COVER SHEET TO AMENDMENT 83

INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

AERONAUTICAL TELECOMMUNICATIONS

ANNEX 10
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME I
RADIO NAVIGATION AIDS

SIXTH EDITION — JULY 2006

INTERNATIONAL CIVIL AVIATION ORGANIZATION

Checklist of Amendments to Annex 10, Volume I

	Effective date	*Date of applicability*
Sixth Edition (incorporates Amendments 1 to 81)	17 July 2006	23 November 2006
Amendment 82 (adopted by the Council on 26 February 2007)	16 July 2007	22 November 2007
Amendment 83 (adopted by the Council on 10 March 2008) Replacement pages (iii), (xviii), 1-1, 1-2, 2-3, 2-4, 2-5, 3-3, 3-4, 3-6, 3-61 to 3-71, APP B-12, APP B-18 to APP B-20, APP B-49, APP B-51, APP B-54 to APP B-57, APP B-60, APP B-62, APP B-66, APP B-69 to APP B-73, APP B-106 to APP B-108, APP B-125, ATT D-1 to ATT D-30, ATT D-48 and ATT G-43	20 July 2008	20 November 2008

Transmittal note

Amendment 83

to the

International Standards and
Recommended Practices

AERONAUTICAL TELECOMMUNICATIONS

(Annex 10, Volume I, to the Convention on International Civil Aviation)

1. Insert the following replacement pages in Annex 10, Volume I (Sixth Edition) to incorporate Amendment 83 which becomes applicable on 20 November 2008:

    a) Page (iii) — Table of Contents

    b) Page (xviii) — Foreword

    c) Pages 1-1 and 1-2 — Chapter 1

    d) Pages 2-3, 2-4 and 2-5 — Chapter 2

    e) Pages 3-3, 3-4, 3-6, 3-61 to 3-71 — Chapter 3

    f) Pages APP B-12, APP B-18 to APP B-20, APP B-49, APP B-51, APP B-54 to APP B-57, APP B-60, APP B-62, APP B-66, APP B-69 to APP B-73, APP B-106 to APP B-108 and APP B-125 — Appendix B to Chapter 3

    g) Pages ATT D-1 to ATT D-30 and ATT D-48 — Attachment D

    h) Page ATT G-43 — Attachment G

2. Record the entry of this amendment on page (ii).

20/7/08

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ATTACHMENTS

Amendment	*Source(s)*	*Subject(s)*	*Adopted* *Effective* *Applicable*
70	ANC; Third Meeting of the Aeronautical Fixed Service Systems Planning for Data Interchange Panel; 34th Meeting of the European Air Navigation Planning Group	Restructuring of Annex 10 into five volumes; deletion of obsolete specifications and guidance material on manual Morse code procedures and teletypewriter systems; inclusion of material on common ICAO data interchange network (CIDIN).	20 March 1995 24 July 1995 9 November 1995
71	ANC; Special COM/OPS Divisional Meeting (1995); 12th, 13th and 14th Meetings of the All Weather Operations Panel; Secretariat proposals for deletion of obsolete material	Finalization of SARPs and guidance material for the microwave landing system (MLS), incorporation of a new strategy for introduction and application of non-visual aids to approach and landing in place of the ILS/MLS transition plan; relocation of material to Volumes III, IV and V, as appropriate; deletion of obsolete specifications for Consol and Loran-A systems and guidance material on the utilization of facilities, research, development and evaluation.	12 March 1996 15 July 1996 7 November 1996
72	—	No change.	—
73	Air Navigation Commission	Introduction of Human Factors-related material.	19 March 1998 20 July 1998 5 November 1998
74	Sixteenth Meeting of the All Weather Operations Panel; Air Navigation Commission	Introduction of: a) required navigation performance (RNP) for approach, landing and departure operation; b) updating of specifications for instrument landing system (ILS) and microwave landing system (MLS); and c) associated guidance material.	18 March 1999 19 July 1999 4 November 1999
75	—	No change.	—
76	Third meeting of the Global Navigation Satellite System Panel (GNSSP); proposal by the United Kingdom for continuity of service requirements for ILS and MLS	Global navigation satellite system (GNSS); continuity of service requirements for ILS localizers and MLS azimuth facilities used in support of Category IIIA operations; updating of references to the ITU Radio Regulations.	12 March 2001 16 July 2001 1 November 2001
77	Global Navigation Satellite System Panel (GNSSP)	Incorporation of GLONASS-related technical specifications in the satellite-based augmentation system (SBAS) and ground-based augmentation system (GBAS) sections of GNSS requirements; provision for use of GBAS positioning service in support of terminal area navigation (RNAV) operations; provision for use of new Message Type 28 to enhance performance of SBAS; and incorporation of additional guidance material and clarifications/editorial corrections to SARPs and guidance material.	27 February 2002 15 July 2002 28 November 2002
78	—	No change.	—

Amendment	*Source(s)*	*Subject(s)*	*Adopted Effective Applicable*
79	Fourth meeting of the Global Navigation Satellite System Panel	Changes to GNSS SARPs and related guidance material concerning performance specifications for approach with vertical guidance (APV); global positioning system (GPS) selective availability (SA) discontinuation and clarification of signal power level; specifications for modernized GLObal NAvigation Satellite System (GLONASS-M); frequency planning criteria for ground-based augmentation system (GBAS) and a number of other enhancements.	23 February 2004 12 July 2004 25 November 2004
80	Eleventh Air Navigation Conference	Updates to the strategy for introduction and application of non-visual aids to approach and landing.	25 February 2005 11 July 2005 24 November 2005
81	Navigation Systems Panel (NSP)	a) Introduction of ground-based regional augmentation system (GRAS) Standards and Recommended Practices (SARPs); b) Amendments to SARPs for instrument landing system (ILS), distance measuring equipment (DME) and microwave landing system (MLS).	24 February 2006 17 July 2006 23 November 2006
82	Aeronautical Communications Panel (ACP)	Identification of the universal access transceiver (UAT) operating frequency.	26 February 2007 16 July 2007 22 November 2007
83	Secretariat with the assistance of the Required Navigation Performance and Special Operations Requirements Study Group (RNPSORSG); Navigation Systems Panel (NSP)	a) Amendments to definitions and Standards to align required navigation performance (RNP) and area navigation (RNAV) terminology with the performance-based navigation (PBN) concept; and b) Amendments to resolve certain navigation systems implementation issues and to reflect the evolution of existing global navigation satellite systems (GNSS) and equipment.	10 March 2008 20 July 2008 20 November 2008

* Did not affect any Standards or Recommended Practices.

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

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.— Annex 10, Volume I includes Standards and Recommended Practices for certain forms of equipment for air navigation aids. While the Contracting State will determine the necessity for specific installations in accordance with the conditions prescribed in the relevant Standard or Recommended Practice, review of the need for specific installation and the formulation of ICAO opinion and recommendations to Contracting States concerned is carried out periodically by Council, ordinarily on the basis of recommendations of Regional Air Navigation Meetings (Doc 8144 — Directives to Regional Air Navigation Meetings and Rules of Procedure for their Conduct).

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:

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.

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

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.

Note.— The following sources of guidance have been used for such purposes:

a) a suitably located VHF omnidirectional radio range (VOR) conforming to the specifications in Chapter 3, 3.3 or equivalent;

b) a locator or locators conforming with the specifications in Chapter 3, 3.4 or a suitably located non-directional radio beacon (NDB);

c) a suitably located UHF distance measuring equipment (DME) conforming to the specifications in Chapter 3, 3.5 and providing continuous distance information during the approach and missed approach phase of flight.

2.2 Short-distance aids

2.2.1 In localities and along routes where conditions of traffic density and low visibility necessitate a ground-based short-distance radio aid to navigation for the efficient exercise of air traffic control, or where such short-distance aid is required for the safe and efficient conduct of aircraft operations, the standard aid shall be the VHF omnidirectional radio range (VOR) of the continuous wave phase comparison type conforming to the Standards contained in Chapter 3, 3.3.

Note 1.— It is not intended that short-distance radio aids to navigation provided in accordance with 2.2.1 should be required primarily to perform the function of a long-distance navigation aid.

Note 2.— It is intended that, wherever a VOR conforming to the Standard in 2.2.1 has been installed, no change in, or addition to, that Standard will require the replacement of such equipment before 1 January 1995.

2.2.1.1 **Recommendation.—** *Means should be provided for the pre-flight checking of VOR airborne equipment at aerodromes regularly used by international air traffic.*

Note.— Guidance material on the pre-flight checking of VOR airborne equipment is contained in Attachment E.

2.2.2 At localities where for operational reasons, or because of air traffic control reasons such as air traffic density or proximity of routes, there is a need for a more precise navigation service than that provided by VOR, distance measuring equipment (DME) (conforming to the Standards in Chapter 3, 3.5) shall be installed and maintained in operation as a complement to VOR.

2.2.2.1 DME/N equipment first installed after 1 January 1989 shall also conform to the Standards in Chapter 3, 3.5 denoted by ‡.

Note.— It is intended that, wherever a DME conforming to the Standard in 2.2.2 has been installed, no change in, or addition to, that Standard will require the replacement of such equipment before 1 January 2010.

2.3 Radio beacons

2.3.1 Non-directional radio beacons (NDB)

2.3.1.1 An NDB conforming to the Standards in Chapter 3, 3.4 shall be installed and maintained in operation at a locality where an NDB, in conjunction with direction-finding equipment in the aircraft, fulfils the operational requirement for a radio aid to navigation.

2.3.2 En-route VHF marker beacons (75 MHz)

2.3.2.1 **Recommendation.—** *Where a VHF marker beacon is required to mark a position on any air route, a fan marker beacon conforming to the Standard contained in Chapter 3, 3.6 should be installed and maintained in operation.*

Note.— This recommendation does not preclude the use of fan marker beacons at points other than on an air route as, for example, an aid to descent under IFR conditions.

2.3.2.2 **Recommendation.—** *Where a VHF marker beacon is required to mark the position of a radio navigation aid giving directional or track guidance, a Z marker conforming to the Standard in Chapter 3, 3.6 should be installed and maintained in operation.*

2.4 Global navigation satellite system (GNSS)

2.4.1 A standard aid to navigation shall be the global navigation satellite system (GNSS) conforming to the Standards contained in Chapter 3, 3.7.

Note 1.— It is intended that any change in, or addition to, Standards in Chapter 3, 3.7 that will require the replacement of GNSS equipment can become applicable on the basis of a six-year advance notice.

Note 2.— GNSS is expected to support all phases of flight and aerodrome surface operations, however, present SARPs provide for en-route, terminal and approach and landing operations down to Category I precision approach.

2.4.2 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.

2.4.3 Recording and retention of GNSS data

2.4.3.1 **Recommendation.—** *A State that approves GNSS-based operations should ensure that GNSS data relevant to those operations are recorded.*

Note 1.— These recorded data are primarily intended for use in accident and incident investigations. They may also support periodic confirmation that accuracy, integrity, continuity and availability are maintained within the limits required for the operations approved.

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

2.4.3.2 **Recommendation.—** *Recordings should be retained for a period of at least fourteen days. When the recordings are pertinent to accident and incident investigations, they should be retained for longer periods until it is evident that they will no longer be required.*

2.5 [Reserved]

2.6 Distance measuring aids

2.6.1 **Recommendation.—** *If a distance measuring facility is installed and maintained in operation for any radio navigational purpose additional to that specified in 2.2.2, it should conform to the specification in Chapter 3, 3.5.*

2.7 Ground and flight testing

2.7.1 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 is contained in Attachment C and in the Manual on Testing of Radio Navigation Aids *(Doc 8071).*

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

2.8.1 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.

2.9 Secondary power supply for radio navigation aids and communication systems

2.9.1 Radio navigation aids and ground elements of communication systems of the types specified in Annex 10 shall be provided with suitable power supplies and means to ensure continuity of service appropriate to the needs of the service provided.

Note.— Guidance material on this subject is contained in Section 8 of Attachment C.

2.10 Human Factors considerations

2.10.1 **Recommendation.—** *Human Factors principles should 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).

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) VHF marker beacons, or distance measuring equipment (DME) in accordance with section 3.5, together with associated monitor system and remote control and indicator equipment.

Note.— Guidance material relative to the use of DME as an alternative to the marker beacon component of the ILS is contained in Attachment C, 2.11.

3.1.2.1.1 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 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 3.1.2.1.1, 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 **Recommendation.—** *At those locations where two separate ILS facilities serve opposite ends of a single runway and where a Facility Performance Category I — ILS is to be used for auto-coupled approaches and landings in visual conditions an interlock should ensure that only the localizer serving the approach direction in use radiates, providing the other localizer is not required for simultaneous operational use.*

Note.— If both localizers radiate there is a possibility of interference to the localizer signals in the threshold region. Additional guidance material is contained in 2.1.9 and 2.13 of Attachment C.

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 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*

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 if coverage is provided;

except that, where topographical features dictate or operational requirements permit, the limits may be reduced 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 facilities 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. 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.— Guidance material on localizer coverage is given in 2.1.11 of Attachment C.

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 **Recommendation.—** *Above 7 degrees, the signals should be reduced to as low a value as practicable.*

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 and 2.2.4 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 **Recommendation.—** *For Facility Performance Category III localizers, the ratio of the two carrier signal strengths in space within the front course sector should not be less than 16 dB.*

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:

b) range rate error of any satellite — 0.02 m (0.07 ft) per second;

c) range acceleration error of any satellite — 0.007 m (0.02 ft) per second-squared; and

d) root-mean-square range error over all satellites — 6 m (20 ft).

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

≥99 per cent horizontal service availability, average location (36 m 95 per cent threshold)

≥99 per cent vertical service availability, average location (77 m 95 per cent threshold)

≥90 per cent horizontal service availability, worst-case location (36 m 95 per cent threshold)

≥90 per cent vertical service availability, worst-case location (77 m 95 per cent threshold)

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

a) frequency of a major service failure — not more than three per year for the constellation (global average);

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

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

3.7.3.1.4 *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.

3.7.3.1.5 *Radio frequency (RF) characteristics*

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

3.7.3.1.5.1 *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.

3.7.3.1.5.2 *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.

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

3.7.3.1.5.4 *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 output 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.

3.7.3.1.5.5 *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.

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

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

3.7.3.1.8 *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 *GLONASS Channel of Standard Accuracy (CSA) (L1)*

Note.— In this section, the term GLONASS refers to all satellites in the constellation. Standards relating only to GLONASS-M satellites are qualified accordingly.

3.7.3.2.1 *Space and control segment accuracy*

Note.— The following accuracy Standards do not include atmospheric or receiver errors as described in Attachment D, 4.2.2.

3.7.3.2.1.1 *Positioning accuracy*. The GLONASS CSA position errors shall not exceed the following limits:

	Global average 95% of the time	Worst site 95% of the time
Horizontal position error	19 m (62 ft)	44 m (146 ft)
Vertical position error	29 m (96 ft)	93 m (308 ft)

3.7.3.2.1.2 *Time transfer accuracy*. The GLONASS CSA time transfer errors shall not exceed 700 nanoseconds 95 per cent of the time.

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

a) range error of any satellite — 30 m (98.43 ft);

b) range rate error of any satellite — 0.04 m (0.12 ft) per second;

c) range acceleration error of any satellite — 0.013 m (0.039 ft) per second squared;

d) root-mean-square range error over all satellites — 7 m (22.97 ft).

3.7.3.2.2 *Availability*. The GLONASS CSA availability shall be as follows:

a) ≥99 per cent horizontal service availability, average location (44 m, 95 per cent threshold);

b) ≥99 per cent vertical service availability, average location (93 m, 95 per cent threshold);

c) ≥90 per cent horizontal service availability, worst-case location (44 m, 95 per cent threshold);

d) ≥90 per cent vertical service availability, worst-case location (93 m, 95 per cent threshold).

3.7.3.2.3 *Reliability*. The GLONASS CSA reliability shall be within the following limits:

a) frequency of a major service failure — not more than three per year for the constellation (global average); and

b) reliability — at least 99.7 per cent (global average).

3.7.3.2.4 *Coverage*. The GLONASS CSA shall cover the surface of the earth up to an altitude of 2 000 km.

Note.— Guidance material on GLONASS accuracy, availability, reliability and coverage is given in Attachment D, 4.2.

3.7.3.2.5 *RF characteristics*

Note.— Detailed RF characteristics are specified in Appendix B, 3.2.1.1.

3.7.3.2.5.1 *Carrier frequency.* Each GLONASS satellite shall broadcast CSA navigation signal at its own carrier frequency in the L1 (1.6 GHz) frequency band using frequency division multiple access (FDMA).

Note 1.— GLONASS satellites may have the same carrier frequency but in this case they are located in antipodal slots of the same orbital plane.

Note 2.— GLONASS-M satellites will broadcast an additional ranging code at carrier frequencies in the L2 (1.2 GHz) frequency band using FDMA.

3.7.3.2.5.2 *Signal spectrum.* GLONASS CSA signal power shall be contained within a ±5.75 MHz band centred on each GLONASS carrier frequency.

3.7.3.2.5.3 *Polarization*. The transmitted RF signal shall be right-hand circularly polarized.

3.7.3.2.5.4 *Signal power level*. Each GLONASS satellite shall broadcast CSA 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 output of a 3 dBi linearly polarized antenna is within the range of –161 dBW to –155.2 dBW for all antenna orientations orthogonal to the direction of propagation.

Note 1.— The power limit of 155.2 dBW is based on the predetermined characteristics of a user antenna, atmospheric losses of 0.5 dB and an error of an angular position of a satellite that does not exceed one degree (in the direction causing the signal level to increase).

Note 2.— GLONASS-M satellites will also broadcast a ranging code on L2 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 output of a 3 dBi linearly polarized antenna is not less then –167 dBW for all antenna orientations orthogonal to the direction of propagation.

3.7.3.2.5.5 *Modulation*

3.7.3.2.5.5.1 Each GLONASS satellite shall transmit at its carrier frequency the navigation RF signal using a BPSK-modulated binary train. The phase shift keying of the carrier shall be performed at π-radians with the maximum error ±0.2 radian. The pseudo-random code sequence shall be repeated each millisecond.

3.7.3.2.5.5.2 The modulating navigation signal shall be generated by the Modulo-2 addition of the following three binary signals:

a) ranging code transmitted at 511 kbits/s;

b) navigation message transmitted at 50 bits/s; and

c) 100 Hz auxiliary meander sequence.

3.7.3.2.6 *GLONASS time.* GLONASS time shall be referenced to UTC(SU) (as maintained by the National Time Service of Russia).

3.7.3.2.7 *Coordinate system*. The GLONASS coordinate system shall be PZ-90.

Note.— Conversion from the PZ-90 coordinate system used by GLONASS to the WGS-84 coordinates is defined in Appendix B, 3.2.5.2.

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

a) satellite time of transmission;

b) satellite position;

c) satellite health;

d) satellite clock correction;

e) time transfer to UTC; and

f) constellation status.

Note.— Structure and contents of data are specified in Appendix B, 3.2.1.2 and 3.2.1.3, respectively.

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.

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.

3.7.3.4.2 *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*. The SBAS service area shall be a defined area within an SBAS coverage area where SBAS meets the requirements of 3.7.2.4 and supports the corresponding approved operations.

Note 1.— The coverage area is that area within which the SBAS broadcast can be received (e.g. the geostationary satellite footprints).

Note 2.— 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.— After 2005, when the upper GLONASS frequencies are vacated, another type of SBAS may be introduced using some of these frequencies.

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 *Signal power level*. Each SBAS satellite 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 output 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.

3.7.3.4.4.4 *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 1.— Except where specifically annotated, GBAS Standards and Recommended Practices apply to GBAS and GRAS.

Note 2.— Except where specifically annotated, reference to approach with vertical guidance (APV) means APV-I and APV-II.

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.

Note.— GBAS is intended to support all types of approach, landing, 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 Category I precision approach, approach with vertical guidance, and a GBAS positioning service. In order to achieve interoperability and enable efficient spectrum utilization, it is intended that the data broadcast is the same for all operations.

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.

Note.— Additional GBAS SARPs will be developed to provide ground-based ranging function.

3.7.3.5.3 *Coverage*

3.7.3.5.3.1 *Category I precision approach and approach with vertical guidance.* The GBAS coverage to support each Category I precision approach or approach with vertical guidance 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) 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. This coverage applies between 30 m (100 ft) and 3 000 m (10 000 ft) height above threshold (HAT).

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

3.7.3.5.3.1.1 **Recommendation.—** *For Category I precision approach, the data broadcast as specified in 3.7.3.5.4 should extend down to 3.7 m (12 ft) above the runway surface.*

3.7.3.5.3.1.2 **Recommendation.—** *The data broadcast should be omnidirectional when required to support the intended applications.*

Note.— Guidance material concerning coverage for Category I precision approach and APV is provided in Attachment D, 7.3.

3.7.3.5.3.2 *GBAS positioning service.* The GBAS positioning service area shall be that area 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 coverage 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.— 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.

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 radiated power (ERP) 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 0.350 volts per metre (–35 dBW/m^2) within the GBAS coverage volume. The field strength shall be measured as an average over the period of the synchronization and ambiguity resolution field of the burst. The RF phase offset between the HPOL and any VPOL components shall be such that the minimum signal power defined in Appendix B, 3.6.8.2.2.3 is achieved for HPOL users throughout the coverage volume.

3.7.3.5.4.4.2 *GBAS/E*

3.7.3.5.4.4.2.1 **Recommendation.—** *An elliptically polarized signal should be broadcast whenever practical.*

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 radiated power (ERP) 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 0.221 volts per metre (–39 dBW/m^2) within the GBAS coverage volume. The field strength shall be measured as an average over the period of the synchronization and ambiguity resolution field of the burst. The RF phase offset between the HPOL and VPOL components, shall be such that the minimum signal power defined in Appendix B, 3.6.8.2.2.3 is achieved for HPOL and VPOL users throughout the coverage volume.

Note.— The minimum and maximum field strengths in 3.7.3.5.4.4.1.2 and 3.7.3.5.4.4.2.2 are consistent with a minimum receiver sensitivity of –87 dBm and minimum distance of 200 m (660 ft) from the transmitter antenna for a coverage range of 43 km (23 NM).

3.7.3.5.4.5 *Power transmitted in adjacent channels*. 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, 3.2 (for GLONASS), Appendix B, 3.3 (for combined GPS and GLONASS), 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 and GLONASS 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, Annex 11, Annex 14 and Annex 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.

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. These alert limits are:
   A range of vertical limits for Category I precision approach relates to the range of vertical accuracy requirements.

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	40.0 m (130 ft)	20.0 m (66 ft)
Category I precision approach	40.0 m (130 ft)	15.0 m to 10.0 m (50 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 for Category II and III precision approach operations are under review and will be included at a later date.
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 metre or more radiated from an LF/MF NDB or locator operating within the tolerances permitted by this Annex and in the presence also of an unwanted signal from a direction 90 degrees from the wanted signal and:

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-15. Elements of coordinate systems

$A = \left(\sqrt{A}\right)^2$	Semi-major axis
$n_0 = \sqrt{\dfrac{\mu}{A^3}}$	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)
$v_k = \tan^{-1}\left\{\dfrac{\sin v_k}{\cos v_k}\right\} = \tan^{-1}\left\{\dfrac{\sqrt{1-e^2}\sin E_k/(1-e\cos E_k)}{(\cos E_k - e)/(1-e\cos E_k)}\right\}$	True anomaly
$E_k = \cos^{-1}\left\{\dfrac{e + \cos v_k}{1 + e\cos v_k}\right\}$	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
$\left.\begin{array}{l} x'_k = r_k \cos u_k \\ y'_k = r_k \sin u_k \end{array}\right\}$	Positions in orbital plane
$\Omega_k = \Omega_0 + (\dot{\Omega} - \Omega_e)t_k - \dot{\Omega}_e t_{oe}$	Corrected longitude of ascending node
$\left.\begin{array}{l} x_k = x'_k \cos \Omega_k - y'_k \cos i_k \sin \Omega_k \\ y_k = x'_k \sin \Omega_k - y'_k \cos i_k \cos \Omega_k \\ z_k = y'_k \sin i_k \end{array}\right\}$	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 satellite designated unhealthy by the GPS satellite ephemeris health flag.

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 Global navigation satellite system (GLONASS) channel of standard accuracy (CSA) (L1)

Note.— In this section the term GLONASS refers to all satellites in the constellation. Standards relating only to GLONASS-M satellites are qualified accordingly.

3.2.1 NON-AIRCRAFT ELEMENTS

3.2.1.1 *RF CHARACTERISTICS*

3.2.1.1.1 *Carrier frequencies*. The nominal values of L1 carrier frequencies shall be as defined by the following expressions:

$$f_{k1} = f_{01} + k\Delta f_1$$

where

k = –7, …, 0, 1, …, 6 are carrier numbers (frequency channels) of the signals transmitted by GLONASS satellites in the L1 sub-band;

f_{01} = 1 602 MHz; and

$\Delta f_1 = 0.5625$ MHz.

Carrier frequencies shall be coherently derived from a common on-board time/frequency standard. The nominal value of frequency, as observed on the ground, shall be equal to 5.0 MHz. The carrier frequency of a GLONASS satellite shall be within $\pm 2 \times 10^{-11}$ relative to its nominal value f_k.

Note 1.— The nominal values of carrier frequencies for carrier numbers k are given in Table B-16.

Note 2.— For GLONASS-M satellites, the L2 channel of standard accuracy (CSA) navigation signals will occupy the 1 242.9375 – 1 251.6875 MHz ±0.511 MHz bandwidth as defined by the following expressions:

$$f_{k2} = f_{02} + k\Delta f_2,$$

$$f_{02} = 1\,246 \text{ MHz}; \Delta f_2 = 0.4375 \text{ MHz}.$$

For any given value of k the ratio of carrier frequencies of L1 and L2 sub-bands will be equal to:

$$\frac{f_{k2}}{f_{k1}} = \frac{7}{9}$$

Table B-16. L1 carrier frequencies

Carrier number	H^A_n (see 3.2.1.3.4)	Nominal value of frequency in L1 sub-band (MHz)
06	6	1 605.3750
05	5	1 604.8125
4	4	1 604.2500
3	3	1 603.6875
2	2	1 603.1250
1	1	1 602.5625
0	0	1 602.0000
–1	31	1 601.4375
–2	30	1 600.8750
–3	29	1 600.3125
–4	28	1 599.7500
–5	27	1 599.1875
–6	26	1 598.6250
–7	25	1 598.0625

3.2.1.1.2 *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 provides the accuracy of carrier phase tracking not worse than 0.1 radian (1 sigma).

3.2.1.1.3 *GLONASS pseudo-random code generation*. The pseudo-random ranging code shall be a 511-bit sequence that is sampled at the output of the seventh stage of a 9-stage shift register. The initialisation vector to generate this sequence shall be “111111111”. The generating polynomial that corresponds to the 9-stage shift register shall be:

$$G(x) = 1 + x^5 + x^9.$$

3.2.1.1.4 *Spurious emissions*. The power of the transmitted RF signal beyond the GLONASS allocated bandwidth shall not be more than –40 dB relative to the power of the unmodulated carrier.

Note 1.— GLONASS satellites launched during 1998 to 2005 and beyond use filters limiting out-of-band emissions to the harmful interference limit contained in Recommendation ITU-R RA.769 for the 1 660 – 1 670 MHz band.

Note 2.— GLONASS satellites launched beyond 2005 use filters limiting out-of-band emissions to the harmful interference limit contained in Recommendation ITU-R RA.769 for the 1 610.6 – 1 613.8 MHz and 1 660 – 1 670 MHz bands.

3.2.1.1.5 *Correlation loss*. The loss in the recovered signal power due to imperfections in the signal modulation and waveform distortion shall not exceed 0.8 dB.

Note.— The loss in signal power is the difference between the broadcast power in a 1.022 MHz bandwidth and the signal power recovered by a noise-free, loss-free receiver with 1-chip correlator spacing and a 1.022 MHz bandwidth.

3.2.1.2 *DATA STRUCTURE*

3.2.1.2.1 *General*. The navigation message shall be transmitted as a pattern of digital data which are coded by Hamming code and transformed into relative code. Structurally, the data pattern shall be generated as continuously repeating superframes. The superframe shall consist of the frames and the frames shall consist of the strings. The boundaries of strings, frames and superframes of navigation messages from different GLONASS satellites shall be synchronized within 2 milliseconds.

3.2.1.2.2 *Superframe structure*. The superframe shall have a 2.5-minute duration and shall consist of 5 frames. Within each superframe a total content of non-immediate information (almanac for 24 GLONASS satellites) shall be transmitted.

Note.— Superframe structure with indication of frame numbers in the superframe and string numbers in the frames is shown in Figure B-7.

3.2.1.2.3 *Frame structure*. Each frame shall have a 30-second duration and shall consist of 15 strings. Within each frame the total content of immediate information (ephemeris and time parameters) for given satellite and a part of non-immediate information (almanac) shall be transmitted. The frames 1 through 4 shall contain the part of almanac for 20 satellites (5 satellites per frame) and frame 5 shall contain the remainder of almanac for 4 satellites. The almanac for one satellite shall occupy two strings.

Note.— Frame structures are shown in Figures B-8 and B-9.

3.2.1.2.4 *String structure*. Each string shall have a 2-second duration and shall contain binary chips of data and time mark. During the last 0.3 second within this 2-second interval (at the end of each string) the time mark shall be transmitted. The time mark (shortened pseudo-random sequence) shall consist of 30 chips with a time duration for each chip of 10 milliseconds and having the following sequence:

1 1 1 1 1 0 0 0 1 1 0 1 1 1 0 1 0 1 0 0 0 0 1 0 0 1 0 1 1 0.

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;
$(\Delta t_{SV,i})_{L1}$ = 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 *GLONASS clock correction*. The clock correction for a GLONASS satellite *i* is applied in accordance with the following equation:

$$t = t_{SV,i} + \tau_n(t_b) - \gamma_n(t_b)(t_{SV,i} - t_b) - \delta\Delta t_{SV,i}$$

where

t = SBAS network
$t_{SV,i}$ = the GLONASS satellite time at transmission of message
t_b, $\tau_n(t_b)$, $\gamma_n(t_b)$ = the GLONASS time parameters as defined in 3.2.2.2
$\delta\Delta t_{SV,i}$ = the code phase offset correction

The code phase offset correction $\delta\Delta t_{SV,i}$ for a GLONASS satellite *i* is:

$$\delta\Delta t_{SV,i} = \delta a_{i,f0} + \delta a_{i,f1}(t - t_{i,LT}) + \delta a_{i,GLONASS}$$

where $(t - t_{i,LT})$ is corrected for end-of-day crossover. If the velocity code = 0, then $\delta a_{i,f1} = 0$.

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:

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}_{corrected} = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} + \begin{bmatrix} \delta x_i \\ \delta y_i \\ \delta z_i \end{bmatrix} + \begin{bmatrix} \delta \dot{x}_i \\ \delta \dot{y}_i \\ \delta \dot{z}_i \end{bmatrix} (t - t_{i,LT})$$

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 $\left[\delta \dot{x}_i\ \delta \dot{y}_i\ \delta \dot{z}_i\right]^T = \left[0\ \ 0\ \ 0\right]^T$.

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:

$$RRC_i = \frac{FC_{i,current} - FC_{i,previous}}{t_{i,0f} - t_{i,0f\_previous}}$$

where

$FC_{i,current}$ = the most recent fast correction;
$FC_{i,previous}$ = a previous fast correction;
$t_{i,0f}$ = the time of applicability of $FC_{i,current}$; and
$t_{i,0f\_previous}$ = the time of applicability of $FC_{i,previous}$.

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.

Note.— For GLONASS satellites, the ionospheric correction (IC_i) is to be multiplied by the square of the ratio of the GLONASS to the GPS frequencies ($(f_{GLONASS}/f_{GPS})^2$).

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:

$$HPL_{SBAS} = \begin{cases} K_{H,NPA} \times d_{major} & \text{for en-route through non-precision approach (NPA) modes} \\ K_{H,PA} \times d_{major} & \text{for precision approach (PA) and approach with vertical guidance (APV) modes} \end{cases}$$

$$VPL_{SBAS} = K_{V,PA} \times d_V$$

where

$d_V^2 = \sum_{i=1}^{N} s_{v,i}^2 \sigma_i^2$ = 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;

$d_{xy} = \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma_i^2$ = 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

σ^2_i = $\sigma^2_{i,flt} + \sigma^2_{i,UIRE} + \sigma^2_{i,air} + \sigma^2_{i,tropo}$.

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:

$$S \equiv \begin{bmatrix} S_{x,1} & S_{x,2} & \dots & S_{x,N} \\ S_{y,1} & S_{y,2} & \dots & S_{y,N} \\ S_{v,1} & S_{v,2} & \dots & S_{v,N} \\ S_{t,1} & S_{t,2} & \dots & S_{t,N} \end{bmatrix} = (G^T \times W \times G)^{-1} \times G^T \times W$$

where

G_i = [–cos El_i cos Az_i –cos El_i sin Az_i –sin El_i 1] = i^{th} row of G;

$$W^{-1} = \begin{bmatrix} w_1 & 0 & \dots & 0 \\ 0 & w_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & & \dots & w_i \end{bmatrix};$$

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:

$$K_{H,NPA} = 6.18;$$

$$K_{H,PA} = 6.0; \text{ and}$$

$$K_{V,PA} = 5.33.$$

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:

$$\sigma^2_{i,flt} = \begin{cases} [(\sigma_{i,UDRE})(\delta_{UDRE}) + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er}]^2, & \text{if } RSS_{UDRE} = 0 \text{ (Message Type 10)} \\ [(\sigma_{i,UDRE})(\delta_{UDRE})]^2 + \varepsilon^2_{fc} + \varepsilon^2_{rrc} + \varepsilon^2_{ltc} + \varepsilon^2_{er}, & \text{if } RSS_{UDRE} = 1 \text{ (Message Type 10)} \end{cases}$$

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, $\delta_{UDRE} = 1$.

If fast corrections and long-term corrections/GEO ranging parameters are applied, but degradation parameters are not applied:

$$\sigma^2_{i,flt} = [(\sigma_{i,UDRE})(\delta_{UDRE}) + 8\text{m}]^2$$

3.5.5.6.2.1 *Fast correction degradation.* The degradation parameter for fast correction data is:

$$\varepsilon_{fc} = \frac{a(t - t_u + t_{lat})^2}{2}$$

where

t = the current time;

t_u = (UDREI$_i$ reference time): if 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 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 ith 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 $\varepsilon_{rrc} = 0$.

3.5.5.6.2.2.2 If the RRC ≠ 0 and IODF ≠ 3, the degradation parameter for fast correction data is:

$$\varepsilon_{rrc} = \begin{cases} 0, & \text{if } (IODF_{current} - IODF_{previous}) MOD3 = 1 \\ \left(\dfrac{aI_{fc}}{4} + \dfrac{B_{rrc}}{\Delta t}\right)(t - t_{0f}), & \text{if } (IODF_{current} - IODF_{previous}) MOD3 \neq 1 \end{cases}$$

3.5.5.6.2.2.3 If RRC ≠ 0 and IODF = 3, the degradation parameter for range rate data is:

$$\varepsilon_{rrc} = \begin{cases} 0, & \text{if } \left|\Delta t - \dfrac{I_{fc}}{2}\right| = 0 \\ \left(\dfrac{a\left|\Delta t - \dfrac{I_{fc}}{2}\right|}{2} + \dfrac{B_{rrc}}{\Delta t}\right)(t - t_{0f}), & \text{if } \left|\Delta t - \dfrac{I_{fc}}{2}\right| \neq 0 \end{cases}$$

where

t	=	the current time;
$IODF_{current}$	=	IODF associated with most recent fast correction;
$IODF_{previous}$	=	IODF associated with previous fast correction;
Δt	=	$t_{i,0f} - t_{i,0f\_previous}$; 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:

$$\varepsilon_{ltc} = C_{ltc\_v0}\left[\frac{t - t_{ltc}}{I_{lt-v0}}\right]$$

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

$$I = \begin{bmatrix} i_x \\ i_y \\ i_z \\ 1 \end{bmatrix},$$

$\begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix}$ = the unit vector from the user to the satellite in the WGS-84 ECEF coordinate frame

$C = R^T \cdot R$

$\varepsilon_C = C_{covariance} \cdot SF$

$SF = 2^{\text{scale exponent}-5}$

$R = E \cdot SF$

$$E = \begin{bmatrix} E_{1,1} & E_{1,2} & E_{1,3} & E_{1,4} \\ 0 & E_{2,2} & E_{2,3} & E_{2,4} \\ 0 & 0 & E_{3,3} & E_{3,4} \\ 0 & 0 & 0 & E_{4,4} \end{bmatrix}$$

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:

$$\sigma^2_{UIRE} = F^2_{pp} \times \sigma^2_{UIVE}$$

where

F_{pp} = (as defined in 3.5.5.5.2);

$$\sigma^2_{UIVE} = \sum_{n=1}^{4} W_n \cdot \sigma^2_{n,ionogrid} \text{ or } \sigma^2_{UIVE} = \sum_{n=1}^{3} W_n \cdot \sigma^2_{n,ionogrid}$$

using the same ionospheric pierce point weights (W_n) and grid points selected for the ionospheric correction (3.5.5.5). For each grid point:

$$\sigma^2_{i,\text{ionogrid}} = \begin{cases} (\sigma_{GIVE} + \varepsilon_{iono})^2, & \text{if } RSS_{iono} = 0 \text{ (Type 10 message)} \\ \sigma^2_{GIVE} + \varepsilon^2_{iono}, & \text{if } RSS_{iono} = 1 \text{ (Type 10 message)} \end{cases}$$

where

$$\varepsilon_{iono} = C_{iono\_step}\left\lfloor \frac{t - t_{iono}}{I_{iono}} \right\rfloor + C_{iono\_ramp}(t - t_{iono});$$

t = the current time;
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.

Note.— For GLONASS satellites, both σ_{GIVE} and σ_{IONO} parameters are to be multiplied by the square of the ratio of the GLONASS to the GPS frequencies $(f_{GLONASS}/f_{GPS})^2$.

3.5.5.6.3.2 *Ionospheric corrections.* If SBAS-based ionospheric corrections are not applied, σ^2_{UIRE} is:

$$\sigma^2_{UIRE} = \text{MAX}\left\{\left(\frac{T_{iono}}{5}\right)^2, (F_{pp} \cdot \tau_{vert})^2\right\}$$

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.

3.5.5.6.3.3 *GLONASS clock.* The degradation parameter for GLONASS clock correction is:

$$\varepsilon_{GLONASS\_CLOCK} = C_{GLONASS\_CLOCK} \bullet [t - t_{GLONASS\_CLOCK}]$$

where

t = the current time
$t_{GLONASS\_CLOCK}$ = the time of transmission of the first bit of the timing message (MT12) at the GEO
[sc] = the greatest integer less than sc.

Note 1.— For non-GLONASS satellites $\varepsilon_{GLONASS\_CLOCK} = 0$.

Note 2.— $C_{GLONASS\_CLOCK} = 0.00833$ cm/s.

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
$\dot{X}_G$	17	±40.96 m/s	0.000625 m/s
$\dot{Y}_G$	17	±40.96 m/s	0.000625 m/s
$\dot{Z}_G$	18	±524.288 m/s	0.004 m/s
$\ddot{X}_G$	10	±0.0064 m/s^2	0.0000125 m/s^2
$\ddot{Y}_G$	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
GLONASS indicator	1	0 or 1	1
$\delta a_{i,\ GLONASS}$ (Note 2)	24	$\pm 2.0 \cdot 10^{-8}$ s	$2.0 \cdot 10^{-31}$ s
Spare	50	—	—

Notes.—
1. *All parameters are defined in 3.5.4.8.*
2. *Applies only if SBAS sends GLONASS timing information in message Type 12 (see 3.5.7.4.4, Timing data).*

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-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 *Almanac data*. SBAS shall broadcast almanac data for SBAS satellites (defined in 3.5.4.3) with error less than 150 km (81 NM) of the true satellite position. Unused almanac slots in Type 17 messages shall be coded with a PRN code number of "0". The health and status shall indicate satellite status and the service provider as defined in 3.5.4.3.

3.5.7.1.5 **Recommendation.—** *SBAS should broadcast almanac data for all SBAS satellites, regardless of the service provider.*

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.

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 3.5.8.1.1. 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 and 25 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				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
Timing data	300 s	R (see Note 3)	R (see Note 3)	R (see Note 3)	R (see Note 3)	12
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. Type 12 messages are only required if data are provided for GLONASS satellites.
4. I_{fc} refers to the PA/APV time-out interval for fast corrections, as defined in Table B-57.

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 or APV-II operations, and 8 seconds for an SBAS that supports APV-I 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 3.5.8.1.1. 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 **Recommendation.—** *When the IGP mask is changed, SBAS should repeat the Type 18 message several times before referencing it in a Type 26 message to ensure that users receive the new mask. The same* $IODI_k$ *should be used for all bands.*

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 pseudo-range 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 or APV II (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-229C, 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) and/or 3.2.3.1 (GLONASS receiver). Pseudo-range measurements for each satellite shall be smoothed using carrier measurements and a smoothing filter which deviates less than 0.1 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 0.01 metre per second.

3.5.8.1.1 *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 and all data from that satellite shall be discarded for at least 1 minute. 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. For GLONASS satellites, the receiver shall apply long-term corrections only if the time of reception (t_r) of the GLONASS ephemeris is inside the following IOD validity interval, as defined in 3.5.4.4.1:

$$t_{LT} - L - V \leq t_r \leq t_{LT} - L$$

Note 1.— For SBAS satellites, there is no mechanism that links GEO ranging function data (Type 9 message) and long-term corrections.

Note 2.— This requirement does not imply that the receiver has to stop tracking the SBAS satellite.

3.5.8.1.1.1 The receiver shall use integrity or correction data only if the IODP associated with that data matches the IODP associated with the PRN mask.

3.5.8.1.1.2 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.

3.5.8.1.1.3 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).

3.5.8.1.1.4 The receiver shall apply any regional degradation to the $\sigma^2_{i,UDRE}$ as defined by a Type 27 service message. If a Type 27 message with a new IODS indicates a higher δUDRE for the user location, the higher δUDRE shall be applied immediately. A lower δUDRE in a new Type 27 message shall not be applied until the complete set of messages with the new IODS has been received.

3.5.8.1.1.5 The receiver shall apply satellite-specific degradation to the $\sigma_{i,UDRE}{}^2$ as defined by a Type 28 clock-ephemeris covariance matrix message. The δ_{UDRE} derived from a Type 28 message shall be applied immediately.

3.5.8.1.1.6 In the event of a loss of four successive SBAS messages, the receiver shall no longer support SBAS-based precision approach or APV operations.

3.5.8.1.1.7 The receiver shall not use a broadcast data parameter after it has timed out as defined in Table B-56.

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
GLONASS time offset	12	600 s	600 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

3.5.8.1.1.8 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 8Δt.

3.5.8.1.1.9 The calculation of the RRC shall be reinitialized if a "Do Not Use" or "Not Monitored" indication is received for that satellite.

3.5.8.1.1.10 For SBAS-based precision approach or APV operations, the receiver shall only use satellites with elevation angles at or above 5 degrees.

3.5.8.1.1.11 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.

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 **Recommendation.—** *The almanac data provided by the SBAS should be used for acquisition.*

Note.— Health and status information is provided in the GEO almanac data to support acquisition, but need not be used as a condition for use of that satellite.

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 or to exclude GLONASS satellites based on GLONASS-provided ephemeris health flag as required in 3.2.3.1.1.

Note 1.— In the case of a satellite designated 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 received signal power level (Chapter 3, 3.7.3.1.5.4) under the worst interference environment as defined in 3.7 shall be less than or equal to 0.4 metres, excluding multipath effects, tropospheric and ionospheric residual errors. The RMS of the total airborne contribution to the error in a corrected pseudo-range for a GLONASS satellite at the minimum received signal power level (Chapter 3, 3.2.5.4) under the worst interference environment as defined in 3.7 shall be less than or equal to 0.8 metres, 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 compute and apply long-term corrections, fast corrections, range rate corrections and the broadcast ionospheric corrections. For GLONASS satellites, the ionospheric corrections received from the SBAS shall be multiplied by the square of the ratio of GLONASS to GPS frequencies $(f_{GLONASS}/f_{GPS})^2$.

3.5.8.4.2.2 The receiver shall use a weighted-least-squares position solution.

3.5.8.4.2.3 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 1 sigma deviation less than 0.07 metres.

Note.— A model was developed that meets this requirement. Guidance is provided in Attachment D, 6.7.3.

3.5.8.4.2.4 The receiver shall compute and apply horizontal and vertical protection levels defined in 3.5.5.6. In this computation, σ_{tropo} shall be:

$$\frac{1}{\sqrt{0.002+\sin^2(\theta_i)}}\times 0.12\text{ m}$$

where θ_i is the elevation angle of the i^{th} satellite.

In addition, σ_{air} shall satisfy the condition that a normal distribution with zero mean and a standard deviation equal to σ_{air} bounds the error distribution for residual aircraft pseudo-range 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 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.

3.5.8.4.2.5 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.— 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 in that it contains the SBAS HAL and VAL for the particular approach procedure. For approaches conducted using SBAS pseudo-range corrections, the service provider ID in the FAS data block is the same as the service provider ID broadcast as part of the health and status information in Type 17 message. 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.

3.5.8.4.3 *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, 6.7.3.

Table B-71. 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°
Spare	5	—	—
$\sigma_{vert\_iono\_gradient}$	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
$K_{md\_e\_POS,GPS}$	8	0 to 12.75	0.05
$K_{md\_e,GPS}$	8	0 to 12.75	0.05
$K_{md\_e\_POS,GLONASS}$	8	0 to 12.75	0.05
$K_{md\_e,GLONASS}$	8	0 to 12.75	0.05
Additional data block 2 (if provided)			
Additional data block length	8	2 to 255	1
Additional data block number	8	2 to 255	1
Additional data parameters	Variable	—	—

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 indicates APV-I (APD coded as 0)		0 to 50.8 m	0.2 m
(2) when associated approach performance designator does not indicate APV-I (APD 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

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. GBAS — GLONASS accuracy requirement parameters

Ground accuracy designator letter	θ_n (degrees)	a_0 (metres)	a_1 (metres)	θ_0 (degrees)	a_2 (metres)
A	≥ 5	1.58	5.18	14.3	0.078
B	≥ 5	0.3	2.12	15.5	0.078
C	> 35	0.3	1.68	15.5	0.042
	5 to 35	0.48	0	—	0.042

3.6.7.1.1.2 The RMS of the ground subsystem contribution to the corrected pseudo-range accuracy for SBAS satellites shall be:

$$RMS_{pr\_gnd} \leq \frac{1.8}{\sqrt{M}} \text{(metres)}$$

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 *Category I precision approach and APV.* For a GBAS ground subsystem that provides the Category I precision approach or APV, 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 3.6.7.2.6 and the integrity risk associated with the monitoring in 3.6.7.3.

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 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 Category I precision approach or APV protection level and, if additional data block 1 is broadcast, the ephemeris error position bound.

3.6.7.1.2.1.1.1 The GBAS ground subsystem maximum time-to-alert shall be less than or equal to 3 seconds when Type 1 messages are broadcast.

Note.— The 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.

3.6.7.1.2.1.1.2 The GBAS ground subsystem maximum time-to-alert shall be less than or equal to 5.5 seconds when Type 101 messages are broadcast.

3.6.7.1.2.1.1.3 For Category I precision approach, 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.

3.6.7.1.2.1.1.4 For APV, 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.

3.6.7.1.2.1.2 *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 3.6.7.2.6 and the integrity risk associated with the monitoring in 3.6.7.3.

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-to-alert. 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.

3.6.7.1.2.1.2.1 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 the Category I precision approach or APV, the protection level integrity risk shall be less than 5×10^{-8} per approach.

Note.— The Category I precision approach and APV protection level integrity risk is the integrity risk due to undetected errors in position 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; and

b) faulted measurement conditions defined in 3.6.5.5.1.2.

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 Category I precision approach and APV.* 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 *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 rates*

3.6.7.2.1.1.1 A GBAS ground subsystem that supports Category I precision approach or APV-II shall broadcast Type 1 messages. A GBAS ground subsystem that does not support Category I precision approach or APV-II shall broadcast either Type 1 or Type 101 messages. A GBAS ground subsystem shall not broadcast both Type 1 and Type 101 messages.

Table B-86. Interference thresholds for pulsed interference

	GPS and SBAS	GLONASS
Frequency range	1 575.42 MHz ± 10 MHz	1 592.9525 MHz to 1 609.36 MHz
Interference threshold (Pulse peak power)	–20 dBW	–20 dBW
Pulse width	≤125 μs	≤250 μs
Pulse duty cycle	≤1%	≤1%

Table B-87. Minimum antenna gain — GPS/SBAS and GLONASS

Elevation angle degrees	Minimum gain dBic
0	–7.5
5	–4.5
10	–3
15 to 90	–2

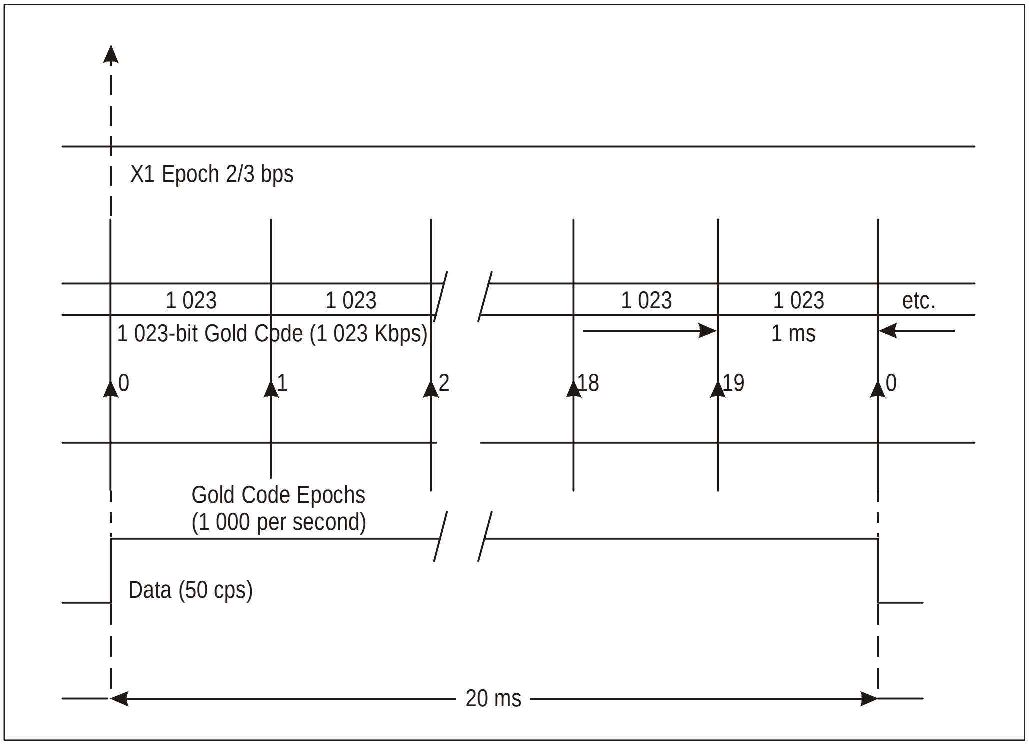

Figure B-1. C/A code timing relationships

SUBFRAME 1	TLM	HOW	GPS week number, SV accuracy and health
SUBFRAME 2	TLM	HOW	Ephemeris parameters
SUBFRAME 3	TLM	HOW	Ephemeris parameters
SUBFRAME 4 (25 pages)	TLM	HOW	Almanac and health for satellites 25–32, special messages, satellite configuration, flags, ionospheric and UTC
SUBFRAME 5 (25 pages)	TLM	HOW	Almanac and health for satellites 1–24 and almanac reference time and GPS week number

Figure B-2. Frame structure

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 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 on-board 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 non-precision 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 $6 \times g_i$/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 and alert limits 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.

3.2.8 Specific alert limits have been defined for each augmentation system. For GBAS, technical provision has been made to broadcast the alert limit to aircraft. GBAS standards require the alert limit of 10 m. For SBAS, technical provisions have been made to standardize the alert limit through an updateable database (see *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System (GPS/WAAS) Airborne Equipment* (RTCA/DO-229C)).

3.2.9 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 (Attachment D, 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.

3.2.9.1 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).

3.2.9.2 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 (Attachment D, 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)

3.2.10 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-229C, as amended by United States FAA TSO-C145A/TSO-C146A (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 RTCA/DO-253A, as amended by United States FAA TSO-C161 and TSO-C162 (or equivalent).

3.3 Integrity and time-to-alert

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 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.

3.3.7 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.

3.3.8 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.

3.3.9 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.

3.3.10 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.

3.4 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 satellite-based 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, 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, constitute continuity failures. 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 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*, October 2001, and Interface Control Document (ICD)-GPS-200C.*

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: designed in accordance with ICD-GPS-200C; uses a 5-degree masking angle; 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; generates a position and time solution from data broadcast by all satellites in view; compensates for dynamic Doppler shift effects on nominal SPS ranging signal carrier phase and C/A code measurements; excludes GPS unhealthy satellites from the position solution; uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and loses track in the event that a GPS satellite stops transmitting C/A code. The time transfer accuracy applies to a stationary receiver operating at a surveyed location. 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.

4.1.2 *Accuracy*. The 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. The accuracy is derived based on the worst two of 24 satellites being removed from the constellation and a 6-metre constellation RMS SIS user range error (URE).

4.1.3 *Range domain accuracy*. 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. Exceedance of the range error limit constitutes a major service failure as described in 4.1.6. 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. The root-mean-square range error accuracy is the average of the RMS URE of all satellites over any 24-hour 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 6-metre RMS SIS URE. The standards are restricted to range domain errors allocated to space and control segments.

4.1.4 *Availability*. 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 36-metre horizontal 95 per cent threshold; a 77-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 the worst combination of two satellites out of service.

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. Twenty-four operational satellites are available 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 24 nominal plane/slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (yearly averaged).

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 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. As defined in Chapter 3, 3.7.3.1.1.3 a), the range error limit is the larger of:

a) 30 m; or

b) 4.42 times the URA, not to exceed 150 m.

4.1.7 *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 GLONASS

Note.— Additional information concerning GLONASS can be found in the GLONASS Interface Control Document *published by Scientific Coordination Information Center, Russian Federation Ministry of Defence, Moscow.*

4.2.1 *Assumptions.* The performance standard is based upon the assumption that a representative channel of standard accuracy (CSA) receiver is used. A representative receiver has the following characteristics: designed in accordance with GLONASS ICD; uses a 5-degree masking angle; accomplishes satellite position and geometric range computations in the most current realization of the PZ-90 and uses PZ-90 – WGS-84 transformation parameters as indicated in Appendix B, 3.2.5.2; generates a position and time solution from data broadcast by all satellites in view; compensates for dynamic Doppler shift effects on nominal CSA ranging signal carrier phase and standard accuracy signal measurements; excludes GLONASS unhealthy satellites from the position solution; uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and loses track in the event that a GLONASS satellite stops transmitting standard accuracy code. The time transfer accuracy applies to a stationary receiver operating at a surveyed location.

4.2.2 *Accuracy*. 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. The accuracy is derived based on the worst two of 24 satellites being removed from the constellation and a 7-metre constellation RMS SIS user range error (URE).

4.2.3 *Range domain accuracy*. Range domain accuracy is conditioned by the satellite indicating a healthy status and transmitting standard accuracy 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. Exceeding the range error limit constitutes a major service failure as described in 4.2.6. 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. The root-mean-square range error accuracy is the average of the RMS URE of all satellites over any 24-hour 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 7-metre RMS SIS URE. The standards are restricted to range domain errors allocated to space and control segments.

4.2.4 *Availability*. 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 44-metre horizontal 95 per cent threshold and a 93-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 the worst combination of two satellites out of service.

4.2.4.1 *Relationship to augmentation availability*. The availability of ABAS, GBAS and SBAS does not directly relate to the GLONASS availability defined in Chapter 3, 3.7.3.2.2. Availability analysis is based on an assumed satellite constellation and the probability of having a given number of satellites. Twenty-four operational satellites are available in 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 24 nominal plane/slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (yearly averaged).

4.2.5 *Reliability*. Reliability is the percentage of time over a specified time interval that the instantaneous CSA SIS URE is maintained within the range error limit, at any given point within the coverage area, for all healthy GLONASS satellites. The reliability standard is based on a measurement interval of one year and the average of daily values within the coverage area. The 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).

4.2.6 *Major service failure*. A major service failure is defined as a condition over a time interval during which a healthy GLONASS satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the range error limit of 30 m (as defined in Chapter 3, 3.7.3.2.1.3 a)) and/or failures in radio frequency characteristics of the CSA ranging signal, navigation message structure or navigation message contents that deteriorate the CSA receiver's ranging signal reception or processing capabilities.

4.2.7 *Coverage*. The GLONASS CSA supports the terrestrial coverage area, which is from the surface of the earth up to an altitude of 2 000 km.

4.2.8 *GLONASS time*. GLONASS time is generated based on GLONASS Central Synchronizer time. Daily instability of the Central Synchronizer hydrogen clock is not worse than 5×10^{-14}. The difference between GLONASS time and UTC(SU) is within 1 millisecond. The navigation message contains the requisite data to relate GLONASS time to UTC(SU) within 0.7 microsecond.

4.2.8.1 *Transformation of GLONASS-M current data information into common form*. A satellite navigation message contains current data information in N_T parameter. It could be transformed into the common form by the following algorithm:

a) Current year number J in the four-year interval is calculated:

If $1 \le N_T \le 366$; J = 1;
If $367 \le N_T \le 731$; J = 2;
If $732 \le N_T \le 1096$; J = 3;
If $1097 \le N_T \le 1461$; J = 4.

b) Current year in common form is calculated by the following formula:

$Y = 1996 + 4 (N_4 – 1) + (J – 1)$.

c) Current day and month (dd/mm) are extracted from the reference table stored in user equipment ROM. The table interrelates N_T parameter and common form dates.

4.2.9 *GLONASS coordinate system*. The GLONASS coordinate system is PZ-90 as described in *Parameters of Earth, 1990 (PZ-90)*, published by the Topographic Service, Russian Federation Ministry of Defence, Moscow.

4.2.9.1 PZ-90 parameters include fundamental geodetic constants, dimensions of the common terrestrial ellipsoid, the characteristics of the gravitational field of the earth, and the elements of the Krasovsky ellipsoid (coordinate system 1942) orientation relative to the common terrestrial ellipsoid.

4.2.9.2 By definition, the coordinate system PZ-90 is a geocentric Cartesian space system whose origin is located at the centre of the earth's body. The Z-axis is directed to the Conventional Terrestrial Pole as recommended by the International Earth Rotation Service. The X-axis is directed to the point of intersection of the earth's equatorial plane and zero meridian established by the Bureau International de l'Heure. The Y-axis completes the right-handed coordinate system.

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 receiver

4.4.1 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.

4.4.2 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 comprises one or more service areas, each capable of supporting 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 Figure D-1* shows the initial coverage areas and approximated initial service areas for three SBASs: the Wide Area Augmentation System (WAAS), the European Geo-stationary Navigation Overlay Service (EGNOS) and the Multifunction Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS).

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. The only potential for integrity to be compromised is if there is a satellite ephemeris error that cannot be observed by the SBAS ground network while it creates an unacceptable error outside the service area. For alert limits of 0.3 NM specified for non-precision approach and greater, this is very unlikely.

6.2.4 Each State is responsible for defining SBAS service areas and approving SBAS-based operations within its airspace. In some cases, States will field SBAS ground infrastructure linked to an existing SBAS. This would be required to achieve APV or precision approach performance. In other cases, States may simply approve service areas and SBAS-based 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

* All figures are located at the end of the attachment.

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 $\sigma^2_{air} = \sigma^2_{receiver} + \sigma^2_{multipath}$, where it is assumed that $\sigma_{receiver}$ is defined by the RMS_{pr_air} specified for GBAS Airborne Accuracy Designator A equipment, and $\sigma_{multipath}$ 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*. 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 or non-RNSS sources. The minimum aircraft equipment (e.g. RTCA/DO-229D) is required to operate with a minimum signal strength of –158.5 dBW in the presence of non-RNSS interference (Appendix B, 3.7) and an aggregate RNSS noise density of –173 dBm/Hz. Receivers may not have reliable tracking performance for a signal strength between –158.5 dBW and –161 dBW (minimum signal strength as specified in the SARPs) in the presence of interference from RNSS or non-RNSS sources.

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-229C, 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 Attachment D, 8.11. For GEOs for which the on-board RF filter characteristics have been published in RTCA/DO229D, 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/DO229D. 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*. RTCA/DO-229D, Appendix A, provides two methods for SBAS PRN code generation.

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, 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-229C, 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 *GLONASS issue of data.* Since the existing GLONASS design does not provide a uniquely defined identifier for sets of ephemeris and clock data, SBAS will use a specific mechanism to avoid any ambiguity in the application of the broadcast corrections. This mechanism is explained in Figure D-3. The definitions of the latency time and validity interval along with the associated coding requirements can be found in Appendix B, section 3.5.4. The user can apply the long-term corrections received only if the set of GLONASS ephemeris and clock data used on board have been received within the validity interval.

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 Table D-1. It is the same as the GBAS FAS data block defined in Appendix B, section 3.6.4.5, with the exception that the SBAS FAS data block also contains the HAL and VAL to be used for the approach procedure as described in 6.3.4.

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. The FAS block for a particular approach procedure is described in Appendix B, 3.6.4.5.1 and Table B-66.

Table D-1. SBAS 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 (Note 1)	6	0 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 threshold crossing height (TCH) (Note 2)	15	0 to 1 638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)
Approach TCH units selector	1	–	–
Glide path angle (GPA)	16	0 to 90.0°	0.01°
Course width at threshold (Note 1)	8	80.0 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2 032 m	8 m
Horizontal alert limit (HAL)	8	0 to 50.8 m	0.2 m
Vertical alert limit (VAL) (Note 3)	8	0 to 50.8 m	0.2 m
Final approach segment CRC	32	–	–

Note 1.— When the runway number is set to 00, then the course width field is ignored and the course width is 38 m.

Note 2.— Information can be provided in either feet or metres as indicated by the approach TCH unit sector.

Note 3.— VAL of 0 indicates that the vertical deviations are not to be used (i.e. a lateral guidance only approach).

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 coverage providing the aircraft with approach data, corrections and integrity information for GNSS satellites in view. All international aircraft supporting APV should maintain approach data within a database on board the aircraft. The Type 4 message must be broadcast when the ground subsystem supports Category I precision approaches. The Type 4 message must also be broadcast when the ground subsystem supports APV approaches if the approach data is not required by the State to be maintained in the on-board database.

Note.— Allocation of performance requirements between the GBAS subsystems and allocation methodology can be found in RTCA/DO-245, Minimum Aviation System Performance Standards for the Global Positioning System/Local Area Augmentation System (GPS/LAAS). Minimum Operational Performance Standards for GRAS airborne equipment are under development by RTCA.

7.1.2 GBAS ground subsystems provide two services: the approach service and the GBAS positioning service. The approach service provides deviation guidance for FASs in Category I precision approach, APV, and NPA within the operational coverage area. The GBAS positioning service provides horizontal position information to support RNAV operations within the service area. The two 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.

7.1.3 A primary 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 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*. There are multiple configurations possible of GBAS ground subsystems conforming to the GNSS Standards, such as:

a) configuration that supports Category I precision approach only;

b) a configuration that supports Category I precision approach and APV, and also broadcasts the additional ephemeris error position bound parameters;

c) a configuration that supports Category I precision approach, APV, and the GBAS positioning service, while also broadcasting the ephemeris error position bound parameters referred to in b); and

d) a configuration that supports APV and the GBAS positioning service, and is used within a GRAS.

7.1.5 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 APV 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 APV operations 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. This permits detection and mitigation of measurement errors and receiver faults.

7.1.6 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-253A 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 GRAS MOPS, will be compatible with GBAS ground subsystems. SARPs-compliant GBAS receivers may not be able to decode the FAS data correctly for APV transmitted from GBAS ground subsystems. These receivers will apply the FASLAL and FASVAL as if conducting a Category I precision approach. Relevant operational restrictions have to apply to ensure the safety of the operation.

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 vertically-polarized 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.

7.2 RF characteristics

7.2.1 *Frequency and time slot planning*

7.2.1.1 *Performance factors*

7.2.1.1.1 The geographical separation between a candidate GBAS station and existing VOR or GBAS installations must consider the following factors:

a) the coverage volume, minimum field strength and effective radiated power (ERP) of the candidate GBAS including the GBAS positioning service, if provided. The minimum requirements for coverage and field strength are found in Chapter 3, 3.7.3.5.3 and 3.7.3.5.4.4, respectively. The ERP is determined from these requirements;

b) the coverage volume, minimum field strength and ERP 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.

7.2.1.1.2 The nominal link budget for VDB is shown in Table D-3. The figures in the table assume a 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 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.

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.

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
$\lvert f_{VOR} - f_{VDB} \rvert = 25$ kHz	0
$\lvert f_{VOR} - f_{VDB} \rvert = 50$ kHz	–34
$\lvert f_{VOR} - f_{VDB} \rvert = 75$ kHz	–46
$\lvert f_{VOR} - f_{VDB} \rvert = 100$ kHz	–65

Table D-3. Nominal VDB link budget

VDB link elements	Vertical component link budget at coverage edge	Horizontal component link budget 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 radiated power (dBm)	43	47

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:

$$P_{Uallowed}(\text{dBm}) = (P_{D,min}\ (\text{dBm}) - [D/U]_{required}\ (\text{dB}))$$

The undesired signal power P_U converted to dBm is:

$$P_U(\text{dBm}) = (Tx_U\ (\text{dBm}) - L\ (\text{dB}))$$

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:

$$L(\text{dB}) \geq ([D/U]_{required}\ (\text{dB}) + Tx_U(\text{dBm}) - P_{D,min}\ (\text{dBm}))$$

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 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.

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 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*. Until compatibility criteria are developed for GBAS VDB and ILS, VDB cannot be assigned to channels below 112.025 MHz. If there is an ILS with a high assigned frequency at the same airport as a VDB with a frequency near 112 MHz, it is necessary to consider ILS and VDB compatibility. 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 sensitivity. For GBAS equipment with transmitter power of up to 150 W (GBAS/E, 100 W for horizontal component and 50 W for vertical component) or 100 W (GBAS/H), the 16th channel (and beyond) will be below –106 dBm at a distance of 200 m from the VDB transmitter, including allowing for a +5 dB positive reflection. This –106 dBm figure assumes a –86 dBm localizer signal at the ILS receiver input and a minimum 20 dB signal-to-noise ratio.

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 sensitivity.

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.— No geographic transmitter restrictions are expected between co-frequency, adjacent time slots provided the undesired VDB transmitting antenna is located at least 200 m from areas where the desired signal is at minimum field strength.

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)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 25 kHz	126	774 km (418 NM)	732 km (395 NM)	599 km (323 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 50 kHz	92	351 km (189 NM)	309 km (166 NM)	176 km (94 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 75 kHz	80	344 km (186 NM)	302 km (163 NM)	169 km (91 NM)
$\lvert f_{Desired} - f_{Undesired} \rvert$ = 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.

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 component and 50 W for vertical component), the 64th channel (and beyond) will be below –120 dBm at a distance of 200 m from the VDB transmitter including allowing for a +5 dB positive reflection. For GBAS/H equipment with a transmitter maximum power of 100 W, the 32nd channel (and beyond) will be below –120 dBm at a distance of 200 m from the VDB transmitter including allowing for a +5 dB positive reflection, and a 10 dB polarization isolation. It must be noted that due to differences in the VDB and VDL transmitter masks, separate analysis must be performed to ensure VDL does not interfere with the VDB.

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 coverage 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 coverage 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 coverage volume.

7.3 Coverage

7.3.1 The GBAS coverage to support approach services is depicted in Figure D-4. 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. Where practical, it is operationally advantageous to provide valid guidance along the visual segment of an approach.

7.3.2 The coverage required to support the GBAS positioning service is dependent upon the specific operations intended. The optimal coverage for this service is intended to be omnidirectional in order to support operations using the GBAS positioning service that are performed outside of the precision approach coverage volume. Each State is responsible for defining a service area 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.

7.3.3 The limit on the use of the GBAS positioning service information is given by the Maximum Use Distance (D_{max}), which defines the range within which the required integrity is assured and differential corrections can be used for either the positioning service or precision approach. D_{max} however does not delineate the coverage area where field strength requirements specified in Chapter 3, 3.7.3.5.4.4 are met nor matches this area. Accordingly, operations based on the GBAS positioning service can be predicated only in the coverage area(s) (where the field strength requirements are satisfied) within the D_{max} range.

7.3.4 As the desired coverage area 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 coverage. 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-4A 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-5.

Note.— Additional information on the data structure of the VHF data broadcast is given in RTCA/DO-246B, 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 Category I 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 signal-in-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 signal-in-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. The protection level integrity risk allocation covers rare fault-free 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 the aircraft receiver are taken into account. This is described in more detail in the following paragraphs.

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 Category I precision approach and APV, 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 operation. 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 Category I precision approach and APV, a lateral error bound (LEB) and a vertical error bound (VEB) are defined. For the positioning service a horizontal ephemeris error bound (HEB) is defined.

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.

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; and

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”, “GLONASS”, “POS, GPS” or “POS, GLONASS”), the maximum use distance for the differential corrections (D_{max}), 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 (or minimum detectable error (MDE)) that it can detect. The relationship between the P parameter and the MDE for a particular satellite can be approximated by $P_i = MDE_i/R_i$ 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. Being dependent on satellite geometry, the P parameters values are slowly varying. However, it is not a requirement for the ground subsystem to dynamically vary P. Static P parameters could be sent if they properly ensure integrity. In this latter case, the availability would be slightly degraded. Generally, as MDE 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 MDE;

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 achieves small MDEs; and

c) *Ephemeris data monitoring*. This approach involves comparing the broadcast ephemeris over consecutive satellite orbits. There is an assumption that the only threat of failure is due to a failure in ephemeris upload from the constellation ground control network. Failures due to uncommanded satellite manoeuvres must be sufficiently improbable to ensure that this approach provides the required integrity.

7.5.10.1 The monitor design (for example, its achieved MDE) 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 The GLONASS control segment monitors the ephemeris and time parameters, and in case of any abnormal situation it starts to input the new and correct navigation message. The ephemeris and time parameter failures do not exceed 70 m of range errors. The failure rate of GLONASS satellite including the ephemeris and time parameter failures does not exceed 4×10^{-5} per satellite per hour.

7.5.11 A typical GBAS ground subsystem processes measurements from 2 to 4 reference receivers installed in the immediate vicinity of the reference point. The aircraft receiver is protected against a large error or fault condition in a single reference receiver by computing and applying the B parameters from the Type 1 or Type 101 message to compare data from the various reference receivers. 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.

7.6 Continuity of service

7.6.1 *Ground continuity and integrity designator*. The ground continuity and integrity designator (GCID) provides a classification of GBAS ground subsystems. The ground subsystem meets the requirements of Category I precision approach or APV when GCID is set to 1. GCID 2, 3 and 4 are intended to support future operations with requirements that are more stringent than Category I operations. 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 specified in Appendix B to Chapter 3, 3.6.7.1.3 in order to support Category I precision approach and APV. 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 Category I precision approach or APV required continuity ($1\text{-}3.3 \times 10^{-6}$/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.

7.7 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 an APV are obtained from the on-board database.

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.

7.10 GBAS identification

The GBAS identification (ID) is used to uniquely identify a GBAS ground subsystem broadcasting on a given frequency within the coverage region 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

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.

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-6.

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 ILS requirements.

7.11.3.1 *Lateral deviation definition*. Figure D-6 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. 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 GBAS 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 relationship between GPA and the vertical deviation sensitivity is equivalent to the glide path displacement sensitivity provided by 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-7. 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 airport should be chosen to reduce the potential for confusion and misidentification. The approach identification should appear on the published charts that describe the approach.

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 should be located so that an unobstructed line-of-sight exists from the antenna to any point within the coverage 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. In order to provide the required coverage for multiple FASs at a given airport, and in order to allow flexibility in VBD antenna siting, the actual coverage volume 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 volume. A suitable antenna height trade-off must be made based on analysis, to ensure the signal strength requirements are met within the entire volume. Consideration should also be given to the effect of terrain features and buildings on the multipath environment.

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 coverage area. 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 coverage 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 coverage area that adhere to the specified minimum and maximum data broadcast rates and field strengths, without exceeding the receiver's ability to adapt to transmission-to-transmission variations in signal strength in a given slot. To avoid receiver processing issues concerning lost or duplicated messages, all transmissions of the Type 1 or Type 101 message, or linked pair of Type 1 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 or two assigned slots of each frame for each antenna. Type 1 or Type 101 messages are broadcast once per frame, per antenna. This allows for reception of one or two Type 1 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 for Category I precision approach 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-8.

7.13.2 The vertical alert limit for Category I precision approach 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 APV procedures associated with channel numbers 40 001 to 99 999 are computed in the same manner as for APV procedures using SBAS as given in Attachment D, 3.2.8.

7.14 Monitoring and maintenance actions

7.14.1 Specific monitoring requirements or built-in tests may be necessary 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 coverage area 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 3 seconds.

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 a period equal to or greater than 3 seconds will be detected.

7.14.2 Upon detection of a failure, and in the absence of a backup transmitter, termination of the VDB service should be considered if the signal cannot be used reliably within the coverage area 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.

7.15 Examples of VDB messages

7.15.1 Examples of the coding of VDB messages are provided in Tables D-7 through D-10. 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.

7.15.5 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. The Type 2 message includes additional data block 1.

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 block 2

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.

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.

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.

8.11.6 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 Table D-13.

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.

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	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 ≤ 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. GLONASS tracking constraints for early-late correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing range (chips)	Instantaneous correlator spacing range (chips)	Differential group delay
1	7 < BW ≤ 9 MHz	0.05 – 1.0	0.045 – 1.1	≤100 ns
2	9 < BW ≤ 15 MHz	0.05 – 0.2	0.045 – 0.22	≤ 100 ns
3	15 < BW ≤ 18 MHz	0.05 – 0.1	0.045 – 0.11	≤ 100 ns

Table D-13. GPS tracking constraints for double-delta correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing range (chips)	Instantaneous correlator spacing range (chips)	Differential group delay
1	(-50 × X) + 12 < BW < 7 MHz	0.1 – 0.2	0.09 – 0.22	≤ 600 ns
	2 < BW ≤ 7 MHz	0.2 – 0.6	0.18 – 0.65	
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 ≤ 16 MHz	0.07 – 0.24	0.06 – 0.26	≤ 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

14.2.2 When conducted to a parallel secondary runway these operations require the airborne system to compute both lateral and vertical guidance. Decision heights may be limited by the MLS signal coverage and computed guidance accuracy achievable.

14.2.3 MLS ground equipment meeting Level 2 service objectives may be sufficient for computed centre line operations when:

a) the operation is conducted to Category I decision heights or higher; and

b) reference path construction and computed lateral and vertical guidance by the airborne equipment meets the same level of integrity as the MLS receiver for a basic MLS operation.

14.2.4 When computed centre line operations are conducted below Category I decision heights, the service level of the MLS ground equipment must be commensurate with the decision height used. Identically the airborne equipment providing computed guidance must have the same integrity as the basic receiver would have to conduct MLS basic operations to an equivalent decision height.

14.3 MLS curved path procedures

14.3.1 These procedures must be examined carefully to determine the level of service needed for the ground equipment. With MLS curved path operations the most stringent requirement for integrity and continuity of service may be based on a portion of the flight path prior to decision height. In these situations, the integrity and continuity of service objectives of the MLS ground equipment cannot be predicated solely on the category of the landing. For operations where the obstacle clearance requirements place a high degree of reliance on guidance accuracy, the ground equipment integrity and continuity of service objectives can be determined using the risk tree method described in Attachment A. The following requirements must also be considered:

a) airborne equipment must have the capability of reference path construction and computed vertical and lateral guidance with positive control in the turns; and

b) airborne integrity and continuity of service must be consistent with the degree of reliance on the guidance accuracy necessary to safely execute the procedure.

15. Application of simplified MLS configurations

15.1 While SARPs for basic and expanded MLS configurations state a single signal-in-space standard, a simplified MLS configuration is defined in Chapter 3, 3.11.3.4 to permit the use of MLS in support of performance-based navigation operations.

15.2 Relaxed coverage, accuracy, and monitor limits do not exceed those specified in Chapter 3, 3.1 for a Facility Performance Category I ILS. Such a simplified MLS configuration is capable of supporting Category I operations with significant reductions in size of azimuth and elevation antennas. Further reductions in equipment complexity can be achieved as the CMN requirement is waived for applications in support of approach and landing operations which do not require autopilot coupling.

15.3 The simplified MLS is compatible with the basic and expanded MLS configurations.

Table G-1. System power budget
(±40° azimuth coverage; 0–20° vertical coverage; 37 km (20 NM) range)

Power budget items (Note 1)	Approach azimuth function					Elevation function			Back azimuth function			
			Angle BW				Angle BW			Angle BW		
	DPSK	Clearance	1°	2°	3° (Note 2)	DPSK	1°	2°	DPSK	1°	2°	3°
Signal required at aircraft (dBm)	–95.0	–93.5	–91.2	–85.2	–81.7	–95.0	–93.5	–90.0	–95.0	–93.5	–88.2	–84.7
Propagation loss (dB) (Notes 3, 4)	139.0	139.0	139.0	139.0	139.0	138.1	138.1	138.1	133.9	133.9	133.9	133.9
Probabilistic losses (dB):												
a) Polarization	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
b) Rain	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	1.3	1.3	1.3	1.3
c) Atmospheric	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
d) Horizontal multipath	3.0	3.0	0.5	0.5	0.5	3.0	–	–	3.0	0.5	0.5	0.5
e) Vertical multipath	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	2.0
Root – sum – square (RSS) total a) through e) (dB)	4.3	4.3	3.1	3.1	3.1	4.3	2.5	2.5	3.9	2.5	2.5	2.5
Horizontal and vertical pattern loss (dB)	–	1.0	2.0	2.0	2.0	–	6.0	6.0	–	2.0	2.0	2.0
Monitor margin (dB)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Antenna gain (dB) (Note 5)	–	–13.3	–23.0	–20.0	–18.0	–	–20.8	–17.8	–	–23.0	–20.0	–18.0
Net power gain at coverage extremes (dB)	–7.3	–	–	–	–	–7.3	–	–	–7.3	–	–	–
Required transmitter power (dBm)	42.5	39.0	31.4	40.4	41.1	41.6	33.8	40.3	37.1	23.4	31.7	37.2
Example 20 watt transmitter (dBm)	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.0
Transmitter power margin (dB)	0.5	4.0	11.6	2.6	1.9	1.4	9.2	2.7	5.9	19.6	11.3	5.8

NOTES.—

1. Losses and antenna gains are representative values.
2. High data rate for 3° azimuth beamwidth will reduce required transmitter power by 4.8 dB.
3. Distance to azimuth antenna taken as 41.7 km (22.5 NM).
4. Distance to back azimuth antenna taken as 23.1 km (12.5 nautical miles).
5. The required transmitter power can be reduced by using higher efficiency antennas.