COVER SHEET TO AMENDMENT 89

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)	20 July 2008	20 November 2008
Amendment 84 (adopted by the Council on 6 March 2009)	20 July 2009	19 November 2009
Amendment 85 (adopted by the Council on 26 February 2010)	12 July 2010	18 November 2010
Amendment 86 (adopted by the Council on 4 March 2011)	18 July 2011	17 November 2011
Amendment 87 (adopted by the Council on 7 March 2012)	16 July 2012	15 November 2012
Amendment 88-A (did not affect Volume I)	—	—
Amendment 88-B (adopted by the Council on 27 February 2013)	15 July 2013	13 November 2014
Amendment 89 (adopted by the Council on 3 March 2014) Replacement pages (*iv*), (*xix*), 3-60 to 3-62, 3-66, APP B-18, APP B-45, APP B-57, APP B-65 to APP B-113F, ATT D-5 to ATT D-18D, ATT D-51 and ATT D-53	14 July 2014	13 November 2014

Transmittal note

Amendment 89

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 89 which becomes applicable on 13 November 2014.

   a) Page (*iv*) — Table of Contents

   b) Page (*xix*) — Foreword

   c) Pages 3-60 to 3-62, 3-66 — Chapter 3

   d) Pages APP B-18, APP B-45, APP B-57 and APP B-65 to APP B-113F — Appendix B

   e) Pages ATT D-5 to ATT D-18D, ATT D-51 and ATT D-53 — Attachment D

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

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ATTACHMENTS

Amendment	*Source(s)*	*Subject(s)*	*Adopted Effective Applicable*
85	Navigation Systems Panel (NSP)	a) improvement of the instrument landing system (ILS) localizer signal quality at aerodromes where building or terrain reflections cause interference of the reflected signal with the desired signal; b) extension of global navigation satellite system (GNSS) Category I approach operations; and c) evolution of the GLObal NAvigation Satellite System (GLONASS).	26 February 2010 12 July 2010 18 November 2010
86	Navigation Systems Panel (NSP)	Changes reflecting experience gained with initial implementation of the global navigation satellite system (GNSS) ground-based augmentation system (GBAS).	4 March 2011 18 July 2011 17 November 2011
87	Navigation Systems Panel (NSP)	a) changes to satellite-based augmentation system (SBAS) received signal power requirements; b) introduction of two new SBAS service provider identifiers; c) changes to the encoding of the runway number field in the final approach segment (FAS) data block; and d) changes to GNSS antenna gain requirements.	7 March 2012 16 July 2012 15 November 2012
88-A	—	No change.	—
88-B	Secretariat supported by the Approach Classification Task Force (ACTF) in coordination with the Aerodromes Panel (AP), the Instrument Flight Procedures Panel (IFPP), the Navigation Systems Panel (NSP) and the Operations Panel (OPSP)	Mapping of Annex 10 system performance requirements to the new approach classification in Annex 6	27 February 2013 15 July 2013 13 November 2014
89	Navigation Systems Panel (NSP) Working Group of the Whole	Global Navigation Satellite System (GNSS); editorial amendments	3 March 2014 14 July 2014 13 November 2014

* Did not affect any Standards or Recommended Practices.

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

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

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

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

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

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

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

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

3.7.2 General

3.7.2.1 *Functions*

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

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

3.7.2.2 *GNSS elements*

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

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

b) Global Navigation Satellite System (GLONASS) that provides the Channel of Standard Accuracy (CSA) navigation signal as defined in 3.7.3.2;

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

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

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

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

g) aircraft GNSS receiver as defined in 3.7.3.6.

3.7.2.3 *Space and time reference*

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

Note 1.— SARPs for WGS-84 are contained in Annex 4, Chapter 2, Annex 11, Chapter 2, Annex 14, Volumes I and II, Chapter 2 and Annex 15, Chapter 3.

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

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

3.7.2.4 *Signal-in-space performance*

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

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

3.7.3 GNSS elements specifications

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

3.7.3.1.1 *Space and control segment accuracy*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

3.7.3.1.7 *Radio frequency (RF) characteristics*

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

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

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

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

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

3.7.3.1.7.4 *Signal power level*. Each GPS satellite shall broadcast SPS navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at an elevation angle of 5 degrees or higher, the level of the received RF signal at the 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.

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

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

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

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

a) satellite time of transmission;

b) satellite position;

c) satellite health;

d) satellite clock correction;

e) propagation delay effects;

f) time transfer to UTC; and

g) constellation status.

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

3.7.3.2 *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	5 m (17 ft)	12 m (40 ft)
Vertical position error	9 m (29 ft)	25 m (97 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 — 18 m (59.7 ft);

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 (0.023 ft) per second squared;

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*

3.7.3.4.4.3.1 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.

3.7.3.4.4.3.2 Each SBAS satellite placed in orbit after 31 December 2013 shall broadcast navigation signals with sufficient power such that, at all unobstructed locations near the ground from which the satellite is observed at or above the minimum elevation angle for which a trackable GEO signal needs to be provided, the level of the received RF signal at the output of the antenna specified in Appendix B, Table B-88, is at least –164.0 dBW.

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

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

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.

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
$\Omega_k = \Omega_0 + \left(\dot{\Omega} - \dot{\Omega}_e\right)t_k - \dot{\Omega}_e t_{oe}$	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 marginal or unhealthy satellite.

Note.— Conditions indicating that a satellite is "healthy", "marginal" or "unhealthy" can be found in the United States Department of Defense, Global Positioning System – Standard Positioning Service – Performance Standard, *4th Edition, September 2008, Section 2.3.2.*

3.1.3.1.2 *Satellite tracking*. The receiver shall provide the capability to continuously track a minimum of four satellites and generate a position solution based upon those measurements.

3.1.3.1.3 *Doppler shift*. The receiver shall be able to compensate for dynamic Doppler shift effects on nominal SPS signal carrier phase and C/A code measurements. The receiver shall compensate for the Doppler shift that is unique to the anticipated application.

3.1.3.1.4 *Resistance to interference*. The receiver shall meet the requirements for resistance to interference as specified in Chapter 3, 3.7.

3.1.3.1.5 *Application of clock and ephemeris data*. The receiver shall ensure that it is using the correct ephemeris and clock data before providing any position solution. The receiver shall monitor the IODC and IODE values, and to update ephemeris and clock databased upon a detected change in one or both of these values. The SPS receiver shall use clock and ephemeris data with corresponding IODC and IODE values for a given satellite.

3.1.4 TIME

GPS time shall be referenced to a UTC (as maintained by the U.S. Naval Observatory) zero time-point defined as midnight on the night of 5 January 1980/morning of 6 January 1980. The largest unit used in stating GPS time shall be 1 week, defined as 604 800 seconds. The GPS time scale shall be maintained to be within 1 microsecond of UTC (Modulo 1 second) after correction for the integer number of leap seconds difference. The navigation data shall contain the requisite data for relating GPS time to UTC.

3.2 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

3.5.4.7 *Degradation parameters.* Degradation parameters, whenever used, shall be as follows:

Fast correction degradation factor indicator (ai_i): an indicator of the fast correction degradation factor (a_i) for the i^{th} satellite as described in Table B-34.

Note.— The ai_i is also used to define the time-out interval for fast corrections, as described in 3.5.8.1.2.

System latency time (t_{lat}): the time interval between the origin of the fast correction degradation and the user differential range estimate indicator (UDREI) reference time.

B_{rrc}: a parameter that bounds the noise and round-off errors when computing the range rate correction degradation as in 3.5.5.6.2.2.

C_{ltc_lsb}: the maximum round-off error due to the resolution of the orbit and clock information.

C_{ltc_v1}: the velocity error bound on the maximum range rate difference of missed messages due to clock and orbit rate differences.

I_{ltc_v1}: the update interval for long-term corrections if velocity code = 1 (3.5.4.4.1).

C_{ltc_v0}: a parameter that bounds the difference between two consecutive long-term corrections for satellites with a velocity code = 0.

I_{ltc_v0}: the minimum update interval for long-term messages if velocity code = 0 (3.5.4.4.1).

C_{GEO_lsb}: the maximum round-off error due to the resolution of the orbit and clock information.

C_{GEO_v}: the velocity error bound on the maximum range rate difference of missed messages due to clock and orbit rate differences.

I_{GEO}: the update interval for GEO ranging function messages.

Table B-34. Fast correction degradation factor

Fast correction degradation factor indicator (ai_i)	Fast correction degradation factor (a_i)
0	0.0 mm/s^2
1	0.05 mm/s^2
2	0.09 mm/s^2
3	0.12 mm/s^2
4	0.15 mm/s^2
5	0.20 mm/s^2
6	0.30 mm/s^2
7	0.45 mm/s^2
8	0.60 mm/s^2
9	0.90 mm/s^2
10	1.50 mm/s^2
11	2.10 mm/s^2
12	2.70 mm/s^2
13	3.30 mm/s^2
14	4.60 mm/s^2
15	5.80 mm/s^2

C_{er}: the bound on the residual error associated with using data beyond the precision approach/approach with vertical guidance time-out.

C_{iono_step}: the bound on the difference between successive ionospheric grid delay values.

I_{iono}: the minimum update interval for ionospheric correction messages.

$C_{iono\ ramp}$: the rate of change of the ionospheric corrections.

RSS_{UDRE}: the root-sum-square flag for fast and long-term correction residuals.

Coding: 0 = correction residuals are linearly summed
1 = correction residuals are root-sum-squared

RSS_{iono}: the root-sum-square flag for ionospheric residuals.

Coding: 0 = correction residuals are linearly summed
1 = correction residuals are root-sum-squared

$C_{covariance}$: the term which is used to compensate for quantization effects when using the Type 28 message.

Note 1.— The parameters a_i and t_{lat} are broadcast in Type 7 message. All other parameters are broadcast in Type 10 message.

Note 2.— If message Type 28 is not broadcast, $C_{covariance}$ is not applicable.

3.5.4.8 *Time parameters.* Time parameters, whenever used, shall be as follows:

UTC standard identifier: an indication of the UTC reference source as defined in Table B-35.

GPS time-of-week count: the number of seconds that have passed since the transition from the previous GPS week (similar to the GPS parameter in 3.1.1.2.6.1 but with a 1-second resolution).

Table B-35. UTC standard identifier

UTC standard identifier	UTC standard
0	UTC as operated by the Communications Research Laboratory, Tokyo, Japan
1	UTC as operated by the U.S. National Institute of Standards and Technology
2	UTC as operated by the U.S. Naval Observatory
3	UTC as operated by the International Bureau of Weights and Measures
4	Reserved for UTC as operated by a European laboratory
5 to 6	Spare
7	UTC not provided

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:

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

where

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

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

where

T_{iono} = the ionospheric delay estimated by the chosen model (GPS correction or other model);
F_{pp} = (as defined in 3.5.5.5.2);

$$\tau_{vert} = \begin{cases} 9 \text{ m}, & 0 \le |\phi_{pp}| \le 20 \\ 4.5 \text{ m}, & 20 < |\phi_{pp}| \le 55 \text{; and} \\ 6 \text{ m}, & 55 < |\phi_{pp}| \end{cases}$$

ϕ_{pp} = latitude of the ionospheric pierce point.

3.5.5.6.3.3 *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-53. Type 28 clock-ephemeris covariance matrix

Data content	Bits used	Range of values	Resolution
IODP	2	0 to 3	1
For two satellites			
PRN mask number	6	0 to 51	1
Scale exponent	3	0 to 7	1
$E_{1,1}$	9	0 to 511	1
$E_{2,2}$	9	0 to 511	1
$E_{3,3}$	9	0 to 511	1
$E_{4,4}$	9	0 to 511	1
$E_{1,2}$	10	±512	1
$E_{1,3}$	10	±512	1
$E_{1,4}$	10	±512	1
$E_{2,3}$	10	±512	1
$E_{2,4}$	10	±512	1
$E_{3,4}$	10	±512	1

Notes.—
1. The parameters PRN mask number and IODP are defined in 3.5.4.1.
2. All other parameters are defined in 3.5.4.10.

3.5.7 NON-AIRCRAFT ELEMENTS

Note 1.— Depending on the level of service offered by a particular SBAS, different functions can be implemented as described in Chapter 3, 3.7.3.4.2.

Note 2.— The parameters that are referred to in this section are defined in 3.5.4.

3.5.7.1 *GENERAL*

3.5.7.1.1 *Required data and broadcast intervals*. SBAS shall broadcast the data required for the supported functions as shown in Table B-54. If the SBAS broadcasts data that are not required for a particular function, the requirements for that data supporting other functions shall apply. The maximum interval between broadcasts for all data of each data type provided shall be as defined in Table B-54.

3.5.7.1.2 *SBAS radio frequency monitoring.* The SBAS shall monitor the SBAS satellite parameters shown in Table B-55 and take the indicated action.

Note.— SBAS may broadcast null messages (Type 63 messages) in each time slot for which no other data are broadcast.

3.5.7.1.3 *"Do Not Use"*. SBAS shall broadcast a "Do Not Use" message (Type 0 message) when necessary to inform users not to use the SBAS satellite ranging function and its broadcast data.

3.5.7.1.4 The Doppler shift in the GEO satellite signal seen at any fixed location within the GEO footprint for any GEO shall not exceed ±450 Hz.

Note.— This maximum Doppler shift corresponds approximately to the maximum GEO satellite orbit inclination that can be supported by the coding ranges for Type 9 and Type 17 messages.

3.5.7.1.5 *Geostationary orbit (GEO) ranging function parameters.* Each SBAS satellite shall broadcast geostationary orbit (GEO) ranging function parameters (defined in 3.5.4.2).

Note.— It is necessary to broadcast geostationary orbit ranging function parameters even when a ranging function is not provided, so that airborne receivers may implement a positive identification of the broadcasting SBAS satellite. When ranging is not provided, the accuracy of the Type 17 data (and Type 9 data) only needs to support the acquisition of the satellite.

3.5.7.1.5.1 The error in the Doppler shift of a GEO satellite derived from any Type 9 message that has not timed out, with respect to the true GEO Doppler shift seen at any fixed location within the GEO footprint, shall not exceed ±210 Hz.

3.5.7.1.6 *Almanac data.* Each SBAS satellite shall broadcast almanac data (defined in 3.5.4.3) for all SBAS satellites of the same service provider.

3.5.7.1.6.1 The error in the estimated position of the satellite derived from any Type 17 message broadcast within the previous 15 minutes, with respect to the true satellite position, shall not exceed 3 000 km.

3.5.7.1.6.2 The separation distance between the estimated position of the satellite derived from any Type 17 message broadcast within the previous 15 minutes and the position of the satellite derived from the GEO ranging parameters in any Type 9 message that has not timed out shall not exceed 200 km.

3.5.7.1.6.3 The error in the Doppler shift of a GEO satellite derived from any Type 17 message broadcast within the previous 15 minutes, with respect to the true GEO Doppler shift seen at any fixed location within the GEO footprint, shall not exceed ±210 Hz.

3.5.7.1.6.4 SBAS shall not broadcast almanac data for any SBAS satellite from a different service provider for which the position estimated from the almanac data broadcast within the previous 15 minutes would be within 200 km of the position of any of its own GEOs as derived from the GEO ranging parameters from any Type 9 message that has not timed out.

3.5.7.1.6.5 Where the estimated position of a GEO satellite providing a ranging function, derived from the Type 17 message broadcast within the previous 15 minutes, is within 200 km of the position of another GEO satellite of the same service provider, derived from a Type 9 message for this GEO that has not timed out, the GEO UDRE value shall be set sufficiently large to account for the possibility that a user could misidentify the PRN of the GEO providing the ranging function.

3.5.7.1.6.6 The health and status parameter shall indicate the satellite status and the service provider identifier, as defined in 3.5.4.3.

3.5.7.1.6.7 Unused almanac slots in Type 17 messages shall be coded with a PRN code number of "0".

3.5.7.1.6.8 The service provider shall ensure the correctness of the service provider ID broadcast in any almanac.

3.5.7.2 *Ranging function.* If an SBAS provides a ranging function, it shall comply with the requirements contained in this section in addition to the requirements of 3.5.7.1.

3.5.7.2.1 *Performance requirements*

Note.— See Chapter 3, 3.7.3.4.2.1.

3.5.7.2.2 *Ranging function data*. SBAS shall broadcast ranging function data such that the SBAS satellite position error projected on the line-of-sight to any user in the satellite footprint is less than 256 metres. Each SBAS satellite shall broadcast a URA representing an estimate of the standard deviation of the ranging errors referenced to SNT.

3.5.7.3 *GNSS satellite status function*. If an SBAS provides a satellite status function, it shall also comply with the requirements contained in this section.

Note.— An SBAS may be able to provide integrity on some GPS satellites that are designated either marginal or unhealthy.

3.5.7.3.1 *Performance of satellite status functions*. Given any valid combination of active data, the probability of a horizontal error exceeding the HPL_{SBAS} (as defined in 3.5.5.6) for longer than 8 consecutive seconds shall be less than 10^{-7} in any hour, assuming a user with zero latency.

Note.— Active data is defined to be data that have not timed out per 3.5.8.1.2. This requirement includes core satellite constellation(s) and SBAS failures.

3.5.7.3.2 *PRN mask and Issue of data — PRN (IODP)*. SBAS shall broadcast a PRN mask and IODP (Type 1 message). The PRN mask values shall indicate whether or not data are being provided for each GNSS satellite. The IODP shall change when there is a change in the PRN mask. The change of IODP in Type 1 messages shall occur before the IODP changes in any other message. The IODP in Type 2 to 5, 7, 24 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	R	R	R	9
Fast correction degradation	120 s		R*	R	R	7
Degradation parameters	120 s				R	10
Ionospheric grid mask	300 s				R	18
Ionospheric corrections, GIVEI	300 s				R	26
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.

Table B-55. SBAS radio frequency monitoring

Parameter	Reference	Alarm limit	Required action
Signal power level	Chapter 3, 3.7.3.4.4.3	minimum = –161 dBW maximum = –153 dBW (*Note 2*)	Minimum: cease ranging function (*Note 1*). Maximum: cease broadcast.
Modulation	Chapter 3, 3.7.3.4.4.5	monitor for waveform distortion	Cease ranging function (*Note 1*).
SNT-to-GPS time	Chapter 3, 3.7.3.4.5	N/A (*Note 3*)	Cease ranging function unless URA reflects error.
Carrier frequency stability	3.5.2.1	N/A (*Note 3*)	Cease ranging function unless σ^2_{UDRE} and URA reflect error.
Code/frequency coherence	3.5.2.4	N/A (*Note 3*)	Cease ranging function unless σ^2_{UDRE} and URA reflect error.
Maximum code phase deviation	3.5.2.6	N/A (*Notes 2* and *3*)	Cease ranging function unless σ^2_{UDRE} and URA reflect error.
Convolutional encoding	3.5.2.9	all transmit messages are erroneous	Cease broadcast.

Notes.—

1. *Ceasing the ranging function is accomplished by broadcasting a URA and σ^2_{UDRE} of "Do Not Use" for that SBAS satellite.*
2. *These parameters can be monitored by their impact on the received signal quality (C/N_0 impact), since that is the impact on the user.*
3. *Alarm limits are not specified because the induced error is acceptable, provided it is represented in the σ^2_{UDRE} and URA parameters. If the error cannot be represented, the ranging function must cease.*

3.5.7.3.2.1 **Recommendation.—** *When the PRN mask is changed, SBAS should repeat the Type 1 message several times before referencing it in other messages to ensure that users receive the new mask.*

3.5.7.3.3 *Integrity data*. If SBAS does not provide the basic differential correction function, it shall transmit fast corrections, long-term corrections and fast correction degradation parameters coded to zero for all visible satellites indicated in the PRN mask.

3.5.7.3.3.1 If SBAS does not provide the basic differential correction function, SBAS shall indicate that the satellite is unhealthy ("Do Not Use") if the pseudo-range error exceeds 150 metres.

3.5.7.3.3.2 If SBAS does not provide the basic differential correction function, SBAS shall indicate that the satellite is "Not Monitored" if the pseudo-range error cannot be determined.

3.5.7.3.3.3 If SBAS does not provide the basic differential correction function, SBAS shall transmit a $UDREI_i$ of 13 if the satellite is not "Do Not Use" or "Not Monitored".

3.5.7.3.3.4 The $IODF_j$ parameter in Type 2 to 5, 6 or 24 messages shall be equal to 3.

3.5.7.4 *Basic differential correction function*. If an SBAS provides a basic differential correction function, it shall comply with the requirements contained in this section in addition to the GNSS satellite status function requirements defined in 3.5.7.3.

3.5.7.4.1 *Performance of basic differential correction function*. Given any valid combination of active data, the probability of a horizontal error exceeding the HPL_{SBAS} (as defined in 3.5.5.6) for longer than 8 consecutive seconds shall be less than 10^{-7} in any hour, assuming a user with zero latency.

Note.— Active data is defined to be data that has not timed out per 3.5.8.1.2. This requirement includes core satellite constellation(s) and SBAS failures.

3.5.7.4.2 *Long-term corrections*. Except for SBAS satellites from the same service provider, SBAS shall determine and broadcast long-term corrections for each visible GNSS satellite (see *Note*) indicated in the PRN mask (PRN mask value equal to "1"). The long-term corrections shall be such that the core satellite constellation(s) satellite position error projected on the line-of-sight to any user in the satellite footprint after application of these long-term corrections is less than 256 metres. For each GLONASS satellite, SBAS shall translate satellite coordinates into WGS-84 as defined in 3.5.5.2 prior to determining the long-term corrections. For each GPS satellite, the broadcast IOD shall match both the GPS IODE and 8 LSBs of IODC associated with the clock and ephemeris data used to compute the corrections (3.1.1.3.1.4 and 3.1.1.3.2.2). Upon transmission of a new ephemeris by a GPS satellite, SBAS shall continue to use the old ephemeris to determine the fast and long-term error corrections for at least 2 minutes and not more than 4 minutes. For each GLONASS satellite, SBAS shall compute and broadcast an IOD that consists of a latency and a validity interval as defined in 3.5.4.4.1.

Note.— The criteria for satellite visibility include the locations of reference stations and the achieved mask angle at those locations.

3.5.7.4.2.1 **Recommendation.—** *To ensure accurate range rate corrections, SBAS should minimize discontinuities in the satellite ephemerides after application of long-term corrections.*

3.5.7.4.3 *Fast corrections*. SBAS shall determine fast corrections for each visible GNSS satellite indicated in the PRN mask (PRN mask value equal to "1"). Unless the IODF = 3, each time any fast correction data in Type j (j = 2, 3, 4 or 5) message changes, the $IODF_j$ shall sequence "0, 1, 2, 0, ...".

Note.— If there is an alarm condition, the $IODF_j$ may equal 3 (see 3.5.7.4.5).

3.5.7.4.4 *Timing data*. If data are provided for GLONASS, SBAS shall broadcast the timing message (Type 12 message) including GLONASS time offset as defined in Table B-44.

3.5.7.4.5 *Integrity data*. For each satellite for which corrections are provided, SBAS shall broadcast integrity data ($UDREI_i$ and, optionally, Type 27 or 28 message data to calculate δUDRE) such that the integrity requirement in 3.5.7.4.1 is met. If the fast corrections or long-term corrections exceed their coding range, SBAS shall indicate that the satellite is unhealthy ("Do Not Use"). If $\sigma^2_{i,UDRE}$ cannot be determined, SBAS shall indicate that the satellite is "Not Monitored".

If Type 6 message is used to broadcast $\sigma^2_{i,UDRE}$, then:

a) the $IODF_j$ shall match the $IODF_j$ for the fast corrections received in Type j message to which the $\sigma^2_{i,UDRE}$ apply; or

b) the $IODF_j$ shall equal 3 if the $\sigma^2_{i,UDRE}$ apply to all valid fast corrections received in Type j message which have not timed out.

3.5.7.4.6 *Degradation data*. SBAS shall broadcast degradation parameters (Type 7 message) to indicate the applicable time out interval for fast corrections and ensure that the integrity requirement in 3.5.7.4.1 is met.

3.5.7.5 *Precise differential correction function*. If SBAS provides a precise differential correction function, it shall comply with the requirements contained in this section in addition to the basic differential correction function requirements in 3.5.7.4.

3.5.7.5.1 *Performance of precise differential correction function*. Given any valid combination of active data, the probability of an out-of-tolerance condition for longer than the relevant time-to-alert shall be less than 2×10^{-7} during any approach, assuming a user with zero latency. The time-to-alert shall be 5.2 seconds for an SBAS that supports precision approach 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 3.5.8.1.2. This requirement includes core satellite constellation(s) and SBAS failures.

Note 2.— Subsequent messages can be transmitted at the normal update rate.

3.5.7.5.2 *Ionospheric grid point (IGP) mask*. SBAS shall broadcast an IGP mask and $IODI_k$ (up to 11 Type 18 messages, corresponding to the 11 IGP bands). The IGP mask values shall indicate whether or not data are being provided for each IGP. If IGP Band 9 is used, then the IGP mask values for IGPs north of 55°N in Bands 0 through 8 shall be set to "0". If IGP Band 10 is used, then the IGP mask values for IGPs south of 55°S in Bands 0 through 8 shall be set to "0". The $IODI_k$ shall change when there is a change of IGP mask values in the k^{th} band. The new IGP mask shall be broadcast in a Type 18 message before it is referenced in a related Type 26 message. The $IODI_k$ in Type 26 message shall equal the $IODI_k$ broadcast in the IGP mask message (Type 18 message) used to designate the IGPs for which data are provided in that message.

3.5.7.5.2.1 **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 *GEO satellite acquisition*. The receiver shall be able to acquire and track GEO satellites for which a stationary receiver at the user receiver location would experience a Doppler shift as large as ±450 Hz.

3.5.8.1.2 *Conditions for use of data*. The receiver shall use data from an SBAS message only if the CRC of this message has been verified. Reception of a Type 0 message from an SBAS satellite shall result in deselection of that satellite 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.

3.5.8.1.2.1 *SBAS satellite identification.* Upon acquisition or re-acquisition of an SBAS satellite, the receiver shall not use SBAS satellite data unless the calculated separation between the satellite position derived from its GEO ranging function parameters and the satellite position derived from the almanac message most recently received from the same service provider within the last 15 minutes is less than 200 km.

Note.— This check ensures that a receiver will not mistake one SBAS satellite for another due to cross-correlation during acquisition or re-acquisition.

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

3.5.8.1.2.3 The receiver shall use SBAS-provided ionospheric data (IGP vertical delay estimate and $GIVEI_i$) only if the $IODI_k$ associated with that data in a Type 26 message matches the $IODI_k$ associated with the relevant IGP band mask transmitted in a Type 18 message.

3.5.8.1.2.4 The receiver shall use the most recently received integrity data for which the $IODF_j$ equals 3 or the $IODF_j$ matches the $IODF_j$ associated with the fast correction data being applied (if corrections are provided).

3.5.8.1.2.5 The receiver shall apply any regional degradation to the $\sigma^2_{i,UDRE}$ 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.

3.5.8.1.2.6 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.

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

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

3.5.8.1.2.9 The receiver shall not use a fast correction if Δt for the associated RRC exceeds the time-out interval for fast corrections, or if the age of the RRC exceeds 8Δt.

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

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

3.5.8.1.2.12 The receiver shall no longer support SBAS-based precision approach or APV operation using a particular satellite if the $UDREI_i$ received is greater than or equal to 12.

Table B-56. Data time-out intervals

Data	Associated message types	En-route, terminal, NPA time-out	Precision approach, APV time-out
Clock-ephemeris covariance matrix	28	360	240
SBAS in test mode	0	N/A	N/A
PRN mask	1	600 s	600 s
UDREI	2 to 6, 24	18 s	12 s
Fast corrections	2 to 5, 24	(see Table B-57)	(see Table B-57)
Long-term corrections	24, 25	360 s	240 s
GEO ranging function data	9	360 s	240 s
Fast correction degradation	7	360 s	240 s
Degradation parameters	10	360 s	240 s
Ionospheric grid mask	18	1 200 s	1 200 s
Ionospheric corrections, GIVEI	26	600 s	600 s
Timing data	12	86 400 s	86 400 s
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

3.5.8.2 *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 provided in the GEO almanac data does not override or invalidate data provided in other SBAS messages. The use of bits 0 to 2 by airborne equipment is optional; there are no requirements covering their usage.

3.5.8.3 *GNSS satellite status function*. The receiver shall exclude satellites from the position solution if they are identified as “Do Not Use” by SBAS. If SBAS-provided integrity is used, the receiver shall not be required to exclude GPS satellites based on the GPS-provided ephemeris health flag as required in 3.1.3.1.1 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 marginal or unhealthy by the core satellite constellation(s) health flag, SBAS may be able to broadcast ephemeris and clock corrections that will allow the user to continue using the satellite.

Note 2.— If satellites identified as “Not Monitored” by SBAS are used in the position solution, integrity is not provided by SBAS. ABAS or GBAS may be used to provide integrity, if available.

3.5.8.4 *BASIC AND PRECISE DIFFERENTIAL FUNCTIONS*

3.5.8.4.1 *Core satellite constellation(s) ranging accuracy*. The root-mean-square (1 sigma) of the total airborne contribution to the error in a corrected pseudo-range for a GPS satellite at the minimum received signal power level (Chapter 3, 3.7.3.1.7.4) under the worst interference environment as defined in 3.7 shall be less than or equal to 0.4 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, 6.5.4.

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 The parameters that define the approach path for a single precision approach or APV shall be contained in the FAS data block.

Note 1.— The FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). The local level plane for the approach is a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). Local vertical for the approach is normal to the WGS-84 ellipsoid at the LTP/FTP. The glide path intercept point (GPIP) is where the final approach path intercepts the local level plane.

Note 2.— For SBAS, FAS data blocks are stored in airborne databases. The format of the data for validation of a cyclic redundancy check is shown in Attachment D, 6.6. It differs from the GBAS FAS data block in 3.6.4.5.

3.5.8.4.2.5.1 FAS data block parameters shall be as follows (see Table B-57A):

Operation type: straight-in approach procedure or other operation types.

Coding: 0 = straight-in approach procedure
1 to 15 = spare

SBAS service provider ID: indicates the service provider associated with this FAS data block.

Coding: See Table B-27.
14 = FAS data block is to be used with GBAS only.
15 = FAS data block can be used with any SBAS service provider.

Airport ID: the three- or four-letter designator used to designate an airport.

Coding: Each character is coded using the lower 6 bits of its IA-5 representation. For each character, b_1 is transmitted first, and 2 zero bits are appended after b_6, so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 “space” are used. The rightmost character is transmitted first. For a three-character airport ID, the rightmost (first transmitted) character shall be IA-5 “space”.

Runway number: the runway orientation, point-in-space final approach course, or SBAS circling only procedure course rounded to the nearest 10 degrees and truncated to two characters.

Coding: 01 to 36 = runway number

Note.— For heliport operations, the runway number value is the integer nearest to one tenth of the final approach course, except when that integer is zero, in which case the runway number is 36.

Runway letter: the one-letter designator used, as necessary, to differentiate between parallel runways.

Coding: 0 = no letter
1 = R (right)
2 = C (centre)
3 = L (left)

Approach performance designator: this field is not used by SBAS.

Route indicator: a “blank” or the one-letter identifier used to differentiate between multiple procedures to the same runway end.

Note.— Procedures are considered to be different even if they only differ by the missed approach segment.

Coding: The letter is coded using bits b_1 through b_5 of its IA-5 representation. Bit b_1 is transmitted first. Only upper case letters, excluding “I” and “O”, or IA-5 “space” (blank) are used. Blank indicates that there is only one procedure to the runway end. For multiple procedures to the same runway end, the route indicator is coded using a letter starting from Z and moving backward in the alphabet for additional procedures.

Reference path data selector (RPDS): this field is not used by SBAS.

Table B-57A. Final approach segment (FAS) data block

Data content	Bits used	Range of values	Resolution
Operation type	4	0 to 15	1
SBAS service provider ID	4	0 to 15	1
Airport ID	32	—	—
Runway number	6	01 to 36	1
Runway letter	2	—	—
Approach performance designator	3	0 to 7	1
Route indicator	5	—	—
Reference path data selector	8	0 to 48	1
Reference path identifier	32	—	—
LTP/FTP latitude	32	±90.0°	0.0005 arcsec
LTP/FTP longitude	32	±180.0°	0.0005 arcsec
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m
ΔFPAP latitude	24	±1.0°	0.0005 arcsec
ΔFPAP longitude	24	±1.0°	0.0005 arcsec
Approach TCH (*Note 1*)	15	0 to 1 638.35 m or 0 to 3 276.7 ft	0.05 m or 0.1 ft
Approach TCH units selector	1	—	—
Glide path angle (GPA)	16	0 to 90.0°	0.01°
Course width	8	80 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2 032 m	8 m
Horizontal alert limit (HAL)	8	0 to 51.0 m	0.2 m
Vertical alert limit (VAL) (*Note 2*)	8	0 to 51.0 m	0.2 m
Final approach segment CRC	32		—

Note 1.— Information can be provided in either feet or metres as indicated by the approach TCH unit selector.

Note 2.— A VAL of 0 indicates that the vertical deviations cannot be used (i.e., a lateral only approach). This does not preclude providing advisory vertical guidance on such approaches, refer to FAA AC 20-138().

Reference path identifier (RPI): four characters used to uniquely designate the reference path. The four characters consist of three alphanumeric characters plus a blank or four alphanumeric characters.

Note.— The best industry practice matches the 2nd and 3rd character encoding to the encoded runway number. The last character is a letter starting from A or a "blank."

Coding: Each character is coded using bits b_1 through b_6 of its IA-5 representation. For each character, b_1 is transmitted first, and 2 zero bits are appended after b_6 so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 "space" are used. The rightmost character is transmitted first. For a three-character reference path identifier, the rightmost (first transmitted) character shall be IA-5 "space".

Note.— The LTP/FTP is a point over which the FAS path passes at a height above the LTP/FTP height specified by the TCH.

LTP/FTP latitude: the latitude of the LTP/FTP point in arc seconds.

Coding: positive value denotes north latitude.
negative value denotes south latitude.

LTP/FTP longitude: the longitude of the LTP/FTP point in arc seconds.

Coding: positive value denotes east longitude.
negative value denotes west longitude.

LTP/FTP height: the height of the LTP/FTP above the WGS-84 ellipsoid.

Coding: This field is coded as an unsigned fixed-point number with an offset of –512 metres. A value of zero in this field places the LTP/FTP 512 metres below the earth ellipsoid.

Note.— The FPAP is a point at the same height as the LTP/FTP that is used to define the alignment of the approach. The origin of angular deviations in the lateral direction is defined to be 305 metres (1 000 ft) beyond the FPAP along the lateral FAS path. For an approach aligned with the runway, the FPAP is at or beyond the stop end of the runway.

Δ*FPAP latitude:* the difference of latitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value denotes the FPAP latitude north of LTP/FTP latitude.
Negative value denotes the FPAP latitude south of the LTP/FTP latitude.

Δ*FPAP longitude:* the difference of longitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value indicates the FPAP longitude east of LTP/FTP longitude.
Negative value indicates the FPAP longitude west of LTP/FTP longitude.

Approach TCH: the height of the FAS path above the LTP/FTP defined in either feet or metres as indicated by the TCH units selector.

Approach TCH units selector: the units used to describe the TCH.

Coding: 0 = feet
1 = metres

Glide path angle (GPA): the angle of the FAS path with respect to the horizontal plane tangent to the WGS-84 ellipsoid at the LTP/FTP.

Course width: the lateral displacement from the path defined by the FAS at the LTP/FTP at which full-scale deflection of a course deviation indicator is attained.

Coding: This field is coded as an unsigned fixed-point number with an offset of 80 metres. A value of zero in this field indicates a course width of 80 metres at the LTP/FTP.

ΔLength offset: the distance from the stop end of the runway to the FPAP.

Coding: 1111 1111 = not provided

HAL: Horizontal alert limit to be used during the approach in metres.

VAL: Vertical alert limit to be used during the approach in metres.

Final approach segment CRC: the 32-bit CRC appended to the end of each FAS data block in order to ensure approach data integrity. The 32-bit final approach segment CRC shall be calculated in accordance with 3.9. The length of the CRC code shall be k = 32 bits.

The CRC generator polynomial shall be:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^{8} + x^{7} + x^{5} + x^{3} + x + 1$$

The CRC information field, M(x), shall be:

$$M(x)=\sum_{i=1}^{288} m_i x^{288-i} = m_1 x^{287} + m_2 x^{286} + \ldots + m_{288} x^0$$

M(x) shall be formed from all bits of the associated FAS data block, excluding the CRC. Bits shall be arranged in the order transmitted, such that m_1 corresponds to the LSB of the operation type field, and m_{288} corresponds to the MSB of the Vertical Alert Limit (VAL) field. The CRC shall be ordered such that r_1 is the LSB and r_{32} is the MSB.

3.5.8.4.2.5.2 For precision approach and APV operations, the service provider ID broadcast Type 17 message shall be identical to the service provider ID in the FAS data block, except if ID equals 15 in the FAS data block.

Note.— If the service provider ID in the FAS data block equals 15, then any service provider can be used. If the service provider ID in the FAS data block equals 14, then SBAS precise differential corrections cannot be used for the approach.

3.5.8.4.2.5.3 *SBAS FAS data points accuracy.* The survey error of all the FAS data points, relative to WGS-84, shall be less than 0.25 metres vertical and 1 metre horizontal.

3.5.8.4.3 *Departure, en-route, terminal, and non-precision approach operations*

3.5.8.4.3.1 The receiver shall compute and apply long-term corrections, fast corrections and range rate corrections.

3.5.8.4.3.2 The receiver shall compute and apply ionospheric corrections.

Note.— Two methods of computing ionospheric corrections are provided in 3.1.2.4 and 3.5.5.5.2.

3.5.8.4.3.3 The receiver shall apply a tropospheric model such that residual pseudo-range errors have a mean value (μ) less than 0.15 metres and a standard deviation less than 0.07 metres.

Note.— A model was developed that meets this requirement. Guidance is provided in Attachment D, 6.5.4.

3.5.8.4.3.4 The receiver shall comput e and apply horizontal and vertical protection levels as defined in 3.5.5.6. In this computation, s_{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 standard deviation equal to σ_{air} bounds the error distribution for residual aircraft pseudo-range errors as follows:

$$\int_y^{\infty} f_n(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \geq 0 \text{ and}$$

$$\int_{-\infty}^{-y} f_n(x)dx \leq Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \geq 0$$

where

$f_n(x)$ = 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.

3.5.8.4.4 **Recommendation.—** *For departure, en-route, terminal, and non-precision approach operations, the receiver should use the broadcast ionospheric corrections, when available, and a tropospheric model with performance equal to that specified in 3.5.8.4.3.*

3.5.9 INTERFACE BETWEEN SBAS

Note.— Guidance material on the interface between different SBAS service providers is given in Attachment D, 6.3.

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

Note.— In this section, except where specifically annotated, reference to approach with vertical guidance (APV) means APV-I and APV-II.

3.6.1 GENERAL

The GBAS shall consist of a ground subsystem and an aircraft subsystem. The GBAS ground subsystem shall provide data and corrections for the GNSS ranging signals over a digital VHF data broadcast to the aircraft subsystem. The GRAS ground subsystem shall consist of one or more GBAS ground subsystems.

Note.— Guidance material is provided in Attachment D, 7.1.

3.6.2 RF CHARACTERISTICS

3.6.2.1 *Carrier frequency stability*. The carrier frequency of the data broadcast shall be maintained within ±0.0002 per cent of the assigned frequency.

3.6.2.2 *Bit-to-phase-change encoding*. GBAS messages shall be assembled into symbols, each consisting of 3 consecutive message bits. The end of the message shall be padded by 1 or 2 fill bits if necessary to form the last 3-bit symbol of the message. Symbols shall be converted to D8PSK carrier phase shifts ($\Delta\phi_k$) in accordance with Table B-58.

Note.— The carrier phase for the k^{th} symbol (ϕ_k) is given by: $\phi_k = \phi_{k-1} + \Delta\phi_k$. The D8PSK signal may be produced as shown in Figure B-19 by combining two quadrature RF signals which are independently suppressed-carrier amplitude-modulated by base band filtered impulses. A positive increase in $\Delta\phi_k$ represents a counterclockwise rotation in the complex I-Q plane of Figure B-19.

3.6.2.3 *Modulation wave form and pulse shaping filters*. The output of differential phase encoder shall be filtered by a pulse shaping filter whose output, s(t), is described as follows:

$$s(t)=\sum_{k=-\infty}^{k=\infty} e^{j\phi_k}\, h\,(t-kT)$$

where

- h = the impulse response of the raised cosine filter;
- ϕ_k = (as defined in 3.6.2.2);
- t = time; and
- T = the duration of each symbol = 1/10 500 second.

This pulse shaping filter shall have a nominal complex frequency response of a raised-cosine filter with α = 0.6. The time response, h(t), and frequency response, H(f), of the base band filters shall be as follows:

$$h(t)=\frac{\sin\left(\frac{\pi t}{T}\right)\cos\left(\frac{\pi\alpha t}{T}\right)}{\frac{\pi t}{T}\left[1-\left(\frac{2\alpha t}{T}\right)^2\right]}$$

$$H(f)=\begin{cases} 1 & \text{for} \quad 0\leq f<\frac{1-\alpha}{2T} \\ \frac{1-\sin\left(\frac{\pi}{2\alpha}(2fT-1)\right)}{2} & \text{for} \quad \frac{1-\alpha}{2T}\leq f\leq\frac{1+\alpha}{2T} \\ 0 & \text{for} \quad f>\frac{1+\alpha}{2T} \end{cases}$$

The output s(t) of the pulse shaping filter shall modulate the carrier.

3.6.2.4 *Error vector magnitude.* The error vector magnitude of the transmitted signal shall be less than 6.5 per cent root-mean-square (1 sigma).

3.6.2.5 *RF data rate*. The symbol rate shall be 10 500 symbols per second ±0.005 per cent, resulting in a nominal bit rate of 31 500 bits per second.

Table B-58. Data encoding

Message bits			Symbol phase shift
I_{3k-2}	I_{3k-1}	I_{3k}	$\Delta\phi_k$
0	0	0	0π/4
0	0	1	1π/4
0	1	1	2π/4
0	1	0	3π/4
1	1	0	4π/4
1	1	1	5π/4
1	0	1	6π/4
1	0	0	7π/4

Note.— I_j is the j^{th} bit of the burst to be transmitted, where I_1 is the first bit of the training sequence.

3.6.2.6 *Emissions in unassigned time slots*. Under all operating conditions, the maximum power over a 25 kHz channel bandwidth, centred on the assigned frequency, when measured over any unassigned time slot, shall not exceed –105 dBc referenced to the authorized transmitter power.

Note.— If the authorized transmitter power is higher than 150 W, the –105 dBc may not protect reception of emissions in a slot assigned to another desired transmitter for receivers within 200 metres from the undesired transmitting antenna.

3.6.3 DATA STRUCTURE

3.6.3.1 *TRANSMITTER TIMING*

3.6.3.1.1 *Data broadcast timing structure*. The time division multiple access (TDMA) timing structure shall be based on frames and time slots. Each frame shall be 500 milliseconds in duration. There shall be 2 such frames contained in each 1-second UTC epoch. The first of these frames shall start at the beginning of the UTC epoch and the second frame shall start 0.5 seconds after the beginning of the UTC epoch. The frame shall be time division multiplexed such that it shall consist of 8 individual time slots (A to H) of 62.5-millisecond duration.

3.6.3.1.2 *Bursts*. Each assigned time slot shall contain at most 1 burst. To initiate the use of a time slot, the GBAS shall broadcast a burst in that time slot in each of 5 consecutive frames. For each time slot in use, the ground subsystem shall broadcast a burst in at least 1 frame of every 5 consecutive frames.

Note 1.— Bursts contain one or more messages and may be of variable length up to the maximum allowed within the slot as required by 3.6.3.2.

Note 2.— During time slot initiation, the airborne receiver may not receive the first 4 bursts.

3.6.3.1.3 *Timing budget for bursts*

3.6.3.1.3.1 Each burst shall be contained in a 62.5-millisecond time slot.

3.6.3.1.3.2 The beginning of the burst shall occur 95.2 microseconds after the beginning of the time slot with a tolerance of ±95.2 microseconds.

3.6.3.1.3.3 For GBAS/E equipment, the start of the synchronization and ambiguity resolution portion of the burst, transmitted with horizontal polarization (HPOL), shall occur within 10 microseconds of the start of the burst transmitted with vertical polarization (VPOL).

Note.— Table B-59 illustrates the burst timing.

3.6.3.1.4 *Ramp-up and transmitter power stabilization*. The transmitter shall ramp up to 90 per cent of the steady-state power level within 190.5 microseconds after the beginning of the burst (2 symbols). The transmitter shall stabilize at the steady-state power within 476.2 microseconds after the beginning of the burst (5 symbols).

Note.— The transmitter power stabilization period may be used by the aircraft receiver to settle its automatic gain control.

3.6.3.1.5 *Ramp-down*. After the final information symbol is transmitted in an assigned time slot, the transmitter output power level shall decrease to at least 30 dB below the steady-state power within 285.7 microseconds (3 symbols).

3.6.3.2 *Burst organization and coding*. Each burst shall consist of the data elements shown in Table B-60. Encoding of the messages shall follow the sequence: application data formatting, training sequence forward error correction (FEC) generation, application FEC generation and bit scrambling.

3.6.3.2.1 *Synchronization and ambiguity resolution*. The synchronization and ambiguity resolution field shall consist of the 48-bit sequence shown below, with the rightmost bit transmitted first:

010 001 111 101 111 110 001 100 011 101 100 000 011 110 010 000

Table B-59. Burst timing

Event	Nominal event duration	Nominal percentage of steady-state power
Ramp-up	190.5 µs	0% to 90%
Transmitter power stabilization	285.7 µs	90% to 100%
Synchronization and ambiguity resolution	1 523.8 µs	100%
Transmission of scrambled data	58 761.9 µs	100%
Ramp-down	285.7 µs (*Note 1*)	100% to 0%

Notes.—

1. *Event duration indicated for transmission of scrambled data is for maximum application data length of 1 776 bits, 2 fill bits and nominal symbol duration.*
2. *These timing requirements provide a propagation guard time of 1 259 microseconds, allowing for a one-way propagation range of approximately 370 km (200 NM).*
3. *Where bursts from a GBAS broadcast antenna can be received at a range more than 370 km (200 NM) greater than the range from another broadcast antenna using the next adjacent slot, a longer guard time is required to avoid loss of both bursts. To provide a longer guard time, it is necessary to limit the application data length of the first burst to 1 744 bits. This allows a difference in propagation ranges of up to 692 km (372 NM) without conflict.*

Table B-60. Burst data content

Element	Data content	Number of bits
Beginning of burst	all zeros	15
Power stabilization		
Synchronization and ambiguity resolution	3.6.3.2.1	48
Scrambled data:	3.6.3.3	
station slot identifier (SSID)	3.6.3.3.1	3
transmission length	3.6.3.3.2	17
training sequence FEC	3.6.3.3.3	5
application data	3.6.3.3.4	up to 1 776
application FEC	3.6.3.3.5	48
fill bits (Note)	3.6.2.2	0 to 2

Note.— Data scrambling of the fill bits is optional (3.6.3.3.6).

3.6.3.3 *SCRAMBLED DATA CONTENT*

3.6.3.3.1 *Station slot identifier (SSID).* The SSID shall be a numeric value corresponding to the letter designation A to H of the first time slot assigned to the GBAS ground subsystem, where slot A is represented by 0, B by 1, C by 2, … and H by 7. The identifier is transmitted LSB first.

3.6.3.3.2 *Transmission length*. The transmission length shall indicate the total number of bits in both application data and application FEC. The transmission length is transmitted LSB first.

3.6.3.3.3 *Training sequence FEC*. The training sequence FEC shall be computed over the SSID and transmission length fields, using a (25, 20) block code, in accordance with the following equation:

$$[P_1, ..., P_5] = [SSID_1, \ldots, SSID_3, TL_1, \ldots, TL_{17}]\, H^T$$

where

P_n = the n^{th} bit of the training sequence FEC (P_1 shall be transmitted first);
$SSID_n$ = the n^{th} bit of the station slot identifier ($SSID_1$ = LSB);
TL_n = the n^{th} bit in the transmission length (TL_1 = LSB); and
H^T = the transpose of the parity matrix, defined below:

$$H^T = \begin{bmatrix} 0&0&0&0&0&0&0&0&1&1&1&1&1&1&1&1&1&1&1&1 \\ 0&0&1&1&1&1&1&1&0&0&0&0&1&1&1&1&1&1&1&1 \\ 1&1&0&0&0&1&1&1&0&0&1&1&0&0&0&0&1&1&1&1 \\ 1&1&0&1&1&0&1&1&0&1&0&1&0&0&1&1&0&0&1&1 \\ 0&1&1&0&1&0&0&1&1&1&1&0&0&1&0&1&0&1&0&1 \end{bmatrix}^T$$

Note.— This code is capable of correcting all single bit errors and detecting 75 of 300 possible double bit errors.

3.6.3.3.4 *Application data*. The application data shall consist of one or more message blocks, as defined in 3.6.3.4. The message blocks shall be mapped directly into the application data with no additional overhead of intervening layers.

3.6.3.3.5 *Application FEC*. The application FEC shall be calculated using the application data by means of a systematic, fixed-length, Reed-Solomon (R-S) (255, 249) code.

3.6.3.3.5.1 The field-defining primitive, p(x), of the R-S code shall be:

$$p(x) = x^8 + x^7 + x^2 + x + 1$$

3.6.3.3.5.2 The generator polynomial of the R-S code, g(x), shall be:

$$g(x) = \prod_{i=120}^{125} (x - \alpha^i) = x^6 + \alpha^{176}x^5 + \alpha^{186}x^4 + \alpha^{244}x^3 + \alpha^{176}x^2 + \alpha^{156}x + \alpha^{225}$$

where α is a root of p(x) used for construction of the Galois Field of size 2^8, GF(256), and α^i is the i^{th} primitive element in GF(256).

3.6.3.3.5.3 In generating the application FEC, the data to be encoded, m(x), shall be grouped into 8-bit R-S symbols. All data fields in the message blocks that define the application data shall be ordered such as specified in Tables B-61 and B-62, and in the message tables in 3.6.6. However, since the R-S code is a block code, application data blocks shorter than 249 bytes (1 992 bits) shall be extended to 249 bytes by virtual fill bits set to zero and appended to the application data. These virtual fill bits shall not be transferred to the bit scrambler. The data to be encoded, m(x), shall be defined by:

$$m(x) = a_{248}x^{248} + a_{247}x^{247} + ... + a_{248\text{-length}+1}\, x^{248\text{-length}+1} + a_{248\text{-length}}\, x^{248\text{-length}} + ... + a_1x+a_0$$

where

length represents the number of 8-bit bytes in the application data block;

a_{248} represents the message block identifier, with the rightmost bit defined as the LSB and the first bit of the application data sent to the bit scrambler;

$a_{248\text{-length}+1}$ represents the last byte of the message block CRC, with the leftmost bit defined as the MSB and the last bit of the application data sent to the bit scrambler; and

$a_{248\text{-length}}$, ..., a_1, a_0 are the virtual fill bits (if any).

3.6.3.3.5.4 The 6 R-S check symbols (b_i) shall be defined as the coefficients of the remainder resulting from dividing the message polynomial $x^6m(x)$ by the generator polynomial g(x):

$$b(x)=\sum_{i=0}^{5} b_i\, x^i + b_5x^5+b_4x^4+b_3x^3+b_2x^2+b_1x^1+b_0 = [x^6m(x)] \bmod g(x)$$

3.6.3.3.5.5 The 8-bit R-S check symbols shall be appended to the application data. Each 8-bit R-S check symbol shall be transmitted MSB first from b_0 to b_5, i.e. the first application FEC bit transferred to the bit scrambler shall be the MSB of b_0 and the last application FEC bit transferred to the bit scrambler shall be the LSB of b_5.

Note 1.— This R-S code is capable of correcting up to 3 symbol errors.

Note 2.— The order of the transmitted 8-bit R-S check symbols of the appended application FEC differs from the VHF data link (VDL) Mode 2. Moreover, for VDL Mode 2 each R-S check symbol is transmitted LSB first.

Note 3.— Example results of application FEC encoding are given in Attachment D, 7.15.

Table B-61. Format of a GBAS message block

Message block	Bits
Message block header	48
Message	up to 1 696
CRC	32

Table B-62. Format of message block header

Data field	Bits
Message block identifier	8
GBAS ID	24
Message type identifier	8
Message length	8

3.6.3.3.6 *Bit scrambling*

3.6.3.3.6.1 The output of a pseudo-noise scrambler with a 15-stage generator register shall be exclusive OR'ed with the burst data starting with the SSID and ending with the application FEC. Bit scrambling of the fill bits is optional and the set value of the fill bits is optional.

Note.— The fill bits are not used by the aircraft receiver and their values have no impact on the system.

3.6.3.3.6.2 The polynomial for the register taps of the scrambler shall be $1 + x + x^{15}$. The register content shall be rotated at the rate of one shift per bit. The initial status of the register, prior to the first SSID bit of each burst, shall be "1101 0010 1011 001", with the leftmost bit in the first stage of the register. The first output bit of the scrambler shall be sampled prior to the first register shift.

Note.— A diagram of the bit scrambler is given in Attachment D, 7.4.

3.6.3.4 *Message block format*. The message blocks shall consist of a message block header, a message and a 32-bit CRC. Table B-61 shows the construction of the message block. All signed parameters shall be two's complement numbers and all unsigned parameters shall be unsigned fixed point numbers. The scaling of the data shall be as shown in the message tables in 3.6.6. All data fields in the message block shall be transmitted in the order specified in the message tables, with the LSB of each field transmitted first.

Note.— All binary representations reading left to right are MSB to LSB.

3.6.3.4.1 *Message block header*. The message block header shall consist of a message block identifier, a GBAS identifier (ID), a message type identifier and a message length, as shown in Table B-62.

Message block identifier: the 8-bit identifier for the operating mode of the GBAS message block.

Coding: 1010 1010 = normal GBAS message
1111 1111 = test GBAS message
All other values are reserved.

GBAS ID: the four-character GBAS identification to differentiate between GBAS ground subsystems.

Coding: Each character is coded using bits b_1 through b_6 of its International Alphabet No. 5 (IA-5) representation. For each character, bit b_1 is transmitted first and six bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 "space" are used. The rightmost character is transmitted first. For a three-character GBAS ID, the rightmost (first transmitted) character shall be IA-5 "space".

Note.— The GBAS ID is normally identical to the location indicator at the nearest airport. Assignment of GBAS IDs will be coordinated as appropriate to avoid conflicts.

Message type identifier: the numeric label identifying the content of the message (Table B-63).

Message length: the length of the message in 8-bit bytes including the 6-byte message block header, the message and the 4-byte message CRC code.

3.6.3.4.2 *Cyclic redundancy check (CRC).* The GBAS message CRC shall be calculated in accordance with 3.9.

3.6.3.4.2.1 The length of the CRC code shall be k = 32 bits.

3.6.3.4.2.2 The CRC generator polynomial shall be:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^{8} + x^{7} + x^{5} + x^{3} + x + 1$$

3.6.3.4.2.3 The CRC information field, M(x), shall be:

$$M(x)= \sum_{i=1}^{n} m_i\, x^{n-i} + m_1 x^{n-1} + m_2 x^{n-2} + \ldots + m_n x^0$$

3.6.3.4.2.4 M(x) shall be formed from the 48-bit GBAS message block header and all bits of the variable-length message, excluding the CRC. Bits shall be arranged in the order transmitted, such that m_1 corresponds to the first transmitted bit of the message block header, and m_n corresponds to the last transmitted bit of the (n-48) message bits.

3.6.3.4.2.5 The CRC shall be ordered such that r_1 is the first bit transmitted and r_{32} is the last bit transmitted.

3.6.4 DATA CONTENT

3.6.4.1 *Message types*. The message types that can be transmitted by GBAS shall be as in Table B-63.

3.6.4.2 *TYPE 1 MESSAGE — PSEUDO-RANGE CORRECTIONS*

3.6.4.2.1 The Type 1 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70). The message shall contain three sections:

a) message information (time of validity, additional message flag, number of measurements and the measurement type);

b) low-frequency information (ephemeris decorrelation parameter, satellite ephemeris CRC and satellite availability information); and

c) satellite data measurement blocks.

Note.— Transmission of the low-frequency data for SBAS ranging sources is optional.

3.6.4.2.2 Each Type 1 message shall include ephemeris decorrelation parameter, ephemeris CRC and source availability duration parameters for one satellite ranging source. The ephemeris decorrelation parameter, ephemeris CRC and source availability duration shall apply to the first ranging source in the message.

3.6.4.2.3 Pseudo-range correction parameters shall be as follows:

Modified Z-count: the indication of the time of applicability for all the parameters in the message.

Coding: the modified Z-count resets on the hour (xx:00), 20 minutes past the hour (xx:20) and 40 minutes past the hour (xx:40) referenced to GPS time.

Additional message flag: an identification of whether the set of measurement blocks in a single frame for a particular measurement type is contained in a single Type 1 message or a linked pair of messages.

Coding: 0 = All measurement blocks for a particular measurement type are contained in one Type 1 message.
1 = This is the first transmitted message of a linked pair of Type 1 messages that together contain the set of all measurement blocks for a particular measurement type.
2 = Spare
3 = This is the second transmitted message of a linked pair of Type 1 messages that together contain the set of all measurement blocks for a particular measurement type.

Note.— When a linked pair of Type 1 messages is used for a particular measurement type, the number of measurements and low-frequency data are computed separately for each of the two individual messages.

Number of measurements: the number of measurement blocks in the message.

Measurement type: the type of ranging signal from which the corrections have been computed.

Table B-63. GBAS VHF data broadcast messages

Message type identifier	Message name
0	Spare
1	Pseudo-range corrections
2	GBAS-related data
3	Null message
4	Final approach segment (FAS) data
5	Predicted ranging source availability
6	Reserved
7	Reserved for national applications
8	Reserved for test applications
9 to 100	Spare
101	GRAS pseudo-range corrections
102 to 255	Spare

Note.— See 3.6.6 for message formats.

Coding: 0 = C/A or CSA code L1
1 = reserved
2 = reserved
3 = reserved
4 to 7 = spare

Ephemeris decorrelation parameter (P): a parameter that characterizes the impact of residual ephemeris errors due to decorrelation for the first measurement block in the message.

For a SBAS geostationary satellite, the ephemeris decorrelation parameter, if transmitted, shall be coded as all zeros.

For GBAS ground subsystems that do not broadcast the additional data block 1 in the Type 2 message, the ephemeris decorrelation parameter shall be coded as all zeros.

Ephemeris CRC: the CRC computed with the ephemeris data used to determine corrections for the first measurement block in the message. The ephemeris CRC for core satellite constellation(s) ranging sources shall be calculated in accordance with 3.9. The length of the CRC code shall be k = 16 bits. The CRC generator polynomial shall be:

$$G(x) = x^{16} + x^{12} + x^5 + 1$$

The CRC information field, M(x), for a given satellite shall be:

$$M(x)=\sum_{i=1}^{n} m_i\, x^{n-1} + m_1 x^{n-1} + m_2 x^{n-2} + \ldots + m_n x^0$$

For a GPS satellite, M(x) shall be of length n = 576 bits. M(x) for a GPS satellite shall be calculated using the first 24 bits from each of words 3 to S10 of subframes 1, 2 and 3 of the data transmission from that satellite, ANDed with the GPS satellite ephemeris mask of Table B-64. M(x) shall be arranged in the order that bytes are transmitted by the GPS satellite, but with each byte ordered LSB first, such that m_1 corresponds to bit 68 of subframe 1, and m_{576} corresponds to bit 287 of subframe 3.

Note.— M(x) for a GPS satellite does not include word 1 (TLM) or word 2 (HOW), which start each subframe, or the 6 parity bits at the end of each word.

For a GLONASS satellite, M(x) shall be of length n = 340 bits. M(x) for a GLONASS satellite shall be calculated using strings 1, 2, 3 and 4 of the data transmission from that satellite, ANDed with the GLONASS satellite ephemeris mask of Table B-65. Bits shall be arranged in transmission order such that m_1 corresponds to bit 85 of string 1, and m_{340} corresponds to bit 1 of string 4.

For a SBAS geostationary satellite, the ephemeris CRC, if transmitted shall be coded as all zeros.

The CRC shall be transmitted in the order r_9, r_{10}, r_{11}...., r_{16}, r_1, r_2, r_3...r_8, where r_i is the i^{th} coefficient of the remainder R(x) as defined in 3.9**.**

Source availability duration: the predicted duration for which corrections for the ranging source are expected to remain available, relative to the modified Z-count for the first measurement block.

Coding: 1111 1110 = The duration is greater than or equal to 2 540 seconds.
1111 1111 = Prediction of source availability duration is not provided by this ground subsystem.

3.6.4.2.4 The measurement block parameters shall be as follows:

Ranging source ID: the identity of the ranging source to which subsequent measurement block data are applicable.

Table B-64. GPS satellite ephemeris mask

Subframe 1:	Byte 1	Byte 2	Byte 3		Byte 1	Byte 2	Byte 3
Word 3	0000 0000	0000 0000	0000 0011	Word 4	0000 0000	0000 0000	0000 0000
Word 5	0000 0000	0000 0000	0000 0000	Word 6	0000 0000	0000 0000	0000 0000
Word 7	0000 0000	0000 0000	1111 1111	Word 8	1111 1111	1111 1111	1111 1111
Word 9	1111 1111	1111 1111	1111 1111	Word 10	1111 1111	1111 1111	1111 1100
Subframe 2:	**Byte 1**	**Byte 2**	**Byte 3**		**Byte 1**	**Byte 2**	**Byte 3**
Word 3	1111 1111	1111 1111	1111 1111	Word 4	1111 1111	1111 1111	1111 1111
Word 5	1111 1111	1111 1111	1111 1111	Word 6	1111 1111	1111 1111	1111 1111
Word 7	1111 1111	1111 1111	1111 1111	Word 8	1111 1111	1111 1111	1111 1111
Word 9	1111 1111	1111 1111	1111 1111	Word 10	1111 1111	1111 1111	0000 0000
Subframe 3:	**Byte 1**	**Byte 2**	**Byte 3**		**Byte 1**	**Byte 2**	**Byte 3**
Word 3	1111 1111	1111 1111	1111 1111	Word 4	1111 1111	1111 1111	1111 1111
Word 5	1111 1111	1111 1111	1111 1111	Word 6	1111 1111	1111 1111	1111 1111
Word 7	1111 1111	1111 1111	1111 1111	Word 8	1111 1111	1111 1111	1111 1111
Word 9	1111 1111	1111 1111	1111 1111	Word 10	1111 1111	1111 1111	1111 1100

Table B-65. GLONASS satellite ephemeris mask

String 1:
0 0000 0000 0000 0000 0000 1111 1111 1111 1111 1111 1111 1111
1111 1111 1111 1111 1111 1111 1111 0000 0000
String 2:
0 0000 0000 0000 0000 0000 1111 1111 1111 1111 1111 1111 1111
1111 1111 1111 1111 1111 1111 1111 0000 0000
String 3:
0 0000 0111 1111 1111 0000 1111 1111 1111 1111 1111 1111 1111
1111 1111 1111 1111 1111 1111 1111 0000 0000
String 4:
0 0000 1111 1111 1111 1111 1111 1100 0000 0000 0000 0000 0000
0000 0000 0000 0000 0000 0000 0000 0000 0000

Coding: 1 to 36 = GPS satellite IDs (PRN)
37 = reserved
38 to 61 = GLONASS satellite IDs (slot number plus 37)
62 to 119 = spare
120 to 138 = SBAS satellite IDs (PRN)
139 to 255 = spare

Issue of data (IOD): The issue of data associated with the ephemeris data used to determine pseudo-range and range rate corrections.

Coding: for GPS, IOD = GPS IODE parameter (3.1.1.3.2.2)
for GLONASS, IOD = GLONASS "t_b" parameter (see 3.2.1.3.1)
for SBAS, IOD = 1111 1111

Note.— For GLONASS insert 0 in the MSB of the IOD.

Pseudo-range correction (PRC): the correction to the ranging source pseudo-range.

Range rate correction (RRC): the rate of change of the pseudo-range correction.

σ_{pr_gnd}: the standard deviation of a normal distribution associated with the signal-in-space contribution of the pseudo-range error at the GBAS reference point (3.6.5.5.1, 3.6.5.5.2 and 3.6.7.2.2.4).

Coding: 1111 1111 = Ranging source correction invalid.

B_1 through B_4: are the integrity parameters associated with the pseudo-range corrections provided in the same measurement block. For the i^{th} ranging source these parameters correspond to $B_{i,1}$ through $B_{i,4}$ (3.6.5.5.1.2, 3.6.5.5.2.2 and 3.6.7.2.2.4). The indices “1-4” correspond to the same physical reference receiver for every frame transmitted from a given ground subsystem during continuous operation.

Coding: 1000 0000 = Reference receiver was not used to compute the pseudo-range correction.

Note.— Some airborne receivers may expect a static correspondence of the reference receivers to the indices for short service interruptions. However, the B-value indices may be reassigned after the ground subsystem has been out of service for an extended period of time, such as for maintenance.

3.6.4.3 *Type 2 message — GBAS-related data.* Type 2 message shall identify the location of the GBAS reference point at which the corrections provided by the GBAS apply and shall give other GBAS-related data (Table B-71). GBAS-related data parameters shall be as follows:

Note.— Additional data blocks may be included in the Type 2 message. Additional data block 1 and additional data block 2 are defined. In the future, other additional data blocks may be defined. Data blocks 2 through 255 are variable length and may be appended to the message after additional data block 1 in any order.

GBAS reference receivers: the number of GNSS reference receivers installed in this GBAS ground subsystem.

Coding: 0 = GBAS installed with 2 reference receivers
1 = GBAS installed with 3 reference receivers
2 = GBAS installed with 4 reference receivers
3 = The number of GNSS reference receivers installed in this GBAS ground subsystem is not applicable

Ground accuracy designator letter: the letter designator indicating the minimum signal-in-space accuracy performance provided by GBAS (3.6.7.1.1).

Coding: 0 = accuracy designation A
1 = accuracy designation B
2 = accuracy designation C
3 = spare

GBAS continuity/integrity designator (GCID): numeric designator indicating the operational status of the GBAS.

Coding: 0 = spare
1 = GCID 1
2 = GCID 2
3 = GCID 3
4 = GCID 4
5 = spare
6 = spare
7 = unhealthy

Note 1.— The values of GCID 2, 3 and 4 are specified in order to ensure compatibility of equipment with future GBAS.

Note 2.— The value of GCID 7 indicates that a precision approach or APV cannot be initiated.

Local magnetic variation: the published magnetic variation at the GBAS reference point.

Coding: Positive value denotes east variation (clockwise from true north), Negative value denotes west variation (counter-clockwise from true north)
100 0000 0000 = Precision approach procedures supported by this GBAS are published based on true bearing.

Note.— Local magnetic variation is chosen to be consistent with procedure design and is updated during magnetic epoch years.

$\sigma_{vert\_iono\_gradient}$: the standard deviation of a normal distribution associated with the residual ionospheric uncertainty due to spatial decorrelation (3.6.5.4).

Refractivity index (N_r): the nominal tropospheric refractivity index used to calibrate the tropospheric correction associated with the GBAS ground subsystem (3.6.5.3).

Coding: This field is coded as two's complement number with an offset of +400. A value of zero in this field indicates a refractivity index of 400.

Scale height (h_o): a scale factor used to calibrate the tropospheric correction and residual tropospheric uncertainty associated with the GBAS ground subsystem (3.6.5.3).

Refractivity uncertainty (σ_n): the standard deviation of a normal distribution associated with the residual tropospheric uncertainty (3.6.5.3).

Latitude: the latitude of the GBAS reference point defined in arc seconds.

Coding: Positive value denotes north latitude.
Negative value denotes south latitude.

Longitude: the longitude of the GBAS reference point defined in arc seconds.

Coding: Positive value denotes east longitude.
Negative value denotes west longitude.

Reference point height: the height of the GBAS reference point above the WGS-84 ellipsoid.

3.6.4.3.1 *Additional data block 1 parameters*. Additional data block 1 parameters shall be as follows:

REFERENCE STATION DATA SELECTOR (RSDS): the numerical identifier that is used to select the GBAS ground subsystem.

Note.— The RSDS is different from every other RSDS and every reference path data selector (RPDS) broadcast on the same frequency by every GBAS ground subsystem within the broadcast region.

Coding: 1111 1111 = GBAS positioning service is not provided

MAXIMUM USE DISTANCE (D_{max}): the maximum distance (slant range) from the GBAS reference point for which the integrity is assured.

Note.— This parameter does not indicate a distance within which VHF data broadcast field strength requirements are met.

Coding: 0 = No distance limitation

GPS EPHEMERIS MISSED DETECTION PARAMETER, GBAS Positioning Service ($K_{md\_e\_POS,GPS}$): the multiplier for computation of the ephemeris error position bound for the GBAS positioning service derived from the probability of missed detection given that there is an ephemeris error in a GPS satellite.

For GBAS ground subsystems that do not broadcast corrections for GPS ranging sources or that do not provide the GBAS positioning service, this parameter shall be coded as all zeros.

GPS EPHEMERIS MISSED DETECTION PARAMETER, Category I Precision Approach and APV ($K_{md\_e,GPS}$): the multiplier for computation of the ephemeris error position bound for Category I precision approach and APV derived from the probability of missed detection given that there is an ephemeris error in a GPS satellite.

For GBAS ground subsystems that do not broadcast corrections for GPS ranging sources, this parameter shall be coded as all zeros.

GLONASS EPHEMERIS MISSED DETECTION PARAMETER, GBAS Positioning Service ($K_{md\_e,\_POS,GLONASS}$): the multiplier for computation of the ephemeris error position bound for the GBAS positioning service derived from the probability of missed detection given that there is an ephemeris error in a GLONASS satellite.

For GBAS ground subsystems that do not broadcast corrections for GLONASS ranging sources or that do not provide positioning service, this parameter shall be coded as all zeros.

GLONASS EPHEMERIS MISSED DETECTION PARAMETER, Category I Precision Approach and APV ($K_{md\_e\_,GLONASS}$): the multiplier for computation of the ephemeris error position bound for Category I precision approach and APV derived from the probability of missed detection given that there is an ephemeris error in a GLONASS satellite.

For GBAS ground subsystems that do not broadcast corrections for GLONASS ranging sources, this parameter shall be coded as all zeros.

3.6.4.3.2 *Additional data blocks*. For additional data blocks other than additional data block 1, the parameters for each data block shall be as follows:

ADDITIONAL DATA BLOCK LENGTH: the number of bytes in the additional data block, including the additional data block length and additional data block number fields.

ADDITIONAL DATA BLOCK NUMBER: the numerical identifier of the type of additional data block.

Coding: 0 to 1 = reserved
2 = additional data block 2, GRAS broadcast stations
3 = reserved for future services supporting Category II/III operations
4 = additional data block 4, VDB authentication parameters
5 to 255 = spare

ADDITIONAL DATA PARAMETERS: the set of data defined in accordance with the additional data block number.

3.6.4.3.2.1 *GRAS broadcast stations*

Parameters for additional data block 2 shall include data for one or more broadcast stations as follows (Table B-65A):

CHANNEL NUMBER: the channel number, as defined in 3.6.5.7, associated with a GBAS broadcast station.

Note.— The channel number in this field refers to a frequency and an RSDS.

Δ*LATITUDE*: the difference of latitude of a GBAS broadcast station, measured from the latitude provided in the latitude parameter of Type 2 message.

Coding: Positive value denotes that the GBAS broadcast station is north of the GBAS reference point.
Negative value denotes that the GBAS broadcast station is south of the GBAS reference point.

Δ*LONGITUDE*: the difference of longitude of a GBAS broadcast station, measured from the longitude provided in the longitude parameter of Type 2 message.

Coding: Positive value denotes that the GBAS broadcast station is east of the GBAS reference point.
Negative value denotes that the GBAS broadcast station is west of the GBAS reference point.

Note.— Guidance material concerning additional data block 2 is provided in Attachment D, 7.17.

3.6.4.3.2.2 *VDB authentication parameters*

Additional data block 4 includes information needed to support VDB authentication protocols (Table B-65B).

Slot group definition: This 8-bit field indicates which of the 8 slots (A-H) are assigned for use by the ground station. The field is transmitted LSB first. The LSB corresponds to slot A, the next bit to slot B, and so on. A “1” in the bit position indicates the slot is assigned to the ground station. A “0” indicates the slot is not assigned to the ground station.

Table B-65A. GRAS broadcast station data

Data content	Bits used	Range of values	Resolution
Channel number	16	20001 to 39999	1
ΔLatitude	8	±25.4°	0.2°
ΔLongitude	8	±25.4°	0.2°

Table B-65B. VDB authentication parameters

Data content	Bits used	Range of values	Resolution
Slot group definition	8	—	—

3.6.4.4 *TYPE 3 MESSAGE — NULL MESSAGE*

3.6.4.4.1 The Type 3 message is a variable length "null message" which is intended to be used by ground subsystems that support the authentication protocols (see section 3.6.7.4).

3.6.4.4.2 The parameters for the Type 3 message shall be as follows:

Filler: a sequence of bits alternating between "1" and "0" with a length in bytes that is 10 less than the value in the message length field in the message header.

3.6.4.5 *Type 4 message — Final approach segment (FAS).* Type 4 message shall contain one or more sets of FAS data, each defining a single precision approach (Table B-72). Each Type 4 message data set shall include the following:

Data set length: the number of bytes in the data set. The data set includes the data set length field and the associated FAS data block, FAS vertical alert limit (FASVAL)/approach status and FAS lateral alert limit (FASLAL)/approach status fields.

FAS data block: the set of parameters to identify a single precision approach or APV and define its associated approach path.

Coding: See 3.6.4.5.1 and Table B-66.

Note.— Guidance material for FAS path definition is contained in Attachment D, 7.11.

FASVAL/approach status: the value of the parameter FASVAL as used in 3.6.5.6.

Coding: 1111 1111 = Do not use vertical deviations.

Note.— The range and resolution of values for FASVAL depend upon the approach performance designator in the associated FAS data block.

FASLAL/approach status: the value of the parameter FASLAL as used in 3.6.5.6.

Coding: 1111 1111 = Do not use approach.

3.6.4.5.1 *FAS data block.* The FAS data block shall contain the parameters that define a single precision approach or APV. The FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). The local level plane for the approach is a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). Local vertical for the approach is normal to the WGS-84 ellipsoid at the LTP/FTP. The glide path intercept point (GPIP) is where the final approach path intercepts the local level plane. FAS data block parameters shall be as follows:

Operation type: straight-in approach procedure or other operation types.

Coding: 0 = straight-in approach procedure
1 to 15 = spare

Table B-66. Final approach segment (FAS) data block

Data content	Bits used	Range of values	Resolution
Operation type	4	0 to 15	1
SBAS provider ID	4	0 to 15	1
Airport ID	32	—	—
Runway number	6	1 to 36	1
Runway letter	2	—	—
Approach performance designator	3	0 to 7	1
Route indicator	5	—	—
Reference path data selector	8	0 to 48	1
Reference path identifier	32	—	—
LTP/FTP latitude	32	±90.0°	0.0005 arcsec
LTP/FTP longitude	32	±180.0°	0.0005 arcsec
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m
ΔFPAP latitude	24	±1.0°	0.0005 arcsec
ΔFPAP longitude	24	±1.0°	0.0005 arcsec
Approach TCH (Note)	15	0 to 1 638.35 m or 0 to 3 276.7 ft	0.05 m or 0.1 ft
Approach TCH units selector	1	—	—
GPA	16	0 to 90.0°	0.01°
Course width	8	80 to 143.75 m	0.25 m
ΔLength offset	8	0 to 2 032 m	8 m
Final approach segment CRC	32	—	—

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

SBAS service provider ID: indicates the service provider associated with this FAS data block.

Coding: See Table B-27.
14 = FAS data block is to be used with GBAS only.
15 = FAS data block can be used with any SBAS service provider.

Note.— This parameter is not used for approaches conducted using GBAS or GRAS pseudo-range corrections.

Airport ID: the three- or four-letter designator used to designate an airport.

Coding: Each character is coded using the lower 6 bits of its IA-5 representation. For each character, b_i is transmitted first, and 2 zero bits are appended after b_6, so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 "space" are used. The rightmost character is transmitted first. For a three-character airport ID, the rightmost (first transmitted) character shall be IA-5 "space".

Runway number: the approach runway number.

Coding: 1 to 36 = runway number

Note.— For heliport and point-in-space operations, the runway number value is the integer nearest to one tenth of the final approach course, except when that integer is zero, in which case the runway number is 36.

Runway letter: the one-letter designator used, as necessary, to differentiate between parallel runways.

Coding: 0 = no letter
1 = R (right)
2 = C (centre)
3 = L (left)

Approach performance designator: the general information about the approach design.

Coding: 0 = APV
1 = Category I
2 = reserved for Category II
3 = reserved for Category III
4 to 7 = spare

Note.— Some airborne equipment designed for Category I performance is insensitive to the value of the APD. It is intended that airborne equipment designed for Category I performance accepts APD values of at least 1-4 as valid to accommodate future extensions to higher performance types using the same FAS data block.

Route indicator: the one-letter identifier used to differentiate between multiple approaches to the same runway end.

Coding: The letter is coded using bits b_1 through b_5 of its IA-5 representation. Bit b_1 is transmitted first. Only upper case letters, excluding "I" and "O", or IA-5 "space" are used.

Reference path data selector (RPDS): the numeric identifier that is used to select the FAS data block (desired approach).

Note.— The RPDS for a given FAS data block is different from every other RPDS and every reference station data selector (RSDS) broadcast on the same frequency by every GBAS within the broadcast region.

Reference path identifier (RPI): the three or four alphanumeric characters used to uniquely designate the reference path.

Coding: Each character is coded using bits b_1 through b_6 of its IA-5 representation. For each character, b_1 is transmitted first, and 2 zero bits are appended after b_6 so that 8 bits are transmitted for each character. Only upper case letters, numeric digits and IA-5 "space" are used. The rightmost character is transmitted first. For a three-character reference path identifier, the rightmost (first transmitted) character shall be IA-5 "space".

Note.— The LTP/FTP is a point over which the FAS path passes at a relative height specified by the TCH. LTP is normally located at the intersection of the runway centreline and the threshold.

LTP/FTP latitude: the latitude of the LTP/FTP point in arc seconds.

Coding: Positive value denotes north latitude.
Negative value denotes south latitude.

LTP/FTP longitude: the longitude of the LTP/FTP point in arc seconds.

Coding: Positive value denotes east longitude.
Negative value denotes west longitude.

LTP/FTP height: the height of the LTP/FTP above the WGS-84 ellipsoid.

Coding: This field is coded as an unsigned fixed-point number with an offset of –512 metres. A value of zero in this field places the LTP/FTP 512 metres below the earth ellipsoid.

Note.— The FPAP is a point at the same height as the LTP/FTP that is used to define the alignment of the approach. The origin of angular deviations in the lateral direction is defined to be 305 metres (1 000 ft) beyond the FPAP along the lateral FAS path. For an approach aligned with the runway, the FPAP is at or beyond the stop end of the runway.

ΔFPAP latitude: the difference of latitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value denotes the FPAP latitude north of LTP/FTP latitude.
Negative value denotes the FPAP latitude south of the LTP/FTP latitude.

ΔFPAP longitude: the difference of longitude of the runway FPAP from the LTP/FTP in arc seconds.

Coding: Positive value indicates the FPAP longitude east of LTP/FTP longitude.
Negative value indicates the FPAP longitude west of LTP/FTP longitude.

Approach TCH: the height of the FAS path above the LTP/FTP defined in either feet or metres as indicated by the TCH units selector.

Approach TCH units selector: the units used to describe the TCH.

Coding: 0 = feet
1 = metres

Glide path angle (GPA): the angle of the FAS path with respect to the horizontal plane tangent to the WGS-84 ellipsoid at the LTP/FTP.

Course width: the lateral displacement from the path defined by the FAS at the LTP/FTP at which full-scale deflection of a course deviation indicator is attained.

Coding: This field is coded as an unsigned fixed-point number with an offset of 80 metres. A value of zero in this field indicates a course width of 80 metres at the LTP/FTP.

ΔLength offset: the distance from the stop end of the runway to the FPAP.

Coding: 1111 1111 = not provided

Final approach segment CRC: the 32-bit CRC appended to the end of each FAS data block in order to ensure approach data integrity. The 32-bit final approach segment CRC shall be calculated in accordance with 3.9. The length of the CRC code shall be k = 32 bits.

The CRC generator polynomial shall be:

$$G(x) = x^{32} + x^{31} + x^{24} + x^{22} + x^{16} + x^{14} + x^{8} + x^{7} + x^{5} + x^{3} + x + 1$$

The CRC information field, M(x), shall be:

$$M(x) = \sum_{i=1}^{272} m_i\, x^{272-i} = m_1 x^{271} + m_2 x^{270} + \ldots + m_{272} x^{0}$$

M(x) shall be formed from all bits of the associated FAS data block, excluding the CRC. Bits shall be arranged in the order transmitted, such that m_1 corresponds to the LSB of the operation type field, and m_{272} corresponds to the MSB of the Δlength offset field. The CRC shall be ordered such that r_1 is the LSB and r_{32} is the MSB.

3.6.4.6 *Type 5 message — predicted ranging source availability.* When used, the Type 5 message shall contain rising and setting information for the currently visible or soon to be visible ranging sources. Predicted ranging source availability parameters shall be as follows:

Modified Z-count: indicates the time of applicability of the parameters in this message.

Coding: Same as modified Z-count field in Type 1 message (3.6.4.2).

Number of impacted sources: the number of sources for which duration information applicable to all approaches is provided.

Coding: 0 = Only specified obstructed approaches have limitations.
1 to 31 = The number of ranging sources impacted.

Ranging source ID: as for Type 1 message (3.6.4.2).

Source availability sense: indicates whether the ranging source will become available or cease to be available.

Coding: 0 = Differential corrections will soon cease to be provided for the associated ranging source.
1 = Differential corrections will soon start to be provided for the associated ranging source.

Source availability duration: the predicted minimum ranging source availability duration relative to the modified Z-count.

Coding: 111 1111 = The duration is greater than or equal to 1 270 seconds.

Number of obstructed approaches: the number of approaches for which the corrections will be reduced due to approach unique constellation masking.

Reference path data selector: an indication of the FAS data block to which the source availability data applies (3.6.4.5.1).

Number of impacted sources for this approach: the number of sources for which duration information applicable only to this approach is provided.

3.6.4.7 *TYPE 6 MESSAGE*

Note.— Type 6 message is reserved for future use to provide the information required for Category II/III precision approaches.

3.6.4.8 *TYPE 7 MESSAGE*

Note.— Type 7 message is reserved for national applications.

3.6.4.9 *TYPE 8 MESSAGE*

Note.— Type 8 message is reserved for local and regional test applications.

3.6.4.10 *TYPE 101 MESSAGE — GRAS PSEUDO-RANGE CORRECTIONS*

3.6.4.10.1 The Type 101 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70A). The message shall contain three sections:

a) message information (time of validity, additional message flag, number of measurements and the measurement type);

b) low-frequency information (ephemeris decorrelation parameter, satellite ephemeris CRC and satellite availability information); and

c) satellite data measurement blocks.

3.6.4.10.2 Each Type 101 message shall include ephemeris decorrelation parameter, ephemeris CRC and source availability duration parameters for one satellite ranging source. The ephemeris decorrelation parameter, ephemeris CRC and source availability duration shall apply to the first ranging source in the message.

3.6.4.10.3 Pseudo-range correction parameters shall be as follows:

Modified Z-count: as defined in 3.6.4.2.3.

Additional message flag: as defined in 3.6.4.2.3 except applicable to Type 101 messages.

Number of measurements: as defined in 3.6.4.2.3.

Measurement type: as defined in 3.6.4.2.3.

Ephemeris decorrelation parameter (P): as defined in 3.6.4.2.3.

Ephemeris CRC: as defined in 3.6.4.2.3.

Source availability duration: as defined in 3.6.4.2.3.

Number of B parameters: an indication of whether the B parameters are included in the measurement block for each ranging source.

Coding: 0 = B parameters are not included
1 = 4 B parameters per measurement block

3.6.4.10.4 The measurement block parameters shall be as follows:

Ranging source ID: as defined in 3.6.4.2.4.

Issue of data (IOD): as defined in 3.6.4.2.4.

Pseudo-range correction (PRC): as defined in 3.6.4.2.4.

Range rate correction (RRC): as defined in 3.6.4.2.4.

σ_{pr_gnd}: as defined in 3.6.4.2.4, with the exception of the range of values and resolution.

B1 through B4: as defined in 3.6.4.2.4.

Note.— Inclusion of the B parameters in the measurement block is optional for Type 101 messages.

3.6.5 DEFINITIONS OF PROTOCOLS FOR DATA APPLICATION

Note.— This section defines the inter-relationships of the data broadcast message parameters. It provides definitions of parameters that are not transmitted, but are used by either or both non-aircraft and aircraft elements, and that define terms applied to determine the navigation solution and its integrity.

3.6.5.1 *Measured and carrier smoothed pseudo-range.* The broadcast correction is applicable to carrier smoothed code pseudo-range measurements that have not had the satellite broadcast troposphere and ionosphere corrections applied to them. The carrier smoothing is defined by the following filter:

$$P_{CSCn} = \alpha P + (1 - \alpha)\left(P_{CSC_{n-1}} + \frac{\lambda}{2\pi}(\phi_n - \phi_{n-1})\right)$$

where

P_{CSCn} = the smoothed pseudo-range;
P_{CSCn-1} = the previous smoothed pseudo-range;
P = the raw pseudo-range measurement where the raw pseudo-range measurements are obtained from a carrier driven code loop, first order or higher and with a one-sided noise bandwidth greater than or equal to 0.125 Hz;
λ = the L1 wavelength;
ϕ_n = the carrier phase;
ϕ_{n-1} = the previous carrier phase; and
α = the filter weighting function equal to the sample interval divided by the time constant of 100 seconds, except as specified in 3.6.8.3.5.1 for airborne equipment.

3.6.5.2 *Corrected pseudo-range.* The corrected pseudo-range for a given satellite at time *t* is:

$$PR_{corrected} = P_{CSC} + PRC + RRC \times (t - \text{tz-count}) + TC + c \times (\Delta t_{sv})_{L1}$$

where

P_{CSC} = the smoothed pseudo-range (defined in 3.6.5.1);
PRC = the pseudo-range correction (defined in 3.6.4.2);
RRC = the pseudo-range correction rate (defined in 3.6.4.2);
t = the current time;
tz-count = the time of applicability derived from the modified Z-count (defined in 3.6.4.2);
TC = the tropospheric correction (defined in 3.6.5.3); and
c and $(\Delta t_{sv})_{L1}$ are as defined in 3.1.2.2 for GPS satellites.

3.6.5.3 *TROPOSPHERIC DELAY*

3.6.5.3.1 The tropospheric correction for a given satellite is:

$$TC = N_r h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(El_i)}}(1 - e^{-\Delta h/h_0})$$

where

N_r = refractivity index from the Type 2 message (3.6.4.3);
Δh = height of the aircraft above the GBAS reference point;

El_i = elevation angle of the ith satellite; and
h_0 = troposphere scale height from the Type 2 message.

3.6.5.3.2 The residual tropospheric uncertainty is:

$$\sigma_{tropo} = \sigma_n h_0 \frac{10^{-6}}{\sqrt{0.002 + \sin^2(El_i)}} (1 - e^{-\Delta h/h_0})$$

where σ_n = the refractivity uncertainty from the Type 2 message (3.6.4.3).

3.6.5.4 *Residual ionospheric uncertainty*. The residual ionospheric uncertainty for a given satellite is:

$$\sigma_{iono} = F_{pp} \times \sigma_{vert\_iono\_gradient} \times (x_{air} + 2 \times \tau \times v_{air})$$

where

F_{pp} = the vertical-to-slant obliquity factor for a given satellite (3.5.5.5.2);
$\sigma_{vert\_iono\_gradient}$ = (as defined in 3.6.4.3);
x_{air} = the distance (slant range) in metres between current aircraft location and the GBAS reference point indicated in the Type 2 message;
τ = 100 seconds (time constant used in 3.6.5.1); and
v_{air} = the aircraft horizontal approach velocity (metres per second).

3.6.5.5 *PROTECTION LEVELS*

3.6.5.5.1 *Category I precision approach and APV*. The signal-in-space vertical and lateral protection levels (VPL and LPL) are upper confidence bounds on the error in the position relative to the GBAS reference point defined as:

$$VPL = MAX\{VPL_{HO}, VPL_{H1}\}$$

$$LPL = MAX\{LPL_{HO}, LPL_{H1}\}$$

3.6.5.5.1.1 *Normal measurement conditions*

3.6.5.5.1.1.1 The vertical protection level (VPL_{H0}) and lateral protection level (LPL_{H0}), assuming that normal measurement conditions (i.e. no faults) exist in all reference receivers and on all ranging sources, is calculated as:

$$VPL_{H0} = K_{ffmd} \sqrt{\sum_{i=1}^{N} s\_vert_i^2 \times \sigma_i^2}$$

$$LPL_{H0} = K_{ffmd} \sqrt{\sum_{i=1}^{N} s\_lat_i^2 \times \sigma_i^2}$$

where

K_{ffmd} = the multiplier derived from the probability of fault-free missed detection;
s_vert_i = $s_{v,i} + s_{x,i} \times \tan(GPA)$;
s_lat_i = $s_{y,i}$;

$s_{x,i}$ = the partial derivative of position error in the x-direction with respect to pseudo-range error on the i^{th} satellite;
$s_{y,i}$ = the partial derivative of position error in the y-direction with respect to pseudo-range error on the i^{th} satellite;
$s_{v,i}$ = the partial derivative of position error in the vertical direction with respect to pseudo-range error on the i^{th} satellite;
GPA = the glidepath angle for the final approach path (3.6.4.5.1);
N = the number of ranging sources used in the position solution; and
i = the ranging source index for ranging sources used in the position solution.

Note.— The coordinate reference frame is defined such that x is along track positive forward, y is crosstrack positive left in the local level tangent plane and v is the positive up and orthogonal to x and y.

3.6.5.5.1.1.2 For a general-least-squares position solution, the projection matrix S is defined as:

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

where

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

$$W = \begin{bmatrix} \sigma_1^2 & 0 & \cdots & 0 \\ 0 & \sigma_2^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_N^2 \end{bmatrix}^{-1}$$

where $\sigma^2_i = \sigma^2_{pr\_gnd,i} + \sigma^2_{tropo,i} + \sigma^2_{pr\_air,i} + \sigma^2_{iono,i}$;

where

$\sigma_{pr\_gnd,i}$ = σ_{pr_gnd} for the i^{th} ranging source (3.6.4.2);
$\sigma_{tropo,i}$ = the residual tropospheric uncertainty for the i^{th} ranging source (3.6.5.3);
$\sigma_{iono,i}$ = the residual ionospheric delay (due to spatial decorrelation) uncertainty for the i^{th} ranging source (3.6.5.4); and
$\sigma_{pr\_air,i}$ = $\sqrt{\sigma^2_{receiver}(El_i) + \sigma^2_{multipath}(El_i)}$, the standard deviation of the aircraft contribution to the corrected pseudo-range error for the i^{th} ranging source. The total aircraft contribution includes the receiver contribution (3.6.8.2.1) and a standard allowance for airframe multipath;

where

$\sigma_{multipath}(El_i)$ = $0.13 + 0.53e^{-El_i/10\ deg}$, the standard model for the contribution of airframe multipath (in metres);
El_i = the elevation angle for the i^{th} ranging source (in degrees); and
Az_i = the azimuth for the i^{th} ranging source taken counterclockwise for the x axis (in degrees).

Note.— To improve readability, the subscript i *was omitted from the projection matrix's equation.*

3.6.5.5.1.2 *Faulted measurement conditions.* When the Type 101 message is broadcast without B parameter blocks, the values for VPL_{H1} and LPL_{H1} are defined as zero. Otherwise, the vertical protection level (VPL_{H1}) and lateral protection level (LPL_{H1}), assuming that a latent fault exists in one, and only one reference receiver, are:

$$VPL_{H1} = \max [VPL_j]$$

$$LPL_{H1} = \max [LPL_j]$$

where VPL_j and LPL_j for j = 1 to 4 are

$VPL_j = |B\_vert_j| + K_{md}\, \sigma_{vert,H1}$ and
$LPL_j = |B\_lat_j| + K_{md}\, \sigma_{lat,H1}$

and

$B\_vert_j = \sum_{i=1}^{N}(s\_vert_i \times B_{i,j})$;

$B\_lat_j = \sum_{i=1}^{N}(s\_lat_i \times B_{i,j})$;

$B_{i,j}$ = the broadcast differences between the broadcast pseudo-range corrections and the corrections obtained excluding the j^{th} reference receiver measurement for the i^{th} ranging source;

K_{md} = the multiplier derived from the probability of missed detection given that the ground subsystem is faulted;

$\sigma^2_{vert,H1} = \sum_{i=1}^{N} (s\_vert_i^2 \times \sigma\_H1_i^2)$;

$\sigma^2_{lat,H1} = \sum_{i=1}^{N} (s\_lat_i^2 \times \sigma\_H1_i^2)$;

$\sigma\_H1^2_i = \left(\frac{M_i}{U_i}\right) \sigma^2_{pr\_gnd,i} + \sigma^2_{pr\_air,i} + \sigma^2_{tropo,i} + \sigma^2_{iono,i}$;

M_i = the number of reference receivers used to compute the pseudo-range corrections for the i^{th} ranging source (indicated by the B values); and

U_i = the number of reference receivers used to compute the pseudo-range corrections for the i^{th} ranging source, excluding the j^{th} reference receiver.

Note.— A latent fault includes any erroneous measurement(s) that is not immediately detected by the ground subsystem, such that the broadcast data are affected and there is an induced position error in the aircraft subsystem.

3.6.5.5.1.3 *Definition of K multipliers for Category I precision approach and APV.* The multipliers are given in Table B-67.

Table B-67. K-multipliers for Category I precision approach and APV

Multiplier	M_i 1(Note)	2	3	4
K_{ffmd}	6.86	5.762	5.81	5.847
K_{md}	Not used	2.935	2.898	2.878

Note.— For APV I approaches supported by Type 101 messages broadcast without the B parameter block.

3.6.5.5.2 *GBAS positioning service.* The signal-in-space horizontal protection level is an upper confidence bound on the horizontal error in the position relative to the GBAS reference point defined as:

$$HPL = MAX\{HPL_{H0}, HPL_{H1}\}$$

3.6.5.5.2.1 *Normal measurements conditions*. The horizontal protection level (HPL_{H0}), assuming that normal measurement conditions (i.e. no faults) exist in all reference receivers and on all ranging sources, is calculated as:

$$HPL_{H0} = K_{ffmd,\,POS}\, d_{major}$$

where: $$d_{major} = \sqrt{\frac{d_x^2 + d_y^2}{2} + \sqrt{\left(\frac{d_x^2 - d_y^2}{2}\right)^2 + d_{xy}^2}}$$

$$d_x^2 = \sum_{i=1}^{N} s_{x,i}^2 \sigma_i^2$$

$$d_y^2 = \sum_{i=1}^{N} s_{y,i}^2 \sigma_i^2$$

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

$s_{x,i}$ = the partial derivative of position error in the x-direction with respect to pseudo-range error on the i^{th} satellite

$s_{y,i}$ = the partial derivative of position error in the y-direction with respect to pseudo-range error on the i^{th} satellite

$K_{ffmd,POS}$ = the multiplier derived from the probability of fault-free missed detection

N = the number of ranging sources used in the position solution

i = the ranging source index for ranging sources used in the position solution

σ_i = the pseudo-range error term as defined in 3.6.5.5.1.1

Note.— For the GBAS positioning service, the x and y axes define an arbitrary orthogonal basis in the horizontal plane.

3.6.5.5.2.2 *Faulted measurement conditions.* When the Type 101 message is broadcast without B parameter blocks, the value for HPL_{H1} is defined as zero. Otherwise, the horizontal protection level (HPL_{H1}), assuming that a latent fault exists in one and only one reference receiver, is:

$$HPL_{H1} = \max\,[HPL_j]$$

where HPL_j for j = 1 to 4 is:

$$HPL_j = |B\_horz_j| + K_{md\_POS}\, d_{major,H1}$$

and

$$B\_horz_j = \sqrt{\left(\sum_{i=1}^{N} S_{x,i} B_{i,j}\right)^2 + \left(\sum_{i=1}^{N} S_{y,i} B_{i,j}\right)^2}$$

$B_{i,j}$ = the broadcast differences between the broadcast pseudo-range corrections and the corrections obtained excluding the j^{th} reference receiver measurement for the i^{th} ranging source.

K_{md_POS} = the multiplier derived from the probability of missed detection given that the ground subsystem is faulted.

$$d_{major,H1} = \sqrt{\frac{d\_H1_x^2 + d\_H1_y^2}{2} + \sqrt{\left(\frac{d\_H1_x^2 - d\_H1_y^2}{2}\right)^2 + d\_H1_{xy}^2}}$$

$$d\_H1_x^2 = \sum_{i=1}^{N} s_{x,i}^2 \sigma\_H1_i^2$$

$$d\_H1_y^2 = \sum_{i=1}^{N} s_{y,i}^2 \sigma\_H1_i^2$$

$$d\_H1_{xy} = \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma\_H1_i^2$$

Note.— For the GBAS positioning service, the x and y axes define an arbitrary orthogonal basis in the horizontal plane.

$$\sigma\_H1_i^2 = \left(\frac{M_i}{U_i}\right) \sigma_{pr\_gnd,i}^2 + \sigma_{pr\_air,i}^2 + \sigma_{tropo,i}^2 + \sigma_{iono,i}^2$$

M_i = the number of reference receivers used to compute the pseudo-range corrections for the i^{th} ranging source (indicated by the B values).

U_i = the number of reference receivers used to compute the pseudo-range corrections for the i^{th} ranging source, excluding the j^{th} reference receiver.

Note.— A latent fault includes any erroneous measurement(s) that is not immediately detected by the ground subsystem, such that the broadcast data are affected and there is an induced position error in the aircraft subsystem.

3.6.5.5.2.3 *Definition of K multipliers for GBAS positioning service.* The multiplier K_{ffmd_POS} is equal to 10.0 and the multiplier K_{md_POS}, is equal to 5.3.

3.6.5.6 *ALERT LIMITS*

Note.— Guidance concerning the calculation of alert limits, including approaches associated with channel numbers 40 000 to 99 999, is provided in Attachment D, 7.13.

3.6.5.6.1 *Category I precision approach alert limits.* The alert limits are defined in Tables B-68 and B-69. For aircraft positions at which the lateral deviation exceeds twice the deviation at which full-scale lateral deflection of a course deviation indicator is achieved, or vertical deviation exceeds twice the deviation at which full-scale fly-down deflection of a course deviation indicator is achieved, both the lateral and vertical alert limits are set to the maximum values given in the tables.

3.6.5.6.2 *APV alert limits*. The alert limits are equal to the FASLAL and FASVAL for approaches with channel numbers in the range of 20 001 to 39 999. For approaches with channel numbers in the range 40 000 to 99 999, the alert limits are stored in the on-board database.

3.6.5.7 *Channel number*. Each GBAS approach transmitted from the ground subsystem is associated with a channel number in the range of 20 001 to 39 999. If provided, the GBAS positioning service is associated with a separate channel number in the range of 20 001 to 39 999. The channel number is given by:

$$\text{Channel number} = 20\,000 + 40(F - 108.0) + 411(S)$$

where

F = the data broadcast frequency (MHz)
S = RPDS or RSDS

and

RPDS = the reference path data selector for the FAS data block (as defined in 3.6.4.5.1)
RSDS = the reference station data selector for the GBAS ground subsystem (as defined in 3.6.4.3.1)

Table B-68. Category I lateral alert limit

Horizontal distance of aircraft position from the LTP/FTP as translated along the final approach path (metres)	Lateral alert limit (metres)
$291 < D \leq 873$	FASLAL
$873 < D \leq 7\,500$	0.0044D (m) + FASLAL – 3.85
$D > 7\,500$	FASLAL + 29.15

Table B-69. Category I vertical alert limit

Height above LTP/FTP of aircraft position translated onto the final approach path (feet)	Vertical alert limit (metres)
$100 < H \leq 200$	FASVAL
$200 < H \leq 1\,340$	0.02925H (ft) + FASVAL – 5.85
$H > 1\,340$	FASVAL + 33.35

For channel numbers transmitted in the additional data block 2 of Type 2 message (as defined in 3.6.4.3.2.1), only RSDS are used.

Note 1.— When the FAS is not broadcast for an APV, the GBAS approach is associated with a channel number in the range 40 000 to 99 999.

Note 2.— Guidance material concerning channel number selection is provided in Attachment D, 7.7.

3.6.5.8 *EPHEMERIS ERROR POSITION BOUND*

Note.— Ephemeris error position bounds are computed only for core satellite constellation ranging sources used in the position solution (j index) and not for other types of ranging sources (SBAS satellites or pseudolites) that are not subject to undetected ephemeris failures. However, the calculations of these position bounds use information from all ranging sources used in the position solution (i index).

3.6.5.8.1 *Category I precision approach and APV.* The vertical and lateral ephemeris error position bounds are defined as:

$$VEB = \underset{j}{MAX}\{VEB_j\}$$

$$LEB = \underset{j}{MAX}\{LEB_j\}$$

The vertical and lateral ephemeris error position bounds for the j^{th} core satellite constellation ranging source used in the position solution are given by:

$$VEB_j = \left|s\_vert_j\right| x_{air} P_j + K_{md\_e,j} \sqrt{\sum_{i=1}^{N} s\_vert_i^2 \times \sigma_i^2}$$

$$LEB_j = \left|s\_lat_j\right| x_{air} P_j + K_{md\_e,j} \sqrt{\sum_{i=1}^{N} s\_lat_i^2 \times \sigma_i^2}$$

where:

$s\_vert_{i\ or\ j}$ is defined in 3.6.5.5.1.1
$s\_lat_{i\ or\ j}$ is defined in 3.6.5.5.1.1
x_{air} is defined in 3.6.5.4
N is the number of ranging sources used in the position solution
σ_i is defined in 3.6.5.5.1.1
P_j is the broadcast ephemeris decorrelation parameter for the j^{th} ranging source
$K_{md\_e,j}$ is the broadcast ephemeris missed detection multiplier for Category I precision approach and APV associated with the satellite constellation for the j^{th} ranging source ($K_{md\_e,GPS}$ or $K_{md\_e,GLONASS}$)

3.6.5.8.2 *GBAS positioning service*. The horizontal ephemeris error position bound is defined as:

$$HEB = \underset{j}{MAX}\{HEB_j\}$$

The horizontal ephemeris error position bound for the j^{th} core satellite constellation ranging source used in the position solution is given by:

$$HEB_j = |s_{horz,j}| x_{air} P_j + K_{md\_e\_POS} d_{major}$$

where:

$S_{horz,j}{}^2 = S_{xj}{}^2 + S_{yj}{}^2$

$s_{x,j}$ is as defined in 3.6.5.5.2.1

$s_{y,j}$ is as defined in 3.6.5.5.2.1

x_{air} is defined in 3.6.5.4

P_j is the broadcast ephemeris decorrelation parameter for the j^{th} ranging source

$K_{md\_e\_POS}$ is the broadcast ephemeris missed detection multiplier for the GBAS positioning service associated with the satellite constellation for the j^{th} ranging source ($K_{md\_e\_POS,GPS}$ or $K_{md\_e\_POS,GLONASS}$)

d_{major} is as defined in 3.6.5.5.2.1

3.6.6 MESSAGE TABLES

Each GBAS message shall be coded in accordance with the corresponding message format defined in Tables B-70 through B-73.

Note.— Message type structure is defined in 3.6.4.1.

Table B-70. Type 1 pseudo-range corrections message

Data content	Bits used	Range of values	Resolution
Modified Z-count	14	0 to 1 199.9 s	0.1 s
Additional message flag	2	0 to 3	1
Number of measurements (N)	5	0 to 18	1
Measurement type	3	0 to 7	1
Ephemeris decorrelation parameter (P)	8	0 to 1.275 × 10^{-3} m/m	5 × 10^{-6} m/m
Ephemeris CRC	16	—	—
Source availability duration	8	0 to 2 540 s	10 s
For N measurement blocks			
Ranging source ID	8	1 to 255	1
Issue of data (IOD)	8	0 to 255	1
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s
σ_{pr_gnd}	8	0 to 5.08 m	0.02 m
B_1	8	±6.35 m	0.05 m
B_2	8	±6.35 m	0.05 m
B_3	8	±6.35 m	0.05 m
B_4	8	±6.35 m	0.05 m

Table B-70A. Type 101 GRAS pseudo-range corrections message

Data content	Bits used	Range of values	Resolution
Modified Z-count	14	0 to 1 199.9 s	0.1 s
Additional message flag	2	0 to 3	1
Number of measurements (N)	5	0 to 18	1
Measurement type	3	0 to 7	1
Ephemeris decorrelation parameter (P)	8	0 to 1.275×10^{-3} m/m	5×10^{-6} m/m
Ephemeris CRC	16	—	—
Source availability duration	8	0 to 2540 s	10 s
Number of B parameters	1	0 or 4	—
Spare	7	—	—
For N measurement blocks			
Ranging source ID	8	1 to 255	1
Issue of data (IOD)	8	0 to 255	1
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s
$\sigma_{pr\ gnd}$	8	0 to 50.8 m	0.2 m
B parameter block (if provided)			
B_1	8	±25.4 m	0.2 m
B_2	8	±25.4 m	0.2 m
B_3	8	±25.4 m	0.2 m
B_4	8	±25.4 m	0.2 m

Table B-71A. Type 2 GBAS-related data message

Data content	Bits used	Range of values	Resolution
GBAS reference receivers	2	2 to 4	—
Ground accuracy designator letter	2	—	—
Spare	1	—	—
GBAS continuity/integrity designator	3	0 to 7	1
Local magnetic variation	11	±180°	0.25°
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)			

Data content	Bits used	Range of values	Resolution
Additional data block length	8	2 to 255	1
Additional data block number	8	2 to 255	1
Additional data parameters	Variable	—	—

Table B-71B. Type 3 null message

Data content	Bits used	Range of values	Resolution
Filler	Variable (Note)	N/A	N/A

Note.— The number of bytes in the filler field is 10 less than the message length field in the message header as defined in section 3.6.3.4.

Table B-72. Type 4 FAS data message

Data content	Bits used	Range of values	Resolution
For N data sets			
Data set length	8	2 to 212	1 byte
FAS data block	304	—	—
FAS vertical alert limit/approach status	8		
(1) when associated approach performance designator 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

3.6.7 NON-AIRCRAFT ELEMENTS

3.6.7.1 *PERFORMANCE*

3.6.7.1.1 *Accuracy*

3.6.7.1.1.1 The root-mean-square (RMS) (1 sigma) of the ground subsystem contribution to the corrected pseudo-range accuracy for GPS and GLONASS satellites shall be:

$$RMS_{pr\_gnd} \leq \sqrt{\frac{(a_0 + a_1 e^{-\theta_n/\theta_0})^2}{M} + (a_2)^2}$$

where

M	=	the number of GNSS reference receivers, as indicated in the Type 2 message parameter (3.6.4.3), or, when this parameter is coded to indicate “not applicable”, the value of M is defined as 1;
n	=	n^{th} ranging source;
θ_n	=	elevation angle for the n^{th} ranging source; and
a_0, a_1, a_2, and θ_0	=	parameters defined in Tables B-74 and B-75 for each of the defined ground accuracy designators (GADs).

Note 1.— The GBAS ground subsystem accuracy requirement is determined by the GAD letter and the number of installed reference receivers.

Note 2.— The ground subsystem contribution to the corrected pseudo-range error specified by the curves defined in Tables B-74 and B-75 and the contribution to the SBAS satellites do not include aircraft noise and aircraft multipath.

Table B-74. GBAS — GPS accuracy requirement parameters

Ground accuracy designator letter	θ_n (degrees)	a_0 (metres)	a_1 (metres)	θ_0 (degrees)	a_2 (metres)
A	≥ 5	0.5	1.65	14.3	0.08
B	≥ 5	0.16	1.07	15.5	0.08
C	> 35	0.15	0.84	15.5	0.04
	5 to 35	0.24	0	—	0.04

Table B-75. 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:

$$\mathrm{RMS}_{\mathrm{pr\_gnd}} \leq \frac{1.8}{\sqrt{\mathrm{M}}}\,(\mathrm{metres})$$

where M is as defined in 3.6.7.1.1.1.

Note.— GAD classifications for SBAS ranging sources are under development.

3.6.7.1.2 *Integrity*

3.6.7.1.2.1 *GBAS ground subsystem integrity risk*

3.6.7.1.2.1.1 *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.

Note.— Guidance material concerning usage of the Type 101 message is provided in Attachment D, 7.18.

3.6.7.2.1.1.2 Each GBAS ground subsystem shall broadcast Type 2 messages.

3.6.7.2.1.1.3 Each GBAS ground subsystem shall broadcast FAS blocks in Type 4 messages for all Category I precision approaches supported by that GBAS ground subsystem. If a GBAS ground subsystem supports APV and does not broadcast FAS blocks for the corresponding approaches, it shall broadcast additional data block 1 in the Type 2 message.

Note.— FAS blocks for APV procedures may be held within a database on board the aircraft. Broadcasting additional data block 1 allows the airborne receiver to select the GBAS ground subsystem that supports the approach procedures in the airborne database. FAS blocks may also be broadcast to support operations by aircraft without an airborne database. These procedures use different channel numbers as described in Attachment D, 7.7.

3.6.7.2.1.1.4 When the Type 5 message is used, the ground subsystem shall broadcast the Type 5 message at a rate in accordance with Table B-76.

Note.— When the standard 5 degree mask is not adequate to describe satellite visibility at either the ground subsystem antennas or at an aircraft during a specific approach, the Type 5 message may be used to broadcast additional information to the aircraft.

3.6.7.2.1.1.5 *Data broadcast rates.* For all message types required to be broadcast, messages meeting the field strength requirements of Chapter 3, 3.7.3.5.4.4.1.2 and 3.7.3.5.4.4.2.2 and the minimum rates shown in Table B-76 shall be provided at every point within the coverage. The total message broadcast rates from all antenna systems of the ground subsystem combined shall not exceed the maximum rates shown in Table B-76.

Note.— Guidance material concerning the use of multiple antenna systems is provided in Attachment D, 7.12.4.

Table B-76. GBAS VHF data broadcast rates

Message type	Minimum broadcast rate	Maximum broadcast rate
1 or 101	For each measurement type: All measurement blocks once per frame (Note)	For each measurement type: All measurement blocks once per slot
2	Once per 20 consecutive frames	Once per frame
4	All FAS blocks once per 20 consecutive frames	All FAS blocks once per frame
5	All impacted sources once per 20 consecutive frames	All impacted sources once per 5 consecutive frames

Note.— One Type 1 or Type 101 message or two Type 1 or Type 101 messages that are linked using the additional message flag described in 3.6.4.2.

3.6.7.2.1.2 *Message block identifier*. The MBI shall be set to either normal or test according to the coding given in 3.6.3.4.1.

3.6.7.2.1.3 *VDB authentication*

Note.— This section is reserved for forward compatibility with future authentication functions.

3.6.7.2.2 *Pseudo-range corrections*

3.6.7.2.2.1 *Message latency*. The time between the time indicated by the modified Z-count and the last bit of the broadcast Type 1 or Type 101 message shall not exceed 0.5 seconds.

3.6.7.2.2.2 *Low-frequency data*. Except during an ephemeris change, the first ranging source in the message shall sequence so that the ephemeris decorrelation parameter, ephemeris CRC and source availability duration for each core satellite constellation's ranging source are transmitted at least once every 10 seconds. During an ephemeris change, the first ranging source shall sequence so that the ephemeris decorrelation parameter, ephemeris CRC and source availability duration for each core satellite constellation's ranging source are transmitted at least once every 27 seconds. When new ephemeris data are received from a core satellite constellation's ranging source, the ground subsystem shall use the previous ephemeris data from each satellite until the new ephemeris data have been continuously received for at least 2 minutes but shall make a transition to the new ephemeris data before 3 minutes have passed. When this transition is made to using the new ephemeris data for a given ranging source, the ground subsystem shall broadcast the new ephemeris CRC for all occurrences of that ranging source in the low-frequency information of Type 1 or Type 101 message in the next 3 consecutive frames. For a given ranging source, the ground subsystem shall continue to transmit data corresponding to the previous ephemeris data until the new CRC ephemeris is transmitted in the low-frequency data of Type 1 or Type 101 message (see *Note*). If the ephemeris CRC changes and the IOD does not, the ground subsystem shall consider the ranging source invalid.

Note.— The delay before the ephemeris transition allow sufficient time for the aircraft subsystem to collect new ephemeris data.

3.6.7.2.2.2.1 **Recommendation.—** *The ephemeris decorrelation parameter and the ephemeris CRC for each core satellite constellation's ranging source should be broadcast as frequently as possible.*

3.6.7.2.2.3 *Broadcast pseudo-range correction*. Each broadcast pseudo-range correction shall be determined by combining the pseudo-range correction estimates for the relevant ranging source calculated from each of the reference receivers. For each satellite, the measurements used in this combination shall be obtained from the same ephemeris data. The corrections shall be based on smoothed code pseudo-range measurements for each satellite using the carrier measurement from a smoothing filter in accordance with 3.6.5.1.

3.6.7.2.2.4 *Broadcast signal-in-space integrity parameters*. The ground subsystem shall provide σ_{pr_gnd} and B parameters for each pseudo-range correction in Type 1 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied. The ground subsystem shall provide σ_{pr_gnd} and, if necessary, B parameters for each pseudo-range correction in Type 101 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

Note.— Broadcast of the B parameters are optional for Type 101 messages. Guidance material regarding the B parameters in Type 101 messages is contained in Attachment D, 7.5.11.

3.6.7.2.2.5 **Recommendation.—** *Reference receiver measurements should be monitored. Faulted measurements or failed reference receivers should not be used to compute the pseudo-range corrections.*

3.6.7.2.2.6 *Repeated transmission of Type 1 or Type 101 messages.* For a given measurement type and within a given frame, all broadcasts of Type 1 or Type 101 messages or linked pairs from all GBAS broadcast stations that share a common GBAS identification, shall have identical data content.

3.6.7.2.2.7 *Issue of data.* The GBAS ground subsystem shall set the IOD field in each ranging source measurement block to be the IOD value received from the ranging source that corresponds to the ephemeris data used to compute the pseudo-range correction.

3.6.7.2.2.8 *Application of signal error models*. Ionospheric and tropospheric corrections shall not be applied to the pseudo-ranges used to calculate the pseudo-range corrections.

3.6.7.2.2.9 *Linked pair of Type 1 or Type 101 messages.* If a linked pair of Type 1 or Type 101 messages is transmitted then,

a) the two messages shall have the same modified Z-count;

b) the minimum number of pseudo-range corrections in each message shall be one;

c) the measurement block for a given satellite shall not be broadcast more than once in a linked pair of messages;

d) the two messages shall be broadcast in different time slots; and

e) the order of the B values in the two messages shall be the same.

3.6.7.2.2.10 *Modified Z-count update.* The modified Z-count for Type 1 or Type 101 messages of a given measurement type shall advance every frame.

3.6.7.2.2.11 *Ephemeris decorrelation parameters*

3.6.7.2.2.11.1 *Category I precision approach and APV*. For ground subsystems that broadcast the additional data block 1 in the Type 2 message, the ground subsystem shall broadcast the ephemeris decorrelation parameter for each core satellite constellation ranging source such that the ground subsystem integrity risk of 3.6.7.1.2.1.1 is met.

3.6.7.2.2.11.2 *GBAS positioning service*. For ground subsystems that provide the GBAS positioning service, the ground subsystem shall broadcast the ephemeris decorrelation parameter for each core satellite constellation's ranging source such that the ground subsystem integrity risk of 3.6.7.1.2.1.2 is met.

3.6.7.2.3 *GBAS-related data*

3.6.7.2.3.1 *Tropospheric delay parameters.* The ground subsystem shall broadcast a refractivity index, scale height, and refractivity uncertainty in a Type 2 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

3.6.7.2.3.2 *GCID indication*. If the ground subsystem meets the requirements of 3.6.7.1.2.1.1, 3.6.7.1.2.2.1 and 3.6.7.1.3.1 the GCID shall be set to 1 otherwise it shall be set to 7.

3.6.7.2.3.3 *GBAS reference antenna phase centre position accuracy*. For each GBAS reference receiver, the reference antenna phase centre position error shall be less than 8 cm relative to the GBAS reference point.

3.6.7.2.3.4 **Recommendation.—** *GBAS reference point survey accuracy. The survey error of the GBAS reference point, relative to WGS-84, should be less than 0.25 m vertical and 1 m horizontal.*

Note.— Relevant guidance material is given in Attachment D, 7.16.

3.6.7.2.3.5 *Ionospheric uncertainty estimate parameter.* The ground subsystem shall broadcast an ionospheric delay gradient parameter in the Type 2 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.

3.6.7.2.3.6 For ground subsystems that provide the GBAS positioning service, the ground subsystem shall broadcast the ephemeris error position bound parameters using additional data block 1 in the Type 2 message.

3.6.7.2.3.7 **Recommendation.—** *All ground subsystems should broadcast the ephemeris error position bound parameters using additional data block 1 in the Type 2 message.*

3.6.7.2.3.8 For ground subsystems that broadcast additional data block 1 in the Type 2 message, the following requirements shall apply:

3.6.7.2.3.8.1 *Maximum use distance*. The ground subsystem shall provide the distance (D_{max}) from the GBAS reference point that defines a volume within which the ground subsystem integrity risk in 3.6.7.1.2.1 and the protection level integrity risk in 3.6.7.1.2.2 are met.

3.6.7.2.3.8.2 *Ephemeris missed detection parameters*. The ground subsystem shall broadcast the ephemeris missed detection parameters for each core satellite constellation such that the ground subsystem integrity risk of 3.6.7.1.2.1 is met.

3.6.7.2.3.8.3 *GBAS positioning service indication*. If the ground subsystem does not meet the requirements of 3.6.7.1.2.1.2 and 3.6.7.1.2.2.2, the ground subsystem shall indicate using the RSDS parameter that the GBAS positioning service is not provided.

3.6.7.2.3.9 If the VHF data broadcast is transmitted at more than one frequency within the GRAS service area, each GBAS broadcast station within the GRAS ground subsystem shall broadcast additional data blocks 1 and 2.

3.6.7.2.3.9.1 **Recommendation.—** *The VHF data broadcast should include additional data block 2 parameters to identify channel numbers and locations of adjacent and nearby GBAS broadcast stations within the GRAS ground subsystem.*

Note.— This facilitates the transition from one GBAS broadcast station to other GBAS broadcast stations in the GRAS ground subsystem.

3.6.7.2.4 *Final approach segment data*

3.6.7.2.4.1 *FAS data points accuracy*. The relative survey error between the FAS data points and the GBAS reference point shall be less than 0.25 metres vertical and 0.40 metres horizontal.

3.6.7.2.4.2 **Recommendation.—** *The final approach segment CRC should be assigned at the time of procedure design, and kept as an integral part of the FAS data block from that time onward.*

3.6.7.2.4.3 **Recommendation.—** *The GBAS should allow the capability to set the FASVAL and FASLAL for any FAS data block to "1111 1111" to limit the approach to lateral only or to indicate that the approach must not be used, respectively.*

3.6.7.2.5 *Predicted ranging source availability data*

Note.— Ranging source availability data are optional for Category I and APV and may be required for possible future operations.

3.6.7.2.6 *Integrity monitoring for GNSS ranging sources*. The ground subsystem shall monitor the satellite signals to detect conditions that will result in improper operation of differential processing for airborne receivers complying with the tracking constraints in Attachment D, 8.11. The ground subsystem shall use the strongest correlation peak in all receivers used to generate the pseudo-range corrections. The monitor time-to-alert shall comply with 3.6.7.1.2. The monitor action shall be to set σ_{pr_gnd} to the bit pattern "1111 1111" for the satellite or to exclude the satellite from the Type 1 or Type 101 message. The ground subsystem shall also detect conditions that cause more than one zero crossing for airborne receivers that use the Early-Late discriminator function as described in Attachment D, 8.11.

3.6.7.3 *MONITORING*

3.6.7.3.1 *RF monitoring*

3.6.7.3.1.1 *VHF data broadcast monitoring.* The data broadcast transmissions shall be monitored. The transmission of the data shall cease within 0.5 seconds in case of continuous disagreement during any 3-second period between the transmitted application data and the application data derived or stored by the monitoring system prior to transmission.

3.6.7.3.1.2 *TDMA slot monitoring.* The risk that the ground subsystem transmits a signal in an unassigned slot and fails to detect an out-of-slot transmission, which exceeds that allowed in 3.6.2.6, within 1 second, shall be less than 1×10^{-7} in any 30-second period. If out-of-slot transmissions are detected, the ground subsystem shall terminate all data broadcast transmissions within 0.5 seconds.

3.6.7.3.1.3 *VDB transmitter power monitor.* The probability that the horizontally or elliptically polarized signal's transmitted power increases by more than 3 dB from the nominal power for more than 1 second shall be less than 2.0×10^{-7} in any 30-second period.

Note.— The vertical component is only monitored for GBAS/E equipment.

3.6.7.3.2 *Data monitoring*

3.6.7.3.2.1 *Broadcast quality monitor*. The ground subsystem monitoring shall comply with the time-to-alert requirements given in 3.6.7.1.2.1. The monitoring action shall be one of the following:

a) to broadcast Type 1 or Type 101 messages with no measurement blocks; or

b) to broadcast Type 1 or Type 101 messages with the $\sigma_{pr\_gnd,i}$ field set to indicate the ranging source is invalid for every ranging source included in the previously transmitted frame; or

c) to terminate the data broadcast.

Note.— Monitoring actions a) and b) are preferred to c) if the particular failure mode permits such a response, because actions a) and b) typically have a reduced signal-in-space time-to-alert.

3.6.7.4 *FUNCTIONAL REQUIREMENTS FOR AUTHENTICATION PROTOCOLS*

3.6.7.4.1 *Functional requirements for ground subsystems that support authentication*

3.6.7.4.1.1 The ground system shall broadcast the additional data block 4 with the Type 2 message with the slot group definition field coded to indicate which slots are assigned to the ground station.

3.6.7.4.1.2 The ground subsystem shall broadcast every Type 2 message in the slot that corresponds to the SSID coding for the ground subsystem. Slot A is represented by SSID = 0, B by 1, C by 2, and H by 7.

3.6.7.4.1.3 *Assigned slot occupancy*. The ground subsystem shall transmit messages such that 87 per cent or more of every assigned slot is occupied. If necessary, Type 3 messages will be used to fill unused space in any assigned time slot.

3.6.7.4.1.4 *Reference path identifier coding*. Every reference path identifier included in every final approach segment data block broadcast by the ground station via the Type 4 messages shall have the first letter selected to indicate the SSID of the ground station in accordance with the following coding.

each location where the operation is to be approved. This assessment is performed over all environmental and operational conditions under which the service is declared available;

b) under system failure conditions, the system design is such that the probability of an error greater than 15 m (50 ft) is lower than 10^{-5}, so that the likelihood of occurrence is remote. The fault conditions to be taken into account are those affecting either the core constellations or the GNSS augmentation under consideration. This probability is to be understood as the combination of the occurrence probability of a given failure with the probability of detection for applicable monitor(s). Typically, the probability of a single fault is large enough that a monitor is required to satisfy this condition.

3.3.10 For GBAS, a technical provision has been made to broadcast the alert limit to aircraft. GBAS standards require the alert limit of 10 m (33 ft). For SBAS, technical provisions have been made to specify the alert limit through an updatable database (see Attachment C).

3.3.11 The approach integrity requirements apply in any one landing and require a fail-safe design. If the specific risk on a given approach is known to exceed this requirement, the operation should not be conducted. One of the objectives of the design process is to identify specific risks that could cause misleading information and to mitigate those risks through redundancy or monitoring to achieve a fail-safe design. For example, the ground system may need redundant correction processors and to be capable of shutting down automatically if that redundancy is not available due to a processor fault.

3.3.12 A unique aspect of GNSS is the time-varying performance caused by changes in the core satellite geometry. A means to account for this variation is included in the SBAS and GBAS protocols through the protection level equations, which provide a means to inhibit use of the system if the specific integrity risk is too high.

3.3.13 GNSS performance can also vary across the service volume as a result of the geometry of visible core constellation satellites. Spatial variations in system performance can further be accentuated when the ground system operates in a degraded mode following the failure of system components such as monitoring stations or communication links. The risk due to spatial variations in system performance should be reflected in the protection level equations, i.e. the broadcast corrections.

3.3.14 GNSS augmentations are also subject to several atmospheric effects, particularly due to the ionosphere. Spatial and temporal variations in the ionosphere can cause local or regional ionospheric delay errors that cannot be corrected within the SBAS or GBAS architectures due to the definition of the message protocols. Such events are rare and their likelihood varies by region, but they are not expected to be negligible. The resulting errors can be of sufficient magnitude to cause misleading information and should be mitigated in the system design through accounting for their effects in the broadcast parameters (e.g. σ_{iono_vert} in GBAS), and monitoring for excessive conditions where the broadcast parameters are not adequate. The likelihood of encountering such events should be considered when developing any system monitor.

3.3.15 Another environmental effect that should be accounted for in the ground system design is the errors due to multipath at the ground reference receivers, which depend on the physical environment of monitoring station antennas as well as on satellite elevations and times in track.

3.4 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 and landing, given that it was available at the start of the operation. In particular, this means that loss of continuity events that can be predicted and for which NOTAMs have been issued do not have to be taken into account when establishing compliance of a given system design against the SARPs continuity requirement. The occurrence of navigation system alerts, either due to rare fault-free performance or to failures, constitutes a loss of continuity event. In this case, the continuity requirement is stated as a probability for a short exposure time.

3.4.3.2 The continuity requirements for approach and landing operations represent only the allocation of the requirement between the aircraft receiver and the non-aircraft elements of the system. In this case, no increase in the requirement is considered necessary to deal with multiple aircraft use of the system. The continuity value is normally related only to the risk associated with a missed approach and each aircraft can be considered to be independent. However, in some cases, it may be necessary to increase the continuity values since a system failure has to be correlated between both runways (e.g. the use of a common system for approaches to closely-spaced parallel runways).

3.4.3.3 For GNSS-based APV and Category I approaches, missed approach is considered a normal operation, since it occurs whenever the aircraft descends to the decision altitude for the approach and the pilot is unable to continue with visual reference. The continuity requirement for these operations applies to the average risk (over time) of loss of service, normalized to a 15-second exposure time. Therefore, the specific risk of loss of continuity for a given approach could exceed the average requirement without necessarily affecting the safety of the service provided or the approach. A safety assessment performed for one system led to the conclusion that, in the circumstances specified in the assessment, continuing to provide the service was safer than withholding it.

3.4.3.4 For those areas where the system design does not meet the average continuity risk specified in the SARPs, it is still possible to publish procedures. However, specific operational mitigations should be put in place to cope with the reduced continuity expected. For example, flight planning may not be authorized based solely on a GNSS navigation means with such a high average continuity risk.

3.5 Availability

3.5.1 The availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.

3.5.2 When establishing the availability requirements for GNSS, the desired level of service to be supported should be considered. If the satellite navigation service is intended to replace an existing en-route navigation aid infrastructure, the availability of the GNSS should be commensurate with the availability provided by the existing infrastructure. An assessment of the operational impact of a degradation in service should be conducted.

3.5.3 Where GNSS availability is low, it is still possible to use the satellite navigation service by restricting the navigation operating times to those periods when it is predicted to be available. This is possible in the case of GNSS since unavailability due to insufficient satellite geometry is repeatable. Under such restrictions, there remains only a continuity risk associated with the failure of necessary system components between the time the prediction is made and the time the operation is conducted.

3.5.4 *En-route*

3.5.4.1 Specific availability requirements for an area or operation should be based upon:

a) traffic density and complexity;

b) alternate navigation aids;

c) primary/secondary surveillance coverage;

d) air traffic and pilot procedures; and

e) duration of outages.

3.5.4.2 For this reason, the GNSS SARPs specify a range of values for availability requirements. The requirements support GNSS sole-means operations in airspace with various levels of traffic and complexity. The lower end of the range is only sufficient for providing sole means of navigation in a low traffic density and complexity airspace.

3.5.4.3 While augmentations can reduce the dependency of the GNSS on a particular core element, they do not provide usable service without the core elements. The requirement for the availability of a particular augmentation in an area should account for potential degradation in the GNSS core elements (i.e. the minimum constellation of core elements (number and diversity of satellites) that is expected). Operational procedures should be developed in case such a degraded configuration occurs.

3.5.5 *Approach*

3.5.5.1 Specific requirements for an area should be based upon:

a) traffic density and complexity;

b) procedures for filing and conducting an approach to an alternate airport;

c) navigation system to be used for an alternate airport;

d) air traffic and pilot procedures;

e) duration of outages; and

f) geographic extent of outages.

3.5.5.2 When developing operating procedures for GNSS approach systems, the duration of an outage and its impact on the alternate airport should be considered. Although GNSS outages can occur which affect many approaches, the approach service can be restored without any maintenance because of the orbiting of the satellites.

3.5.6 *Determining GNSS availability*

The availability of GNSS is complicated by the movement of satellites relative to a coverage area under consideration and the potentially long time needed to restore a satellite in the event of a failure. Accurately measuring the availability would require many years to allow for a measurement period longer than the MTBF and repair times. The availability of GNSS should be determined through design, analysis and modelling, rather than measurement. The availability model should account for the ionospheric, tropospheric and receiver error models used by the receiver to verify integrity (e.g. HPL, LPL and VPL calculations). The availability specified in Chapter 3, 3.7.2.4, applies to the design availability.

Note.— Additional guidance material pertaining to reliability and availability of radio communications and navigation aids is contained in Attachment F.

4. GNSS core elements

4.1 GPS

Note.— Additional information concerning GPS can be found in the Global Positioning System – Standard Positioning Service – Performance Standard, *September 2008, and Interface Specification (IS)-GPS-200E.*

4.1.1 The performance standard is based upon the assumption that a representative standard positioning service (SPS) receiver is used. A representative receiver has the following characteristics:

a) designed in accordance with IS-GPS-200E;

b) uses a 5-degree masking angle;

c) accomplishes satellite position and geometric range computations in the most current realization of the World Geodetic System 1984 (WGS-84) Earth-Centred, Earth-Fixed (ECEF) coordinate system;

d) generates a position and time solution from data broadcast by all satellites in view;

e) compensates for dynamic Doppler shift effects on nominal SPS ranging signal carrier phase and C/A code measurements;

f) excludes marginal and unhealthy satellites from the position solution;

g) uses up-to-date and internally consistent ephemeris and clock data for all satellites it is using in its position solution; and

h) loses track in the event that a GPS satellite stops transmitting a trackable signal.

The time transfer accuracy applies to the data in the broadcast navigation message, which relates GPS SPS time to UTC as maintained by the United States Naval Observatory. A 12-channel receiver will meet performance requirements specified in Chapter 3, 3.7.3.1.1.1 and 3.7.3.1.2. A receiver that is able to track four satellites only (Appendix B, 3.1.3.1.2) will not get the full accuracy and availability performance.

Note.— Conditions indicating that a satellite is "healthy", "marginal" or "unhealthy" can be found in the United States Department of Defense, Global Positioning System – Standard Positioning Service – Performance Standard, *4th Edition, September 2008, Section 2.3.2.*

4.1.2 *Position domain accuracy*. The position domain accuracy is measured with a representative receiver and a measurement interval of 24 hours for any point within the coverage area. The positioning and timing accuracy are for the signal-in-space (SIS) only and do not include such error sources as: ionosphere, troposphere, interference, receiver noise or multipath.

4.1.3 *Range domain accuracy*. The range domain accuracy standard applies to normal operations, which implies that updated navigation data is uplinked to the satellites on a regular basis. Range domain accuracy is conditioned by the satellite indicating a healthy status and transmitting C/A code and does not account for satellite failures outside of the normal operating characteristics. Range domain accuracy limits can be exceeded during satellite failures or anomalies while uploading data to the satellite. The range rate error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. The range acceleration error limit is the maximum for any satellite measured over any 3-second interval for any point within the coverage area. Under nominal conditions, all satellites are maintained to the same standards, so it is appropriate for availability modelling purposes to assume that all satellites have a 4-metre RMS SIS user range error (URE). The standards are restricted to range domain errors allocated to space and control segments.

4.1.4 *Availability*. The availability standard applies to normal operations, which implies that updated navigation data is uplinked to the satellites on a regular basis. Availability is the percentage of time over any 24-hour interval that the predicted 95 per cent positioning error (due to space and control segment errors) is less than its threshold, for any point within the coverage area. It is based on a 17-metre horizontal 95 per cent threshold; a 37-metre vertical 95 per cent threshold; using a representative receiver; and operating within the coverage area over any 24-hour interval. The service availability assumes a constellation that meets the criteria in 4.1.4.2.

4.1.4.1 *Relationship to augmentation availability*. The availability of ABAS, GBAS and SBAS does not directly relate to the GPS availability defined in Chapter 3, 3.7.3.1.2. States and operators must evaluate the availability of the augmented system by comparing the augmented performance to the requirements. Availability analysis is based on an assumed satellite constellation and the probability of having a given number of satellites.

4.1.4.2 *Satellite/constellation availability*. Twenty-four operational satellites will be maintained on orbit with 0.95 probability (averaged over any day), where a satellite is defined to be operational if it is capable of, but is not necessarily transmitting, a usable ranging signal. At least 21 satellites in the nominal 24 slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (normalized annually). At least 20 satellites in the nominal 24 slot positions must be set healthy and must be transmitting a navigation signal with 0.99999 probability (normalized annually).

4.1.5 *Reliability*. Reliability is the percentage of time over a specified time interval that the instantaneous SPS SIS URE is maintained within the range error limit, at any given point within the coverage area, for all healthy GPS satellites. The reliability standard is based on a measurement interval of one year and the average of daily values within the coverage area. The worst single point average reliability assumes that the total service failure time of 18 hours will be over that particular point (3 failures each lasting 6 hours).

4.1.6 *Major service failure.* A major service failure is defined to be a condition over a time interval during which a healthy GPS satellite's ranging signal error (excluding atmospheric and receiver errors) exceeds the range error limit of 4.42 times the upper bound on the user range accuracy (URA) broadcast by a satellite for longer than the allowable time to alert (10 seconds). The probability of 1×10^{-5} in Chapter 3, 3.7.3.1.4 corresponds to a maximum of 3 major service failures for the entire constellation per year assuming a maximum constellation of 32 satellites:

4.1.7 *Continuity*. Continuity for a healthy GPS satellite is the probability that the SPS SIS will continue to be healthy without unscheduled interruption over a specified time interval. Scheduled interruptions which are announced at least 48 hours in advance do not contribute to a loss of continuity

4.1.8 *Coverage*. The SPS supports the terrestrial coverage area, which is from the surface of the earth up to an altitude of 3 000 km.

4.2 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 6-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 6-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 12-metre (40-foot) horizontal 95 per cent threshold and a 25-metre (80-foot) 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 18 m (60 ft) (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 Satellite-based augmentation services are provided by the Wide Area Augmentation System (WAAS) (North America), the European Geostationary Navigation Overlay Service (EGNOS) (Europe and Africa) and the Multifunction Transport Satellite (MTSAT) Satellite-based Augmentation System (MSAS) (Japan). The GPS-aided Geo-augmented Navigation (GAGAN) (India) and the System of Differential Correction and Monitoring (SDCM) (Russia) are also under development to provide these services.

6.2.3 An SBAS may provide accurate and reliable service outside the defined service area(s). The ranging, satellite status and basic differential corrections functions are usable throughout the entire coverage area. The performance of these functions may be technically adequate to support en-route, terminal and non-precision approach operations by providing monitoring and integrity data for core satellite constellations and/or SBAS satellites. 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 for an SBAS provider to monitor and send integrity and correction data for a geostationary orbit satellite that belongs to another SBAS service provider. This improves availability by adding ranging sources. This improvement does not require any interconnection between SBAS systems and should be accomplished by all SBAS service providers.

6.2.9 Other levels of integration can be implemented using a unique connection between the SBAS networks (e.g. separate satellite communication). In this case, SBASs can exchange either raw satellite measurements from one or more reference stations or processed data (corrections or integrity data) from their master stations. This information can be used to improve system robustness and accuracy through data averaging, or integrity through a cross check mechanism. Availability will also be improved within the service areas, and the technical performance will meet the GNSS SARPs throughout the entire coverage (i.e. monitoring of satellites ephemeris would be improved). Finally, SBAS control and status data could be exchanged to improve system maintenance.

6.3 Integrity

6.3.1 The provisions for integrity are complex, as some attributes are determined within the SBAS ground network and transmitted in the signal-in-space, while other attributes are determined within the SBAS equipment on the aircraft. For the satellite status and basic corrections functions, an error uncertainty for the ephemeris and clock corrections is determined by the SBAS ground network. This uncertainty is modelled by the variance of a zero-mean, normal distribution that describes the user differential range error (UDRE) for each ranging source after application of fast and long-term corrections and excluding atmospheric effects and receiver errors.

6.3.2 For the precise differential function, an error uncertainty for the ionospheric correction is determined. This uncertainty is modelled by the variance of a zero-mean, normal distribution that describes the L1 residual user ionospheric range error (UIRE) for each ranging source after application of ionospheric corrections. This variance is determined from an ionospheric model using the broadcast grid ionospheric vertical error (GIVE).

6.3.3 There is a finite probability that an SBAS receiver would not receive an SBAS message. In order to continue navigation in that case, the SBAS broadcasts degradation parameters in the signal-in-space. These parameters are used in a number of mathematical models that characterize the additional residual error from both basic and precise differential corrections induced by using old but active data. These models are used to modify the UDRE variance and the UIRE variance as appropriate.

6.3.4 The individual error uncertainties described above are used by the receiver to compute an error model of the navigation solution. This is done by projecting the pseudo-range error models to the position domain. The horizontal protection level (HPL) provides a bound on the horizontal position error with a probability derived from the integrity requirement. Similarly, the vertical protection level (VPL) provides a bound on the vertical position. If the computed HPL exceeds the horizontal alert limit (HAL) for a particular operation, SBAS integrity is not adequate to support that operation. The same is true for precision approach and APV operations, if the VPL exceeds the vertical alert limit (VAL).

6.3.5 One of the most challenging tasks for an SBAS provider is to determine UDRE and GIVE variances so that the protection level integrity requirements are met without having an impact on availability. The performance of an individual SBAS depends on the network configuration, geographical extent and density, the type and quality of measurements used and the algorithms used to process the data. General methods for determining the model variance are described in Section 14.

6.3.6 *Residual clock and ephemeris error (σ_{UDRE}).* The residual clock error is well characterized by a zero-mean, normal distribution since there are many receivers that contribute to this error. The residual ephemeris error depends upon the user location. For the precise differential function, the SBAS provider will ensure that the residual error for all users within a defined service area is reflected in the σ_{UDRE}. For the basic differential function, the residual ephemeris error should be evaluated and may be determined to be negligible.

6.3.7 *Vertical ionospheric error (σ_{GIVE}).* The residual ionospheric error is well represented by a zero-mean, normal distribution since there are many receivers that contribute to the ionospheric estimate. Errors come from the measurement noise, the ionospheric model and the spatial decorrelation of the ionosphere. The position error caused by ionospheric error is mitigated by the positive correlation of the ionosphere itself. In addition, the residual ionospheric error distribution has truncated tails, i.e. the ionosphere cannot create a negative delay, and has a maximum delay.

6.3.8 *Aircraft element errors*. The combined multipath and receiver contribution is bounded as described in Section 14. This error can be divided into multipath and receiver contribution as defined in Appendix B, 3.6.5.5.1, and the standard model for multipath may be used. The receiver contribution can be taken from the accuracy requirement (Appendix B, 3.5.8.2 and 3.5.8.4.1) and extrapolated to typical signal conditions. Specifically, the aircraft can be assumed to have $\sigma^2_{\mathrm{air}} = \sigma^2_{\mathrm{receiver}} + \sigma^2_{\mathrm{multipath}}$, where it is assumed that $\sigma_{\mathrm{receiver}}$ is defined by the RMS_{pr_air} specified for GBAS Airborne Accuracy Designator A equipment, and $\sigma_{\mathrm{multipath}}$ is defined in Appendix B, 3.6.5.5.1. The aircraft contribution to multipath includes the effects of reflections from the aircraft itself. Multipath errors resulting from reflections from other objects are not included. If experience indicates that these errors are not negligible, they must be accounted for operationally.

6.3.9 *Tropospheric error*. The receiver must use a model to correct for tropospheric effects. The residual error of the model is constrained by the maximum bias and variance defined in Appendix B, 3.5.8.4.2 and 3.5.8.4.3. The effects of this mean must be accounted for by the ground subsystem. The airborne user applies a specified model for the residual tropospheric error (σ_{tropo}).

6.4 RF characteristics

6.4.1 *Minimum GEO signal power level*. The minimum aircraft equipment (e.g. RTCA/DO-229D) is required to operate with a minimum signal strength of –164 dBW at the input of the receiver in the presence of non-RNSS interference (Appendix B, 3.7) and an aggregate RNSS noise density of –173 dBm/Hz. In the presence of interference, receivers may not have reliable tracking performance for an input signal strength below –164 dBW (e.g. with GEO satellites placed in orbit prior to 2014). A GEO that delivers a signal power below –164 dBW at the output of the standard receiving antenna at 5-degree elevation on the ground can be used to ensure signal tracking in a service area contained in a coverage area defined by a minimum elevation angle that is greater than 5 degrees (e.g. 10 degrees). In this case, advantage is taken from the gain characteristic of the standard antenna to perform a trade-off between the GEO signal power and the size of the service area in which a trackable signal needs to be ensured. When planning for the introduction of new operations based on SBAS, States are expected to conduct an assessment of the signal power level as compared to the level interference from RNSS and non-RNSS sources. If the outcome of this analysis indicates that the level of interference is adequate to operate, then operations can be authorized.

6.4.2 *SBAS network time.* SBAS network time is a time reference maintained by SBAS for the purpose of defining corrections. When using corrections, the user's solution for time is relative to the SBAS network time rather than core satellite constellation system time. If corrections are not applied, the position solution will be relative to a composite core satellite constellation/SBAS network time depending on the satellites used and the resulting accuracy will be affected by the difference among them.

6.4.3 *SBAS convolutional encoding.* Information on the convolutional coding and decoding of SBAS messages can be found in RTCA/DO-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 Appendix B, 3.5.8.4.2.5.1 and Table B-57A. It is the same as the GBAS FAS data block defined in Appendix B, section 3.6.4.5.1 and Table B-66, with the following exceptions. The SBAS FAS data block also contains the HAL and VAL to be used for the approach procedure as described in 6.3.4. SBAS user equipment interprets certain fields differently from GBAS user equipment.

6.6.2 FAS data blocks for SBAS and some GBAS approaches are held within a common on-board database supporting both SBAS and GBAS. Within this database, channel assignments must be unique for each approach and coordinated with civil authorities. States are responsible for providing the FAS data for incorporation into the database.

6.6.3 An example of the coding of FAS data block for SBAS is provided in Table D-1. This example illustrates the coding of the various application parameters, including the cyclic redundancy check (CRC). The engineering values for the message parameters in the table illustrate the message coding process.

Table D-1. Example of an SBAS FAS data block

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	CODING RULES (*Note 5*)	PROCEDURE DESIGN VALUES PROVIDED	FAS DB VALUE USED	BINARY DEFINITION	BINARY REPRESENTATION (*Note 1*)	HEXADECIMAL REPRESENTATION
Operation Type	4	[0..15]	1	0 : Straight-in approach procedure 1..15 : Spare	Straight-In	0	$m_4..m_1$	0000	08
SBAS service provider ID	4	[0..15]	1	0 : WAAS 1 : EGNOS 2 : MSAS 3 : GAGAN 4 : SDCM 5..13 : Spare 14 : GBAS only 15 : Any SBAS provider	EGNOS	1	$m_8..m_5$	0001	
Airport ID	32	$\alpha_1\alpha_2\alpha_3\alpha_4$	-	α_1, α_2, α_3 = [0..9, A..Z] α4 = [<space>, 0..9, A..Z] D_{OUT} = ASCII value & 3F	LFBO	LFBO	$m_{40}..m_{33}$ $m_{32}..m_{25}$ $m_{24}..m_{17}$ $m_{16}..m_9$	'L' **00** 001100 'F' **00** 000110 'B' **00** 000010 'O' **00** 001111 (*Note 2*)	F0 40 60 30
Runway number	6	[01..36]	1	-	14	14	$m_{46}..m_{41}$	001110	72
Runway letter	2	[0..3]	1	0 : No letter 1 : Right (R) 2 : Centre (C) 3 : Left (L)	R	1	m_{48} m_{47}	01	
Approach performance designator	3	[0..7]	1	Not used by SBAS	0 (default value)	0	$m_{51}..m_{49}$	000	0B
Route indicator	5	α	-	α = [<space>, A..Z] α ≠ I and α ≠ O	Z	Z	$m_{56}..m_{52}$	11010	
Reference path data selector	8	[0..48]	-	Not used by SBAS	0 (default value)	0	$m_{64}..m_{57}$	00000000	00
Reference path identifier	32	$\alpha_1\alpha_2\alpha_3\alpha_4$	-	α_1 = [E, M, W] α_2, α_3 = [0..9] α_4 = [<space>, A, B, D..K, M..Q, S..Z] D_{OUT} = ASCII value & 3F	E14A	E14A	$m_{96}..m_{89}$ $m_{88}..m_{81}$ $m_{80}..m_{73}$ $m_{72}..m_{65}$	E' **00** 000101 '1' **00** 110001 '4' **00** 110100 'A' **00** 000001 (*Note 2*)	80 2C 8C A0
LTP/FTP latitude	32	[-90.0°.. 90.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 N : D_{OUT} S : Two's complement (D_{OUT})	D_{IN} = 43°38'38.8103" N	D_{CONV1} = 43°38'38.8105" N D_{CONV2} = 157118.8105 sec D_{OUT} = 314 237 621	$m_{128}..m_{121}$ $m_{120}..m_{113}$ $m_{112}..m_{105}$ $m_{104}..m_{97}$	00010010 10111010 11100010 10110101	AD 47 5D 48
LTP/FTP longitude	32	[-180.0°.. 180.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 E : D_{OUT} W : Two's complement (D_{OUT})	D_{IN} = 001°20'45.3591" E	D_{CONV1} = 001°20'45.3590"E D_{CONV2} = 4845.359 sec D_{OUT} = 9 690 718	$m_{160}..m_{153}$ $m_{152}..m_{145}$ $m_{144}..m_{137}$ $m_{136}..m_{129}$	00000000 10010011 11011110 01011110	7A 7B C9 00
LTP/FTP height	16	[-512.. 6041.5]	0.1m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = (D_{IN} + 512) x 10	D_{IN} = 148.74m	D_{CONV} = 148.7 D_{OUT} = 6 607	$m_{176}..m_{169}$ $m_{168}..m_{161}$	00011001 11001111	F3 98
ΔFPAP latitude	24	[-1.0°..1.0°]	0.0005 arcsec	D_{CONV1} = D_{IN} -> rounding method (*Note 3*) D_{CONV2} = D_{CONV1} -> decimal (sec) D_{OUT} = D_{CONV2} x 2 000 + : D_{OUT} - : Two's complement (D_{OUT})	D_{IN} = -0°01'37.8973"	D_{CONV1} = -00°01'37.8975" D_{CONV2} = -97.8975" D_{OUT} = Two's complement (195795) D_{OUT} = 16 581 421	$m_{200}..m_{193}$ $m_{192}..m_{185}$ $m_{184}..m_{177}$	11111101 00000011 00101101	B4 C0 BF

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	CODING RULES (*Note 5*)	PROCEDURE DESIGN VALUES PROVIDED	FAS DB VALUE USED	BINARY DEFINITION	BINARY REPRESENTATION (*Note 1*)	HEXADECIMAL REPRESENTATION
ΔFPAP longitude	24	[-1.0°..1.0°]	0.0005 arcsec	$D_{CONV1} = D_{IN}$ -> rounding method (*Note 3*) $D_{CONV2} = D_{CONV1}$ -> decimal (sec) $D_{OUT} = D_{CONV2}$ x 2 000 + : D_{OUT} - : Two's complement (D_{OUT})	D_{IN} = 0°01'41.9329"	D_{CONV1} = 0°01'41.9330" D_{CONV2} = 101.9330" D_{OUT} = 203 866	$m_{224}..m_{217}$ $m_{216}..m_{209}$ $m_{208}..m_{201}$	00000011 00011100 01011010	5A 38 C0
Approach TCH	15	[0..1638.35m] [0..3276.7ft]	0.05m 0.1ft	D_{CONV} = round (D_{IN}, resolution) m : $D_{OUT} = D_{IN}$ x 20 ft : $D_{OUT} = D_{IN}$ x 10	D_{IN} = 15.00m	D_{CONV} = 15.00m D_{OUT} = 300	$m_{239}..m_{233}$ $m_{232}..m_{225}$	0000001 00101100	34 81
Approach TCH units selector	1	[0,1]	-	0 : feet 1 : metres	m	1	m_{240}	1	
Glide path angle (GPA)	16	[0..90.00°]	0.01°	D_{CONV} = round (D_{IN}, resolution) $D_{OUT} = D_{IN}$ x 100	D_{IN} = 3.00°	D_{CONV} = 3.00° D_{OUT} = 300	$m_{256}..m_{249}$ $m_{248}..m_{241}$	00000001 00101100	34 80
Course width	8	[80.00m.. 143.75m]	0.25m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = (D_{CONV} - 80) x 4	D_{IN} = 105.00m	D_{CONV} = 105.00m D_{OUT} = 100	$m_{264}..m_{257}$	01100100	26
ΔLength offset	8	[0..2032m]	8m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = (integer division of D_{CONV} by 8) + 1 D_{OUT} = 255 : not provided value	D_{IN} = 284.86m	D_{CONV} = 288m D_{OUT} = 36	$m_{272}..m_{265}$	00100100	24
Horizontal alert limit (HAL)	8	[0..50.8m]	0.2m	D_{CONV} = round (D_{IN}, resolution) $D_{OUT} = D_{IN}$ * 5	D_{IN} = 40.0m	D_{CONV} = 40.0m D_{OUT} = 200	$m_{280}..m_{273}$	11001000	13
Vertical alert limit (VAL)	8	[0..50.8m]	0.2m	D_{CONV} = round (D_{IN}, resolution) D_{OUT} = Value * 5 D_{OUT} = 0 : vertical deviations cannot be used	D_{IN} = 50.0m	D_{CONV} = 50.0m D_{OUT} = 250	$m_{288}..m_{281}$	11111010	5F
Final approach segment CRC	32	[0..2^{32}-1]		D_{OUT} = remainder (P(x) / Q(x))	-	-	$r_{32}..r_{25}$ $r_{24}..r_{17}$ $r_{16}..r_9$ $r_8..r_1$	10101110 11000011 01100100 10001111	75 C3 26 F1 (*Note 4*)

Notes.
1. *The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted to the CRC calculator.*
2. *The two most significant bits of each byte are set to 0 (see bold characters).*
3. *The rounding methodology is provided in the PANS-OPS (Doc 8168) Volume II.*
4. *The FAS CRC value is displayed in the order $r_{25}..r_{32}$, $r_{17}..r_{24}$, $r_9..r_{16}$, $r_1..r_8$ where r_i is th i^{th} coefficient of the remainder R(x) as defined in Appendix B, 3.9 .*
5. *D_{IN} : raw data value, D_{CONV} : converted data value according to coding rules, D_{OUT} : coded data value.*

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

Note.— In this section, except where specifically annotated, reference to approach with vertical guidance (APV) means APV-I and APV-II.

7.1 System description

7.1.1 GBAS consists of ground and aircraft elements. A GBAS ground subsystem typically includes a single active VDB transmitter and broadcast antenna, referred to as a broadcast station, and multiple reference receivers. A GBAS ground subsystem may include multiple VDB transmitters and antennas that share a single common GBAS identification (GBAS ID) and frequency as well as broadcast identical data. The GBAS ground subsystem can support all the aircraft subsystems within its 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 *GRAS configurations.* From a user perspective, a GRAS ground subsystem consists of one or more GBAS ground subsystems (as described in 7.1.1 through 7.1.4), each with a unique GBAS identification, providing the positioning service and 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 *VDB transmission path diversity.* All broadcast stations of a GBAS ground subsystem broadcast identical data with the same GBAS identification on a common frequency. The airborne receiver need not and cannot distinguish between messages received from different broadcast stations of the same GBAS ground subsystem. When within coverage of two such broadcast stations, the receiver will receive and process duplicate copies of messages in different time division multiple access (TDMA) time slots.

7.1.7 Interoperability of the GBAS ground and aircraft elements compatible with RTCA/DO-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 coordination*

7.2.1.1 *Performance factors*

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

a) the 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;

Table D-2. Assumed $[D/U]_{required}$ signal ratios to protect VOR from GBAS VDB

Frequency offset	$[D/U]_{required}$ ratio to protect VOR receivers (dB)
Co-channel	26
$\| f_{VOR} - f_{VDB} \| = 25$ kHz	0
$\| f_{VOR} - f_{VDB} \| = 50$ kHz	–34
$\| f_{VOR} - f_{VDB} \| = 75$ kHz	–46
$\| f_{VOR} - f_{VDB} \| = 100$ kHz	–65

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$$\left|\frac{d\phi}{d\omega}(f_c) - \frac{d\phi}{d\omega}(f)\right|$$

where

f_c is the precorrelation band pass filter centre frequency;

f is any frequency within the 3dB bandwidth of the precorrelation filter;

ϕ is the combined phase response of precorrelation band pass filter and antenna; and

ω is equal to $2\pi f$.

8.11.4 For aircraft receivers using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11, except as noted below.

8.11.4.1 For GBAS airborne equipment using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11, except that the region 1 minimum bandwidth will increase to 4 MHz and the average correlator spacing is reduced to an average of 0.21 chips or instantaneous of 0.235 chips.

8.11.5 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 Tables D-13A and D-13B.

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-13A. GPS tracking constraints for GRAS and SBAS airborne receivers with double-delta correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing (X) (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	(–50 × X) + 12 < BW ≤ 7 MHz	0.1 – 0.16	0.09 – 0.18	≤ 600 ns
	4 < BW ≤ 7 MHz	0.16– 0.6	0.14– 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 (133.33 × X) + 2.667 MHz	0.07 – 0.24	0.06 – 0.26	≤ 150 ns

Table D-13B. GPS tracking constraints for GBAS airborne receivers with double-delta correlators

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing range (X) (chips)	Instantaneous correlator spacing range (chips)	Differential group delay
1	(–50 × X) + 12 < BW ≤ 7 MHz	0.1 – 0.16	0.09 – 0.18	≤ 600 ns
	4 < BW ≤ 7 MHz	0.16 – 0.6	0.14 – 0.65	
2	(–50 × X) + 12 < BW ≤ (133.33 × X) + 2.667 MHz	0.07 – 0.085	0.063 – 0.094	≤ 150 ns
	(–50 × X) + 12 < BW ≤ 14 MHz	0.085 – 0.1	0.077 – 0.11	
	7 < BW ≤ 14 MHz	0.1 – 0.24	0.09 – 0.26	
3	14 < BW ≤ 16 MHz	0.1 – 0.24	0.09 – 0.26	≤ 150 ns
	14 < BW ≤ (133.33 × X) + 2.667 MHz	0.085 – 0.1	0.077 – 0.11	

Table D-14. SBAS ranging function tracking constraints

Region	3 dB precorrelation bandwidth, BW	Average correlator spacing (chips)	Instantaneous correlator spacing (chips)	Differential group delay
1	2 < BW ≤ 7 MHz	0.045 – 1.1	0.04 – 1.2	≤ 600 ns
2	7 < BW ≤ 20 MHz	0.045 – 1.1	0.04 – 1.2	≤ 150 ns

9.2 Information on type of degradation

The following information is to be distributed:

a) non-availability of service;

b) downgrade of service, if applicable; and

c) time and expected duration of degradation.

9.3 Timing of notification

For scheduled events, notification should be given to the NOTAM authority at least 72 hours prior to the event. For unscheduled events, notification to the NOTAM authority should be given within 15 minutes. Notification should be given for events of 15-minute, or longer, duration.

10. Interference

10.1 Potential for interference

Satellite radio navigation systems such as GPS and GLONASS feature relatively weak received signal power, meaning that an interference signal could cause loss of service. In order to maintain service, it will be necessary to ensure that the maximum interference levels specified in the SARPs are not exceeded.

10.2 Specification of the interference threshold at the antenna port

The indications of the interference threshold levels are referenced to the antenna port. In this context, the term "antenna port" means the interface between the antenna and the GNSS receiver where the satellite signal power corresponds to the nominal minimum received signal power of –164.5 dBW for GPS and –165.5 dBW for GLONASS. Due to the reduced distance from potential interference sources, GNSS receivers that are used for the approach phase of flight must have a higher interference threshold than receivers that are only used for en-route navigation.

10.3 In-band interference sources

A potential source of in-band harmful interference is Fixed Service operation in certain States. There is a primary allocation to the fixed service for point-to-point microwave links in certain States in the frequency band used by GPS and GLONASS.

10.4 Out-of-band interference sources

Potential sources of out-of-band interference include harmonics and spurious emissions of aeronautical VHF and UHF transmitters. Out-of-band noise, discrete spurious products and intermodulation products from radio and TV broadcasts can also cause interference problems.

10.5 Aircraft generated sources

10.5.1 The potential for harmful interference to GPS and GLONASS on an aircraft depends on the type of aircraft, its size and the transmitting equipment installed. The GNSS antenna location should take into account the possibility of on-board interference (mainly SATCOM).

10.5.2 GNSS receivers that are used on board aircraft with SATCOM equipment must have a higher interference threshold in the frequency range between 1 610 MHz and 1 626.5 MHz than receivers on board aircraft without SATCOM equipment. Therefore, specifications for the interference threshold discriminate between both cases.

Note.— Limits for radiated SATCOM aircraft earth stations are given in Annex 10, Volume III, Part I, Chapter 4, 4.2.3.5.

10.5.3 The principal mitigation techniques for on-board interference include shielding, filtering, receiver design techniques, and, especially on larger aircraft, physical separation of antennas, transmitters and cabling. Receiver design techniques include the use of adaptive filters and interference cancellation techniques that mitigate against narrow in-band interference. Antenna design techniques include adaptive null steering antennas that reduce the antenna gain in the direction of interference sources without reducing the signal power from satellites.