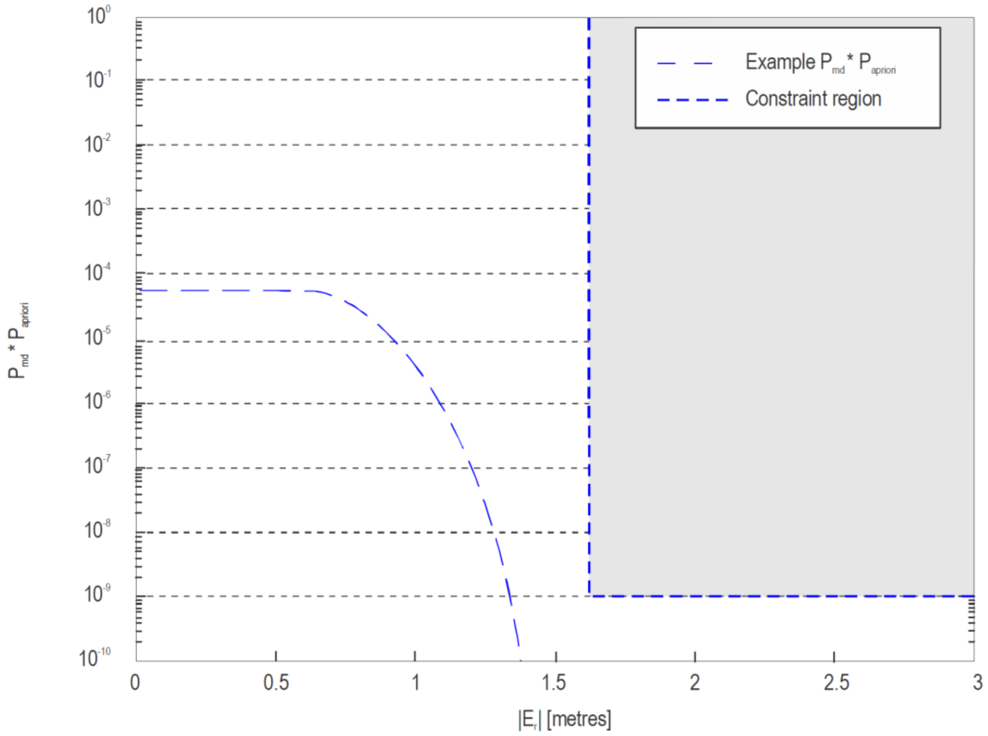


Figure D-11. Example P_{md_limit} constraint region



Note — $P_{apriori}$ is assumed to be $7x10^{-5}$ for this example.

Figure D-12. Example P_{md_limit} constraint with a priori probability

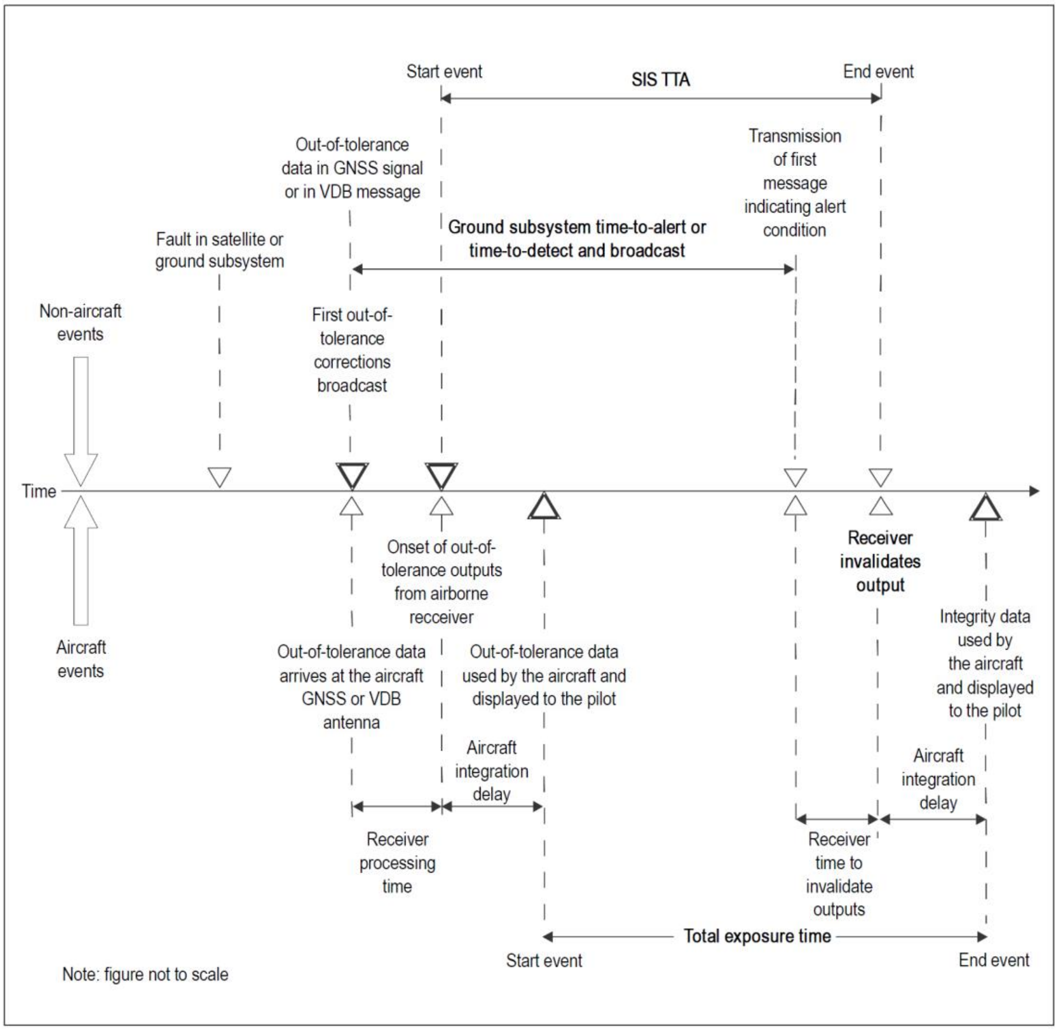


Figure D-13. Nominal GBAS time-to-alert illustration

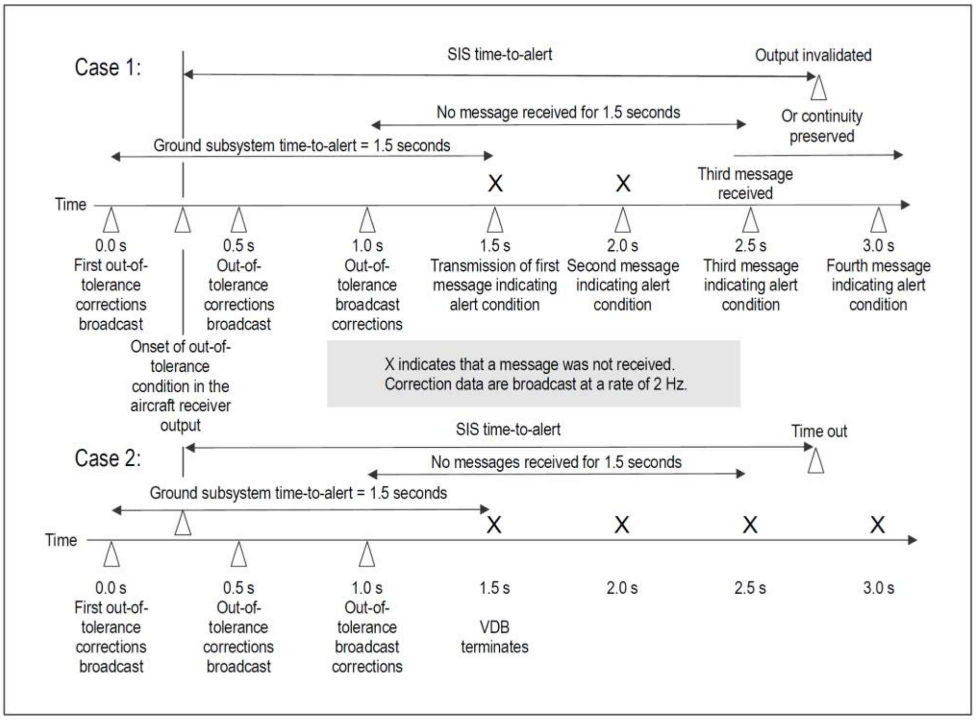
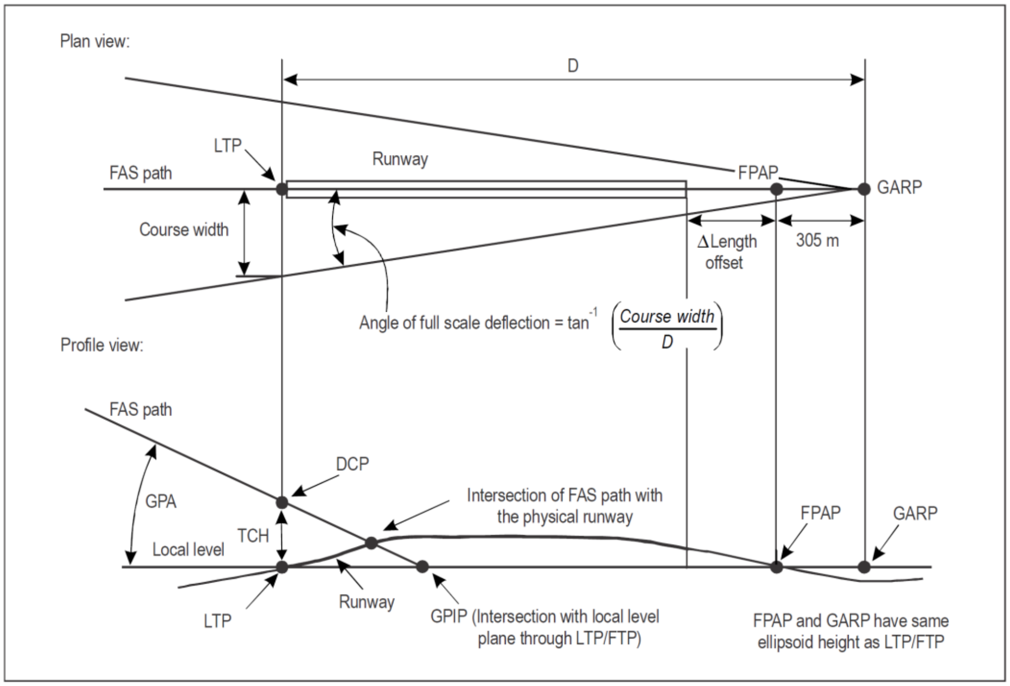
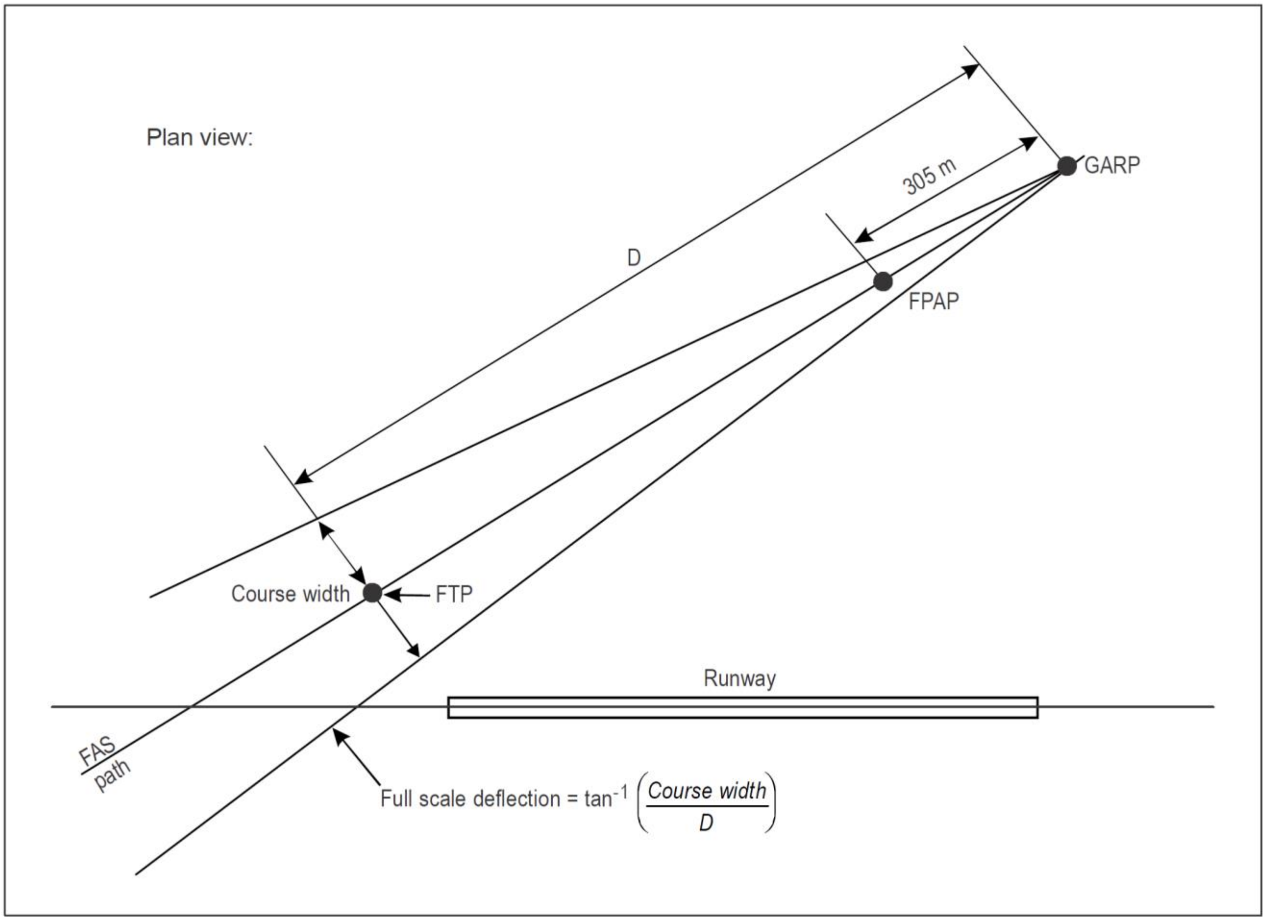


Figure D-14. Effect of missed messages on the GAST D GBAS time-to-alert below 200 ft Case 1 describes the situation for missed messages, Case 2 the one for VDB termination



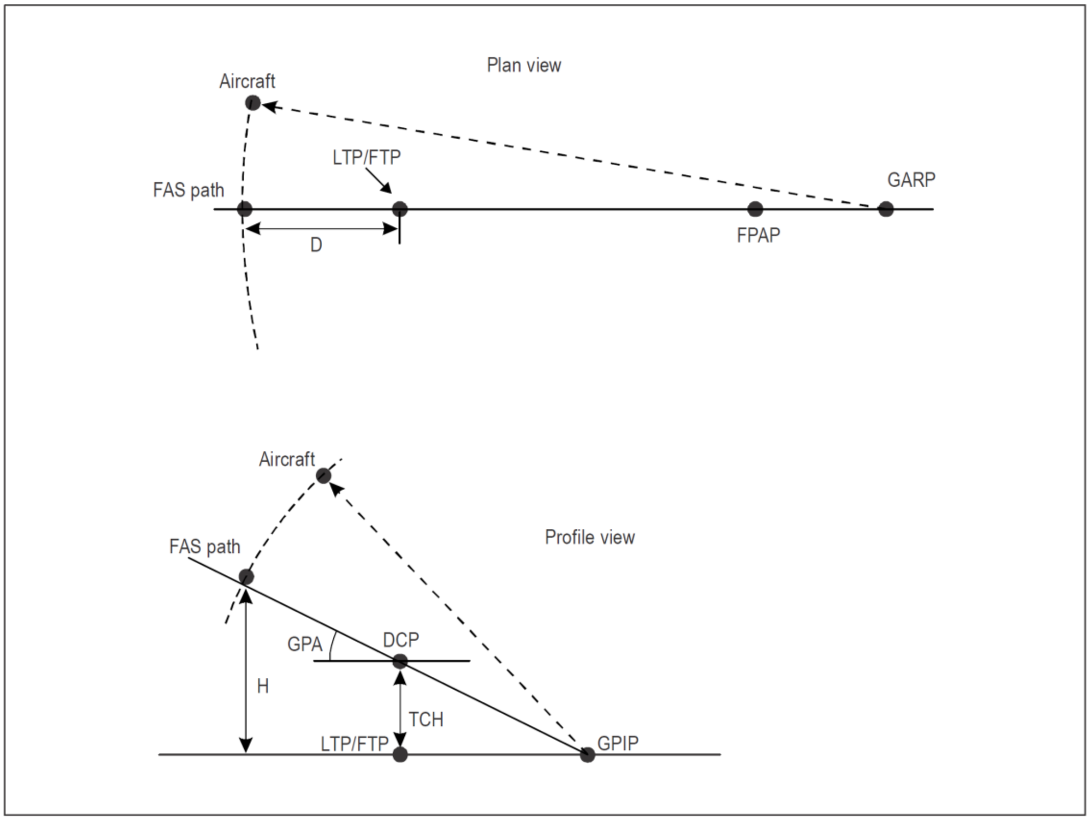
DCP — datum crossing point
FAS — final approach segment
FPAP — flight path alignment point
FTP — fictitious threshold point (see Figure D-7)
GARP — GNSS azimuth reference point
GPA — glide path angle
GPIP — glide path intersection point
LTP — landing threshold point
TCH — threshold crossing height

Figure D-15. FAS path definition



FAS — final approach segment
FPAP — flight path alignment point
FTP — fictitious threshold point
GARP — GNSS azimuth reference point

Figure D-16. FAS path definition for approaches not aligned with the runway



CP — datum crossing point
FAS — final approach segment
FPAP — flight path alignment point
FTP — fictitious threshold point (see Figure D-7)
GARP — GNSS azimuth reference point
GPA — glide path angle
GPIP — glide path intersection point
LTP — landing threshold point
TCH — threshold crossing height

Figure D-17. Definition of D and H parameters in alert limit computations

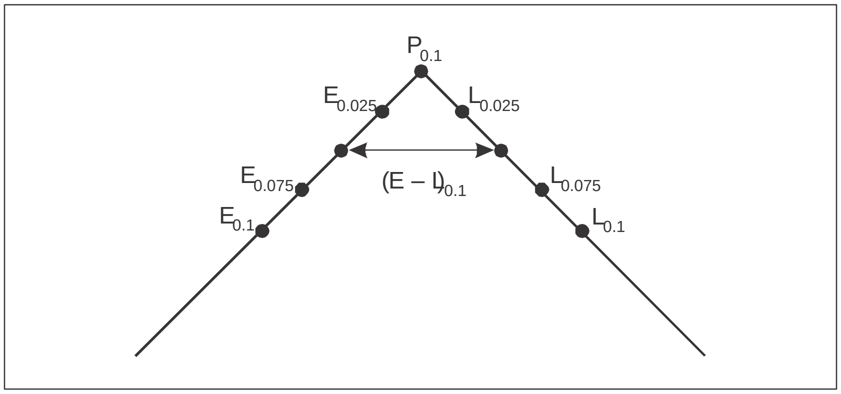


Figure D-18. "Close-in" correlation peak and measured correlator values

ATTACHMENT E. GUIDANCE MATERIAL ON THE PRE-FLIGHT CHECKING OF VOR AIRBORNE EQUIPMENT

1. Specification for a VOR airborne equipment test facility (VOT)

1.1 Introduction

For the guidance of States wishing to provide a test signal for the pre-flight checking of VOR airborne equipment, suggested characteristics for a VOR airborne equipment test facility (VOT) are given hereafter.

1.2 General

1.2.1 The VOT must be designed to provide signals that will permit satisfactory operation of a typical VOR aircraft installation in those areas of the aerodrome where pre-flight checking is convenient and desirable.

1.2.2 The VOT must be constructed and adjusted so that the VOR bearing indicator in the aircraft will indicate zero degrees “FROM” when the receiver has not departed from calibration. This indication remains constant irrespective of the aircraft's angular position with respect to the VOT within the intended coverage.

1.2.3 In view of the manner in which use is made of a VOT, there is no fundamental need for its duplication at any one site.

1.2.4 The VOT is required to radiate a radio frequency carrier with which are associated two separate 30 Hz modulations. The characteristics of these modulations should be identical with the reference phase and variable phase signals associated with VOR. The phases of these modulations should be independent of azimuth and should be coincident with each other at all times.

1.3 Radio frequency

The VOT should operate in the band 108 to 117.975 MHz on an appropriate VOR channel selected so as not to interfere with any VHF navigation or communication services. The highest assignable frequency is 117.95 MHz. The frequency tolerance of the radio frequency carrier should be plus or minus 0.005 per cent, except as specified in Chapter 3, 3.3.2.2 and 3.3.2.3.

1.4 Polarization and accuracy

1.4.1 The emission from the VOT should be horizontally polarized.

1.4.2 The accuracy of the “bearing” information conveyed by the radiation from the VOT should be plus or minus 1 degree.

Note.— Since the two modulations on the radio frequency carrier are in phase coincidence at all times, the vestigial vertically polarized energy will have no effect on the accuracy of the facility.

1.5 Coverage

1.5.1 Coverage requirements, and hence the power which must be radiated, will necessarily depend to a considerable extent on local circumstances. For some installations, a small fraction of 1 W will suffice while in other cases, particularly if two or more closely adjacent aerodromes are to be served by a single test facility, several watts of radio frequency energy may need to be emitted.

1.5.2 Where there is a need to protect co-channel VORs, VOTs and ILS localizers from VOT interference, the radio emission must be limited to that required to provide satisfactory operation and to ensure that interference with other co-channel assignments does not occur.

1.6 Modulation

1.6.1 The radio frequency carrier as observed at any point in space should be amplitude modulated by two signals as follows:

a) a subcarrier of 9 960 Hz of constant amplitude, frequency modulated at 30 Hz and having a deviation ratio of 16 plus or minus 1 (i.e. 15 to 17);

b) 30 Hz.

1.6.2 The depth of modulation due to the 9 960 Hz and the 30 Hz signals should be within the limits of 28 per cent for each component.

1.6.3 The signal which frequency modulates the 9 960 Hz subcarrier and the signal which amplitude modulates the radio frequency carrier should both be maintained at 30 Hz within plus or minus 1 per cent.

1.6.4 The frequency of the 9 960 Hz subcarrier should be maintained within plus or minus 1 per cent.

1.6.5 The percentage of amplitude modulation on the 9 960 Hz subcarrier present at the output of the transmitter should not be greater than 5 per cent.

1.7 Identification

1.7.1 The VOT should transmit a 1 020 Hz identification signal. The identification code for a VOT installation should be selected by the competent authority so as to be unmistakably distinctive as to the test function and, if necessary, as to the location.

Note.— In one State, when the VOT coverage is confined to a single aerodrome, the identification consists of a continuous series of dots.

1.7.2 The depth to which the radio frequency carrier is modulated by the identification signal should be approximately 10 per cent.

1.8 Monitoring

1.8.1 Basically, there is no need for continuous automatic monitoring of VOT provided the relative phase of the AM and FM 30 Hz components are mechanically locked and facilities exist for periodic inspection and remote supervision of the state of the VOT.

1.8.2 Provision of automatic monitoring can double the cost of a VOT installation and, consequently, many competent authorities are likely to employ only remote supervision at a control point. However, where, in the light of the operational use to be made of a VOT, a State decides to provide automatic monitoring, the monitor should transmit a warning to a control point and cause a cessation of transmission if either of the following deviations from established conditions arises:

a) a change in excess of 1 degree at the monitor site of the "bearing" information transmitted by the VOT;

b) a reduction of 50 per cent in the signal level of the 9 960 Hz or 30 Hz signals at the monitor.

Failure of the monitor should automatically cause a cessation of transmission.

2. Selection and use of VOR aerodrome check-points

2.1 General

2.1.1 When a VOR is suitably located in relationship to an aerodrome, the pre-flight checking of an aircraft VOR installation can be facilitated by the provision of suitably calibrated and marked check-points at convenient parts of the aerodrome.

2.1.2 In view of the wide variation in circumstances encountered, it is not practicable to establish any standard requirements or practices for the selection of VOR aerodrome check-points. However, States wishing to provide this facility should be guided by the following considerations in selecting the points to be used.

2.2 Siting requirements for check-points

2.2.1 The signal strength of the nearby VOR has to be sufficient to ensure satisfactory operation of a typical aircraft VOR installation. In particular, full flag action (no flag showing) must be ensured.

2.2.2 The check-points should, within the limits of operating convenience, be located away from buildings or other reflecting objects (fixed or moving) which are likely to degrade the accuracy or stability of the VOR signal.

2.2.3 The observed VOR bearing at any selected point should ideally be within plus or minus 1.5 degrees of the bearing accurately determined by survey or chart plotting.

Note.— The figure of plus or minus 1.5 degrees has no direct operational significance in that the observed bearing becomes the published bearing; however, where a larger difference is observed, there is some possibility of poor stability.

2.2.4 The VOR information at a selected point should be used operationally only if found to be consistently within plus or minus 2 degrees of the published bearing. The stability of the VOR information at a selected point should be checked periodically with a calibrated receiver to ensure that the plus or minus 2-degree tolerance is satisfied, irrespective of the orientation of the VOR receiving antenna.

Note.— The tolerance of plus or minus 2 degrees relates to the consistency of the information at the selected point and includes a small tolerance for the accuracy of the calibrated VOR receiver used in checking the point. The 2-degree figure does not relate to any figure for acceptance or rejection of an aircraft VOR installation, this being a matter for determination by Administrations and users in the light of the operation to be performed.

2.2.5 Check-points which can satisfy the foregoing requirements should be selected in consultation with the operators concerned. Provision of check-points in holding bays, at runway ends and in maintenance and loading areas, is usually desirable.

2.3 Marking of VOR check-points

Each VOR check-point must be distinctively marked. This marking must include the VOR bearing which a pilot would observe on the aircraft instrument if the VOR installation were operating correctly.

2.4 Use of VOR check-points

The accuracy with which a pilot must position the aircraft with respect to a check-point will depend on the distance from the VOR station. In cases where the VOR is relatively close to a check-point, particular care must be taken to place the aircraft's VOR receiving antenna directly over the check-point.

ATTACHMENT F. GUIDANCE MATERIAL CONCERNING RELIABILITY AND AVAILABILITY OF RADIOCOMMUNICATIONS AND NAVIGATION AIDS

1. Introduction and fundamental concepts

This Attachment is intended to provide guidance material which Member States may find helpful in providing the degree of facility reliability and availability consistent with their operational requirement.

The material in this Attachment is intended for guidance and clarification purposes, and is not to be considered as part of the Standards and Recommended Practices contained in this Annex.

1.1 Definitions

Facility availability. The ratio of actual operating time to specified operating time.

Facility failure. Any unanticipated occurrence which gives rise to an operationally significant period during which a facility does not provide service within the specified tolerances.

Facility reliability. The probability that the ground installation operates within the specified tolerances.

Note.— This definition refers to the probability that the facility will operate for a specified period of time.

Mean time between failures (MTBF). The actual operating time of a facility divided by the total number of failures of the facility during that period of time.

Note.— The operating time is in general chosen so as to include at least five, and preferably more, facility failures in order to give a reasonable measure of confidence in the figure derived.

Signal reliability. The probability that a signal-in-space of specified characteristics is available to the aircraft.

Note.— This definition refers to the probability that the signal is present for a specified period of time.

1.2 Facility reliability

1.2.1 Reliability is achieved by a combination of factors. These factors are variable and may be individually adjusted for an integrated approach that is optimum for, and consistent with, the needs and conditions of a particular environment. For example, one may compensate to some extent for low reliability by providing increased maintenance staffing and/or equipment redundancy. Similarly, low levels of skill among maintenance personnel may be offset by providing equipment of high reliability.

1.2.2 The following formula expresses facility reliability as a percentage:

$$R = 100\ e^{-t/m}$$

where:

R = reliability (probability that the facility will be operative within the specified tolerances for a time t, also referred to as probability of survival, P_s);

e = base of natural logarithms;

t = time period of interest;

m = mean time between facility failures.

It may be seen that reliability increases as mean time between failures (MTBF) increases. For a high degree of reliability, and for operationally significant values of t, we must have a large MTBF; thus, MTBF is another more convenient way of expressing reliability.

1.2.3 Experimental evidence indicates that the above formula is true for the majority of electronic equipments where the failures follow a Poisson distribution. It will not be applicable during the early life of an equipment when there is a relatively large number of premature failures of individual components; neither will it be true when the equipment is nearing the end of its useful life.

1.2.4 At many facility types utilizing conventional equipment, MTBF values of 1 000 hours or more have been consistently achieved. To indicate the significance of a 1 000-hour MTBF, the corresponding 24-hour reliability is approximately 97.5 per cent (i.e. the likelihood of facility failure during a 24-hour period is about 2.5 per cent).

1.2.5 Figure F-1 shows the probability of facility survival, P_s, after a time period, t, for various values of MTBF.

Note.— It is significant that the probability of surviving a period of time equal to the MTBF is only 0.37 (37 per cent); thus, it is not assumed that the MTBF is a failure-free period.

1.2.6 It may be seen that adjustment of MTBF will produce the desired degree of reliability. Factors which affect MTBF and hence facility reliability are:

a) inherent equipment reliability;

b) degree and type of redundancy;

c) reliability of the serving utilities such as power and telephone or control lines;

d) degree and quality of maintenance;

e) environmental factors such as temperature and humidity.

1.3 Facility availability

1.3.1 Availability, as a percentage, may be expressed in terms of the ratio of actual operating time divided by specified operating time taken over a long period. Symbolically,

$$A = \frac{\text{Actual time operating (100)}}{\text{Specified operating time}}$$

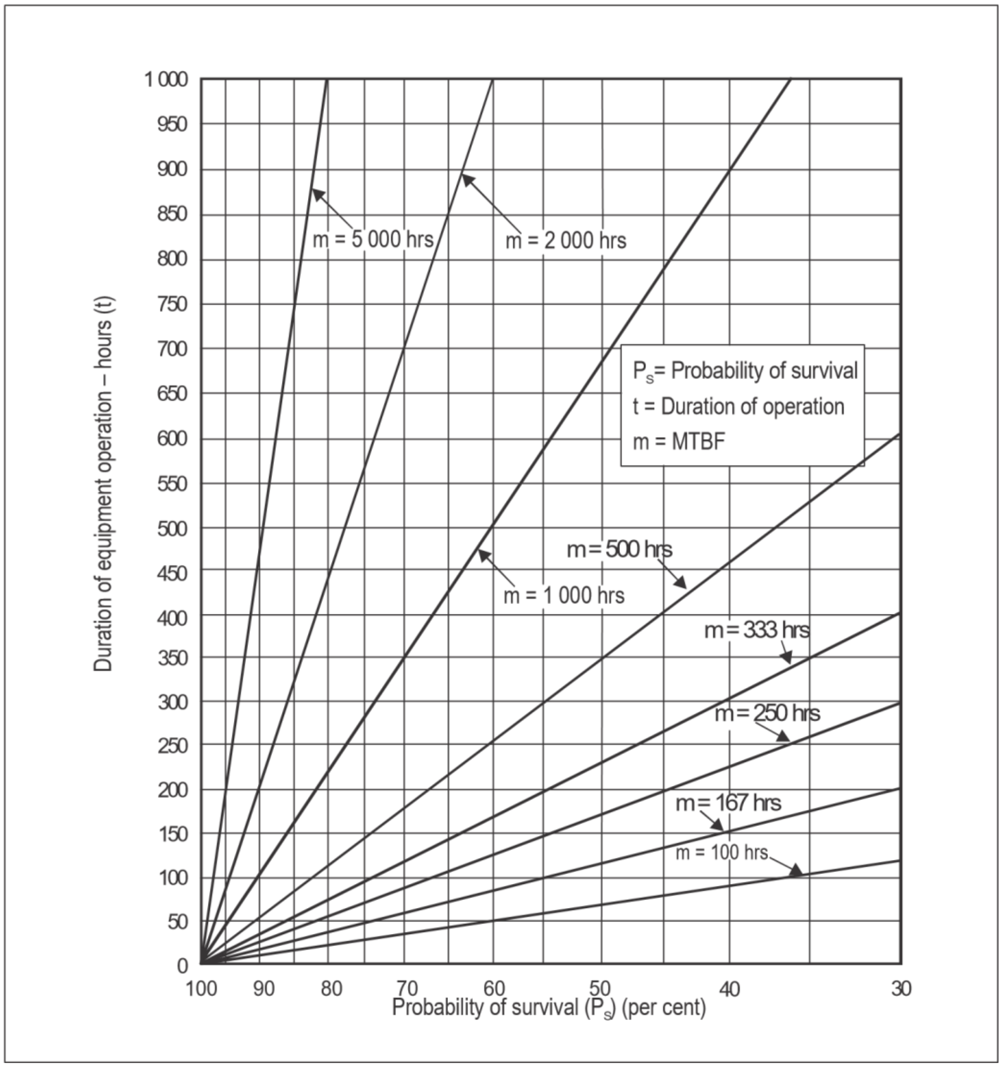


Figure F-1. Plot of $P_s = 100\ e^{-t/m}$

For example, if a facility was operating normally for a total of 700 hours during a 720-hour month, the availability for that month would be 97.2 per cent.

1.3.2 Factors important in providing a high degree of facility availability are:

a) facility reliability;

b) quick response of maintenance personnel to failures;

c) adequate training of maintenance personnel;

d) equipment designs providing good component accessibility and maintainability;

e) efficient logistic support;

f) provision of adequate test equipment;

g) standby equipment and/or utilities.

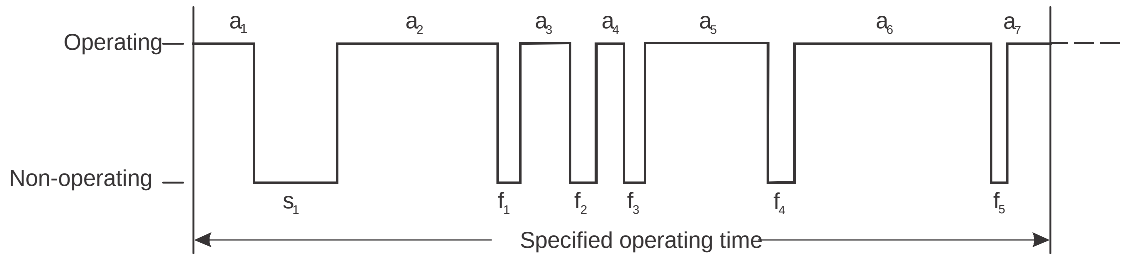
2. Practical aspects of reliability and availability

2.1 Measurement of reliability and availability

2.1.1 *Reliability*. The value that is obtained for MTBF in practice must of necessity be an estimate since the measurement will have to be made over a finite period of time. Measurement of MTBF over finite periods of time will enable Administrations to determine variations in the reliability of their facilities.

2.1.2 *Availability*. This is also important in that it provides an indication of the degree to which a facility (or group of facilities) is available to the users. Availability is directly related to the efficiency achieved in restoring facilities to normal service.

2.1.3 The basic quantities and manner of their measurement are indicated in Figure F-2. This figure is not intended to represent a typical situation which would normally involve a larger number of inoperative periods during the specified operating time. It should also be recognized that to obtain the most meaningful values for reliability and availability the specified operating time over which measurements are made should be as long as practicable.



Actual operating time = $a_1 + a_2 + a_3 + a_4 + \dots + a_n$

a = operating period

Non-operating time = $s_1 + \dots + s_n + f_1 + f_2 + \dots + f_n$

s = scheduled shutdown period

f = failure period

Specified operating time = Sum of actual operating time and non-operating time

Figure F-2. Evaluation of facility availability and reliability

2.1.4 Using the quantities illustrated in Figure F-2, which includes one scheduled shutdown period and five failure periods, one may calculate mean time between failures (MTBF) and availability (A) as follows:

Let:

$a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7 =$ 5 540 hours
$s_1 =$ 20 hours
$f_1 =$ 2½ hours
$f_2 =$ 6¼ hours
$f_3 =$ 3¾ hours
$f_4 =$ 5 hours
$f_5 =$ 2½ hours
Specified operating time = 5 580 hours

$$\text{MTBF} = \frac{\text{Actual operating time}}{\text{Number of failures}}$$

$$= \frac{\sum_{i=1}^{7} a_1}{5}$$

$$= \frac{5\,540}{5} = 1\,108 \text{ hours}$$

$$A = \frac{\text{Actual operating time} \times 100}{\text{Specified operating time}}$$

$$= \frac{\sum_{i=1}^{7} a_i \times 100}{\sum_{i=1}^{7} a_i + s_1 + \sum_{i=1}^{5} f_i}$$

$$= \frac{5\ 540}{5\ 580} \times 100 = 99.3 \text{ per cent}$$

ATTACHMENT G. Reserved

ATTACHMENT H. STRATEGY FOR RATIONALIZATION OF CONVENTIONAL RADIO NAVIGATION AIDS AND EVOLUTION TOWARD SUPPORTING PERFORMANCE-BASED NAVIGATION

(see Chapter 2, 2.1)

1. Introduction

1.1 The shift from facility-referenced navigation to coordinate-based navigation enabled by performance-based navigation (PBN) provides significant benefits, in particular by supplying the flexibility required to design airspace and associated routes and procedures according to operational needs. The most suitable navigation infrastructure to support PBN is GNSS. Consequently, the role of conventional navigation aids is currently evolving towards that of a reversionary terrestrial infrastructure capable of maintaining safety and an adequate level of operations in case of unavailability of GNSS (for example due to outages). During this evolution, terrestrial aids may also enable PBN operations for users not yet equipped with GNSS.

1.2 The aim of the strategy set out in this attachment is to provide guidance to States to enable both a rationalization of navigation aids as well as a coordinated evolution towards the provision of a reversionary terrestrial infrastructure. This strategy should be considered in particular when deciding on investments into new facilities or on facility renewals. The context of this evolution of navigation infrastructure is described in the *Global Air Navigation Plan* (Doc 9750).

1.3 The strategy addresses the application of radio navigation aids to both conventional and performance-based navigation in en-route and terminal airspace, as well as their use as non-precision approach aids. Detailed guidance on PBN navigation infrastructure requirements is available in the *Performance-based Navigation (PBN) Manual* (Doc 9613).

Note.— The strategy relating to approach and landing with vertical guidance (APV) and precision approach and landing operations is contained in Attachment B.

2. Objectives of the strategy

The strategy must:

a) maintain at least the current safety level of en-route and terminal area navigation operations;

b) facilitate the implementation of performance-based navigation (PBN);

c) maintain global interoperability;

d) provide regional flexibility based on coordinated regional planning;

e) encourage airspace users to equip with appropriate PBN avionics; and

f) take account of economic, operational and technical issues.

3. Considerations

3.1 Operational considerations

The following considerations are based on the assumption that the operational requirements are defined, that the required resources are committed, and that the required effort is applied. In particular, changes in radio navigation facility provision require associated efforts in airspace planning, procedure design, consideration of regulatory aspects and broad consultation with impacted airspace users.

3.2 NDB-related considerations

3.2.1 NDBs serve no role in PBN operations except as a means for position cross-checking and general situational awareness. These minor roles should not lead to the requirement to retain NDB facilities.

3.2.2 Except where no other alternative is available due to constraints in user fleet, financial, terrain or safety limitations:

a) the use of NDBs as en-route navigation aids or terminal area markers is generally obsolete;

b) NDBs used to support SID/STAR should be replaced by RNAV waypoints;

c) NDBs used as locators to assist in ILS intercept operations should be replaced by RNAV waypoints;

d) the use of NDB to support missed approach operations should be discouraged except where local safety cases require a non-GNSS missed approach capability; and

e) NDBs used as a non-precision approach aid should be withdrawn, taking the opportunity offered by the implementation of Assembly Resolution 37-11.

3.3 VOR related considerations

3.3.1 The only PBN navigation specification enabled by VOR, provided a co-located DME is present, is RNAV 5. Provision of RNAV 5 based on VOR/DME is subject to significant limitations, since integrated multi-sensor navigation makes very little use of VOR/DME, in some cases limiting the range of use to 25 NM. Also, only very few aircraft operators have a certified RNAV 5 capability which is based only on VOR/DME. Consequently, the use of VOR/DME to provide PBN services is discouraged. The only exception to this could be to support RNAV 5 routes at or near the bottom of en-route airspace (above minimum sector altitude, MSA) where achieving DME/DME coverage is challenging.

3.3.2 In principle, to enable cost savings, VOR facilities should be withdrawn in the context of an overall PBN plan. No new stand-alone VOR facilities (e.g. at new locations) should be implemented. However, VORs may be retained to serve the following residual operational purposes:

a) as a reversionary navigation capability (for example, for general aviation operations in order to assist in avoiding airspace infringements);

b) to provide navigation, cross-checking and situational awareness, especially for terminal area operations (pilot MSA awareness, avoiding premature automatic flight control system arming for ILS intercept, aircraft operational contingency procedures, such as engine failure on take-off, missed approaches, if required by local safety cases), in particular in areas where low altitude DME/DME coverage is limited;

c) for VOR/DME inertial updating where DME/DME updating is not available;

d) for non-precision approaches, as long as users are not equipped for RNP approaches and if no other suitable means of precision approach is available;

e) for conventional SID/STAR to serve non-PBN-capable aircraft;

f) as required to support the operations of State aircraft; and

g) to support procedural separation (as detailed in Doc 4444).

3.3.3 In order to provide DME-based RNAV capabilities, those locations which are retained for VOR should normally also be equipped with a co-located DME.

3.3.4 It is expected that adherence to the above principles should enable a decrease of the current number of facilities by 50 per cent or more in areas which support high densities of traffic. To achieve such results, States should develop a rationalization plan, taking into account the service age, all uses and operational roles of their facilities. This normally requires significant coordination with airspace users. The rationalization plan should be an integral part of the PBN implementation plan. Experience has shown that the associated project effort amounts to less expense than the replacement and refurbishment of a single VOR facility. The rationalization planning for VOR is also an important input into the evolution planning for DME.

3.4 DME-related considerations

3.4.1 DME/DME fully supports PBN operations based on the RNAV 1, RNAV 2 and RNAV 5 navigation specifications. Consequently, DME/DME (for equipped aircraft) is the most suitable current terrestrial PBN capability. DME/DME provides a fully redundant capability to GNSS for RNAV applications, and a suitable reversionary capability for RNP applications requiring an accuracy performance of ±1 NM (95 per cent) laterally, where supported by an adequate DME infrastructure.

Note.— While some aircraft are certified to provide RNP based on DME/DME, the ability of DME to provide RNP on a general basis is currently under investigation.

3.4.2 States are encouraged to plan the evolution of their DME infrastructure by considering the following:

a) Where a terrestrial navigation reversion capability is required, a DME network capable of supporting DME/DME navigation should be provided, where possible;

b) the DME network design should consider cost-savings opportunities whenever possible, such as the withdrawal from a site if an associated VOR is removed, or the possibility to efficiently set up new DME stand-alone sites where other ANSP CNS assets are located;

c) the DME network design should attempt to fill any gaps and provide coverage to as low altitudes as operationally useful without leading to excessive new facilities investments;

d) if satisfactory DME/DME coverage cannot be achieved, States may consider requiring INS equipage from airspace users to bridge gaps in coverage;

e) ANSPs should take maximum advantage of cross-border and military facilities (TACAN), provided the necessary agreements can be put in place; and

f) the frequency assignment of new DME stations should avoid the GNSS L5/E5 band (1 164 – 1 215 MHz) in areas of high DME station density, if possible.

3.4.3 If the above principles are adhered to, it is expected that the density of DME stations in a given area should become more uniform. In other words, the number of facilities in areas of high station density will be reduced, whereas it may need to be increased in areas of low station density.

3.4.4 It is recognized that in some areas, the provision of DME/DME navigation is not possible or practical, such as at very low altitudes, in terrain-constrained environments, or on small islands and areas over water. It should also be noted that some FMS exclude the use of ILS-associated DMEs. As a consequence, it is not possible to ensure consistent DME/DME service to all DME/DME-equipped users based on ILS-associated DMEs, and thus those facilities cannot be used to provide such service (regardless of whether they are published in the en-route section of the AIP).

3.5 Multi-sensor airborne navigation capability considerations

It is recognized that:

a) until all airspace users are both equipped and approved with suitable GNSS-based PBN capabilities, terrestrial navigation aids must be provided either to support conventional procedures or to support DME/DME-based PBN capabilities;

b) once all airspace users are both equipped and approved with suitable GNSS-based PBN capabilities, terrestrial navigation aids may need to be provided to mitigate the risks associated with GNSS outages;

c) it may not be practical or cost-efficient for some airspace users to equip with DME/DME-based and/or INS-based PBN capabilities; and

d) a review of flight plan filings can be an efficient tool to analyse user fleet equipage status; however, actual equipage and approval status may need to be confirmed by the aircraft operator.

3.6 Other considerations

3.6.1 The evolution of terrestrial navigation infrastructure must be accompanied by the development of corresponding operational reversion scenarios. Operational requirements must be balanced with regard to that which is possible at a reasonable cost, while ensuring safety. In particular, coverage requirements at low altitude can be associated with significant facility cost. Leveraging airspace user capabilities, such as INS, as well as other CNS capabilities (surveillance and communication service coverage and associated ATC capabilities) must be considered to the maximum extent practicable, including common mode failures. In some airspaces, it may not be possible to cater to all airspace user equipage levels and, as a consequence, some airspace users may become subject to operational restrictions.

3.6.2 Some States with a high traffic density environment have identified DME/DME as their main PBN reversion capability (providing either a fully redundant or a degraded level of performance). These States then also plan to provide a residual VOR or VOR/DME infrastructure network to cater to users which have a PBN capability exclusively enabled by GNSS or to those without an adequate PBN capability. Operational procedures associated with the use of such reversion capabilities are under development.

3.6.3 It must be noted that the use of the term "network" in this strategy refers only to navigation facilities assessed on a regional scale, and it does not refer to a network of routes or a particular airspace design. In high-density airspace, it is considered impractical to provide an alternate, conventional back-up route network, once the transition to a fully PBN-based route network has been achieved.

3.6.4 In a few limited cases, it may not be possible to provide the same level of benefits through the application of PBN as is possible when using conventional navigation capabilities, due to procedure design limitations or other aspects such as terrain-constrained environments. States are invited to bring these cases to the attention of ICAO.

4. Strategy

Based on the considerations above, the need to consult aircraft operators and international organizations, and to ensure safety, efficiency and cost-effectiveness of the proposed solutions, the global strategy is to:

a) rationalize NDB and VOR and associated procedures;

b) align rationalization planning with equipment life cycles and PBN implementation planning;

c) replace approaches without vertical guidance with vertically guided approaches;

d) where a terrestrial navigation reversion capability is required, evolve the existing DME infrastructure towards providing a PBN infrastructure complementary to GNSS;

e) provide a residual capability based on VOR (or VOR/DME, if possible) to cater to airspace users not equipped with suitable DME/DME avionics, where required; and

f) enable each region to develop an implementation strategy for these systems in line with the global strategy.

— END —