Explanatory note

This file contains two documents in support of the operational validation of the GBAS Category II/III SARPs developed by the Navigation Systems Panel (the technical validation of the SARPs was completed at the 17-28 May 2010 meeting of the NSP Working Group of the Whole).

- The first document ("GBAS CAT II/III Development Baseline SARPs") is the package of SARPs that resulted from the technical validation;
- the second document ("Conceptual Framework for the Proposal for GBAS to Support CAT III Operations") illustrates the key concepts of the technical approach chosen in developing the SARPs.

Following completion of the technical validation, the SARPs are now considered to have a high degree of maturity and to be suitable for industry to pursue airworthiness and operational approvals of the technology, which will constitute the basis for the operational validation.

The material will not be recommended for publication in Annex 10 until after the successful completion of the operational evaluation. Until then, the material will be treated as internal NSP-approved SARPs material and maintained under configuration control by NSP.

At the completion of the operational validation, the material will be reviewed and any change deemed necessary in light of the results of the operational validation will be made. A formal SARPs amendment package will then be prepared and its approval for implementation in Annex 10 recommended by the panel.

GBAS CAT II/III Development Baseline SARPs

(Draft proposed changes to Annex 10, Volume I, as agreed at the 17-28 May 2010 meeting of the Navigation Systems Panel (NSP) Working Group of the Whole)

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CHAPTER 3. SPECIFICATIONS FOR RADIO NAVIGATION AIDS

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3.7 Requirements for the Global Navigation Satellite System (GNSS)

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- 3.7.2.4 Signal-in-space performance
- 3.7.2.4.1 The combination of GNSS elements and a fault-free GNSS user receiver shall meet the signal-in-space requirements defined in Table 3.7.2.4-1 (located at the end of section 3.7).
- Note. 1.— The concept of a fault-free user receiver is applied only as a means of defining the performance of combinations of different GNSS elements. The fault-free receiver is assumed to be a receiver with nominal accuracy and time-to-alert performance. Such a receiver is assumed to have no failures that affect the integrity, availability and continuity performance.
- Note 2.— For GBAS approach service (as defined in Attachment D section 7.1.2.1) intended to support approach and landing operations using CAT III minima, performance requirements are defined that apply in addition to the signal in space requirements defined in Table 3.7.2.4.-1.

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- 3.7.3.5 Ground-based augmentation system (GBAS) and ground-based regional augmentation system (GRAS)
- Note 1.— Except where specifically annotated, GBAS Standards and Recommended Practices apply to GBAS and GRAS.
- Note 2.— Except where specifically annotated, reference to approach with vertical guidance (APV) means APV-I and APV-II.
- 3.7.3.5.1 *Performance*. GBAS combined with one or more of the other GNSS elements and a fault-free GNSS receiver shall meet the requirements for system accuracy, continuity, availability and integrity for the intended operation as stated in 3.7.2.4 within the coverage for the service used to support the operation as defined in 3.7.3.5.3.
- Note.— GBAS is intended to support all types of approach, landing, departure and surface operations and may support en-route and terminal operations. GRAS is intended to support en-route, terminal, non-precision approach, departure, and approach with vertical guidance. The following SARPs are developed to support Category I all categories of precision approach, approach with vertical guidance, and a GBAS positioning service. In order to achieve interoperability and enable efficient spectrum utilization, it is intended that the data broadcast is the same for all operations.

- 3.7.3.5.2 *Functions*. GBAS shall perform the following functions:
- a) provide locally relevant pseudo-range corrections;
- b) provide GBAS-related data;
- c) provide final approach segment data when supporting precision approach;
- d) provide predicted ranging source availability data; and
- e) provide integrity monitoring for GNSS ranging sources.

3.7.3.5.3 *Coverage*

- 3.7.3.5.3.1 <u>Category I precision approach and approach with vertical guidance</u> General Requirement for Approach Services. The minimum GBAS coverage for support each Category I precision approach or approach with vertical guidance services shall be as follows, except where topographical features dictate and operational requirements permit:
 - a) laterally, beginning at 140 m (450 ft) each side of the landing threshold point/fictitious threshold point (LTP/FTP) and projecting out ±35 degrees either side of the final approach path to 28 km (15 NM) and ±10 degrees either side of the final approach path to 37 km (20 NM); and
 - b) vertically, within the lateral region, up to the greater of 7 degrees or 1.75 promulgated glide path angle (GPA) above the horizontal with an origin at the glide path interception point (GPIP) to an upper bound of 3 000 m (10 000 ft) height above threshold (HAT) and 0.45 GPA above the horizontal or to such lower angle, down to 0.30 GPA, as required, to safeguard the promulgated glide path intercept procedure. This coverage applies between The lower bound is half the lowest decision height supported or 3,7 m (12 ft), whichever is larger 30 m (100 ft) and 3 000 m (10 000 ft) height above threshold (HAT).
 - *Note.*—*LTP/FTP and GPIP are defined in Appendix B, 3.6.4.5.1.*
- Note.— Guidance material concerning coverage for precision approach and APV is provided in Attachment D, 7.3
- 3.7.3.5.3.1.1 **Recommendation.** For Category I precision approach, the data broadcast as specified in 3.7.3.5.4 should extend down to 3.7 m (12 ft) above the runway surface.
- 3.7.3.5.3.1.21 **Recommendation.** *The data broadcast should be omnidirectional when required to support the intended applications.*
- 3.7.3.5.3.2 Approach Services Supporting Autoland. The minimum additional GBAS coverage to support approach operations that include automatic landing and rollout shall be as follows, except where operational requirements permit:
 - a) Horizontally within a sector spanning the width of the runway beginning at the stop end of the runway and extending parallel with the runway centre line towards the LTP to join the minimum operational coverage region as described in 3.7.3.5.3.1
 - b) Vertically, between two horizontal surfaces one at 3.7 m (12 ft) and the other at 30 m (100 ft) above the runway centreline to join the minimum operational coverage region as described in 3.7.3.5.3.1.

3.7.3.5.3.3 **Recommendation** – Vertical coverage in sections 3.7.3.5.3.1, 3.7.3.5.3.2 should extend to 2.4 m (8 ft) above the runway surface.

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

3.7.3.5.3.24 *GBAS positioning service*. The GBAS positioning service area shall be that area where the data broadcast can be received and the positioning service meets the requirements of 3.7.2.4 and supports the corresponding approved operations.

Note.— *Guidance material concerning the positioning service coverage is provided in Attachment D,* 7.3.

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Table 3.7.2.4-1 Signal-in-space performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}/h$	5 min	$1 - 1 \times 10^{-4}/h$ to $1 - 1 \times 10^{-8}/h$	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}/h$	15 s	$1 - 1 \times 10^{-4}/h$ to $1 - 1 \times 10^{-8}/h$	0.99 to 0.99999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}/h$	10 s	$1 - 1 \times 10^{-4}/h$ to $1 - 1 \times 10^{-8}/h$	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1-2\times10^{-7}$ in any approach	10 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1-2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999
Category I precision approach (Note 7)	16.0 m (52 ft)	6.0 m to 4.0 m (20 ft to 13 ft) (Note 6)	$1-2 \times 10^{-7}$ in any approach	6 s	$1 - 8 \times 10^{-6}$ per 15 s	0.99 to 0.99999

NOTES.—

^{2.} The definition of the integrity requirement includes an alert limit against which the requirement can be assessed. For Category I precision approach, a vertical alert limit (VAL) greater than 10 m for a specific system design may only be used if a system-specific safety analysis has been completed. Further guidance on the alert limits is provided in Attachment D, 3.3.6 to 3.3.10. These alert limits are:

Typical operation	Horizontal alert limit	Vertical alert limit
En-route (oceanic/continental low density)	7.4 km (4 NM)	N/A
En-route (continental)	3.7 km (2 NM)	N/A
En-route, Terminal	1.85 km (1 NM)	N/A

^{1.} The 95th percentile values for GNSS position errors are those required for the intended operation at the lowest height above threshold (HAT), if applicable. Detailed requirements are specified in Appendix B and guidance material is given in Attachment D, 3.2.

Typical operation	Horizontal alert limit	Vertical alert limit	
NPA	556 m (0.3 NM)	N/A	
APV-I	40 m (130 ft)	50 m (164 ft)	
APV- II	40.0 m (130 ft)	20.0 m (66 ft)	
Category I precision approach	40.0 m (130 ft)	35.0 m to 10.0 m (115 ft to 33 ft)	

- 3. The accuracy and time-to-alert requirements include the nominal performance of a fault-free receiver.
- 4. Ranges of values are given for the continuity requirement for en-route, terminal, initial approach, NPA and departure operations, as this requirement is dependent upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigation aids. The lower value given is the minimum requirement for areas with low traffic density and airspace complexity. The higher value given is appropriate for areas with high traffic density and airspace complexity (see Attachment D, 3.4.2). Continuity requirements for APV and Category I operations apply to the average risk (over time) of loss of service, normalized to a 15-second exposure time (see Attachment D, 3.4.3).
- 5. A range of values is given for the availability requirements as these requirements are dependent upon the operational need which is based upon several factors including the frequency of operations, weather environments, the size and duration of the outages, availability of alternate navigation aids, radar coverage, traffic density and reversionary operational procedures. The lower values given are the minimum availabilities for which a system is considered to be practical but are not adequate to replace non-GNSS navigation aids. For en-route navigation, the higher values given are adequate for GNSS to be the only navigation aid provided in an area. For approach and departure, the higher values given are based upon the availability requirements at airports with a large amount of traffic assuming that operations to or from multiple runways are affected but reversionary operational procedures ensure the safety of the operation (see Attachment D, 3.5).
- 6. A range of values is specified for Category I precision approach. The 4.0 m (13 feet) requirement is based upon ILS specifications and represents a conservative derivation from these specifications (see Attachment D, 3.2.7).
- 7. GNSS performance requirements intended to support for Category II and III precision approach operations necessitate are under review and will be included at a later date lower level requirements in the technical appendix (Appendix B, section 3.6) to be applied in addition to these signal in space requirements (see Attachment D, 7.5.1)..
- 8. The terms APV-I and APV-II refer to two levels of GNSS approach and landing operations with vertical guidance (APV) and these terms are not necessarily intended to be used operationally.

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APPENDIX B. TECHNICAL SPECIFICATIONS FOR THE GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

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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.*

- 3.6.1.1 *GBAS Service Types*. A GBAS ground subsystem shall support either the positioning service, approach service or both types of service.
- Note 1 Service Types refers to a matched set of ground and airborne functional and performance requirements that ensure that quantifiable navigation performance is achieved by the airborne equipment. Guidance material concerning service types is given in Attachment D section 7.1.1.1.
- Note 2 GBAS ground facilities are characterized by a GBAS Facility Classification (GFC). Many GBAS performance and functional requirements depend on the GFC. These SARPS are organized according to which requirements apply for a given facility classification element (i.e. the Facility Approach Service Type (FAST), the Facility Polarization etc.) Guidance material concerning Facility Classifications is given in Attachment D section 7.1.4.1)
- 3.6.1.2 All GBAS ground subsystems shall comply with the requirements of 3.6.1, 3.6.2, 3.6.3, 3.6.4, 3.6.6. and 3.6.7 unless otherwise stated. A FAST D ground subsystem shall also comply with all FAST C requirements in addition to the specific FAST D requirements.

3.6.2 RF CHARACTERISTICS

- 3.6.2.1 Carrier frequency stability. The carrier frequency of the data broadcast shall be maintained within ± 0.0002 per cent of the assigned frequency.
- 3.6.2.2 Bit-to-phase-change encoding. GBAS messages shall be assembled into symbols, each consisting of 3 consecutive message bits. The end of the message shall be padded by 1 or 2 fill bits if necessary to form the last 3-bit symbol of the message. Symbols shall be converted to D8PSK carrier phase shifts $(\Delta \varphi_k)$ in accordance with Table B-58.
- Note.— The carrier phase for the k^{th} symbol (ϕ_k) is given by: $\phi_k = \phi_{k-1} + \Delta \phi_k$ 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 $\Delta \varphi_k \square$ represents a counter clockwise 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 = 1/10500 second.

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

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

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

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}	$\Delta \phi_{ m k}$
0	0	0	$0\pi/4$
0	0	1	$1\pi/4$
0	1	1	$2\pi/4$
0	1	0	$3\pi/4$

1	1	0	$4\pi/4$
1	1	1	$5\pi/4$
1	0	1	$6\pi/4$
1	0	0	$7\pi/4$

Note.— I_j is the j^{th} bit of the burst to be transmitted, where I_l 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).

- 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

Nominal percentage Event Nominal event duration of steady-state power 0% to 90% Ramp-up 190.5 us 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%

Table B-59. Burst timing

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 1259 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	3.6.3.2.1	48	
resolution			
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	

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:

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

where

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

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

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

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

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

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

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

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

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

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

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-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

 $a_{248-length}$, ..., 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):

$$b(x) = \sum_{i=0}^{5} b_i x^i + b_5 x^5 + b_4 x^4 + b_3 x^3 + b_2 x^2 + b_1 x + b_0 = [x^6 m(x)] \mod g(x)$$

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	8
identifier 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 b₁ through b₆ of its International Alphabet No. 5 (IA-5) representation. For each character, bit b₁ 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.

- 3.6.4.2.1 The Type 1 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70). The message shall contain three sections:
 - a) message information (time of validity, additional message flag, number of measurements and the measurement type);
 - b) low-frequency information (ephemeris decorrelation parameter, satellite ephemeris CRC and satellite availability information); and
 - c) satellite data measurement blocks.
 - Note 1.— Transmission of the low-frequency data for SBAS ranging sources is optional.
- Note 2 .— All parameters in this message type apply to 100 second carrier-smoothed pseudoranges.
- 3.6.4.2.2 Each Type 1 message shall include ephemeris decorrelation parameter, ephemeris CRC and source availability duration parameters for one satellite ranging source. The ephemeris decorrelation parameter, ephemeris CRC and source availability duration shall apply to the first ranging source in the message.
 - 3.6.4.2.3 Pseudo-range correction parameters shall be as follows:

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

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

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

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

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

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

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

Table B-63. GBAS VHF data broadcast messages

Message type identifier	Message name
0	Spare
1	Pseudo-range corrections
2	GBAS-related data
3	Null Message
4	Final approach segment (FAS) data
5	Predicted ranging source availability
6	Reserved
7	Reserved for national applications
8	Reserved for test applications
9 to 10	Spare
11	Pseudo-range corrections – 30 second smoothed pseudoranges
9 12 to 100	Spare
101	GRAS pseudo-range corrections
102 to 255	Spare

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.

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-64. GPS satellite ephemeris mask

Table B-65. GLONASS satellite ephemeris mask

```
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<sub>b</sub>" 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 ith ranging source these parameters correspond to $B_{i,1}$ through $B_{i,4}$ (3.6.5.5.1.2, 3.6.5.5.2.2 and 3.6.7.2.2.4). The indices "1-4" correspond to the same physical reference receiver for every epoch 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.. 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 $\frac{2}{2}$, 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 all approach services supported by the ground facility or APV cannot be initiated. are unavailable.

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

Coding: Positive value denotes east variation (clockwise from true north), Negative value denotes west variation (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, GBAS Approach Service Types A, B or C Category I Precision Approach and APV (K_{md e,GPS}): the multiplier for computation of the ephemeris error position bound for Category I precision GBAS Approach Service Types A, B and C 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, GBAS Approach Service Types A, B or C Category I Precision Approach and APV (K_{md_e} , GLONASS): the multiplier for computation of the ephemeris error position bound for Category I precision GBAS approach Service Types A, B and C 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 additional data

block 3, GAST D Parameters

4 = additional data block 4, VDB Authentication Parameters

5 to 255 = spare

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

3.6.4.3.2.1 *GRAS broadcast stations*

Parameters for additional data block 2 shall include data for one or more broadcast stations as follows:

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.*

 $\Delta LATITUDE$: 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.

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

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

Negative value denotes that the GBAS broadcast station is west of the GBAS reference point.

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

3.6.4.3.2.2 GAST D Parameters

Parameters for additional data block 3 shall include parameters (Table B-65B) to be used when the active service type is GAST D as follows:

Kmd_e_D,GLONASS: is the multiplier for computation of the ephemeris error position bound for GAST D derived from the probability of missed detection given that there is an ephemeris error in a GLONASS satellite. For GBAS ground sub-systems that do not broadcast corrections for GLONASS ranging sources, this parameter is coded as all zeros.

Note — This parameter, Kmd_e_D,GLONASS, may be different than the ephemeris decorrelation parameter Kmd_e_GLONASS provided in additional datablock 1 of the Type 2 message. Additional information regarding the difference in these parameters is given in D.7.5.6.1.2 and D.7.5.6.1.3.

Kmd_e_D,GPS: is the multiplier for computation of the ephemeris error position bound for GAST D derived from the probability of missed detection given that there is an ephemeris error in a GPS satellite. For GBAS ground sub-systems that do not broadcast corrections for GPS ranging sources, this parameter is coded as all zeros.

Note — This parameter, Kmd_e_D,GPS, may be different than the ephemeris decorrelation parameter Kmd_e_GPS provided in additional datablock 1 of the Type 2 message. Additional information regarding the difference in these parameters is given in D.7.5.6.1.2 and D.7.5.6.1.3.

Sigma_vert_iono_gradient_D ($\sigma_{\text{vert iono gradient D}}$): is the standard deviation of a normal distribution associated with the residual ionospheric uncertainty due to spatial decorrelation. This parameter is used by airborne equipment when its active Approach Service Type is D.

Note — This parameter, Sigma_vert_iono_gradient_D, may be different than the ionospheric decorrelation parameter Sigma_vert_iono_gradient provided in the Type 2 message. Additional information regarding the difference in these parameters is given in D.7.5.6.1.2 and D.7.5.6.1.3..

TableB-65B. Ad	ditional Dat	a Block 3 GAST D	Parameters
Data content	Bits	used Range of values	Resolution
Kmd_e_D,GPS	8	0 to 12.75	0.05
Kmd_e_D,GLONASS	8	0 to 12.75	0.05
Sigma_vert_iono_gradien	t_D 8	$0 - 25.5 \times 10^{\circ}$	0.1×10^{-6}
		m/m	m/m
Spare	8		

3.6.4.3.2.23 *VDB Authentication Parameters*

Additional data block 4 includes information needed to support VDB authentication Protocols

Slot Group Definition: This 8-bit field indicates which of the 8 slots (A-H) are assigned for use by the ground subsystem. 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 subsystem. A "0" indicates the slot is not assigned to the ground subsystem.

Table B-65C. VDB Authentication Parameters

Data content	Bits used	Range of values	Resolution
Slot Group Definition	8	-	-

3.6.4.4 TYPE 3 MESSAGE – NULL MESSAGE

- 3.6.4.4.1 The Type 3 message is a variable length 'Null Message' which is intended to be used by ground subsystems that support the authentication protocols (see section 3.6.7.4).
- 3.6.4.4.2 The parameters for the Type 3 message shall be as follows:

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

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

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

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

Coding: See 3.6.4.5.1 and Table B-66.

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

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

Coding: 1111 1111 = Do not use vertical deviations.

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

Coding: 1111 1111 = Do not use approach.

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-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	0 to 36	1
Runway letter	2	_	_
Approach performance designator	3	0 to 7	1
Route indicator	5	_	_
Reference path data selector	8	0 to 48	1
Reference path identifier	32	_	_
LTP/FTP latitude	32	±90.0°	0.0005 arcsec
LTP/FTP longitude	32	±180.0°	0.0005 arcsec
LTP/FTP height	16	-512.0 to 6 041.5 m	0.1 m
ΔFPAP latitude	24	±1.0°	0.0005 arcsec
ΔFPAP longitude	24	±1.0°	0.0005 arcsec
Approach TCH (Note 2)	15	0 to 1 638.35 m or	0.05 m or
		0 to 3 276.7 ft	0.1 ft
Approach TCH units selector	1	_	_
GPA	16	0 to 90.0°	0.01°
Course width (Note 1)	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 1.— When the runway number is set to 0, then the course width field is ignored and the course width is 38 metres.

 $Note \ 2.-Information \ can \ be \ provided \ in \ either \ feet \ or \ metres \ as \ indicated \ by \ the \ approach \ TCH \ unit \ selector.$

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
```

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 pseudorange 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 b₆, 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: 0 = heliport
1 to 36 = runway number
```

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

```
Coding: 0 = \text{no letter}

1 = R \text{ (right)}

2 = C \text{ (centre)}

3 = L \text{ (left)}
```

Approach performance designator: the general information about the approach design Approach Service Type or Types supported for the approach.

```
Coding: 0 = APVGAST A or B

1 = Category I-GAST C

2 = reserved for Category IIGAST C and GAST D

3 = GAST C, GAST D and an additional Approach Service Type to be defined in the future

4 = GAST C, GAST D and two additional Approach Service Types to be defined in the future

3 = reserved for Category III

45 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 CAT 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 b₁ through b₅ of its IA-5 representation. Bit b₁ 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 b₁ through b₆ of its IA-5 representation. For each character, b₁ is transmitted first, and 2 zero bits are appended after b₆ 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.

 $\Delta FPAP$ 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 = feet1 = 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.

△Length 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 Δ length offset field. The CRC shall be ordered such that r_1 is the LSB and r_{32} is the MSB.

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

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

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

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

Coding: 0 = Only specified obstructed approaches have limitations. 1 to 31 = The number of ranging sources impacted. Ranging source ID: as for Type 1 message (3.6.4.2).

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

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

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

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

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

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

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

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

3.6.4.7 *Type 6 Message*

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

3.6.4.8 *TYPE 7 MESSAGE*

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

3.6.4.9 *Type 8 Message*

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

3.6.4.10 Type 101 message — GRAS pseudo-range corrections

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

- a) message information (time of validity, additional message flag, number of measurements and the measurement type);
- b) low-frequency information (ephemeris decorrelation parameter, satellite ephemeris CRC and satellite availability information); and
- c) satellite data measurement blocks.

Note .— All parameters in this message type apply to 100 second carrier-smoothed pseudoranges.

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} and as defined in 3.6.4.2.4, with the exception of the range of values and resolution.

B1 through B4: as defined in 3.6.4.2.4.

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

3.6.4.11 Type 11 message — pseudo-range corrections – 30 second smoothed pseudoranges

3.6.4.11.1 The Type 11 message shall provide the differential correction data for individual GNSS ranging sources (Table B-70B) with 30 second code-carrier smoothing applied. The message shall contain three sections:

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

- b) low-frequency information (ephemeris decorrelation parameter); and
- c) satellite data measurement blocks.

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

3.6.4.11.2 Each Type 11 message shall include ephemeris decorrelation parameter 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.

Note.-, The ephemeris CRC and source availability duration parameters are not included in the Type 11 message because they are provided in the Type 1 message.

3.6.4.11.3 Pseudo-range correction parameters for the Type 11 message shall be as follows:

Modified Z-count: as defined in 3.6.4.2.3.

Additional message flag: an identification of whether the set of measurement blocks in a single frame for a particular measurement type is contained in a single Type 11 message or a linked pair of messages.

Coding: 0 = All measurement blocks for a particular measurement type are contained in one Type 11 message.

- 1 = This is the first transmitted message of a linked pair of Type 11 messages that together contain the set of all measurement blocks for a particular measurement type.
- 2 = Spare
- 3 = This is the second transmitted message of a linked pair of Type 11 messages that together contain the set of all measurement blocks for a particular measurement type.

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

Measurement type: as defined in 3.6.4.2.3.

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

Note — This parameter, P_D , may be different than the ephemeris decorrelation parameter P provided in the Type 1 message. Additional information regarding the difference in these parameters is given in D.7.5.6.1.3 and D.7.5.6.1.4.

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

3.6.4.11.4 The measurement block parameters shall be as follows:

Ranging source ID: as defined in 3.6.4.2.3.

Pseudo-range correction (PRC_{30}): the correction to the ranging source pseudo-range based on 30 second carrier smoothing.

Range rate correction (RRC₃₀): the rate of change of the pseudo-range correction based on 30 second carrier smoothing.

Sigma_PR_gnd_D ($\sigma_{pr\ gnd\ D}$): the standard deviation of a normal distribution associated with the signal-in-space contribution of the pseudo-range error in the 100 second smoothed correction in the Type 1 message at the GBAS reference point (3.6.5.5.1 and 3.6.7.2.2.4).

Note - The parameter σ_{pr} $_{gnd_D}$ differs from σ_{pr} $_{gnd}$ for the corresponding measurement in the Type 1 message in that σ_{pr} $_{gnd_D}$ should include no inflation to address overbounding of decorrelated ionospheric errors.

Coding: 1111 1111 = Ranging source correction invalid.

Sigma_PR_GND_30s ($\sigma_{pr \ gnd \ 30}$): the standard deviation of a normal distribution that describes the nominal accuracy of corrected pseudorange smoothed with a time constant of 30 seconds at the GBAS reference point.

Note - The normal distribution $N(0, \sigma_{pr gnd 30})$ is intended to be an appropriate description of the errors to be used in optimizing the weighting used in a weighted least squares position solution. The distribution need not bound the errors as described in section (3.6.5.5.1 and 3.6.7.2.2.4)

Coding: 1111 1111 = Ranging source correction invalid.

3.6.5 DEFINITIONS OF PROTOCOLS FOR DATA APPLICATION

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

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

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

where

 P_{CSCn} = the smoothed pseudo-range;

 P_{CSCn-1} = the previous smoothed pseudo-range;

P = the raw pseudo-range measurement where the raw pseudo-range measurements are obtained from a carrier driven code loop, first order or higher and with a one-sided noise bandwidth greater than or equal to 0.125 Hz;

 λ = the L1 wavelength; ϕ_n = the carrier phase;

 ϕ_{n-1} = the previous carrier phase; and

 α = the filter weighting function equal to the sample interval divided by the smoothing time constant. For GBAS pseudorange corrections in Message Type 1 and Message Type 101, the smoothing time constant is of 100 seconds. For GBAS pseudorange corrections in Message Type 11, the smoothing time constant is 30 seconds. For SBAS, the smoothing time constant is 100 seconds.

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

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

where

 P_{CSC} = the smoothed pseudo-range (defined in 3.6.5.1);

PRC = the pseudo-range correction from the appropriate message

a) For 100 second smoothed pseudoranges, PRC is taken from message type 1 or type 101 (defined in 3.6.4.2,

b) For 30 second smoothed pseudoranges, PRC is PRC_{30} taken from message type 11 defined in 3.6.4.11 $\frac{1}{12}$

RRC = the pseudo-range correction rate from the appropriate message

a) (For 100 second smoothed pseudoranges, RRC is taken from message type 1 or type 101 defined in 3.6.4.2,

b) For 30 second smoothed pseudoranges, RRC is RRC₃₀ taken from message type 11 defined in 3.6.4.11);

t = the current time;

tz-count = the time of applicability derived from the modified Z-count of the message containing PRC and RRC (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:

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

 F_{pp} = the vertical-to-slant obliquity factor for a given satellite (3.5.5.5.2);

 $\sigma_{\text{vert iono gradient}}$ $\sigma_{\text{vig}} = \sigma_{\text{vig}}$ is dependent on the active GAST.

For GAST A, B or C, $\sigma_{\text{vig}} = \sigma_{\text{vert iono gradient}}$ (as defined in 3.6.4.3);

For GAST D, $\sigma_{\text{vig}} = \sigma_{\text{vert iono gradient D}}$ (as defined in 3.6.4.3.2.2);

 x_{air} = the distance (slant range) in metres between current aircraft location and the GBAS reference point indicated in the Type 2 message;

 τ = is dependent on the active GAST.

For GAST A, B or C, τ =100 seconds (time constant used in 3.6.5.1); and For GAST D, the value of τ depends on whether σ_{iono} is applied in measurement weighting or in integrity bounding. τ =100 seconds when σ_{iono} is used for integrity bounding (per section 3.6.5.5.1.1.1) and τ =30 seconds when σ_{iono} is used for measurement weighting (per section 3.6.5.5.1.1.2).

v_{air} = the aircraft horizontal approach velocity (metres per second).

3.6.5.5 PROTECTION LEVELS

3.6.5.5.1 Protection Levels for all GBAS Approach Service Types 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:

$$VPL_{_{H0}} = K_{_{ffmd}} \sigma_{_{vert}}$$

$$\begin{split} LPL_{H0} &= K_{ffmd} \sigma_{lat} \\ \hline VPL_{H0} &= K_{ffmd} \sqrt{\sum_{i=1}^{N} s_vert_{i}^{2} \times \sigma_{i}^{2}} \\ \hline LPL_{H0} &= K_{ffmd} \sqrt{\sum_{i=1}^{N} s_lat_{i}^{2} \times \sigma_{i}^{2}} \end{split}$$

where

$$\sigma_{vert} = \sqrt{\sum_{i=1}^{N} s_{vert}^{2} \times \sigma_{i}^{2}}$$

$$\sigma_{lat} = \sqrt{\sum_{i=1}^{N} s_{-} lat_{i}^{2} \times \sigma_{i}^{2}}$$

$$\sigma_{i}^{2} = \sigma_{pr \text{ gnd,i}}^{2} + \sigma_{tropo,i}^{2} + \sigma_{pr \text{ air,i}}^{2} + \sigma_{iono,i}^{2}$$

and

 $\sigma_{pr \ gnd,i}$ = _____is dependent on the active GAST. For GAST A, B or C: $\sigma_{pr_gnd,i} = \sigma_{pr_gnd}$ for the ith ranging source as defined in (3.6.4.2);

For GAST D: $\sigma_{\text{pr gnd,i}} = \sigma_{\text{pr gnd D}}$ for the ith ranging source (3.6.4.11); $\sigma_{\text{tropo,i}}^2$, $\sigma_{\text{pr air,i}}^2$ and $\sigma_{\text{iono,i}}^2$ are as defined in section 3.6.5.5.1.1.2;

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

 $s_{v,i} + s_{x,i} \times tan (GPA);$

 $s_{lat_i} = s_{y,i};$

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

 $\hat{s}_{y,i}$ = 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 ith 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 y 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:

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

where

 $G_i = [-\cos El_i \cos Az_i - \cos El_i \sin Az_i - \sin El_i 1] = i^{th} \text{ row of } G;$ and

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

$$W = \begin{bmatrix} \sigma_{w,1}^2 & 0 & \dots & 0 \\ 0 & \sigma_{w,1}^2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sigma_{w,N}^2 \end{bmatrix}^{-1}$$

where
$$\sigma^2_{w,i} = \sigma^2_{pr gnd,i} + \sigma^2_{tropo,i} + \sigma^2_{pr air,i} + \sigma^2_{iono,j}$$

where

 $\sigma_{pr \text{ end,i}}$ = is dependent on the active GAST.

For GAST A, B or C or the GBAS positioning service: $\sigma_{pr \text{ end, i}} = \sigma_{pr \text{ end}}$ for the ith ranging source as defined in (3.6.4.2); For GAST D: $\sigma_{pr_gnd,i} = \sigma_{pr_gnd_30}$ for the ith ranging source (3.6.4.11);

= the residual tropospheric uncertainty for the ith ranging source (3.6.5.3); $\sigma_{tropo,i}$

= the residual ionospheric delay (due to spatial decorrelation) uncertainty for the ith $\sigma_{iono,i}$ ranging source (3.6.5.4); and

 $\sigma_{\text{pr_air,i}} = \sqrt{\sigma_{\text{receiver}}^2(\text{El}_i) + \sigma_{\text{multipath}}^2(\text{El}_i)}$, the standard deviation of the aircraft contribution to the corrected pseudo-range error for the ith ranging source. The total aircraft contribution includes the receiver contribution (3.6.8.2.1) and a standard allowance for airframe multipath;

where

 $\sigma_{multipath}(El_i) = 0.13 + 0.53e^{-El_i/10 \text{ deg}}$, the standard model for the contribution of airframe multipath (in metres);

= the elevation angle for the ith ranging source (in degrees); and El_i

= the azimuth for the ith ranging source taken counterclockwise for the x axis (in Az_i 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:

$$VPL_{H1} = max [VPL_i]$$

$$LPL_{H1} = max [LPL_i]$$

where VPL_i and LPL_i for j = 1 to 4 are

$$\begin{array}{lll} VPL_j & = & |B_vert_j| + K_{md} \ \sigma_{vert,H1} \ and \\ LPL_j & = & |B_lat_j| + K_{md} \ \sigma_{lat,H1} \end{array}$$

and

$$B_vert_j = \sum_{i=1}^{N} (s_vert_i \times B_{i,j});$$

$$B_lat_j \qquad = \qquad \quad \sum_{i=1}^{N} \ (s_lat_i \times B_{i,j});$$

 $B_{i,j}$ = 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;

$$\sigma^2_{\text{vert,H1}} = \sum_{i=1}^{N} (s_{\text{vert}}^2_i \times \sigma_{\text{H1}}^2_i);$$

$$\sigma^2_{lat,H1}$$
 = $\sum_{i=1}^{N} (s_lat_i^2 \times \sigma_H1_i^2);$

$$\sigma_{-}H1^{2}_{i} = \left(\frac{M_{i}}{U_{i}}\right)\sigma^{2}_{pr_gnd,i} + \sigma^{2}_{pr_air,i} + \sigma^{2}_{tropo,i} + \sigma^{2}_{iono,i};$$

 $\sigma_{pr \text{ gnd,i}}$ = is dependent on the active GAST.

For GAST A, B or C: $\sigma_{pr_gnd,i} = \sigma_{pr_gnd}$ for the ith ranging source as defined in (3.6.4.2);

For GAST D: $\sigma_{\text{pr gnd,i}} = \sigma_{\text{pr gnd D}}$ for the ith ranging source (3.6.4.11); $\sigma_{\text{tropo i}}^2 = \sigma_{\text{pr gnd,i}}^2$ and $\sigma_{\text{iono,i}}^2$ are as defined in section 3.6.5.5.1.1.2;

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

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

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

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

Table B-67. K-multipliers for GBAS approach services 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

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:

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

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

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

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

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

s_{y,i} = the partial derivative of position error in the y-direction with respect to pseudo-range error on the ith 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:

$$HPL_{H1} = max [HPL_i]$$

where HPL_i for j = 1 to 4 is:

$$HPL_{j} = |B_horz_{j}| + K_{md_POS \ major,H1}^{d}$$

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 jth reference receiver measurement for the ith ranging source.

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

$$\begin{split} d_{major,H1} &= \sqrt{\frac{d_{-}H1_{x}^{2} + d_{-}H1_{y}^{2}}{2}} + \sqrt{\left(\frac{d_{-}H1_{x}^{2} - d_{-}H1_{y}^{2}}{2}\right)^{2} + d_{-}H1_{xy}^{2}} \\ \\ d_{-}H1_{x}^{2} &= \sum_{i=1}^{N} s_{x,i}^{2} \sigma_{-}H1_{i}^{2} \\ \\ d_{-}H1_{y}^{2} &= \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma_{-}H1_{i}^{2} \\ \\ d_{-}H1_{xy} &= \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma_{-}H1_{i}^{2} \end{split}$$

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 ith ranging source (indicated by the B values).

U_i = the number of reference receivers used to compute the pseudo-range corrections for the ith ranging source, excluding the jth reference receiver.

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

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

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.

Note. – Computation of alert limits depends on the active service type.

- 3.6.5.6.1 GAST C and D Alert Limits 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 *GAST A and B APV alert limits*. The alert limits are equal to the FASLAL and FASVAL taken from the Type 4 message for approaches with channel numbers in the range of 20 001 to 39 999. For approaches with channel numbers in the range 40 000 to 99 999, the alert limits are stored in the on-board database.
- 3.6.5.7 *Channel number*. Each GBAS approach transmitted from the ground subsystem is associated with a channel number in the range of 20 001 to 39 999. If provided, the GBAS positioning service is associated with a separate channel number in the range of 20 001 to 39 999. The channel number is given by:

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) the reference station data selector for the GBAS ground subsystem (as defined in 3.6.4.3.1)

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.

Table B-68. GAST C and D 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 ≤ 873 873 < D ≤ 7 500	FASLAL 0.0044D (m) + FASLAL – 3.85
D > 7500	FASLAL + 29.15

Table B-69. GAST C and D Category I vertical alert limit

Height above LTP/FTP of aircraft position translated onto the final approach path (feet)	Vertical alert limit (metres)
10 0 < H ≤ 200	FASVAL
$200 < H \le 1340$	0.02925H (ft) + FASVAL - 5.85
H > 1340	FASVAL + 33.35

Note 1.— When the FAS is not broadcast for an approach supported by GAST A or B 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 aGBAS Approach Services—and APV*. The vertical and lateral ephemeris error position bounds are defined as:

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

$$j$$

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

$$j$$

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:

$$VEB_{j} = \left| s_{vert_{j}} \right| x_{air} P_{j} + K_{md_{e,j}} \sqrt{\sum_{i=1}^{N} s_{vert_{i}^{2}} \times \sigma_{i}^{2}}$$

$$VEB_{j} = \left| s_{vert_{j}} \right| x_{air} P_{ej} + K_{md_{ej}} \sqrt{\sum_{i=1}^{N} s_{vert_{i}}^{2} \times \sigma_{i}^{2}}$$

$$\frac{LEB_{j} = \left| s_lat_{j} \right| x_{air}P_{j} + K_{md_e,j} \sqrt{\sum_{i=1}^{N} s_lat_{i}^{2} \times \sigma_{i}^{2}}$$

$$LEB_{j} = \left| s _ lat_{j} \right| x_{air} P_{ej} + K_{md}_{ej} \sqrt{\sum_{i=1}^{N} s _ lat_{i}^{2} \times \sigma_{i}^{2}}$$

where:

 $\begin{array}{ll} s_vert_{i\ or\ j} & \text{is defined in } 3.6.5.5.1.1 \\ s_lat_{i\ or\ j} & \text{is defined in } 3.6.5.5.1.1 \\ x_{air} & \text{is defined in } 3.6.5.4 \end{array}$

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

 σ_i is defined in 3.6.5.5.1.1

P_{ej} is the broadcast ephemeris decorrelation parameter for the jth ranging source. The source of

this parameter depends on the active GBAS Approach Service Type:

GAST A, B or C: P_{ei}=P from the Type 1 or Type 101 Message corresponding to the jth ranging

source. (section 3.6.4.2.3)

GAST D: P_{ei}=P_D from the Type 11 Message corresponding to the jth ranging source. (section

3.6.4.11.3).

 $K_{md_e,j} \qquad \text{is the broadcast ephemeris missed detection multiplier for } \frac{\text{Category I precision}}{\text{approach and APV GAST A-C}} \text{ associated with the satellite constellation for the j^{th}} \\ \text{ranging source } \frac{\text{($K_{md_e,GPS}$ or $K_{md_e,GLONASS)}}}{\text{($K_{md_e,GPS}$ or $K_{md_e,GLONASS)}}} \text{ . The source of this parameter depends on } \frac{\text{(K_{md} or $K_{md_e,GLONASS)}}}{\text{(K_{md} or $K_{md_e,GLONASS)}}} \\ \text{(K_{md} or $K_{md_e,GLONASS)}$} \\ \text{(K_{md} or K_{md} or$

the active GBAS Approach Service Type:

GAST A, B or C: $K_{md\ e,i} = K_{md\ e,GPS}$ or $K_{md\ e,GLONASS}$ as obtained from the Type 2

Message Additional Datablock 1 (section 3.6.4.3.1)

GAST D: $K_{md e,j} = Kmd = D,GPS$ or Kmd = D,GLONASS are from the Type 2

Message Additional Datablock 3. (section 3.6.4.3.2.2).

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

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

$$j$$

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

$$HEB_{j} = \left| s_{horz,j} \right| x_{air} P_{j} + K_{md_e_POS_major}^{d}$$

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 s_{air} is defined in 3.6.5.4

 P_j is the broadcast ephemeris decorrelation parameter for the j^{th} ranging source. The source of this parameter does not depend on the active GBAS Approach Service Type. In all cases P_j =P from the Type 1 or Type 101 Message (section 3.6.4.2.3) corresponding to the jth ranging source.

 $K_{md_e_POS}$ is the broadcast ephemeris missed detection multiplier for the GBAS positioning service associated with the satellite constellation for the 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.*

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:

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

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 nth 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-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	$5 \times 10^{-6} \text{ m/m}$
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	$\pm 32.767 \text{ m/s}$	0.001 m/s
$\sigma_{ m pr}$ and	8	0 to 5.08 m	0.02 m
\mathbf{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	$5 \times 10^{-6} \text{m/m}$
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	$\pm 32.767 \text{ m/s}$	0.001 m/s
$\sigma_{ m pr~gnd}$	8	0 to 50.8 m	0.2 m
B parameter block (if provided)			
\mathbf{B}_{1}	8	±25.4 m	0.2 m
B_2	8	±25.4 m	0.2 m
B_3	8	±25.4 m	0.2 m
B_4	8	±25.4 m	0.2 m

Table B-70B. Format of Type 11 30 s Smoothed Pseudo-range Corrections Message

Data Content	Bits Used	Range of Values	Resolution
Modified Z-count	14	0 - 1199.9 sec	0.1 sec
Additional Message Flag	2	0 - 3	1
Number of Measurements	5	0 - 18	1
Measurement Type	3	0 - 7	1
Ephemeris Decorrelation Parameter	8	$0 - 1.275 \times 10^{-3}$	$5x10^{-6}$
D (P _D) (Notes 1, 3)			m/m
For N Measurement Blocks:			
Ranging Source ID	8	1 - 255	1
Pseudorange Correction (PRC ₃₀)	16	± 327.67 m	0.01 m
Range Rate Correction (RRC 30)	16	$\pm 32.767 \text{ m/s}$	0.001 m/s
Sigma_PR_gnd_D ($\sigma_{pr gnd D}$) (Note	8	0 - 5.08 m	0.02 m
2)	_		
Sigma_PR_gnd_30s (σ _{pr gnd 30})	8	0 - 5.08 m	0.02 m
(Note 2)			
Notes:			

- 1) 2) 3) For SBAS satellites, the parameter is set to all 0's.
- 1111 1111 indicates the source is invalid.
- Parameter is associated with the first transmitted measurement block.

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

Data content	Bits used	Range of values	Resolution
GBAS reference receivers	2	2 to 4	_
Ground accuracy designator letter	2	_	
Spare	1	_	_
GBAS continuity/integrity designator	3	0 to 7	1
Local magnetic variation	11	±180°	0.25°
Spare	5	<u> </u>	_
σ _{vert_iono_gradient}	8	0 to 25.5×10^{-6} m/m	$0.1 \times 10^{-6} \text{ m/m}$
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(s) (if provided)			
Additional data block length	8	2 to 255	1
Additional data block number	8	2 to 255	1
Additional data parameters	Variable		_

Table B-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		0 to 50.8 m	0.2 m
performance designator indicates			
APV-I (APD) is coded as 0)			
(2) when associated approach		0 to 25.4 m	0.1 m
performance designator does not			
indicate APV-I (APD) is not			
coded as 0)			
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			

Data content	Bits used	Range of values	Resolution
Ranging source ID	8	1 to 255	1
Source availability sense	1	_	_
Source availability duration	7	0 to 1 270 s	10 s

Table B-74. GBAS — GPS accuracy requirement parameters

Ground accuracy designator letter	$\theta_n \\ (degrees)$	a ₀ (metres)	a ₁ (metres)	θ_0 (degrees)	a ₂ (metres)
A	≥ 5	0.5	1.65	14.3	0.08
В	≥ 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	$\theta_n \\ (degrees)$	a ₀ (metres)	a ₁ (metres)	θ_0 (degrees)	a ₂ (metres)
A	≥ 5	1.58	5.18	14.3	0.078
В	≥ 5	0.3	2.12	15.5	0.078
C	> 35	0.3	1.68	15.5	0.042
	5 to 35	0.48	0		0.042

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

$$RMS_{pr_gnd} \leq \frac{1.8}{\sqrt{M}} (metres)$$

where M is as defined in 3.6.7.1.1.1.

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

3.6.7.1.2 *Integrity*

3.6.7.1.2.1 *GBAS ground subsystem integrity risk*

3.6.7.1.2.1.1 Ground Subsystem Integrity Risk for GBAS Approach Services

- 3.6.7.1.2.1.1.1 Ground Subsystem Signal-in-Space Integrity Risk for GBAS Approach Service Types A, B or C Category I precision approach and APV. For a GBAS ground subsystem that classified as FAST A, B or C 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 3.6.7.3.3 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 signal-in-space time-to-alert. An out-of-tolerance lateral or vertical relative position error is defined as an error that exceeds the GBAS approach services Category I precision approach or APV protection level and, if additional data block 1 is broadcast, the ephemeris error position bound.
- 3.6.7.1.2.1.1.2 Ground Subsystem Signal in Space Integrity Risk for GBAS Approach Service Type D For a GBAS ground subsystem classified as FAST D the integrity risk for all effects other than errors induced by anomalous inonosphereic conditions shall be less than 1.5×10^{-7} per approach.
- Note 1.— The integrity risk assigned to the GBAS ground subsystem classified as FAST D is a subset of the GBAS signal-in-space integrity risk, where the protection level integrity risk (3.6.7.1.2.2.1) has been excluded and the effects of all other GBAS, SBAS and core satellite constellations failures are included.
- Note 2.— For GAST D the GBAS signal-in-space integrity risk is defined as the probability that the ground subsystem provides information which when processed by a fault-free receiver, using any GBAS data that could be used by the aircraft, in the absence of an ionospheric anomaly results in an out-of-tolerance lateral or vertical relative position error without annunciation for a period longer than the maximum signal-in-space time-to-alert. An out-of-tolerance lateral or vertical relative position error is defined as an error that exceeds the GBAS approach services protection level and the ephemeris error position bound. For GAST D, out of tolerance conditions caused by anomalous ionospheric errors are excluded from this integrity risk as the risk due to ionospheric anomalies has been allocated to and is mitigated by the airborne segment.
- 3.6.7.1.2.1.1.3 *Ground Subsystem Integrity Risk for GAST D.* For a GBAS ground subsystem classified as FAST D, the probability that the ground subsystem internally generates and transmits non-compliant information for longer than 1.5 seconds shall be less than 1×10^{-9} in any one landing.
- Note 1.— This additional integrity risk requirement assigned to FAST D GBAS ground subsystems is defined in terms of the probability that internal ground subsystem faults generate noncompliant information. Non-compliant information in this context is defined in terms of the intended function of the ground subsystem to support landing operations in Category III minima. For example, non-compliant information includes any broadcast signal or broadcast information that is not monitored in accordance with the standard.
- Note 2.— Environmental conditions (such as anomalous ionosphere, troposphere, radio frequency interference, GNSS signal multipath, etc...) are not considered faults; however, faults in ground subsystem equipment used to monitor for or mitigate the effects of these environmental conditions are included in this requirement. Similarly, the core satellite constellation ranging source faults are excluded from this requirement; however, the ground subsystem's capability to provide integrity monitoring for these ranging sources is included. Monitoring requirements for ranging source faults and ionosphere environmental conditions are separately specified in 3.6.7.3.3.2, 3.6.7.3.3.3 and 3.6.7.3.4.

- Note 3.— Faults that occur in ground receivers used to generate the broadcast corrections are excluded from this requirement if they occur in any one, and only one, ground receiver at any time. Such faults are constrained by the requirement in 3.6.7.1.2.2.1.1 and the associated integrity risk requirement in 3.6.7.1.2.2.1.
 - 3.6.7.1.2.1.2. *Ground Subsystem Time to Alert for GBAS approach services*
 - 3.6.7.1.2.1.2.1 Maximum Time to Alert for Approach Services
- 3.6.7.1.2.1.4.2.1.1 For a ground segment classified as FAST A, B, C or D, Tthe GBAS ground subsystem maximum time-to-alert shall be less than or equal to 3 seconds for all signal-in-space integrity requirements (See Appendix B, 3.6.7.1.2.1.1.1, 3.6.7.1.2.1.1.2, 3.6.7.1.2.2.1) when Type 1 messages are broadcast.
- Note 1.— The ground subsystem time-to-alert above is the time between the onset of the out-of-tolerance lateral or vertical relative position error and the transmission of the last bit of the message that contains the integrity data that reflects the condition (See Attachment D, Section 7.5.12.3)
- Note $2 For\ FAST\ D$ ground subsystems, additional range domain monitoring requirements apply as defined in section 3.6.7.3.3.2, 3.6.7.3.3.3 and 3.6.7.3.4.. In these sections, time limits are defined for the ground system to detect and alert the airborne receiver of out-of-tolerance differential pseudorange errors.
- 3.6.7.1.2.1.4.2.1.2 For a ground segment classified as FAST A, The GBAS ground subsystem maximum signal-in-space time-to-alert shall be less than or equal to 5.5 seconds when Type 101 messages are broadcast.
 - 3.6.7.1.2.1.3 Ground Subsystem FASLAL and FASVAL
- 3.6.7.1.2.1.4.3.1 For Message Type 4 FAS datablocks with APD coded as 1, 2, 3 or 4 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.
- 3.6.7.1.2.1.1.3.2.4 For Message Type 4 FAS datablocks with APD coded as zero 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 for the intended operational use.
- 3.6.7.1.2.1.24 Ground Subsystem Signal in Space Integrity Risk for *GBAS positioning service*. For GBAS ground subsystem that provides the GBAS positioning service, integrity risk shall be less than 9.9×10^{-8} per hour.
- Note 1.— The integrity risk assigned to the GBAS ground subsystem is a subset of the GBAS signal-in-space integrity risk, where the protection level integrity risk (3.6.7.1.2.2.2) has been excluded and the effects of all other GBAS, SBAS and core satellite constellations failures are included. The GBAS ground subsystem integrity risk includes the integrity risk of satellite signal monitoring required in 3.6.7.2.63.6.7.3.3 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.

3.6.7.1.2.1.24.1 *Time to alert for GBAS Positioning Service*. The GBAS ground subsystem maximum time-to-alert shall be less than or equal to 3 seconds when Type 1 messages are broadcast and less than or equal to 5.5 seconds when Type 101 messages are broadcast.

Note.— The time-to-alert above is the time between the onset of the out-of-tolerance horizontal relative position error and the transmission of the last bit of the message that contains the integrity data that reflects the condition.

3.6.7.1.2.2 Protection level integrity risk

3.6.7.1.2.2.1 For a GBAS ground subsystem that provides the GBAS Approach Services Category I precision approach or APV, the protection level integrity risk shall be less than 5×10^{-8} per approach.

Note.— For Approach Services, 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.

3.6.7.1.2.2.1.1 Additional Bounding Requirements for FAST D Ground Subsystems. The σ_{vert} (used in computing the protection level VPL_{H0}) and σ_{lat} (used in computing the protection level LPL_{H0}) for GAST D formed based on the broadcast parameters (defined in 3.6.5.5.1.1.1) and excluding the airborne contribution shall satisfy the condition that a normal distribution with zero mean and a standard deviation equal to σ_{vert} and σ_{lat} bounds the vertical and lateral error distributions of the combined differential correction errors as follows:

$$\int_{y}^{\infty} f_{n}(x) dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0 \text{ and}$$

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

where

 $f_n(x)$ = probability density function of the differential vertical or lateral position error excluding the airborne contribution, and

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{t^2}{2}} dt$$

The $\sigma_{vert,H1}$ (used in computing the protection level VPL_{H1}) and $\sigma_{lat,H1}$ (used in computing the protection level LPL_{H1}) for GAST D formed based on the broadcast parameters (defined in 3.6.5.5.1.2) and excluding the airborne contribution, shall bound the combined differential correction errors (as defined above) formed by all possible subsets with one reference receiver excluded.

Note — The airborne contribution is addressed in 3.6.8.3.2.1 in combination with the use of the standard airborne multipath model defined in 3.6.5.5.1.1.2.

- 3.6.7.1.2.2.1.2 For a GBAS ground subsystem classified as FAST D, the rate of faulted measurements from any one, and only one, reference receiver shall be less than 1×10^{-5} per 150 seconds.
- Note.—Faulted measurements can occur from faults within the receiver or from environmental conditions unique to a single reference receiver location.
- 3.6.7.1.2.2.2 For a GBAS ground subsystem that provides the positioning service, protection level integrity risk shall be less than 10^{-9} per hour.
- Note.— The GBAS positioning service protection level integrity risk is the integrity risk due to undetected errors in the horizontal position relative to the GBAS reference point greater than the GBAS positioning service protection level under the two following conditions:
 - a) normal measurement conditions defined in 3.6.5.5.2.1; and
 - b) faulted measurement conditions defined in 3.6.5.5.2.2.

3.6.7.1.3 *Continuity of service*

- 3.6.7.1.3.1 Continuity of service for Approach Services. 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 that 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 requiremt must be accounted for by the ground subsystem provider.
- 3.6.7.1.3.2 Additional continuity of service requirements for FAST D. The probability of a GBAS ground subsystem failure or false alert, excluding ranging source monitoring, causing an unscheduled interruption of service for a period equal to or greater than 1.5 seconds shall not exceed 2.0x10⁻⁶ during any 15 second interval. The probability that the ground subsystem excludes any individual fault-free ranging source from the Type 1 or Type 11 corrections due to a false detection by the ground integrity monitors shall not exceed 2.0x10⁻⁷ during any 15 second interval.
- Note 1.- Loss of service includes failures resulting in loss of the VHF data broadcast, failure to meet the VHF data broadcast field strength, failures resulting in transmission of out of tolerance VHF broadcast data, and alert due to an integrity failure. Guidance material on the potential causes of loss of service and monitor false detections are contained in Attachment D, section 7.6.2.1.
- Note 2. Continuity for FAST D is defined as the probability that the ground subsystem continues to provide the services associated with the intended ground subsystem functions. Ultimate continuity of navigation system performance in the position domain must be evaluated in the context of a specific satellite geometry and airplane integration. Evaluation of position domain navigation service continuity is the responsibility of the airborne user for GAST D. Additional information regarding continuity is given in Attachement D section 7.6.2.1.
- 3.6.7.1.3.32 *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.

3.6.7.1.4 Siting Criteria

- 3.6.7.1.4.1 The distance between the reference point of a FAST D ground subsystem and the LTP of any runway for which the ground subsystem supports GAST D shall be less than or equal to 5 km.
- Note Guidance material concerning siting constraints for mitigation of anomalous ionosphere is given in Attachment D, section 7.5.6.1.6.
- 3.6.7.2 FUNCTIONAL REQUIREMENTS
- 3.6.7.2.1 *General*
- 3.6.7.2.1.1 *Data broadcast requirements rates*.
- 3.6.7.2.1.1.1 A GBAS ground subsystem shall broadcast Message Types as defined in Table B-75A according to the ground subsystem FAST classification.
- 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 with additional data blocks as required to support the intended operations.
- Note Guidance material concerning usage of the Type 2 message additional data blocks is provided in Attachment D 7.17
- 3.6.7.2.1.1.3 Each GBAS ground subsystem shall broadcast FAS blocks in Type 4 messages for all Category I precision approaches which support GBAS Approach Service Type (GAST) C or D supported by that GBAS ground subsystem. If a GBAS ground subsystem supports APV any approach using GAST A or B and does not broadcast FAS blocks for the corresponding approaches, it shall broadcast additional data block 1 in the Type 2 message.
- Note.— FAS blocks for APV procedures may be held within a database on board the aircraft. Broadcasting additional data block I 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.
- 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.
- 3.6.7.2.1.3.1 *Recommendation* All GBAS ground subsystems should support VDB authentication (section 3.6.7.4)
- 3.6.7.2.1.3.2 All ground subsystems classified as FAST D shall support VDB authentication (section 3.6.7.4)
- 3.6.7.2.2 Pseudo-range corrections
- 3.6.7.2.2.1 *Message latency*. The time between the time indicated by the modified Z-count and the last bit of the broadcast Type 1, Type 11 or Type 101 message shall not exceed 0.5 seconds.

Table B-75A. GBAS Message Types Required for Each Service Level Supported

Message Type	FAST A	FAST B	FAST C	FAST D
MT 1	Optional – Note 1	Required	Required	Required
MT 2	Required	Required	Required	Required
MT2-ADB 1	Optional	Optional	Optional	Required
MT2-ADB 2	Optional	Optional	Optional	Optional
MT2-ADB 3	Optional	Optional	Optional	Required
MT2-ADB 4	Optional	Optional	Optional	Required
MT 3	Optional	Optional	Optional	Required
MT 4	Optional	Required	Required	Required
MT 5	Optional	Optional	Optional	Optional
MT 11 – Note 2	Not Allowed	Not Allowed	Not Allowed	Required
MT 101	Optional – Note 1	Not Allowed	Not Allowed	Not Allowed

Note 1.—FAST A Ground Subsystems may broadcast Type 1 or 101 Messages but not both. Guidance material concerning usage of the Type 101 message is provided in Attachment D, section 7.18

Note 2.— Guidance material concerning usage of the Type 11 message is provided in Attachment D, Section 7.20

Table B-76. GBAS VHF data broadcast rates

Message type	Minimum broadcast rate	Maximum broadcast rate
1 or 101	For each measurement type: All measurement blocks once per frame (Note)	For each measurement type: All measurement blocks once per slot
2	Once per 20 consecutive frames	Once per frame
3	Rate depends on message length and scheduling of other messages (see section 3.6.7.4.1.3.)	Once per slot and eight times per frame
4	All FAS blocks once per 20 consecutive frames	All FAS blocks once per frame
5	All impacted sources once per 20 consecutive frames	All impacted sources once per 5 consecutive frames
11	For each measurement type: All measurement blocks once per frame (Note)	For each measurement type: All measurement blocks once per slot

Note.— One Type 1, Type 11 or Type 101 message or two Type 1, Type 11 or Type 101 messages that are linked using the additional message flag described in 3.6.4.2, 3.6.4.10.3 or 3.6.4.11.3.

3.6.7.2.2.2 Low-frequency data. Except during an ephemeris change, the first ranging source in the Type 1, Type 11 or Type 101 message shall sequence so that the ephemeris decorrelation parameter, ephemeris CRC and source availability duration for each core satellite constellation's ranging source are transmitted at least once every 10 seconds. During an ephemeris change, the first ranging source shall sequence so that the ephemeris decorrelation parameter, ephemeris CRC and source availability duration for each core satellite constellation's ranging source are transmitted at least once every 27 seconds. When new ephemeris data are received from a core satellite constellation's ranging source, the ground subsystem shall use the previous ephemeris data from each satellite until the new ephemeris data have been continuously received for at least 2 minutes but shall make a transition to the new ephemeris data before 3 minutes have passed. When this transition is made to using the new ephemeris data for a given ranging source, the ground subsystem shall broadcast the new ephemeris CRC for all occurrences of that ranging source in the low-frequency information of Type 1, Type 11 or Type 101 message in the next 3 consecutive frames. For a given ranging source, the ground subsystem shall continue to transmit data corresponding to the previous ephemeris data until the new CRC ephemeris is transmitted in the lowfrequency data of Type 1, Type 11 or Type 101 message (see Note). If the ephemeris CRC changes and the IOD does not, the ground subsystem shall consider the ranging source invalid.

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

- 3.6.7.2.2.2.1 **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 and the Approach Service Type specific smoothing parameters in accordance with Appendix B, Section 3.6.5.1.

- 3.6.7.2.2.4 Broadcast signal-in-space integrity parameters. The ground subsystem shall provide σ_{pr_gnd} and B parameters for each pseudo-range correction in Type 1 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 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.
- 3.6.7.2.2.4.1 Broadcast signal-in-space integrity parameters for FAST D Ground Subsystems. Ground subsystems that support GAST D shall provide Sigma_PR_gnd_D in the Type 11 message and B parameters for each pseudo-range correction in the Type 1 message such that the protection level integrity risk requirement defined in 3.6.7.1.2.2.1 are satisfied.
- 3.6.7.2.2.4.2 For FAST D systems broadcasting the Type 11 message, if σ_{pr} gnd is coded as invalid in the Type 1 message, then the Sigma_PR_gnd_D for the associated satellite in the Type 11 message shall also be coded as invalid.
- 3.6.7.2.2.5 **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, Type 11, or Type 101 messages or linked pairs from all GBAS broadcast stations that share a common GBAS identification, shall have identical data content.
- 3.6.7.2.2.7 *Issue of data*. The GBAS ground subsystem shall set the IOD field in each ranging source measurement block to be the IOD value received from the ranging source that corresponds to the ephemeris data used to compute the pseudo-range correction.
- 3.6.7.2.2.8 *Application of signal error models*. Ionospheric and tropospheric corrections shall not be applied to the pseudo-ranges used to calculate the pseudo-range corrections.
- 3.6.7.2.2.9 Linked pair of Type 1, Type 11 or Type 101 messages. If a linked pair of Type 1, Type 11 or Type 101 messages is transmitted then,
 - a) the two messages shall have the same modified Z-count;
 - b) the minimum number of pseudo-range corrections in each message shall be one;
 - the measurement block for a given satellite shall not be broadcast more than once in a linked pair of messages; and
 - 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.
 - f) for a particular measurement type, the number of measurements and low-frequency data shall be computed separately for each of the two individual messages.
 - g) in the case of FAST D, when a pair of linked Type 1 messages are transmitted, there shall also be a linked pair of Type 11 messages; and

- h) if linked message types of Type 1 or 11 are used, the satellites shall be divided into the same sets and order in both Type 1 and Type 11 messages.
 - Note: Type 1 messages may include additional satellites not available in Type 11 messages, but the relative order of those satellites available in both messages is the same in Type 1 and Type 11 messages. Airborne processing is not possible for satellites included in the Type 11 message but not included in the associated Type 1 message.
- 3.6.7.2.2.9.1 *Recommendation* Linked messages should only be used when there are more pseudorange corrections to transmit than will fit in one Type 1 message.

3.6.7.2.2.10 *Modified Z-Count Requirements*

- 3.6.7.2.2.10.1 *Modified Z-count update.* The modified Z-count for Type 1, Type 11 or Type 101 messages of a given measurement type shall advance every frame.
- 3.6.7.2.2.10.2 If Message Type 11 is broadcast, the associated Type 1 and Type 11 Messages shall have the same Modified Z-count.
- 3.6.7.2.2.11 *Ephemeris decorrelation parameters*
- 3.6.7.2.2.11.1 Ephemeris Decorrelation Parameter for Approach Servcices 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 in the Type 1 message for each core satellite constellation ranging source such that the ground subsystem integrity risk of 3.6.7.1.2.1.1.1 is met.
- 3.6.7.2.2.11.2 Ephemeris Decorrelation Parameter for GAST D. Ground subsystems classified as FAST D shall broadcast the ephemeris decorrelation parameter in the Type 11 message for each core satellite constellation ranging source such that the ground subsystem integrity risk of 3.6.7.1.2.1.1.2 is met.
- 3.6.7.2.2.11.2.3 *GBAS positioning service*. For ground subsystems that provide the GBAS positioning service, the ground subsystem shall broadcast the ephemeris decorrelation parameter in the Type 1 message for each core satellite constellation's ranging source such that the ground subsystem integrity risk of 3.6.7.1.2.1.42 is met.

3.6.7.2.3 *GBAS-related data*

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

3.6.7.2.3.2 GCID indication.

- 3.6.7.2.3.2.1 *GCID indication for FAST A, B or C.* If the ground subsystem meets the requirements of 3.6.7.1.2.1.1, 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.
- 3.6.7.2.3.2.2 *GCID indication for FAST D.* If the ground subsystem meets the requirements of 3.6.7.1.2.1.1.1, 3.6.7.1.2.1.1.2, 3.6.7.1.2.2.1, 3.6.7.1.3.1, 3.6.7.1.3.2 and 3.6.7.3.2 the GCID shall be set to 2, otherwise it shall be set in accordance with 3.6.7.2.3.2.1.
 - 3.6.7.2.3.2.3 GCID values of 3 and 4 are reserved for future service types and shall not be used.

- 3.6.7.2.3.3 *GBAS reference antenna phase centre position accuracy*. For each GBAS reference receiver, the reference antenna phase centre position error shall be less than 8 cm relative to the GBAS reference point.
- 3.6.7.2.3.4 **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.*
- 3.6.7.2.3.5.1 *Ionosperic uncertainty estimate parameter for all Ground Subsystems*. The ground subsystem shall broadcast an ionospheric delay gradient parameter in the Type 2 message such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.
- 3.6.7.2.3.5.2 *Ionospheric uncertainty estimate parameter for FAST D Ground Subsystems*. The ground subsystem shall broadcast an ionospheric delay gradient parameter in the Type 2 message, additional data block 3, such that the protection level integrity risk requirements defined in 3.6.7.1.2.2 are satisfied.
- Note –Guidance material concerning FAST D position domain error bounding for ionospheric errors may be found in Attachement D Section 7.5.6.1.3 and 7.5.6.1.4.
- 3.6.7.2.3.6 For ground subsystems that provide the GBAS positioning service, the ground subsystem shall broadcast the ephemeris error position bound parameters using additional data block 1 in the Type 2 message.
- 3.6.7.2.3.7 **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 *SBAS FAS data points accuracy.* For use with SBAS, 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.
- 3.6.7.2.4.3 **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.
- 3.6.7.2.4.4 **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.
- 3.6.7.2.4.5 *LTP/FTP for FAST D*. For an approach that supports GAST D, the LTP/FTP point in the corresponding FAS definition shall be located at the intersection of the runway centerline and the landing threshold.
- Note Airborne systems may compute the distance to the landing threshold using the LTP/FTP. For GAST D approaches, the LTP/FTP must be at the threshold so that these distance to go computations reliably reflect the distance to the threshold.
- 3.6.7.2.4.6 FPAP Location for FAST D. For an approach that supports GAST D, the FPAP point in the corresponding FAS definition shall be located on the extended runway centerline and the Δ Length offset parameter shall be coded to correctly indicate the stop end of the runway.

3.6.7.2.5 Predicted ranging source availability data

Note.— Ranging source availability data are optional for Category I and APV FAST A, B, C or D ground subsystems 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.

3.6.7.2.6 General Functional Requirements on Augmentation

3.6.7.2.6.1. Recommendation - Core Satellite Constellations to be augmented - GBAS ground subsystems classified as FAST C or FAST D should provide augmentation based on GPS at a minimum.

- 3.6.7.2.6.2. Recommendation Ground subsystems classified as FAST C should be able to process and broadcast corrections for at least 12 satellites of each core constellation for which differential corrections are provided
- 3.6.7.2.6.3 Ground subsystems classified as FAST D shall be able to process and broadcast differential corrections for at least 12 satellites of one core constellation.

Note – Technical validation has only been completed for GAST D when applied to GPS.

3.6.7.2.6.4. Recommendation – whenever possible differential corrections for all visible satellites with an elevation greater than 5 degrees above the local horizontal plane tangent to the ellipsoid at the ground subsystem reference location should be provided for each core constellation for which augmentation is provided.

Note – The phrase whenever possible in this context means whenever meeting another requirement in this SARPS

(for example 3.6.7.3.3.1) does not preclude providing a differential correction for a particular satellite.

3.6.7.3 *MONITORING*

3.6.7.3.1 *RF monitoring*

3.6.7.3.1.1 VHF data broadcast monitoring. The data broadcast transmissions shall be monitored. The transmission of the data shall cease within 0.5 seconds in case of continuous disagreement during any 3-second period between the transmitted application data and the application data derived or stored by the monitoring system prior to transmission. For FAST D ground subsystems the transmission of the data shall cease within 0.5 seconds in case of continuous disagreement during any 1-second period between the transmitted application data and the application data derived or stored by the monitoring system prior to transmission.

Note — For ground subsystems that support authentication, ceasing the transmission of data means ceasing the transmission of Type 1 messages and Type 11 messages if applicable or ceasing the transmission of Type 101 messages. In accordance with 3.6.7.4.1.3 the ground subsystem must still transmit messages such that 95% or more of every assigned slot is occupied. This can be accomplished by transmitting Type 2, Type 3 and/or Type 4 messages.

- 3.6.7.3.1.2 *TDMA slot monitoring*. The risk that the ground subsystem transmits a signal in an unassigned slot and fails to detect an out-of-slot transmission, which exceeds that allowed in 3.6.2.6, within 1 second, shall be less than 1×10^{-7} in any 30-second period. If out-of-slot transmissions are detected, the ground subsystem shall terminate all data broadcast transmissions within 0.5 seconds.
- 3.6.7.3.1.3 *VDB transmitter power monitor*. The probability that the horizontally or elliptically polarized signal's transmitted power increases by more than 3 dB from the nominal power for more than 1 second shall be less than 2.0×10^{-7} in any 30-second period.

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

3.6.7.3.2 Data monitoring

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

- a) to broadcast Type 1 (and Type 11 if broadcast) or Type 101 messages with no measurement blocks; or
- b) to broadcast Type 1 (and Type 11 if broadcast) or Type 101 messages with the σ_{pr_gnd,i} (and σ_{pr_gnd_D,l} if broadcast) field set to indicate the ranging source is invalid for every ranging source included in the previously transmitted frame; or
- c) to terminate the data broadcast.

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

3.6.7.3.3 Integrity Monitoring for GNSS Ranging Sources

- 3.6.7.3.3.1 The ground subsystem shall monitor the satellite signals to detect conditions that will result in improper operation of differential processing for airborne receivers complying with the tracking constraints in Attachment D, 8.11. The monitor time-to-alert shall comply with 3.6.7.1.2. The monitor action shall be to set $\sigma_{pr\ gnd}$ to the bit pattern "1111 1111" for the satellite or to exclude the satellite from the Type 1, Type 11 or Type 101 message.
- 3.6.7.3.3.1.1 The ground subsystem shall use the strongest correlation peak in all receivers used to generate the pseudo-range corrections. The ground subsystem shall also detect conditions that cause more than one zero crossing for airborne receivers that use the Early-Late discriminator function as described in Attachment D, 8.11.
- 3.6.7.3.3.2 For FAST D ground subsystems, the probability that the error, |Er|, on the 30 second smoothed corrected pseudorange (section 3.6.5.2) caused by a ranging source fault, is not detected and reflected in the broadcast Type 11 message within 1.5 s shall fall within the region specified in Table B-76 A.

Ranging source faults for which this requirement applies are:

- a. Signal deformation (Note 1)
- b. Code/Carrier divergence
- c. Excessive pseudorange acceleration, such as a step or other rapid change.
- d. Erroneous broadcast of ephemeris data from the satellite.

Note 1—Refer to Appendix D, Section 8.11 for further information on AEC-D avionics relating to signal deformation fault.

- Note 2. Upon detection, a ranging source fault may be reflected in the Type 11 message by either: a) removing the correction for the associated satellite from the Type 11 Message, or b) marking the satellite as invalid using the coding of σ_{pr} and σ_{pr} (section 3.6.4.11.4)
- Note 3 The acceptable probability of missed detection region is defined with respect to differentially corrected pseudorange error. The differentially corrected pseudorange error, |Er|, includes the error resulting from a single ranging source fault, given the correct application of GBAS ground subsystem Message Type 11 broadcast corrections (i.e. Pseudorange Correction and Range Rate Corrections defined in Section 3.6.4.11) by the aircraft avionics as specified within section 3.7. Evaluation of Pmd performance includes GBAS ground subsystem fault-free noise.

Note 4 - Additional information regarding the ranging source fault conditions and monitoring requirements for FAST D ground subsystems may be found in Attachment D section 7.5.12

Table	B-76 A	P	Parameters
ranie	D-/U/A	I md limit	rafameters

Probability of Missed Detection	Pseudorange Error (metres)
$P_{md\ limit} \leq 1$	$0 \le E_r < 0.75$
$P_{\text{md limit}} \le 10^{(-2.56 \times \text{Er} + 1.92)}$	$0.75 \le E_r < 2.7$
$P_{\text{md limit}} \leq 10^{-5}$	$2.7 \le E_r < \infty$

3.6.7.3.3.3 For FAST D ground subsystems, the probability of a error, |Er|, greater than 1.6 meters on the 30 second smoothed corrected pseudorange (section 3.6.5.2), caused by a ranging source failure, is not detected and reflected in the broadcast Type 11 message within 1.5 seconds shall be less than 1×10^{-9} in any one landing when multiplied by the prior probability ($P_{apriori}$).

Ranging source faults for which this requirement applies are:

- a. Signal deformation (Note 1)
- b. Code/Carrier divergence
- c. Excessive pseudorange acceleration, such as a step or other rapid change.
- d. Erroneous broadcast of ephemeris data from the satellite.

Note 1—Refer to Appendix D, Section 8.11 for further information on AEC-D avionics relating to signal deformation fault.

Note 2. – It is intended that the prior probability of each ranging source fault ($P_{apriori}$) be the same value that is used in the analysis to show compliance with error bounding requirements for FAST C and D (see Appendix B, Section 3.6.5.5.1.1.1).

Note 3 - Upon detection, a ranging source fault may be reflected in the Type 11 message by either:

- a) removing the faulty satellite correction from the Type 11 message, or
- b) marking the satellite as invalid using the coding of σ_{pr} and D (section 3.6.4.11.4)

3.6.7.3.4. Ionospheric Gradient Monitoring.

A ground subsystem classified as FAST D shall within 1.5 seconds mark the differential corrections for affected satellites as invalid in MT11 ($\sigma_{pr \ gnd \ D}$ bit pattern "1111 1111"), if the probability that there is an undetected spatial ionospheric delay gradient with a magnitude greater than 1.5m/D in the direction of any approach supporting GAST D is greater than 1×10^{-9} . D is the distance between the reference point of the FAST D ground subsystem and the threshold. The direction of the approach is defined by the runway heading.

Note - The total probability of an undetected delay gradient includes the prior probability of the gradient and the monitor probability of missed detection. For example, if the distance to the threshold is 5 km then the magnitude of the gradient that needs to be detected is 1.5 m/5 km = 300 mm/km. The magnitude of the undetected ionospheric spatial delay gradient as observed over a baseline parallel to runway being served must not exceed 300 mm/km with a total probability of greater than $1x10^{-9}$

- 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 properly coded to indicate which slots are assigned to the ground subsystem.
- 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 95% 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 Indicator Coding*. Every RPI included in every Final Approach Segment datablock broadcast by the ground subsystem via the Type 4 messages shall have the first letter selected to indicate the SSID of the ground subsystem in accordance with the following coding.

Coding: A = SSID of 0 X = SSID of 1 Z = SSID of 2 J = SSID of 3 C = SSID of 4 V = SSID of 5

P = SSID of 6

T = SSID of 7

- 3.6.7.4.2 Functional Requirements for Ground Subsystems that Do Not Support Authentication
- 3.6.7.4.2.1 *Reference Path Indicator Coding.* Characters in this set: { A X Z J C V P T } shall not be used as the first character of the Reference Path Identifier included in any Final Approach Segment data block broadcast by the ground subsystem via the Type 4 messages.

3.6.8 AIRCRAFT ELEMENTS

3.6.8.1 *GNSS receiver*. The GBAS-capable GNSS receiver shall process signals of GBAS in accordance with the requirements specified in this section as well as with requirements in 3.1.3.1 and/or 3.2.3.1 and/or 3.5.8.1.

Note - In order to ensure the required performance and functional objectives for GAST D are achieved, it is necessary for the airborne equipment to meet defined performance and functional standards. The relevant minimum operational performance standards are detailed in RTCA DO-253C.

- 3.6.8.2 PERFORMANCE REQUIREMENTS
- 3.6.8.2.1 *GBAS aircraft receiver accuracy*

3.6.8.2.1.1 The RMS of the total aircraft receiver contribution to the error for GPS and GLONASS shall be:

$$RMS_{pr~air}\left(\theta_{n}\right) \leq a_{0} + a_{1} \times e^{-\left(\theta_{n}/\theta_{0}\right)}$$

where

n = the nth ranging source;

 θ_n = the elevation angle for the nth ranging source; and

 a_0 , a_1 , and θ_0 = as defined in Table B-77 for GPS and Table B-78 for GLONASS.

3.6.8.2.1.2 The RMS of the total aircraft receiver contribution to the error for SBAS satellites shall be as defined in 3.5.8.2.1 for each of the defined aircraft accuracy designators.

Note.— The aircraft receiver contribution does not include the measurement error induced by airframe multipath.

3.6.8.2.2 *VHF data broadcast receiver performance*

- 3.6.8.2.2.1 *VHF data broadcast tuning range*. The VHF data broadcast receiver shall be capable of tuning frequencies in the range of 108.000 117.975 MHz in increments of 25 kHz.
- 3.6.8.2.2.2 VHF data broadcast capture range. The VHF data broadcast receiver shall be capable of acquiring and maintaining lock on signals within ± 418 Hz of the nominal assigned frequency.
- Note.— The frequency stability of the GBAS ground subsystem, and the worst-case doppler shift due to the motion of the aircraft, are reflected in the above requirement. The dynamic range of the automatic frequency control should also consider the frequency-stability error budget of the aircraft VHF data broadcast receiver.
- 3.6.8.2.2.3 VHF data broadcast sensitivity, range and message failure rate. The VHF data broadcast receiver shall achieve a message failure rate less than or equal to one failed message per 1 000 full-length (222 bytes) application data messages, while operating over a range from –87 dBm to –1 dBm, provided that the variation in the average received signal power between successive bursts in a given time slot does not exceed 40 dB. Failed messages include those lost by the VHF data broadcast receiver system or which do not pass the CRC after application of the FEC.

 Table B-77.
 Aircraft GPS receiver accuracy requirement

Aircraft accuracy designator	θ_n (degrees)	a ₀ (metres)	a ₁ (metres)	θ_0 (degrees)
A	≥5	0.15	0.43	6.9
В	≥5	0.11	0.13	4

Table B-78. Aircraft GLONASS receiver accuracy requirement

Aircraft accuracy Designator	θ_n (degrees)	a ₀ (metres)	a ₁ (metres)	θ_0 (degrees)
A	≥5	0.39	0.9	5.7
В	≥5	0.105	0.25	5.5

- Note.— Aircraft VHF data broadcast receiving antenna can be horizontally or vertically polarized. Due to the difference in the signal strength of horizontally and vertically polarized components of the broadcast signal, the total aircraft implementation loss is limited to 15 dB for horizontally polarized receiving antennas and 11 dB for vertically polarized receiving antennas.
- 3.6.8.2.2.4 *VHF data broadcast time slot decoding*. The VHF data broadcast receiver shall meet the requirements of 3.6.8.2.2.3 for all Message Types required (section 3.6.8.3.1.2.1) Type 1, 2 and 4 messages from the selected GBAS ground subsystem. These requirements shall be met in the presence of other GBAS transmissions in any and all time slots respecting the levels as indicated in 3.6.8.2.2.5.1 b).
- Note.— Other GBAS transmissions may include: a)-messages other message types than Type 1, 2 and 4 with the same SSID, and b) messages with different SSIDs.
- 3.6.8.2.2.4.1 Decoding of Type 101 messages. A VHF data broadcast receiver capable of receiving Type 101 messages, shall meet the requirements of 3.6.8.2.2.3 for all Type 101 messages from the selected GBAS ground subsystem. These requirements shall be met in the presence of other GBAS transmissions in any and all time slots respecting the levels as indicated in 3.6.8.2.2.5.1 b).

3.6.8.2.2.5 Co-channel rejection

- 3.6.8.2.2.5.1 *VHF data broadcast as the undesired signal source*. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of an undesired co-channel VHF data broadcast signal that is either:
 - a) assigned to the same time slot(s) and 26 dB below the desired VHF data broadcast signal power or lower; or
 - b) assigned different time slot(s) and whose power is up to 15 dBm at the receiver input.
- 3.6.8.2.2.5.2 *VOR as the undesired signal*. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of an undesired co-channel VOR signal that is 26 dB below the desired VHF data broadcast signal power.

3.6.8.2.2.6 Adjacent channel rejection

- 3.6.8.2.2.6.1 First adjacent 25 kHz channels (± 25 kHz). The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of a transmitted undesired signal offset by 25 kHz on either side of the desired channel that is either:
 - a) 18 dB above the desired signal power when the undesired signal is another VHF data broadcast signal assigned to the same time slot(s); or
 - b) equal in power when the undesired signal is VOR.

- 3.6.8.2.2.6.2 Second adjacent 25 kHz channels (± 50 kHz). The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of a transmitted undesired signal offset by 50 kHz on either side of the desired channel that is either:
 - a) 43 dB above the desired signal power when the undesired signal is another VHF data broadcast source assigned to the same time slot(s); or
 - b) 34 dB above the desired signal power when the undesired signal is VOR.
- 3.6.8.2.2.6.3 Third and beyond adjacent 25 kHz channels (± 75 kHz or more). The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of a transmitted undesired signal offset by 75 kHz or more on either side of the desired channel that is either:
 - a) 46 dB above the desired signal power when the undesired signal is another VHF data broadcast signal assigned to the same time slot(s); or
 - b) 46 dB above the desired signal power when the undesired signal is VOR.
- 3.6.8.2.2.7 Rejection of off-channel signals from sources inside the 108.000 117.975 MHz band. With no on-channel VHF data broadcast signal present, the VHF data broadcast receiver shall not output data from an undesired VHF data broadcast signal on any other assignable channel.
- 3.6.8.2.2.8 Rejection of signals from sources outside the 108.000 117.975 MHz band
- 3.6.8.2.2.8.1 *VHF data broadcast interference immunity*. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of one or more signals having the frequency and total interference levels specified in Table B-79.
- 3.6.8.2.2.8.2 *Desensitization*. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of VHF FM broadcast signals with signal levels shown in Tables B-80 and B-81.
- 3.6.8.2.2.8.3 VHF data broadcast FM intermodulation immunity. The VHF data broadcast receiver shall meet the requirements specified in 3.6.8.2.2.3 in the presence of interference from two-signal, third-order intermodulation products of two VHF FM broadcast signals having levels in accordance with the following:

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

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

$$2N_1 + N_2 + 3\left(24 - 20\log\frac{\Delta f}{0.4}\right) \le 0$$

for VHF FM sound broadcasting signals below 107.7 MHz

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

 N_1 and N_2 are the levels (dBm) of the two VHF FM sound broadcasting signals at the VHF data broadcast receiver input. Neither level shall exceed the desensitization criteria set forth in 3.6.8.2.2.8.2.

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

Note.— The FM intermodulation immunity requirements are not applied to a VHF data broadcast channel operating below 108.1 MHz, hence frequencies below 108.1 MHz are not intended for general assignments. Additional information is provided in Attachment D, 7.2.1.2.

3.6.8.3 AIRCRAFT FUNCTIONAL REQUIREMENTS

Note – Unless otherwise specified, the following requirements apply to all GBAS Airborne Equipment Classifications as described in Attachement D section 7.1.4.3

3.6.8.3.1 *Conditions for use of data*

- 3.6.8.3.1.1 The receiver shall use data from a GBAS message only if the CRC of that message has been verified.
- 3.6.8.3.1.2 The receiver shall use message data only if the message block identifier is set to the bit pattern "1010 1010".
- 3.6.8.3.1.2.1 *GBAS message processing capability.* The GBAS receiver shall at a minimum process GBAS message types in accordance with Table B-82.

Table B-82. Airborne equipment message type processing

Airborne equipment designed performance GBAS Airborne	Minimum message types processed
Equipment Classification (GAEC)	
APV-I GAEC A	MT 1 or 101, MT 2 (including ADB 1 and 2 if provided)
APV-II-GAEC B	MT 1, MT 2 (including ADB 1 and 2 if provided), MT 4
Category I GAEC C	MT 1, MT 2 (including ADB 1 if provided), MT 4
GAEC D	MT 1, MT 2 (including ADB 1, 2, 3 and 4), MT 4, MT 11

3.6.8.3.1.2.2 *Airborne processing for forward compatibility*

- Note.— Provisions have been made to enable future expansion of the GBAS Standards to support new capabilities. New message types may be defined, new additional data blocks for message Type 2 may be defined and new data blocks defining reference paths for inclusion within message Type 4 may be defined. To facilitate these future expansions, all equipment should be designed to properly ignore all data types that are not recognized.
- 3.6.8.3.1.2.2.1 *Processing of unknown message types.* The existence of messages unknown to the airborne receiver shall not prevent correct processing of the required messages.
- 3.6.8.3.1.2.2.2 *Processing of unknown Type 2 extended data blocks*. The existence of message Type 2 additional data blocks that are not recognized by the airborne receiver shall not prevent correct processing of the required messages.
- 3.6.8.3.1.2.2.3 *Processing of unknown Type 4 data blocks*. The existence of message Type 4 data blocks that are not recognized by the airborne receiver shall not prevent correct processing of the required messages.

Note.— While the current SARPs include only one definition of a data block for inclusion within a Type 4 message, future GBAS Standards may include other reference path definitions.

3.6.8.3.1.3 The receiver shall use only ranging source measurement blocks with matching modified Z-counts.

Table B-79. Maximum levels of undesired signals

Frequency	Maximum level of undesired signals at the receiver input (dBm)
50 kHz up to 88 MHz	-13
88 MHz – 107.900 MHz	(see 3.6.8.2.2.8.2)
108.000 MHz – 117.975 MHz	Excluded
118.000 MHz	-44
118.025 MHz	–41
118.050 MHz up to 1 660.5 MHz	-13

Notes.-

Table B-80. Desensitization frequency and power requirements that apply for VDB frequencies from 108.025 to 111.975 MHz

Frequency	Maximum level of undesired signals at the receiver input (dBm)	
$88 \text{ MHz} \le f \le 102 \text{ MHz}$	15	
104 MHz	10	
106 MHz	5	
107.9 MHz	-10	

Notes.—

- 3.6.8.3.1.4 If D_{max} is broadcast by the ground subsystem, the receiver shall only apply pseudorange corrections when the distance to the GBAS reference point is less than D_{max} .
- 3.6.8.3.1.5 The receiver shall only apply pseudo-range corrections from the most recently received set of corrections for a given measurement type. If the number of measurement fields in the most

^{1.} The relationship is linear between single adjacent points designated by the above frequencies.

^{2.} These interference immunity requirements may not be adequate to ensure compatibility between VHF data broadcast receivers and VHF communication systems, particularly for aircraft that use the vertically polarized component of the VHF data broadcast. Without coordination between COM and NAV frequencies assignments or respect of a guard band at the top end of the 112 – 117.975 MHz band, the maximum levels quoted at the lowest COM VHF channels (118.000, 118.00833, 118.01666, 118.025, 118.03333, 118.04166, 118.05) may be exceeded at the input of the VDB receivers. In that case, some means to attenuate the COM signals at the input of the VDB receivers (e.g. antenna separation) will have to be implemented. The final compatibility will have to be assured when equipment is installed on the aircraft.

^{1.} The relationship is linear between single adjacent points designated by the above frequencies.

^{2.} This desensitization requirement is not applied for FM carriers above 107.7 MHz and VDB channels at 108.025 or 108.050 MHz. See Attachment D, 7.2.1.2.2.

recently received message types (as required in Appendix B, Section 3.6.7.2.1.1.1 for the Active Service Type) Type 1 or Type 101 message indicates that there are no measurement blocks, then the receiver shall not apply GBAS corrections for that measurement type.

3.6.8.3.1.6 Validity of pseudorange corrections

3.6.8.3.1.6.1 When the active service type is A, B or C, tThe receiver shall exclude from the differential navigation solution any ranging sources for which σ_{pr_gnd} in the Type 1 or Type 101 messages is set to the bit pattern "1111 1111".

3.6.8.3.1.6.2 If the active service type is D, the receiver shall exclude from the differential navigation solution any ranging source for which $\sigma_{pr_gnd_D}$ in the Type 11 message or σ_{pr_gnd} in the Type 1 message is set to the bit pattern "1111 1111".

Table B-81. Desensitization frequency and power requirements that apply for VDB frequencies from 112.000 to 117.975 MHz

Frequency	Maximum level of undesired signals at the receiver input (dBm)
$88 \text{ MHz} \le \text{f} \le 104 \text{ MHz}$	15
106 MHz	10
107 MHz	5
107.9 MHz	0

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

3.6.8.3.1.7 The receiver shall only use a ranging source in the differential navigation solution if the time of applicability indicated by the modified Z-count in the Type 1, Type 11 or Type 101 message containing the ephemeris decorrelation parameter for that ranging source is less than 120 seconds old.

3.6.8.3.1.8 Conditions for use of data to support Category I precision approach and APV services.

3.6.8.3.1.8.1 During the final stages of a Category I or APV an approach, the receiver shall use only measurement blocks from Type 1 or Type 101 messages that were received within the last 3.5 seconds.

Note: Guidance material concerning time to alert is given in Attachement D section 7.5.12.3.

3.6.8.3.1.8.2 *GCID Indications*.

3.6.8.3.1.8.2.1 When the Active Service Type is A, B or C, tThe receiver shall use message data from a GBAS ground subsystem for Category I precision approach or APV guidance only if the GCID indicates 1, 2, 3 or 4 prior to initiating the final stages of an approach.

3.6.8.3.1.8.2.2 When the Active Service Type is D, the receiver shall use message data from a GBAS ground subsystem for guidance only if the GCID indicates 2, 3 or 4 prior to initiating the final stages of an approach.

- 3.6.8.3.1.8.3 The receiver shall ignore any changes in GCID during the final stages of an approach.
- 3.6.8.3.1.8.4 The receiver shall not provide approach vertical guidance based on a particular FAS data block transmitted in a Type 4 message if the FASVAL received prior to initiating the final stages of the approach is set to "1111 1111".
- 3.6.8.3.1.8.5 The receiver shall not provide approach guidance based on a particular FAS data block transmitted in a Type 4 message if the FASLAL received prior to initiating the final stages of the approach is set to "1111 1111".
- 3.6.8.3.1.8.6 Changes in the values of FASLAL and FASVAL data transmitted in a Type 4 message during the final stages of an approach shall be ignored by the receiver.
- 3.6.8.3.1.8.7 The receiver shall use FAS data only if the FAS CRC for that data has been verified.
- 3.6.8.3.1.8.8 The receiver shall only use messages for which the GBAS ID (in the message block header) matches the GBAS ID in the header of the Type 4 message which contains the selected FAS data or the Type 2 message which contains the selected RSDS.

3.6.8.3.1.8.9 *Use of FAS data*

- 3.6.8.3.1.8.9.1 The receiver shall use the Type 4 messages to determine the FAS for precision approach.
- 3.6.8.3.1.8.9.2 The receiver shall use the Type 4 messages to determine the FAS for APV associated with a channel number between 20 001 and 39 999.
- 3.6.8.3.1.8.9.3 The receiver shall use the FAS held within the on-board database for APV associated with a channel number between 40 000 and 99 999.
- 3.6.8.3.1.8.10 When the GBAS ground subsystem does not broadcast the Type 4 message and the selected FAS data are available to the receiver from an airborne database, the receiver shall only use messages from the intended GBAS ground subsystem.
- 3.6.8.3.1.9 Conditions for use of data to provide the GBAS positioning service
- 3.6.8.3.1.9.1 The receiver shall only use measurement blocks from Type 1 messages that were received within the last 7.5 seconds.
- 3.6.8.3.1.9.2 The receiver shall only use measurement blocks from Type 101 messages that were received within the last 5 seconds.
- 3.6.8.3.1.9.3 The receiver shall only use message data if a Type 2 message containing additional data block 1 has been received and the RSDS parameter in this block indicates that the GBAS positioning service is provided.
- 3.6.8.3.1.9.4 The receiver shall only use messages for which the GBAS ID (in the message block header) matches the GBAS ID in the header of the Type 2 message which contains the selected RSDS.

3.6.8.3.2 *Integrity*

3.6.8.3.2.1 Bounding of aircraft errors. For each satellite used in the navigation solution, the receiver shall compute a $\sigma_{receiver}$ such that a normal distribution with zero mean and a standard deviation equal to $\sigma_{receiver}$ bounds the receiver contribution to the corrected pseudo-range error as follows:

$$\int_{y}^{\infty} f(x) dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0 \text{ and}$$

$$\int_{-\infty}^{-y} f(x) dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0$$

where

f(x) = probability density function of the residual aircraft pseudo-range error and

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{t^2}{2}} dt.$$

3.6.8.3.2.2 Use of GBAS integrity parameters. The aircraft element shall compute and apply the vertical, lateral and horizontal protection levels described in 3.6.5.5 using the GBAS broadcast σ_{pr_gnd} , σ_{Ni} , h_0 , $\sigma_{ver_iono_gradient}$, and B parameters as well as the σ_{pr_air} -parameter. If a $B_{i,j}$ parameter is set to the bit pattern "1000 0000" indicating that the measurement is not available, the aircraft element shall assume that $B_{i,j}$ has a value of zero. For Category I precision approach and APV any active service type, the aircraft element shall verify that the computed vertical and lateral protection levels are smaller than the corresponding vertical and lateral alert limits defined in 3.6.5.6.

3.6.8.3.3 *Use of satellite ephemeris data*

- 3.6.8.3.3.1 *IOD check.* The receiver shall only use satellites for which the IOD broadcast by GBAS in the Type 1 or Type 101 message matches the core satellite constellation IOD for the clock and ephemeris data used by the receiver.
- 3.6.8.3.3.2 *CRC check*. The receiver shall compute the ephemeris CRC for each core satellite constellation's ranging source used in the position solution. The computed CRC shall be validated against the ephemeris CRC broadcast in the Type 1 or Type 101 messages within one second of receiving a new broadcast CRC. The receiver shall immediately cease using any satellite for which the computed and broadcast CRC values fail to match.
- Note.— During initial acquisition of the VHF data broadcast, the receiver may incorporate a satellite into the position solution before receiving the broadcast ephemeris CRC for that satellite. At all other times, the receiver may not incorporate a satellite into the position solution before verifying that the computed and broadcast CRCs match.

3.6.8.3.3.3 *Ephemeris error position bounds*

- 3.6.8.3.3.3.1 Ephemeris error position bounds for Category I precision GBAS approach services and APV. If the ground subsystem provides additional data block 1 in the Type 2 messages, the aircraft element shall compute the ephemeris error position bounds defined in 3.6.5.8.1 for each core satellite constellation's ranging source used in the position solution within 1s of receiving the necessary broadcast parameters. The aircraft element shall exclude from the position solution satellites for which the computed vertical or lateral ephemeris error position bounds (VEB_j or LEB_j) are larger than the corresponding vertical and lateral alert limits defined in 3.6.5.6.
- Note.— During initial acquisition of the VHF data broadcast, the receiver may incorporate a satellite into the position solution before receiving the necessary broadcast parameters for that satellite to compute the ephemeris error position bounds. At all other times, the receiver may not include a satellite in the position solution if the computed vertical or lateral ephemeris error bounds are larger than the corresponding vertical and lateral alert limits in accordance with 3.6.5.8.1. As the alert limits change with user location relative to the ground subsystem, it is expected that this check is constantly performed.
- 3.6.8.3.3.3.2 Ephemeris error position bound for the GBAS positioning service. The aircraft element shall compute and apply the horizontal ephemeris error position bound (HEB_j) defined in 3.6.5.8.2 for each core satellite constellation's ranging source used in the position solution.

3.6.8.3.4 *Message loss*

- 3.6.8.3.4.1 For Category I precision approach airborne equipment operating with GAST C as the active service type, the receiver shall provide an appropriate alert if no Type 1 or Type 101 message was received during the last 3.5 seconds.
- 3.6.8.3.4.2 For APV airborne equipment operating with GAST A or B as the active service type, the receiver shall provide an appropriate alert if no Type 1 and no Type 101 message was received during the last 3.5 seconds.
- 3.6.8.3.4.3 For the airborne equipment operating with GAST D as the active service type, the receiver shall provide an appropriate alert or modify the active service type if any of the following conditions are met:
 - a) The computed position solution is less than 200 feet above the LTP/FTP for the selected approach and no Type 1 message was received during the last 1.5 seconds.
 - b) The computed position solution is less than 200 feet above the LTP/FTP for the selected approach and no Type 11 message was received during the last 1.5 seconds.
 - c) The computed position solution is 200 feet or more above the LTP/FTP of the selected approach no Type 1 message was received during the last 3.5 seconds.
 - d) The computed position solution is 200 feet or more above the LTP/FTP of the selected approach no Type 11 message was received during the last 3.5 seconds.
- 3.6.8.3.4.34 For the GBAS positioning service using Type 1 messages, the receiver shall provide an appropriate alert if no Type 1 message was received during the last 7.5 seconds.
- 3.6.8.3.4.45 For the GBAS positioning service using Type 101 messages, the receiver shall provide an appropriate alert if no Type 101 message was received during the last 5 seconds.

- 3.6.8.3.5 *Airborne pseudo-range measurements*.
- 3.6.8.3.5.1 Carrier smoothing for airborne equipment. Airborne equipment shall utilize the standard 100 second carrier smoothing of code phase measurements defined in 3.6.5.1. During the first 100 seconds after filter start up, the unit less parameter α shall be either:
 - 1) a constant equal to the sample interval divided by 100 seconds or,
 - 2) a variable quantity defined by the sample interval divided by the time in seconds since filter start-up.
- 3.6.8.3.5.2 Carrier Smoothing of airborne equipment operating with GAST D as the active service type. Airborne equipment operating with GAST D as the active service type, shall utilize 30 second carrier smoothing of code phase measurements as defined in 3.6.5.1.
- Note For equipment that supports GAST D, two set of smoothed pseudoranges are used. The form of the smoothing filter given in section 3.6.5.1 above is the same for both sets, and only the time constant differs (i.e. 100 seconds and 30 seconds). Guidance material concerning carrier smoothing for GAST D is given in Attachment D section 7.19.3.
- 3.6.8.3.6 Service Type Specific Differential Position Solution Requirements. The airborne equipment shall compute all position solutions in a manner that is consistent with the protocols for application of the data (section 3.6.5.5.1.1.2).
- Note The general form for the weighting used in the differential position solution is given in 3.6.5.5.1.1.2. Exactly which information from the ground subsystem is used in the differential position solution depends on the type of service (i.e. positioning service vs. approach service) and the active Approach Service Type. The specific requirements for each Service Type are defined in RTCA DO-253C. Additional information concerning the normal processing of position information is given in Attachment D section 7.19).

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ATTACHMENT D. INFORMATION AND MATERIAL FOR GUIDANCE IN THE APPLICATION OF THE GNSS STANDARDS AND RECOMMENDED PRACTICES

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- 3.2.7 A range of vertical accuracy values is specified for Category I precision approach operations which bounds the different values that may support an equivalent operation to ILS. A number of values have been derived by different groups, using different interpretations of the ILS standards. The lowest value from these derivations was adopted as a conservative value for GNSS; this is the minimum value given for the range. Because this value is conservative, and because GNSS error characteristics are different from ILS, it may be possible to achieve Category I operations using larger values of accuracy within the range. The larger values would result in increased availability for the operation. The maximum value in the range has been proposed as a suitable value, subject to validation.
- 3.2.7.1 Requirements for position domain accuracy to support precision approach operations below Category I are not defined in the SARPs. GBAS service types intended to support operations with lower than Category I minimums are required to meet the SIS accuracy requirements for Category I at a minimum. In addition, specific pseudo range accuracy requirements apply to support the assessment of adequate performance during aircraft certification. The additional requirements on pseudorange accuracy may be combined with geometry screening to ensure the resulting position domain accuracy is adequate for a given airplane design to achieve suitable landing performance. See section D 7.5.12.2.

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- 3.3.10 For GBAS, technical provision has been made to broadcast the alert limit to aircraft. GBAS standards require the alert limit of 10 m. For SBAS, technical provisions have been made to specify the alert limit through an updateable database (see Attachment C, paragraph 6.6).
- 3.3.10.1For GBAS Approach Service Type D (see section 7.1.2.1) additional lower level performance and functional requirements are introduced in order to maintain an equivalent level of safety for landing operations supported by ILS.

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

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. GBAS ground and aircraft elements are classified according to the types of service they support (as defined in section 7.1.2). 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.

- 7.1.1.1 To facilitate interoperability and consistent, predictable performance, the airborne and ground subsystem performance requirements for GBAS are organized into matched sets that are intended to be used in conjunction. These matched sets of performance and functional requirements are referred to collectively as GBAS Service Types (GST). The specific requirements for the Ground and Airborne subsystems are then organized by Ground Facility Classifications (GFC) and GBAS Airborne Equipment Classifications (GAEC) which in turn reference the GBAS Service Types.
- 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 may provide two types of services: the approach services 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 types of services are also distinguished by different performance requirements associated with the particular operations supported (see Table 3.7.2.4-1) including different integrity requirements as discussed in 7.5.1.
- 7.1.2.1 GBAS approach services are further differentiated into multiple types referred to as GBAS Approach Service Types (GAST). A GAST is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used in concert in order to provide approach guidance with quantifiable performance. Four types of approach service, GAST A, GAST B, GAST C and GAST D are currently defined. GAST A, B and C are intended to support typical APV I, APV II and Category I operations respectively. GAST D has been introduced to support landing operations in lower visibility conditions including Category III operations. Note that provisions for a separate service type to support Category II operations, but not Category I nor Category III, have not been made. Since equipment supporting GAST D will function the same when supporting Category II minima as when supporting Category III minima, GAST D provides one means of supporting Category II operations. Category II operations may potentially be supported using GAST C in conjunction with an appropriate airplane level integration. A relevant analogy is the authorization in at least one state of lower than Category I minimums based on guidance from a Facility Performance Category I ILS used in conjunction with a Head-Up Display (HUD). Requirements for the approval of Category II operations using GBAS will be defined by the airworthiness and operational approval authorities within states.
- 7.1.2.1.1 A GBAS ground subsystem may support multiple service types simultaneously. There are two types of ground subsystems, those that support multiple types of approach service and those that do not. Equipment designed in compliance with earlier versions of these SARPs may only support a single type of approach service, GAST C. Equipment designed in compliance with these SARPs may or may not support multiple types of service on one or more runway ends. The type of services supported for each approach are indicated in the Approach Performance Designation field in a FAS data block

within the Type 4 message. The GBAS Continuity/Integrity Designator (GCID) parameter in the Type 2 message indicates whether a GBAS ground subsystem is currently supporting multiple types of approach service. Airborne equipment that can support multiple service types will first check the GCID to determine if the ground segment supports multiple types of service. If it does the equipment will then check the Approach Performance Designator (APD) field of the selected FAS data block within the Type 4 message to determine which types of service are supported by the ground segment for the approach selected (using the channel selection scheme described in section 7.7 below). The airborne equipment will then determine which approach service to select based on APD, the current status of GCID and the airborne equipment type. Operators should understand that the available operations may be restricted by many factors including pilot qualifications or temporary ANSP limitations which are not reflected in the APD value. Therefore APD should not be interpreted as an indication of the availability of any operational use, only as an indication of the services types that are supported for the given runway.

- 7.1.2.1.2 GBAS airborne equipment may attempt to automatically select the highest type of service supported by both the airborne equipment and the ground segment for the selected approach (as indicated in APD). If the desired type of service is not available, the airborne equipment may select the next lower available type of service and annunciate this appropriately. Therefore, during a GBAS operation, there is the Selected Service Type and the Active Service Type. The Selected Service Type (SST) is the service type that the airborne equipment would use if it were available, and can be no higher than the highest type of service offered by the ground segment for the selected approach. The Active Service Type (AST) is the service type that the airborne equipment is actually using at a particular time. The AST may differ from the SST if the SST is unavailable for some reason. The airborne equipment annunciates both the SST and AST so that proper action (e.g. annunciations) may be taken in the context of the airborne integration and operational procedures.
- 7.1.2.1.3 Service providers should give consideration to what service type or types are actually required for each runway given the planned operations and encode the availability of the appropriate service types in the APD field of the associated FAS block.
- 7.1.3 A primary significant distinguishing feature for GBAS ground subsystem configurations is whether additional ephemeris error position bound parameters are broadcast. This feature is required for the positioning service, but is optional for some approach services. If the additional ephemeris error position bound parameters are not broadcast, the ground subsystem is responsible for assuring the integrity of ranging source ephemeris data without reliance on the aircraft calculating and applying the ephemeris bound as discussed in 7.5.9.
- 7.1.4 *GBAS Configurations*. There are multiple configurations possible of GBAS ground subsystems conforming to the GNSS Standards, examples of such as—configurations are:
 - a) configuration that supports Category I precision approach GAST C only;
 - b) a configuration that supports Category I precision approach and APV GAST A, GAST B, GAST C, and also broadcasts the additional ephemeris error position bound parameters;
 - c) a configuration that supports Category I precision approach, APV only GAST C and GAST D, and the GBAS positioning service, while also broadcasting the ephemeris error position bound parameters referred to in b); and
 - d) a configuration that supports APV only GAST A and the GBAS positioning service, and is used within a GRAS.
- 7.1.4.1 A *GBAS Facility Classification (GFC)*. A GBAS ground subsystem is classified according to key configuration options. A GFC is composed of the following elements:

- a) Facility Approach Service Type (FAST)
- b) Ranging Source Types
- c) Facility Coverage
- d) Polarization:

7.1.4.1.1 Facility Approach Service Type (FAST) – The FAST is a collection of letters from A to D indicating the Service Types that are supported by the ground subsystem. For example, FAST C denotes a ground subsystem that meets all the performance and functional requirements necessary to support GAST C. As another example, a FAST ACD designates a ground subsystem that meets the performance and functional requirements necessary to support service types A, C, and D.

Note - The facility classification scheme for GBAS includes an indication of which Service Types the ground subsystem can support. This means the ground subsystem meets all the performance requirements and functional requirements such that a compatible airborne user can apply the information from the ground subsystem and have quantifiable performance at the output of the processing. It does not necessarily mean that the ground subsystem supports all service types on every runway end. Which GBAS Approach Service Types are supported on a given runway end is indicated in the Type 4 Message and is included as part of the Approach Facility Designation defined in section 7.1.4.2 below.

7.1.4.1.2 *Ranging Source Types*: The Ranging Source Type designation indicates what ranging sources are augmented by the ground subsystem. The coding for this parameter is as follows:

G1 - GPS

G2 - SBAS

G3 - GLONASS

G4 -- Reserved for Galileo

G5+ - Reserved for future Ranging Sources

7.1.4.1.3 Facility Coverage: The Facility Coverage designation defines the horizontal coverage of the GBAS positioning service. The facility coverage is coded as 0 for Ground facilities that do not provide the Positioning Service. For other cases, the facility coverage indicates the radius of D_{max} expressed in nautical miles.

Note.— Coverage for specific approaches is defined as part of the Approach Facility Designations defined in section 7.1.4.2.

- 7.1.4.1.4 *Polarization*: The polarization designation indicates the polarization of the VHF Data Broadcast (VDB) signal. E indicates elliptical polarization and H indicates horizontal polarization.
- 7.1.4.1.5 *GBAS Facility Classification Examples*. The facility classification for a specific facility is specified by a concatenated series of codes for the elements described in sections 7.1.4.1 through 7.1.4.1.4 above. The general form of the Facility Classification is

GFC= Facility Approach Service Type/Ranging Source Type /Facility Coverage/Polarization.

For example a facility with the designation of: GFC – C/G1/50/H, denotes a ground subsystem that meets all the performance and functional requirements necessary to support Service Type C on at least one approach, using GPS ranges only, with the GBAS positioning service available to a radius of 50 NM from the GBAS reference position and a VDB that broadcasts in Horizontal polarization only. Similarly: GFC - CD/G1G2G4/0/E denotes a ground subsystem that supports at least one approach with a service type of C and D, provides corrections for GPS, Galileo and SBAS satellites, does not support the positioning service and broadcasts on Elliptical polarization.

7.1.4.2 Approach Facility Designations

A GBAS ground subsystem may support many approaches to different runway ends at the same airport or even runways at adjacent airports. It is even possible that a GBAS will support multiple approaches to the same runway end with different Types of Service (intended, for example, to support different operational minimums). Each approach provided by the ground system may have unique characteristics and in some sense may appear to the user to be a separate facility. Therefore, in addition to the GBAS Facility Classification, a system for classifying or designating the unique characteristics of each individual approach path is needed. For this purpose a system of Approach Facility Designations is defined. Figure XX illustrates the relationship between GBAS Facility Classifications and Approach Facility Designations. The classification is intended to be used for pre-flight planning and published in the AIP.

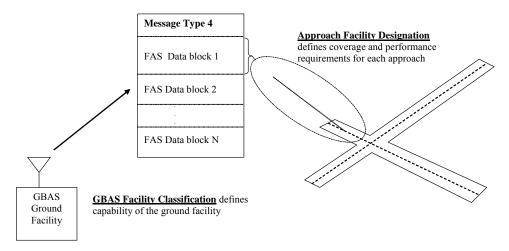


Figure XX Relationship between GBAS Facility Classification and Approach Facility Designation

7.1.4.2.1 *Approach Facility Designation Elements*. Each approach supported by a GBAS can be characterized by an Approach Facility Designation (AFD). The AFD is composed of the following pieces of information:

<u>GBAS Identification</u> - Indicates the GBAS facility identifier that supports the approach (4-character GBAS ID).

<u>Approach Identifier</u> - This is the approach identifier associated with the approach in the Message Type 4 data block. It is 4 characters and must be unique for each approach within radio range of the GBAS facility.

<u>Channel Number</u> – This is the channel number associated with the approach selection. It is a 5 digit channel number between 20000 and 39999.

<u>Approach Coverage</u> - Associated with each published approach, indicates the coverage either by a numerical value in feet corresponding to the minimum decision height (DH) or by the GBAS points as defined below (i.e. GBAS Points A, B, C, T, D, E, or S).

<u>Supported Service Types</u> – Designates the GBAS Service Types (A-D) that are supported for the approach by the ground subsystem. This field can never be given a value greater than the Facility Approach Service Type for the GBAS ground subsystem that supports the approach.

The GBAS points A, B, C, T, D and E define the same locations relative to the runway as the ILS Points in Attachment C Figure C-1 used to define the ILS localizer course and glide path bend amplitude limits. Point S is a new point defining the stop end of the runway. For GBAS, the points are used to indicate the location along the nominal approach and/or along the runway for which GBAS coverage for the supported service type(s) has been verified. When a decision height is used instead to define the approach coverage, the coverage is provided to a height of half the DH as defined in Chapter 3 §3.7.3.5.3.1. The choice of coding using a DH or GBAS Points depends upon the intended operational use of the runway. For example, if the approach identifier corresponds to a Category I instrument approach procedure from

which automatic landings are authorized, the Approach Coverage field is intended to indicate at what point along the runway the coverage has been verified. The point definitions are given below:

- **GBAS Point "A".** A point on a GBAS Final Approach Segment measured along the extended runway centre line in the approach direction a distance of 7.5 km (4 NM) from the threshold.
- **GBAS Point "B".** A point on the GBAS Final Approach Segment measured along the extended runway centre line in the approach direction a distance of 1 050 m (3 500 ft) from the threshold.
- **GBAS Point "C".** A point through which the downward extended straight portion of the nominal GBAS Final Approach Segment passes at a height of 30 m (100 ft) above the horizontal plane containing the threshold.
- **GBAS Point "D".** A point 3.7 m (12 ft) above the runway centre line and 900 m (3 000 ft) from the threshold in the direction of the GBAS Azimuth Reference Point (GARP).
- **GBAS Point** "E". A point 3.7 m (12 ft) above the runway centre line and 600 m (2 000 ft) from the stop end of the runway in the direction of the threshold.
- GBAS Point "S". A point 3.7 m (12 ft) above the runway centre line at the stop end of the runway.
- **GBAS reference datum (Point "T").** A point at a height specified by TCH located above the intersection of the runway centre line and the threshold.

7.1.4.2.2 Approach Facility Designation Examples

The Approach Facility Designation consists of the concatenation of the parameters defined in section 7.1.4.2.1 as: GBAS ID/Approach ID/ranging sources/Approach Coverage/ Required Service Type. An example application of this concept to a particular approach at the US Washington, DC Ronald Reagan International Airport is:

"KDCA/XDCA/21279/150/CD"

where:

KDCA indicates the approach is supported by the GBAS installation at DCA

XDCA indicates the approach ident (echoed to the pilot on approach selection) for this specific approach is "XDCA".

21279 is the 5-digit channel number used to select the approach.

150 indicates the GBAS coverage has been verified to be sufficient to support a DH as low as 150

CD indicates that GBAS Approach Service Types C and D are supported by the ground subsystem for the approach

Another example application of this concept to a particular approach at Boeing Field is:

"KBFI/GBFI/35789/S/C"

where:

KBFI - indicates the approach is supported by the GBAS installation at BFI (with GBAS Station identifier KBFI).

- GBFI indicates the approach ident (echoed to the pilot on approach selection) for this specific approach is "GBFI".
- 35789 is the 5-digit channel number used to select the approach.
- S indicates the GBAS coverage extends along the approach and the length of the runway surface (i.e. 12 ft above the runway to the stop end).
- C indicates that GBAS Approach Service Type C is supported by the ground subsystem for this FAS.

7.1.4.3 GBAS Airborne Equipment Classification (GAEC)

GBAS airborne equipment may or may not support multiple types of approach service that could be offered by a specific ground subsystem. The GBAS Airborne Equipment Classifications (GAEC) specifies which subsets of potentially available services types the airborne equipment can support. The GAEC includes the following elements:

<u>Airborne Approach Service Type (AAST)</u> – The AAST designation is a series of letters in the range from A to D indicating which GASTs are supported by the airborne equipment. For example, AAST C denotes airborne equipment that supports only GAST C. Similarly AAST ABCD indicates the airborne equipment can support GASTs A, B, C & D.

Note - For airborne equipment, designating only the highest GBAS Approach Service Type supported is insufficient as not all airborne equipment is required to support all Service Types. For example, a particular type of airborne equipment may be classified as AAST CD, meaning the airborne equipment supports GAST C and D (but not A or B).

<u>Ranging Source Types:</u> - This field indicates which ranging sources can be used by the airborne equipment. The coding is the same as for the Ground Facility Classification (see section 7.1.4.1.2 above).

- 7.1.4.3.1 *Multiple Service Type Capable equipment*. Ground and airborne equipment designed and developed in accordance with previous versions of these SARPs (Amendment XX) and RTCA DO-253A will only support GAST C. The current version of the standards has been designed such that legacy GBAS airborne equipment will still operate correctly when a ground subsystem supports multiple types of service. Also, airborne equipment which can support multiple types of service will operate correctly when operating with a ground subsystem that supports only GAST C.
- 7.1.4.3.2 *GBAS Airborne Equipment Classification Examples*. GBAS Airborne Equipment Classifications consist of a concatenated series of codes for the parameters defined in Section 7.1.4.3. The general form of the GAEC is:

GAEC = (Airborne Approach Service Type)/(Ranging Source Type)

For example:

GAEC of C/G1 - denotes airborne equipment that supports only GAST C and uses only GPS ranges.

Similarly:

GAEC of ABC/G1G4 - denotes airborne equipment that supports all GASTs except GAST D and can use both GPS and Galileo ranging sources.

Finally:

GAEC - CD/G1G2G4

Denotes airborne equipment that supports GASTs C and D and uses GPS, Galileo and SBAS ranging sources.

- 7.1.5 GRAS Configurations. From a user perspective, a GRAS ground subsystem consists of one or more GBAS ground subsystems (as described in 7.1.1 through 7.1.4), each with a unique GBAS identification, providing the positioning service and APV one or more approach service types where required. By using multiple GBAS broadcast stations, and by broadcasting the Type 101 message, GRAS is able to support en-route operations via the GBAS positioning service, while also supporting terminal, departure, and 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/DO-310 GRAS MOPS, will be compatible with GBAS ground subsystems. SARPs-compliant GBAS receivers may not be able to decode the FAS data correctly for APV transmitted from GBAS ground subsystems (i.e. a FAS data block with APD coded as "0"). These receivers will apply the FASLAL and FASVAL as if the Active Service Type is GAST C—conducting a Category I precision approach. ANSP's should be cognizant of this fact and rRelevant operational restrictions may have to be appliedy to ensure the safety of the operation. For GBAS ground subsystems providing GAST D, APD in the FAS data blocks may be coded as values of 1 or 2 (Appendix B 3.6.4.5.1). SARPS compliant GBAS receivers developed in accordance with SARPS prior to Amendment XX may not be able to use FAS data blocks with APD equal to 2 or above.
- 7.1.8 The GBAS VDB transmits with either horizontal or elliptical polarization (GBAS/H or GBAS/E). This allows service providers to tailor the broadcast to their operational requirements and user community.
- 7.1.9 The majority of aircraft will be equipped with a horizontally-polarized VDB receiving antenna, which can be used to receive the VDB from both GBAS/H and GBAS/E equipment. A subset of aircraft will be equipped with a 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.
- 7.1.11 Availability Considerations for GBAS and GRAS. A single GBAS ground subsystem (or GRAS VDB) may provide multiple types of service to multiple users and service for multiple runway ends simultaneously. These different types of service may have different availability and consequently

one type of service may be available when another is not. Furthermore, as some elements of GBAS are optional (e.g. augmentation of multiple constellations or use of SBAS ranging sources), the capabilities of different users will vary. For this reason, it is not practical for the service provider to predict if a given user will find a specific service type to be available at any given time. All that can be known by the service provider is the status of the ground subsystem and satellite constellation. An assessment can be made as to whether the ground subsystem is meeting the allocated requirements for some target service type and further, the availability of service can be predicted based on an assumed level of performance and a nominal user. The definition of the nominal user includes which elements of GNSS are used (core satellite systems, SBAS ranges etc.) and within that, which subset of satellites are used in the position solution. For GBAS supporting GAST D this is further complicated by the fact that certain parameters (e.g. geometry screening thresholds) may be adjusted by the airframe designer to insure adequate landing performance given the characteristics of the specific aircraft type. Air Navigation Service Providers and Air Space designers should be cognizant of the fact that availability of service for GNSS augmentation systems in general is less predictable than conventional navigation aids. Variations in user capabilities will result in times where service may be available to some users and unavailable to others.

7.2 RF characteristics

7.2.1 Frequency coordination

7.2.1.1 Performance factors

- 7.2.1.1.1 The geographical separation between a candidate GBAS station 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.;
 - f) that between GBAS installations RPDS and RSDS numbers are assigned only once on a given frequency within radio range of a particular GBAS ground subsystem. The requirement is found in Appendix B, 3.6.4.3.1;

- g) that between GBAS installations within radio range of a particular GBAS ground subsystem the reference path identifier is assigned to be unique. The requirement is found in Appendix B, 3.6.4.5.1; and
- h) the four-character GBAS ID to differentiate between GBAS ground subsystems. The GBAS ID is normally identical to the location indicator at the nearest airport. The requirement is found in Appendix B, 3.6.3.4.1.
- i) Slot Assignment. The relative assignment of slots to a GBAS ground subsystem can impact performance in instances where messages in multiple slots need to be received by the airborne subsystem prior to processing. This will occur when using linked messages and/or for a GAST D ground subsystem where correction data is contained in both the Type 1 and Type 11 messages. In these cases slot assignments for all MT 1 and 11 should be adjacent to avoid unnecessary latency and complexity of design. Non-adjacent assignments may, depending on the design of the ground subsystem, result in a lack of time for the ground subsystem to process fault detections, render some slot combinations unusable and thus result in lower efficiency of spectrum use.
- 7.2.1.1.2 Nominal link budgets for VDB are shown in Table D-3. The first example in Table D-3 assumes a user receiver height of 3 000 m (10 000 ft) MSL and a transmit antenna designed to suppress ground illumination in order to limit the fading losses to a maximum of 10 dB at coverage edge. In the case of GBAS/E equipment, the 10 dB also includes any effects of signal loss due to interference between the horizontal and vertical components. The second example in Table D-3 provides a link budget for longer range positioning service. It is for a user receiver height sufficient to maintain radio line-of-sight with a multi-path limiting transmitting antenna. No allowance is given for fading as it is assumed that the receiver is at low elevation angles of radiation and generally free from significant null for the distances shown in the table (greater than 50 NM).

7.2.1.2 *FM immunity*

7.2.1.2.1 Once a candidate frequency is identified for which the GBAS and VOR separation criteria are satisfied, compatibility with FM transmissions must be determined. This is to be accomplished using the methodology applied when determining FM compatibility with VOR. If FM broadcast violates this criterion, an alternative candidate frequency has to be considered.

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

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

Table D-3. Nominal VDB link budget

VDB link elements	Vertical component link budget at coverage edge	Horizontal component link budget at coverage edge
For approach service	Vertical component at coverage edge	Horizontal component at coverage edge
Required receiver sensitivity (dBm)	-87	-87
Maximum aircraft implementation loss (dB)	11	15
Power level after aircraft antenna (dBm	n) —76	-72
Operating margin (dB)	3	3
Fade margin (dB)	10	10
Free space path loss (dB) at 43 km (23 NM)	106	106
Nominal effective radiated power (ERI (dBm)	2) 43	47
For longer range and low radiation angle associated with positioning service	Vertical component	Horizontal component
Required receiver sensitivity (dBm)	-87	-87
Maximum aircraft implementation loss (dB)	11	15
Power level after aircraft antenna (dBm	.)	-72
Operating margin (dB)	3	3
Fade margin (dB)	0	0
Nominal ERP (dBm)		
Range (NM) Free space loss (dB)	ERP (dBm) ERP (W)	ERP ERP (dBm) (W)
50 113	39.9 10	43.9 25
100 119	45.9 39	49.9 98
150 122 200 125	49.4 87 51.9 155	53.4 219 55.9 389

Note 1.— In this table ERP is referenced to an isotropic antenna model.

Note 2.— It is possible, with an appropriately sited multipath limiting VDB transmitting antenna with an ERP sufficient to meet the field strength requirements for approach service and considering local topographical limitations, to also satisfy the field strength requirements such that positioning service can be supported at the ranges in the table above.

Note 3.— Actual aircraft implementation loss (including antenna gain, mismatch loss, cable loss, etc.) and actual receiver sensitivity may be balanced to achieve the expected link budget. For example, if the aircraft implementation loss is 19 dB, the receiver sensitivity must exceed the minimum requirement and achieve -91 dBm to satisfy the nominal link budget.

- 7.2.1.2.2 The desensitization is not applied for FM carriers above 107.7 MHz and VDB channels at 108.050 MHz because the off-channel component of such high-level emissions from FM stations above 107.7 MHz will interfere with GBAS VDB operations on 108.025 and 108.050 MHz, hence those assignments will be precluded except for special assignments in geographic areas where the number of FM broadcast stations in operation is small and would unlikely generate interference in the VDB receiver.
- 7.2.1.2.3 The FM intermodulation immunity requirements are not applied to a VDB channel operating below 108.1 MHz, hence assignments below 108.1 MHz will be precluded except for special assignments in geographic areas where the number of FM broadcast stations in operation is small and would unlikely generate intermodulation products in the VDB receiver.

7.2.1.3 Geographic separation methodologies

- 7.2.1.3.1 The methodologies below may be used to determine the required GBAS-to-GBAS and GBAS-to-VOR geographical separation. They rely on preserving the minimum desired-to-undesired signal ratio. [D/U]_{required} is defined as the signal ratio intended to protect the desired signal from co-channel or adjacent channel interference from an undesired transmission. [D/U]_{required} values required for protection of a GBAS receiver from undesired GBAS or VOR signals are defined in Appendix B, 3.6.8.2.2.5 and 3.6.8.2.2.6. [D/U]_{required} values intended for protection of a VOR receiver from GBAS VDB transmissions as shown in Table D-2 are not defined in SARPs and represent the assumed values based on test results.
- 7.2.1.3.2 Geographic separation is constrained by preserving $[D/U]_{required}$ at the edge of the desired signal coverage where the desired signal power is derived from the minimum field strength requirements in Chapter 3. This desired signal level, converted to dBm, is denoted $P_{D,min}$. The allowed signal power of the undesired signal $(P_{U,allowed})$ is:

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

The undesired signal power P_U converted to dBm is:

$$P_{IJ}(dBm) = (Tx_{IJ}(dBm) - L(dB))$$

where

Tx_{II} is the effective radiated power of the undesired transmitter; and

L is the transmission loss of the undesired transmitter, including free-space path loss, atmospheric and ground effects. This loss depends upon the distance between the undesired transmitter and the edge of the desired signal coverage.

To ensure D/U_{required} is satisfied, $P_u \le D_{Uallowed}$. The constraint for assigning a channel is therefore:

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

7.2.1.3.3 The transmission loss can be obtained from standard propagation models published in ITU-R Recommendation P.528-2 or from free-space attenuation until the radio horizon and then a constant 0.5 dB/NM attenuation factor. These two methodologies result in slightly different geographical separation for co-channel and first adjacent channels, and identical separation as soon as the second

adjacent channel is considered. The free-space propagation approximation is applied in this guidance material.

- 7.2.1.4 Example of GBAS/GBAS geographical separation criteria
- 7.2.1.4.1 For GBAS VDB co-channel transmissions assigned to the same time slot, the parameters for horizontal polarization are:

D/U = 26 dB (Appendix B, 3.6.8.2.2.5.1);

 $P_{D,min} = -72 \text{ dBm (equivalent to 215 microvolts per metre, Chapter 3, 3.7.3.5.4.4); and$

 $Tx_U = 47 \text{ dBm (example link budget, Table D-3)};$

so

$$L \ge (47 + 26 - (-72)) = 145 \text{ dB}.$$

- 7.2.1.4.2 The geographic separation for co-channel, co-slot GBAS VDB assignments is obtained by determining the distance at which the transmission loss equals 145 dB for receiver altitude of 3 000 m (10 000 ft) above that of the GBAS VDB transmitter antenna. This distance is 318 km (172 NM) using the free-space attenuation approximation and assuming a negligible transmitter antenna height. The minimum required geographical separation can then be determined by adding this distance to the nominal distance between the edge of coverage and the GBAS transmitter 43 km (23 NM). This results in a co-channel, co-slot reuse distance of 361 km (195 NM).
- 7.2.1.5 Guidelines on GBAS/GBAS geographical separation criteria. Using the methodology described above, typical geographic separation criteria can be defined for GBAS to GBAS and GBAS to VOR. The resulting GBAS/GBAS minimum required geographical separation criteria are summarized in Table D-4.
- Note.— Geographical separation criteria between the GBAS transmitters providing the GBAS positioning service are under development. A conservative value corresponding to the radiohorizon may be used as an interim value for separation between co-frequency, adjacent time slot transmitters to ensure time slots do not overlap.
- 7.2.1.6 *Guidelines on GBAS/VOR geographical separation criteria.* The GBAS/VOR minimum geographical separation criteria are summarized in Table D-5 based upon the same methodology and the nominal VOR coverage volumes in Attachment C.
- Note 1.— When determining the geographical separation between VOR and GBAS, VOR as the desired signal is generally the constraining case due to the greater protected altitude of the VOR coverage region.
- Note 2.— Reduced geographical separation requirements can be obtained using standard propagation models defined in ITU-R Recommendation P.528-2.

Table D-4. Typical GBAS/GBAS frequency assignment criteria

		Minimum required geographical
	Path loss	separation for $Tx_U = 47 \text{ dBm}$
Channel of undesired VDB in the same time slots	(dB)	and $P_{D,min} = -72 \text{ dBm in km (NM)}$

Cochannel	145	361 (195)
1st adjacent channel (±25 kHz)	101	67 (36)
2nd adjacent channel (±50 kHz)	76	44 (24)
3rd adjacent channel (±75 kHz)	73	No restriction
4th adjacent channel (±100 kHz)	73	No restriction

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

Table D-5. Minimum required geographical separation for a VOR coverage (12 000 m (40 000 ft) level)

	Path loss		VOR coverage radius	
Channel of undesired GBAS VDB	(dB)	342 km (185 NM)	300 km (162 NM)	167 km (90 NM)
Co-channel	152	892 km (481 NM)	850 km (458 NM)	717 km (386 NM)
$ f_{Desired} - f_{Undesired} = 25 \text{ kHz}$	126	774 km (418 NM)	732 km (395 NM)	599 km (323 NM)
$ f_{Desired} - f_{Undesired} = 50 \text{ kHz}$	92	351 km (189 NM)	309 km (166 NM)	176 km (94 NM)
$ f_{Desired} - f_{Undesired} = 75 \text{ kHz}$	80	344 km (186 NM)	302 km (163 NM)	169 km (91 NM)
$ f_{Desired} - f_{Undesired} = 100 \text{ kHz}$	61	No restriction	No restriction	No restriction

Note.— Calculations are based on reference frequency of 112 MHz and assume GBAS $Tx_U = 47 \text{ dBm}$ and $VOR P_{D,min} = -79 \text{ dBm}$.

- 7.2.2 The geographical separation criteria for GBAS/ILS and GBAS/VHF communications are under development.
- 7.2.3 Compatibility with ILS. Until compatibility criteria are developed for GBAS VDB and ILS, VDB cannot be assigned to channels below 112.025 MHz. If there is an ILS with a high assigned frequency at the same airport as a VDB with a frequency near 112 MHz, it is necessary to consider ILS and VDB compatibility. Considerations for assignment of VDB channels include the frequency separation between the ILS and the VDB, the distance separation between the ILS coverage area and the VDB, the VDB and ILS field strengths, and the VDB and ILS sensitivity. For GBAS equipment with transmitter power of up to 150 W (GBAS/E, 100 W for horizontal component and 50 W for vertical component) or 100 W (GBAS/H), the 16th channel (and beyond) will be below –106 dBm at a distance of 200 m from the VDB transmitter, including allowing for a +5 dB positive reflection. This –106 dBm figure assumes a –86 dBm localizer signal at the ILS receiver input and a minimum 20 dB signal-to-noise ratio.
- 7.2.4 Compatibility with VHF communications. For GBAS VDB assignments above 116.400 MHz, it is necessary to consider VHF communications and GBAS VDB compatibility. Considerations for assignment of these VDB channels include the frequency separation between the VHF communication and the VDB, the distance separation between the transmitters and coverage areas, the field strengths, the polarization of the VDB signal, and the VDB and VHF sensitivity. Both aircraft and ground VHF communication equipment are to be considered. For GBAS/E equipment with a transmitter maximum power of up to 150 W (100 W for horizontal component and 50 W for vertical component), the 64th channel (and beyond) will be below –120 dBm at a distance of 200 m from the VDB transmitter including allowing for a +5 dB positive reflection. For GBAS/H equipment with a transmitter maximum power of 100 W, the 32nd channel (and beyond) will be below –120 dBm at a distance of 200 m from the VDB transmitter including allowing for a +5 dB positive reflection, and a 10 dB polarization isolation. It

must be noted that due to differences in the VDB and VDL transmitter masks, separate analysis must be performed to ensure VDL does not interfere with the VDB.

7.2.5 For a GBAS ground subsystem that only transmits a horizontally-polarized signal, the requirement to achieve the power associated with the minimum sensitivity is directly satisfied through the field strength requirement. For a GBAS ground subsystem that transmits an elliptically-polarized component, the ideal phase offset between HPOL and VPOL components is 90 degrees. In order to ensure that an appropriate received power is maintained throughout the GBAS coverage volume during normal aircraft manoeuvres, transmitting equipment should be designed to radiate HPOL and VPOL signal components with an RF phase offset of 90 degrees. This phase offset should be consistent over time and environmental conditions. Deviations from the nominal 90 degrees must be accounted for in the system design and link budget, so that any fading due to polarization loss does not jeopardize the minimum receiver sensitivity. System qualification and flight inspection procedures will take into account an allowable variation in phase offset consistent with maintaining the appropriate signal level throughout the GBAS coverage volume. One method of ensuring both horizontal and vertical field strength is to use a single VDB antenna that transmits an elliptically-polarized signal, and flight inspect the effective field strength of the vertical and horizontal signals in the coverage volume.

7.3 Coverage

7.3.1 The GBAS coverage to support approach services is depicted in Figure D-4. When the additional ephemeris error position bound parameters are broadcast, differential corrections may only be used within the Maximum Use Distance (D_{max}) defined in the Type 2 message. Where practical, it is operationally advantageous to provide valid guidance along the visual segment of an approach. In addition, autoland may be used at facilities or runways not intended to support or not currently supporting Category II or III GLS operations. Even in Category I or better visual conditions, use of an approved autoland system with GAST C can aid pilots in achieving stabilized approaches and reliable touchdown performance, for Category II or III training, to exercise the airborne system to ensure suitable performance, and for maintenance checks. Use of this capability may also provide pilot workload relief. Autoland coverage requirements are contained in Chapter 3 §3.7.3.5.3.2. VDB reception on the runway surface is significantly affected by the transmit antenna design and its installed height as well as the geography of the airport. Coverage along all runways at an airport using a single VDB antenna/transmitter location may be difficult. However, where practical, coverage to support autoland operations should be provided at suitable runways supporting any precision approach. The Approach Coverage Field of the Approach Facility Designation allows this information to be contained in the AIP (refer to section 7.1.4.2.1). A useful autoland capability may be achievable for some aircraft even when the requirements of Chapter 3 §3.7.3.5.3.2 are not entirely met. Similarly, some aircraft may not be able to conduct automatic landings with only the minimum coverage provided. For approaches with a FAS data path not aligned with the runway centerline, autoland coverage is not required.

Note.— *Guidance material on these requirements is under development.*

7.3.2 The coverage required to support the GBAS positioning service is dependent upon the specific operations intended. The optimal coverage for this service is intended to be omnidirectional in order to support operations using the GBAS positioning service that are performed outside of the precision approach coverage volume. Each State is responsible for defining a service area for the GBAS positioning service and ensuring that the requirements of Chapter 3, 3.7.2.4 are satisfied. When making this determination, the characteristics of the fault-free GNSS receiver should be considered, including the reversion to ABAS-based integrity in the event of loss of GBAS positioning service.

- 7.3.3 The limit on the use of the GBAS positioning service information is given by the Maximum Use Distance (D_{max}), which defines the range within which the required integrity is assured and differential corrections can be used for either the positioning service or precision approach. D_{max} however does not delineate the coverage area where field strength requirements specified in Chapter 3, 3.7.3.5.4.4 are met nor matches this area. Accordingly, operations based on the GBAS positioning service can be predicated only in the coverage area(s) (where the field strength requirements are satisfied) within the D_{max} range.
- 7.3.4 As the desired coverage area of a GBAS positioning service may be greater than that which can be provided by a single GBAS broadcast station, a network of GBAS broadcast stations can be used to provide the coverage. These stations can broadcast on a single frequency and use different time slots (8 available) in neighbouring stations to avoid interference or they can broadcast on different frequencies. Figure D-4A details how the use of different time slots will allow a single frequency to be used without interference subject to guard time considerations noted under Table B-59. For a network based on different VHF frequencies, guidance material in 7.17 should be considered.

7.4 Data structure

A bit scrambler/descrambler is shown in Figure D-5.

Note.— Additional information on the data structure of the VHF data broadcast is given in RTCA/DO-246B, GNSS Based Precision Approach Local Area Augmentation System (LAAS)—Signal-in-Space Interface Control Document (ICD).

7.5 Integrity

- 7.5.1 Different levels of integrity are specified for precision approach operations and operations based on the GBAS positioning service. The signal-in-space integrity risk for Category I approach services is 2×10^{-7} per approach. GBAS ground subsystems that are also intended to support other operations through the use of the GBAS positioning service have to also meet the signal-in-space integrity risk requirement specified for terminal area operations, which is 1×10^{-7} /hour (Chapter 3, Table 3.7.2.4-1). Therefore additional measures are necessary to support these more stringent requirements for positioning service. The signal-in-space integrity risk is allocated between the ground subsystem integrity risk and the protection level integrity risk. The ground subsystem integrity risk allocation covers failures in the ground subsystem as well as core constellation and SBAS failures such as signal quality failures and ephemeris failures. For GAST A, B, and C the The protection level integrity risk allocation covers rare fault-free position domain performance risks and the case of failures in one of the reference receiver measurements. In both cases the protection level equations ensure that the effects of the satellite geometry used by the an aircraft fault-free receiver are taken into account. This is described in more detail in the following paragraphs. For GAST D, the position domain integrity is delegated to the aircraft and a FAST D ground subsystem provides additional data and ranging source monitoring for aircraft using this service type.
- 7.5.1.1 Additional integrity requirements apply for GAST D, which is intended to support precision approach and automatic landing in low visibility conditions with minima less than Category I. The same requirements for bounding the position solution within a protection level that is compared to an alert limits apply, for all error sources except single ground reference receiver faults and errors induced by ionospheric anomalies. Single ground reference receiver faults are mitigated as described in section 7.5.11. The responsibility for some errors induced by anomalous ionospheric conditions has been allocated to the airborne. Mitigation of errors due to ionospheric anomalies is described in section 7.5.6.1.6. Additional monitoring requirements and design assurance requirements are needed to allow a FAST D GBAS ground

subsystems to provide a service that can provide equivalent safety to Category III ILS operations. Some additional monitoring requirements are allocated to the ground subsystem (see sections D.7.5.6.1 to D.7.5.6.1.7) and some are allocated to the airborne equipment. The additional monitoring performance requirements for the ground subsystem can be found in Appendix B, section 3.6.7.3.3.

- 7.5.1.2 The ground subsystem integrity risk requirement for GAST D (Appendix B, section 3.6.7.1.2.1.1.3) limits the probability of a ground subsystem failure resulting in the transmission of erroneous data during a minimum exposure time of "any one landing." Typically the critical period of exposure to failures for vertical guidance in Category III operations is taken to be the period between the Category I Decision Height (200 ft) and the threshold (50 ft height). This is nominally 15 seconds, depending upon the aircraft approach speed. The critical period of exposure to failures for lateral guidance in Category III operations is taken to be the period between the Category I Decision Height and completion of the rollout, which occurs when the aircraft decelerates to a safe taxi speed (typically less than 30 knots). This is nominally 30 seconds, again depending upon the aircraft approach speed and rate of deceleration. The term "any one landing" is used to emphasize that the time period where faults could occur extends prior to the critical period of exposure. The reason for this is that the fault may develop slowly over time and it could occur earlier in the landing phase and become a hazard during the critical period of exposure.
- 7.5.2 The GBAS ground subsystem defines a corrected pseudo-range error uncertainty for the error relative to the GBAS reference point (σ_{pr_gnd}) and the errors resulting from vertical (σ_{tropo}) and horizontal (σ_{iono}) spatial decorrelation. These uncertainties are modelled by the variances of zero-mean, normal distributions which describe these errors for each ranging source.
- 7.5.3 The individual error uncertainties described above are used by the receiver to compute an error model of the navigation solution. This is done by projecting the pseudo-range error models to the position domain. General methods for determining that the model variance is adequate to guarantee the protection level integrity risk are described in Section 14. The lateral protection level (LPL) provides a bound on the lateral position error with a probability derived from the integrity requirement. Similarly, the vertical protection level (VPL) provides a bound on the vertical position. For Category I precision approach and APV approach services, if the computed LPL exceeds the lateral alert limit (LAL) or the VPL exceeds the vertical alert limit (VAL), integrity is not adequate to support the selected service type support the operation. For the positioning service the alert limits are not defined in the standards, with only the horizontal protection level and ephemeris error position bounds required to be computed and applied. The alert limits will be determined based on the Active Service Type operation being conducted. The aircraft will apply the computed protection level and ephemeris bounds by verifying they are smaller than the alert limits. Two protection levels are defined, one to address the condition when all reference receivers are fault-free (H_0 – Normal Measurement Conditions), and one to address the condition when one of the reference receivers contains failed measurements (H₁ - Faulted Measurement Conditions). Additionally an ephemeris error position bound provides a bound on the position error due to failures in ranging source ephemeris. For Category I precision approach and APV approach services, a lateral error bound (LEB) and a vertical error bound (VEB) are defined. For the positioning service a horizontal ephemeris error bound (HEB) is defined.
- 7.5.3.1 The GBAS signal-in-space integrity risk (Appendix B, section 3.6.7.1.2.1.1) is defined as the probability that the ground subsystem provides information which when processed by a fault-free receiver, using any combination of GBAS data allowed by the protocols for data application (Appendix B section 3.6.5), results in an out-of-tolerance lateral or vertical relative position error without annunciation for a period longer than the maximum time-to-alert. An out-of-tolerance lateral or vertical relative position error is defined as an error that exceeds the GBAS approach services protection level and, if additional data block 1 is broadcast, the ephemeris error position bound. Hence it is the responsibility of the ground subsystem to provide a consistent set of data including the differential corrections, and all parameters that are used by the protocols for data application (e.g., σ_{pr} and the B values as defined in the

Type 1 message), so that the protection levels bound the position error with the required integrity risk. This error bounding process must be valid for any set of satellites that the user might be using. To ensure the computed protection levels actually bound the error with the required probability, it may in some cases be necessary to inflate or otherwise manipulate one or more of the parameters that are used by the protocols for data application. For example, to address the impact of anomalous ionospheric effects one strategy that has been used is to inflate σ_{pr_gnd} and $\sigma_{vert\ iono\ gradient}$ to insure that airborne equipment that complies with the protocols for data application will be adequately protected.

- 7.5.4 Ground system contribution to corrected pseudo-range error (σ_{pr_gnd}). Error sources that contribute to this error include receiver noise, multipath, and errors in the calibration of the antenna phase centre. Receiver noise has a zero-mean, normally distributed error, while the multipath and antenna phase centre calibration can result in a small mean error.
- 7.5.5 Residual tropospheric errors. Tropospheric parameters are broadcast in Type 2 messages to model the effects of the troposphere, when the aircraft is at a different height than the GBAS reference point. This error can be well-characterized by a zero-mean, normal distribution.
- 7.5.6 Residual ionospheric errors. An ionospheric parameter is broadcast in Type 2 messages to model the effects of the ionosphere between the GBAS reference point and the aircraft. This error can be well-characterized by a zero-mean, normal distribution during nominal conditions.
- 7.5.6.1 *Ionospheric Anomalies*. Small scale structures in the ionosphere can result in non-differentially corrected errors in the GBAS position. Such phenomenon are typically associated with solar storm activity and may be characterized by steep gradients in the ionospheric delay over a relatively short distance (e,g, a few 10's of kilometers). The errors that may be induced by these phenomena result when the airborne receiver and ground subsystem are receiving satellite signals that have different propagation delays. Also, since GBAS uses code-carrier smoothing with a relatively long time constant, biases build up in these filters that are a function of the rate of change of ionospheric delay. If the ground subsystem and airborne receivers experience significantly different delays and rates of change of the ionospheric delays, the biases that build up in these filters will not match and be cancelled by the differential processing.
- 7.5.6.1.1 *Ionospheric Anomaly Mitigation*. Ionospheric anomalies can produce position errors which are significant (i.e. 10's of meters) in the context of approach operations. To mitigate these errors, different strategies are used depending on the GBAS Approach Service Type.
- 7.5.6.1.2 Ionospheric Anomaly Mitigation for GAST A, B and C. For GAST A, B or C, the ground subsystem is responsible for mitigating the potential impact of ionospheric anomalies. This may be handled through various monitoring schemes (e.g. far-field monitors or integration with a wide area ground network supporting and SBAS) which detect the presence of ionosphere anomalies and deny service if the resulting user position errors would be unacceptable. One means to deny service is to inflate some combination of the broadcast integrity parameters: $\sigma_{pr \ gnd,}$, $\sigma_{vert \ iono \ gradient,}$ the Ephemeris decorrelation parameter (P), the Ephemeris Missed Detection Parameters $K_{md \ e,GPS,}$ and, $K_{md \ e \ GLONASS,}$ such that any geometry that could be used by an airborne user will not be subjected to intolerably large errors (given the intended operational use). This inflation scheme could also be used without the complexity of monitoring the ionosphere during operations by assuming ionosphere anomalies are present. In this case, a model of the possible ionosphere conditions that could occur is used to determine the proper values of the broadcast integrity parameters. Since the extremes of ionosphere conditions vary significantly through the world, the model is location dependent. Such an inflation scheme results in a reduction in availability because it inflates the values even when anomalies are not present.

- 7.5.6.1.3 Ionospheric Anomaly Mitigation for GAST D. Requirements for monitoring and geometry screening in the airborne equipment have been introduced for GAST D to mitigate the potential impact of ionospheric anomalies. The airborne monitoring consists of monitoring the code-carrier divergence continuously in order to detect high gradients in the ionosphere. In addition, the airborne equipment will screen geometries to ensure that an unacceptably large amplification of residual pseudorange errors (i.e. errors that may exist after airborne monitoring has been applied) will not occur. Another factor which is useful for the mitigation of errors induced by ionospheric anomalies is the use of the 30 second carrier smoothed pseudoranges in a position solution. (The shorter time constant smoothing is inherently less susceptible to filter bias mismatch errors). Finally, GAST D includes parameters: Kmd e D,GLONASS, Kmd e D,GPS, P_D and Sigma vert iono gradient D which are intended to be used in place of the parameters $K_{md\ e\ GLONASS}$, $K_{md\ e\ GPS}$, P and $\sigma_{vert\ iono\ gradient}$, respectively when the active service type is GAST D. This is done so that if the ground subsystem employs inflation of the parameters $K_{md\ e\ ,GLONASS}$, $K_{md\ e\ ,GPS\ ,}$, P and $\sigma_{vert\ iono\ gradient\ }$ to mitigate the effects of ionospheric anomalies for GAST A, B or C, the GAST D user can be provided with non-inflated parameters for use in GAST D where airborne monitoring is employed to address the iono anomaly errors. This enables GAST D service to have improved availability.
- 7.5.6.1.4 Bounding of ionospheric anomaly errors. As stated above ionospheric anomalies may be addressed by inflating one or more of the parameters σ_{pr gnd.}, σ_{vert iono gradient.} the Ephemeris decorrelation parameter (P), the Ephemeris Missed Detection Parameters Kmd_e,GPS, and, Kmd_e_,GLONASS. The ground subsystem is responsible for providing values in these parameters such that the error is appropriately bounded by the VPL and HPL computations at the output of a fault free receiver. In GAST D, responsibility for mitigation of errors due to anomalous ionospheric conditions has been divided between the airborne system and the ground subsystem. Although GAST D still requires the protection levels to bound the errors (as described in section 7.5.3.1), they are not required to bound the errors that result from an anomalous ionospheric event as is the case for GAST C. Hence, the protection levels as computed with P_D, Kmd_e_d,GLONASS, Kmd_e_GPS, and Sigma_vert_iono_gradient_D must bound the error for all error sources as discussed in Section 3.6.7.1.2.1.1.1 except for the errors due to anomalous ionospheric conditions. The protections level computations must bound the nominal ionospheric errors.
- Dual Solution Ionospheric Gradient Monitoring Algorithm (DSIGMA). Another 7.5.6.1.5 component of the airborne mitigation of errors induced by ionospheric anomalies is by the use of dual position solutions computed with two different carrier smoothing time constants simultaneously. (See section 7.19.3). This dual solution computation has two purposes. Firstly, taking the difference of the two solutions as a detection statistic allows the projection of filter build up errors, due to large differences in ionospheric gradients between the ground measurements and airborne measurements, to be directly observable. Hence a threshold can be applied to this detection statistic in order to detect a large portion of the ionospheric anomalies. The second application of the dual solutions is to compute a bound for the 30 second smoothed position (excluding the impact of ionospheric anomalies). The data provided by the ground segment allows a protection level bound to be computed for the 100 second solution. By adding the direct observation of the magnitude of the difference between the 30 second smoothed position and the 100 second smoothed position, to the protection level computation, a protection level, which is guaranteed to bound the 30 second position solution with the required 1×10^{-7} /approach is obtained. This allows airborne equipment, with an active service type of D to provide equivalent bounding performance, as required for approaches to Category I minimums even though the 30 second solution is used to develop the guidance.
- 7.5.6.1.6 Requirements for FAST D ground subsystems to support mitigation of errors caused by ionospheric anomalies. Although much of the responsibility for mitigation of ionospheric errors is allocated to the airborne segment, there are two requirements for FAST D ground subsystems that are necessary to support mitigation of such effects. Appendix B section 3.6.7.1.4 defines a maximum

allowable distance between a FAST D GBAS ground subsystem reference point and the threshold of any approach for which that ground subsystem will support GAST D. This maximum distance is defined so that the worst case error that can exist on a differentially corrected pseudorange after the airborne ionospheric monitoring has been applied can be determined. The second requirement, Appendix B section 3.6.7.3.4 specifies that the ground subsystem monitor for the presence of ionospheric spatial delay gradients directly. The requirement is written such that that product of the largest ionospheric gradient in the direction of an approach supporting GAST D that is undetected with a probability of 1×10^{-9} times the distance between the GBAS ground subsystem reference point and the threshold projected onto the direction of the runway for that approach be less than 1.5 meters. The undetected probability includes both the prior probability of the ionospheric gradient and the monitor missed detection probability. The requirement is formulated in this manner so that ground subsystem siting can be traded against the magnitude of a gradient that must be detected by the ground subsystem. This requirement addresses the special case when the ionospheric front moves slowly (e.g. less than 40 m/s) relative to the ionosphere pierce point (point where the GPS Signals intercept with the ionosphere at an altitude of 350 km above the earth ellipsoid) and the front comes from the ground subsystem side and the front edge resides between the ground subsystem and the airborne user pierce points.

7.5.6.1.7 Ionospheric Anomaly Threat Models Used for GAST D Validation.

As discussed above, the mitigation of errors that could be induced by ionospheric anomalies is accomplished through a combination of airborne and ground system monitoring. The effectiveness of the required monitoring has been demonstrated through simulation and analysis and the maximum errors at the output of the monitoring have been shown to be consistent with airworthiness certification criteria for a range of anomalies described below. This range of anomalies is described in terms of a "standard threat space" consisting of an ionospheric anomaly model which defines physical attributes of the ionospheric anomaly. This model is conservative enough to cover all GBAS ionospheric gradient threat models that have been publicly proposed to date. The threat models define an ionospheric environment for which the standardized monitoring is known to produce acceptable performance on a per-pseudorange basis. Each service provider should evaluate whether the standard threat space model described below is appropriate for the ionospheric characteristics in the region where GBAS is intended to support GAST D service. If a service provider determines that the ionospheric behaviour is not adequately characterized by this threat model, (e.g., for a region of uniquely severe ionospheric behaviour), that service provider must take some action to ensure the users will not be subjected to ionospheric anomalies with characteristics outside the range of the standard threat space. The service provider may elect to:

- 1. alter the characteristics of its ground subsystem, and/or
- 2. introduce additional monitoring (internal or external to the GBAS), and/or
- 3. Introduce other operational mitigations that limit users' exposure to the extreme ionospheric conditions.

Potential ground subsystem changes which could achieve this risk reduction include tighter siting constraints (see section 7.5.6.1.6, and Appendix B section 3.6.7.1.4.1) and improved ground-system monitoring performance (Appendix B section 3.6.7.3.4). Another mitigation strategy is monitoring of space weather (external to the GBAS system) in conjunction with operational limitations on the use of the system during predicted periods of severely anomalous ionospheric activity. Combinations of these strategies may be used to insure that the GAST D user is not subjected to ionospheric anomalies outside the standard threat space.

7.5.6.1.7.1 Ionosphere Anomaly Model: Moving Wedge: This model is a conservative rendition of the model developed by the FAA for CONUS. It models a severe ionospheric spatial gradient as a moving

wedge of constant, linear change in slant ionosphere delay, as shown in Figure A-1. The key parameters of this model are the gradient slope (g) in mm/km, the width (w) of the wedge in km, the amplitude of the change in delay (D) in m, and the speed (v) at which the wedge moves relative to a fixed point on the ground. These values are assumed to remain (approximately) constant over the period in which this wedge affects the satellites tracked by a single aircraft completing a GAST D approach. While the width of the wedge is small, the "length" of the wedge in the East-North coordinate frame (i.e., how far the "ionospheric front" containing the wedge extends) is not constrained.

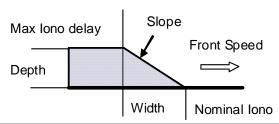


Figure A-1: Moving Wedge Ionospheric Anomaly Model

In this model, the upper bound on g is dependent on wedge speed as specified in Table XX-1. This value is not dependent on satellite elevation angle. Because g is expressed in terms of slant delay, no "obliquity" correction from zenith delay is needed. The width w can vary from 25 to 200 km. The maximum value of D is 50 m. Note that, to make the model consistent, D must equal the product of slope g and width w. In cases where slope and width each fall within their allowed ranges, but their product D exceeds the 50-meter bound, that combination of slope and width is not a valid point within the threat model. For example, both g = 400 mm/km and w = 200 km are individually allowed, but their product equals 80 meters. Since this violates the constraint on D, a wedge with g = 400 mm/km and w = 200 km is not included in this threat model.

Note: In the GAST D validation, it was assumed that a single wedge represented by this model produced the worst case errors on any two ranging sources at the same time. However, the numbers of wedges and impacted ranging sources depend on the ionospheric characteristics in the region where GBAS is intended to support GAST D service.

Table XX-1		
Propagation Speed	Upper Bound on	
(v)	Gradient Slope (g)	
v < 750 m/s	500 mm/km	
750 < v < 1500 m/s	100 mm/km	

Table XX-1

- 7.5.7 Aircraft receiver contribution to corrected pseudo-range error. The receiver contribution is bounded as described in Section 14. The maximum contribution, used for analysis by the GBAS provider, can be taken from the accuracy requirement, where it is assumed that $\sigma_{receiver}$ equals RMS_{pr_air} for GBAS Airborne Accuracy Designator A equipment.
- 7.5.8 Airframe multipath error. The error contribution from airframe multipath is defined in Appendix B, 3.6.5.5.1. Multipath errors resulting from reflections from other objects are not included. If experience indicates that these errors are not negligible, they must be accounted for operationally or through inflation of the parameters broadcast by the ground (e.g. σ_{pr_gnd}).
- 7.5.9 *Ephemeris error uncertainty*. Pseudo-range errors resulting from ephemeris errors (defined as a discrepancy between the true satellite position and the satellite position determined from the broadcast data) are spatially decorrelated and will therefore be different for receivers in different locations.

When users are relatively close to the GBAS reference point, the residual differential error due to ephemeris errors will be small and both the corrections and uncertainty parameters σ_{pr_gnd} sent by the ground subsystem will be valid to correct the raw measurements and compute the protection levels. For users further away from the GBAS reference point, protection against ephemeris failures can be ensured in two different ways:

- a) the ground subsystem does not transmit the additional ephemeris error position bound parameters. In this case, the ground subsystem is responsible for assuring integrity in case of satellite ephemeris failures without reliance on the aircraft calculating and applying the ephemeris bound. This may impose a restriction on the distance between the GBAS reference point and the decision altitude/height depending upon the ground subsystem means of detecting ranging source ephemeris failures. One means of detection is to use satellite integrity information broadcast by SBAS; andor
- b) the ground subsystem transmits the additional ephemeris error position bound parameters which enable the airborne receiver to compute an ephemeris error bound. These parameters are: coefficients used in the ephemeris error position bound equations (K_{md_e_0}), where the subscript () means either "GPS", "GLONASS", "POS, GPS" or "POS, GLONASS"), the maximum use distance for the differential corrections (D_{max}), and the ephemeris decorrelation parameters (P). The ephemeris decorrelation parameter (P) in the Type 1 or Type 101 message characterizes the residual error as a function of distance between the GBAS reference point and the aircraft. The value of P is expressed in m/m. The values of P are determined by the ground subsystem for each satellite. One of the main factors influencing the values of P is the ground subsystem monitor design. The quality of the ground monitor will be characterized by the smallest ephemeris error (or minimum detectable error (MDE)) that it they can detect. The relationship between the P parameter and the MDE smallest detectable error ε_{ephdet} for a particular satellite, i, can be approximated by $P_i = \varepsilon_{\text{ephdet}} \frac{\text{MDE}_i}{R_i}$ where R_i is the smallest of the predicted ranges to the satellite from the ground subsystem reference receiver antenna(s) for the period of validity of P_i. Being dependent on satellite geometrySince R_i varies with time, the P parameters values are slowly varying are time dependent as well. However, it is not a requirement for the ground subsystem to dynamically vary P. Static P parameters could can be sent if they properly ensure integrity. In this latter case, the availability would be slightly degraded. Generally, as MDE ε_{ephdet} becomes smaller, overall GBAS availability improves.
- 7.5.10 *Ephemeris error/failure monitoring*. There are several types of monitoring approaches for detecting ephemeris errors/failures. They include:
 - a) Long baseline. This requires the ground subsystem to use receivers separated by large distances to detect ephemeris errors that are not observable by a single receiver. Longer baselines translate to better performance in MDEsmallest detectable error;
 - b) *SBAS*. Since SBAS augmentation provides monitoring of satellite performance, including ephemeris data, integrity information broadcast by SBAS can be used as an indication of ephemeris validity. SBAS uses ground subsystem receivers installed over very long baselines, therefore this provides optimum performance for ephemeris monitoring and thus makes small errors detectable. achieves small MDEs; and
 - c) Ephemeris data monitoring. This approach involves comparing the broadcast ephemeris over consecutive satellite orbits. There is an assumption This monitoring assumes that the only threat of failure is due to a failure in the ephemeris upload from the constellation ground control network so that the ephemeris is inconsistent with previously broadcast ephemeris. and
 - d) Delta-V (change in velocity) monitoring. This monitoring covers the cases of uncommanded satellite manoeuvres and manoeuvres out of view with unchanged ephemeris. Failures due to uncommanded satellite manoeuvres must be sufficiently improbable to ensure that this approach provides the required integrity.
- 7.5.10.1 The monitor design (for example, its achieved MDE smallest detectable error) is to be based upon the integrity risk requirements and the failure model the monitor is intended to protect against.

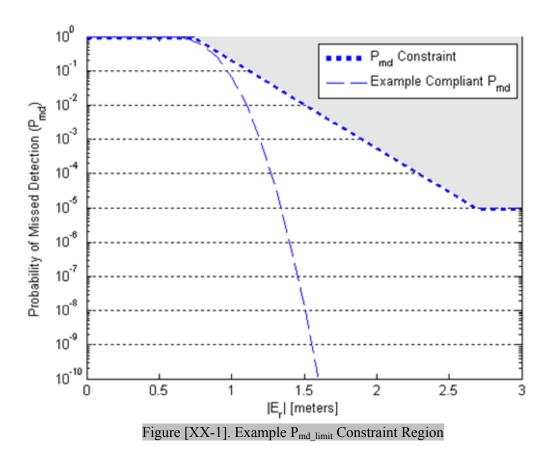
A bound on the GPS ephemeris failure rate can be determined from the reliability requirements defined in Chapter 3, 3.7.3.1.3, since such an ephemeris error would constitute a major service failure.

- 7.5.10.2 The GLONASS control segment monitors the ephemeris and time parameters, and in case of any abnormal situation it starts to input the new and correct navigation message. The ephemeris and time parameter failures do not exceed 70 m of range errors. The failure rate of GLONASS satellite including the ephemeris and time parameter failures does not exceed 4×10^{-5} per satellite per hour.
- 7.5.11 *Ground Reference Receiver Faults.* A typical GBAS ground subsystem processes measurements from 2 to 4 reference receivers installed in the immediate vicinity of the reference point. The For GAST A, B, C and D the aircraft receiver is protected against a large error or fault condition in a single reference receiver by computing and applying a protection level based on the B parameters from the Type 1 or Type 101 message to compare data from the various reference receivers and comparing that protection level to the alert limit. Ground subsystem compliance with the GAST A, B, C and D integrity risk (Appendix B, section 3.6.7.1.2.2.1) is demonstrated taking into account the protocols required of the airborne subsystem (Appendix B, section 3.6.5.5.1.2) and explicit monitoring required in the airborne subsystem. Alternative system architectures with sufficiently high redundancy in reference receiver measurements may employ processing algorithms capable of identifying a large error or fault in one of the receivers. This may apply for a GRAS network with receivers distributed over a wide area and with sufficient density of ionospheric pierce points to separate receiver errors from ionospheric effects. The integrity can then be achieved using only the protection levels for normal measurement conditions (VPL_{H0} and LPL_{H0}), with appropriate values for K_{ffmd} and σ_{pr_gnd} . This can be achieved using the Type 101 message with the B parameters excluded.
- 7.5.11.1 GAST D Ground Reference Receiver Faults. For GAST D, there is an additional standardized monitor implemented in the airborne receiver used to maintain the single reference receiver faulted measurement condition integrity regardless of the satellite geometry used in the aircraft. The aircraft receiver computes a position error estimate based on the B parameters and compares that error estimate directly to a threshold set as low as possible consistent with acceptable continuity risk. Although the monitor is mechanized in the airborne subsystem, the ground subsystem must meet specific requirements for the monitor to provide the required protection. The integrity performance depends on the assumed a priori failure rate (Appendix B, section 3.6.7.1.2.2.1.1) and the probability of missed detection of the monitor. The a priori rate of a single reference receiver providing faulted measurements is required to be less than 1x10⁻⁵ per 150 seconds. The rate per individual receiver is dependent upon the number of reference receivers in the ground subsystem. For example, with four reference receivers the rate per receiver would be required to be less than 2.5x10⁻⁶ per 150 seconds. This a priori rate is achieved through a combination of receiver design requirements and proper reference receiver siting and operational constraints. Because conditions during system operation vary, ground subsystems may monitor receiver outputs to verify continued compliance with the requirement. The integrity performance also depends on the probability of missed detection (Pmd) performance of the monitor implemented in the airborne equipment. The Pmd performance of this monitor in turn depends on the characteristics of the errors that confound the observability of a reference failure. This is also true for the existing protection level integrity risk equations associated with faulted measurement conditions. The ground subsystem is required to broadcast integrity parameters that bound the errors such that a normal distribution can sufficiently characterize the errors and the Pmd can be estimated (Appendix B, section 3.6.7.1.2.2.1.1 and 3.6.7.2.2.4.1).
- 7.5.11.2 GAST D Ground Reference Receiver Fault Magnitude Bounding. Because the airborne subsystem implements the monitor as defined in the MOPS, it is possible to compute the size of the largest error that can result from the failure of a single reference receiver with a probability of greater than 1×10^{-9} . The calculated maximum size of the error will depend on the assumed a priori failure rate (Appendix B, section 3.6.7.1.2.2.1.1) and the probability of missed detection of the monitor. The monitor

Pmd is dependent on the monitor threshold which is computed by the airborne equipment as a function of the geometry and the error distribution associated with the H_1 hypothesis.

7.5.12 Range Domain Monitoring Requirements for GAST D. To support equivalent safety of Category II/III operations, requirements beyond the basic "signal in space" requirements defined for GAST A, B and C are necessary. These requirements include performance requirements for monitors implemented to detect pseudorange errors. Two requirements apply to the post monitoring error in the corrected pseudorange due to specific ranging source failures (Appendix B Section 3.6.7.3.3.2 and 3.6.7.3.3.3) In both cases, the requirement applies to the probability of missed detection as a function of the size of an error due to the failure in the 30 second smoothed pseudorange after the correction is applied.

The first requirement constrains the Pmd performance of the specified ranging source failures without regard for the a priori probability of the ranging source failure. The bound for a ground subsystem's monitor performance defined in Appendix B Section 3.6.7.3.3.2 is illustrated in Figure [XX-1]. GAEC-D equipment will use the 30 second differential corrections to form the position solution used for deviation guidance. The limits of the constraint region define the minimum Pmd that the ground subsystem must ensure for any single ranging source failure condition.



Note -The example compliant Pmd in Figure [XX-1] is based on a hypothetical monitor with a threshold set to 0.8 meters and monitor noise of 0.123 meters. The curve is for illustration purposes only and does not represent the performance of any specific monitor design.

The second requirement constrains the conditional probability of the Pmd performance of the specified ranging source given the a-priori failure probability for the specific ranging source failure. The

conditional probability bound, Pmd×Papriori, for a ground subsystem's monitor performance defined in Appendix B Section 3.6.7.3.3.3 is illustrated in Figure [XX-2]. - The prior probability of each ranging source failure (Papriori), used to evaluate compliance, should be the same value that is used in the analysis to show compliance with the bounding requirements for FAST C and D (see Section 7.5.3.1).

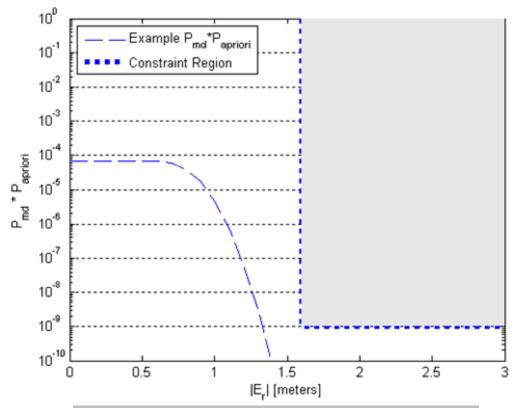


Figure [XX-2]. Example P_{md limit} Constraint with A Priori Probability

Note: $P_{apriori}$ is assumed to be $7x10^{-5}$ for this example illustration of Figure [XX-2].

7.5.12.1 Verification of Ground Subsystem Compliance with Range Domain Monitoring Requirements

Verifying that a ground system design complies with the monitor requirements provided in Appendix B section 3.6.7.3.3.2 and Appendix B section 3.6.7.1.3 is achieved by a combination of testing and analysis. The requirements take the form of a constraint on the probability of missed detection as a function of the size of an error in the corrected pseudorange. The general process that may be used to verify that a specific monitor, included as part of a ground subsystem design, meets the specified performance is as follows:

- Identify the threat space for each fault mode to be considered. (The requirements in section Appendix B section 3.6.7.3.3 apply to 4 specific fault modes). These fault modes (i.e. the threat space), which may be used for evaluating compliance with a ground subsystem design, are provided in 7.5.12.1.3.1 through 7.5.12.1.3.4 These fault modes and fault combinations constitute the threat space. These threat space definitions represent what at least one state has found acceptable as an assumed threat space for each fault mode.
- Identify the Airborne Configuration Space. The airborne system requirements introduce constraints on the design and performance of airborne equipment. These constraints define the

range of critical airborne parameters of the configuration space for each fault mode and/or monitor that must be protected by the ground subsystem. For example, the bandwidth and correlator spacing of a compliant airborne receiver will conform to the requirements in sections 8.11.4 through 8.11.7.1. These are two of the critical parameters of the airborne configuration space for the satellite signal deformation fault mode. A critical airborne parameter directly influences how each point in the threat space translates to an error in the differentially corrected pseudorange.

An error analysis is done considering the specific monitor design under consideration given the
full range of fault characteristics that comprise the threat space. For each characterized fault,
the error that would be induced in the corrected pseudorange (using the 30-second smoothed
pseudoranges and pseudorange corrections) is computed given the full range of critical airborne
parameters that comprise the airborne configuration space.

When assessing the compliance of a ground subsystem design, the performance is characterized by relevant statistical measures. Any monitor is subject to noise and therefore the performance may be characterized by the false detection rate and the missed detection probability. Both of these performance metrics are specified in the ground requirements in appendix B by means of a not-to-exceed constraint. The missed detection probability performance is constrained by the requirements in Appendix B section 3.6.7.3.3.2 and Appendix B section 3.6.7.3.3.3. The false detection rate performance is constrained by the continuity requirements given in Appendix B section 3.6.7.1.3.2. It should be understood that the ground subsystem must meet all requirements in the standards. It is possible that the performance of individual monitors may be further constrained by other requirements, such as the ground subsystem integrity risk requirement in Appendix B section 3.6.7.1.2.1.1.1.

7.5.12.1.1. Compliance of ground subsystem monitoring with Continuity Requirements. The compliance with the false detection rate (continuity) may be established based on collected real data combined with analysis and/or simulation. The required number of truly independent samples should be sufficient to adequately characterize the cumulative distribution (CDF) of the monitor discriminator, which is compared to the threshold set for the monitor. The fault free noise CDF must be such that for the threshold set in the monitor the false detection probability is smaller than that required to support continuity. An allocation of the continuity to each monitor must be done with consideration given to the overall specified probability of false detection (Appendix B section 3.6.7.1.3.2). The achieved probability of false detection is determined by extrapolation of the observed trends in the measured CDF. Additionally, detection events in the ground system may be logged and if, over time, the false detection rates are not maintained at the required levels thresholds may be adjusted as the result of a maintenance action to correct the problem.

7.5.12.1.2. Compliance of ground subsystem monitoring with integrity requirements.

The compliance with the missed detection probability (integrity risk) is typically established based on simulation and analysis. (Given the low allowed probability of observing actual faults, collection of enough real data to establish that the probability is met with any statistical significance is impossible.) The threat space for the fault mode is divided into discrete intervals across the relevant parameters that define the fault behavior. The total space of potential faults is represented by a multidimensional grid of discrete points that span the threat space. The airborne configuration space is also discretized i.e. represented by a multidimensional grid of discrete (critical parameter) points. A simulation is used to compute the expected pseudorange error performance for each point in the threat space, each possible airborne configuration and the ground receiver function with the monitors. The worst case error in the corrected pseudorange is computed as a function of the discriminator value for the monitor addressing the threat (assuming no noise at this point). This also makes it possible to determine the discriminator value as a function of the worst case error in the corrected pseudorange (the inverse mapping). The missed detection probability is obtained by super-imposing noise based on a conservative noise model (using an over bound of the CDF that was generated by the real data), on the discriminator determined from the worst case differential range. This can be done either analytically or by simulation. The mapping from discriminator to worst case error in the corrected pseudorange and the noise levels applied may have

further dependencies (for instance satellite elevation) and the established missed detection probability is therefore also a function of a set of parameters that constitute the detection parameter space which is divided into discrete intervals as well i.e. represented by a multidimensional grid of discrete (detection parameter) points. The final missed detection probability is obtained by searching for the worst case when evaluating all the grid points in the detection parameter space.

7.5.12.1.3 Threat Space and Relevant Airborne Configuration Space for each Fault Mode

7.5.12.1.3.1 Code Carrier Divergence (CCD)

The Code Carrier Divergence threat is a fault condition in a GPS satellite that causes the code and carrier of the broadcast signal to diverge excessively. The threat space in this case is 2-dimensional and corresponds to time of the fault onset relative to initialization of the ground smoothing filter and the divergence rate. The timing of the fault onset relative to the initialization is part of the threat space since no transient error can occur if the fault onset occurs so the airborne smoothing filter already converged before the ground smoothing filter is initialized.

A Code Carrier Divergence fault may cause a differential ranging errors in one or both of the following cases: (1) the aircraft and ground filter designs are not identical, and (2) the aircraft and ground filters start at different times. Both of these cases can results in a difference between the transient responses of the filters in the presence of a CCD event. The critical airborne parameters are:

- The time of initialization of the airborne smoothing filter relative to the fault onset.
- The smoothing filter type (fixed time constant 30 sec or adjustable time constant equal to time from initialization up to 30 sec and thereafter fixed)
- The carrier code divergence rate monitoring required in airborne system for GAST D and the associated fault reaction.
- The time period from initialization of the airborne smoothing filter to the incorporation of the measurement in the position solution

7.5.12.1.3.2 Excessive Acceleration Threat

The Excessive Acceleration threat is a fault condition in a GPS satellite that causes the carrier (and code in unison) of the broadcast signal to accelerate excessively. The threat space is 1-dimensional and corresponds to all possible accelerations.

7.5.12.1.3.3 Ephemeris Error Threat

The Ephemeris Error threat is a fault condition that causes the broadcast ephemeris parameters to yield excessive satellite position errors perpendicular to the ground subsystem's line of sight to the satellite.

Three types of ephemeris errors have been identified. These are referred to as Type B, A1 and A2.

7.5.12.1.3.3.1 Ephemeris Error Threat type B

The broadcast ephemeris data is in error due to an upload blunder or satellite glitch. The threat space is 2-dimensional and corresponds to all possible satellite position error vectors in a plane perpendicular to the line of sight of the ground subsystem.

7.5.12.1.3.3.2 Ephemeris Error Threat type A1

The core threat is broadcast of stale (unchanged) ephemeris parameters after a delta-V manoeuvre that occurred when the satellite is out of view of the ground subsystem. This threat requires that the satellite be indicated as healthy at acquisition even though the delta-V manoeuvre occurred in the recent past before the ground system could acquire the signal.. The threat space is 2-dimensional and corresponds to all possible delta-V manoeuvre (i.e. velocity changes in m/s) combined with all possible times from delta-V (impulse onset) to acquisition of satellite.

This brief description focuses on the core case. Additional corner cases may exist depending on the specific design of the ground subsystem monitoring.

7.5.12.1.3.3.3 Ephemeris Error Threat type A2

The threat is an unannounced (i.e. satellite not set unhealthy) delta-V manoeuvre while the satellite is in view of the ground subsystem. The threat space is 2-dimensional and corresponds to all possible delta-V manoeuvre (velocity change in m/s) combined with all possible times for delta-V (impulse onset) while in view.

For the worst case geometry the differential error is proportional to both the satellite position error and the distance to the airplane from the ground system. The resultant airborne range error is the satellite position error (true compared to broadcast ephemeris) multiplied by the distance between ground subsystem and airborne and scaled by the inverted distance to the satellite.

The critical airborne parameter for the Ephemeris Error Threat is the distance between the user and the ground subsystem.

7.5.12.1.3.4 Signal Deformation Threat

The Signal Deformation threat is a fault condition in the GPS satellite that causes the broadcast C/A code to be distorted so that the correlation peaks used for tracking in the airborne system and the ground system are deformed. The extent of the deformation depends on the receiver bandwidth and the resulting tracking error depends on where the correlator points used for code tracking are located (along the correlator peak).

The Signal deformation monitoring threat space is defined in section 8. There are 3 fault types A, B, C

Most satellites naturally show some degree of correlator peak deformation and these are referred to as natural (correlator measurement) biases. These natural biases may vary over time.

A fault condition (onset) will appear as a step in the raw (unfiltered) code measurement both in the airborne system and in the ground. If both system had exactly the same front end (RF and IF filtering, sampling method), correlator type and correlator spacing the error would be the same in ground and air and no differential error would occur. But typically that is not the case.

The step is filtered by the smoothing algorithm in the ground and in the airborne systems and the steady state differential error will gradually manifest itself in a 60 - 90 second time frame when using corrections from message type 11 (or 200 - 300 sec for message type 1).

If a fault (A, B or C) occur in a satellite it will take about 60 - 90 seconds before the steady state for the error and the monitor discriminator is reached. In essence the fault onset starts a race between the increasing differential error and the monitor discriminator as it moves towards the threshold. This referred to as the transient state. If the range error reaches the limit that must be protect while the discriminator is not yet at past the threshold with sufficient margin to guarantee the required detection probability the requirement is not met. Both the steady state and the transient state performance must be evaluated.

The critical airborne parameters for the Signal Deformation Threat are:

- The time period from initialization of the airborne smoothing filter to incorporation of the measurement in the position solution
- The parameters that have constraints defined in the GAST D standard (attachment B) including
 - o Correlator type Early-Late (EL) or Double Delta (DD)
 - Correlator spacing

- o GPS signal bandwidth (from reception at antenna through RF, IF, and A/D conversion)
- Group delay (from reception at antenna through RF, IF, and A/D conversion)

Apart from the discrete choice of EL versus DD the configuration space is 2-dimensional (correlator spacing and bandwidth). The filters implemented in the airborne system may be of different types (Butterworth, Chebychev, Elliptical etc). The group-delay constraints will exclude some of these filters. However the possible variation in receiver design introduces additional dimensions that the ground subsystem manufacturer must consider. The filter types are part of the configuration space to be considered.

7.5.12.2. Ground Subsystem Requirements and Airworthiness Performance Assessment

Airworthiness certification of autoland systems, for use in Category II/III operations, requires an assessment of landing performance under fault free and faulted conditions. Such landing performance assessments require sufficient definition of expected error characteristics for a GBAS system including both nominal performance and performance in the presence of known fault modes. The nominal performance of a GBAS system can be inferred from the combination of ground accuracy (Appendix B section 3.6.7.1.1), airborne accuracy (Appendix B section 3.6.8.2.2.3) designations and satellite geometry (Appendix B section 3.6.5.5.1.1.2). The error characteristics of a GBAS under faulted conditions can be derived from the integrity monitoring of GNSS ranging sources (Appendix B section 3.6.7.3.3) along with geometry screening introduced by Protection Level computations (Appendix B section 3.6.5.5) and any other geometry screening implemented by the airborne equipment to limit the projection of undetected errors in the pseudorange to the position domain. More information, describing how the technical standards in these SARPs can be used to support assessment of airworthiness, may be found in RTCA document DO-253C "Minimum Operational Performance Requirements for Airborne Equipment using the Local Area Augmentation System" Appendix J.

7.5.12.3 *GBAS Signal-in-Space Time-to-alert*. The GBAS signal-in-space time-to-alert (SIS TTA) is defined below within the context of GBAS based upon the TTA definition in Chapter 2, section 3.7.1. The GBAS SIS TTA is the maximum allowable time elapsed from the onset of an out-of-tolerance condition at the output of the fault-free aircraft GBAS receiver until the aircraft GBAS receiver annunciates the alert. This time is a never to be exceeded limit and is intended to protect the aircraft against prolonged periods of guidance outside the lateral or vertical alert limits.

There are two allocations made to support the GBAS signal-in-space time-to-alert in the standards.

The first allocation, the ground subsystem TTA for signal-in-space requirements, limits the time it takes the ground subsystem to provide an indication that it has detected an out-of-tolerance situation considering the output of a fault-free GBAS receiver. The indication to the aircraft element is either: a) to broadcast Type 1 (and Type 11 if broadcast) or Type 101 messages indicating the condition (in accordance with Appendix B section 3.6.7.3.2.1), or b) terminate all VDB transmissions. The ground subsystem is allocated 3 seconds to take either action.

For airborne receivers using GAST C, at least one Type 1 message signaling the out-of tolerance condition must be received by a fault-free airborne receiver within the message time out to meet the SIS TTA. For airborne receivers using GAST D, at least, one of each (Type 1 and Type 11) message with the same applicable modified z-count (and the same set of satellites) must be received by a fault-free airborne receiver within the message time out to meet the SIS TTA. Because shutting down the VDB may result in an exposure time longer than the SIS TTA for satellite faults, this option is recommended only under conditions where the VDB transmission does not meet its associated performance requirements (reference Appendix B section 3.6.7.3.1.1.).

In addition, for ground subsystems that support GAST D monitoring performance requirements, the ground subsystem is allocated only 1.5 seconds to detect a condition producing out-of-tolerance errors in 30 second corrected pseudoranges and to either exclude the ranging source measurements from the broadcast or mark them as invalid. This time-to-detect and broadcast is similar in definition, but not equivalent in function to the ground subsystem TTA, as an out-of-tolerance condition in a single ranging source does not necessarily lead to out-of-tolerance guidance information.

The second allocation for the GBAS signal-in-space time-to-alert provides for the possible temporary loss of message reception. Airborne equipment operating with GAST C active will generate an alert if a Type 1 message is not received within 3.5 seconds when on the final stages of approach. When the airborne equipment is below 200 feet height above the runway threshold (HAT), airborne equipment operating with GAST D active will generate an alert or change the active service type if a set of Type 1 and Type 11 messages with the same modified z-count are not received within 1.5 seconds. Note that these time-outs will also dictate the achieved signal-in-space time-to-alert when the ground subsystem ceases VDB transmissions instead of broadcasting messages as an alert to the airborne equipment.

Requirements on how quickly the receiver outputs must be invalidated (so annunciating an alert), as well as additional conditions requiring the outputs to be indicated as invalid, are contained in RTCA DO-253(). For example, there is a requirement for the aircraft GBAS receiver position determination function to use the most recently received message content and reflect the message content in its outputs within 400 ms. The SIS TTA is defined by start and stop events at the same point in the aircraft. Any processing that is common to generating outputs under both normal conditions and alert conditions will not change the achieved SIS TTA. That is, this common period acts like a lag to both the start event and end event and does not effect the total exposure time to the aircraft. Within the GBAS receiver, the outputs under both of these conditions must meet the same latency requirement, so large differences are not expected. SIS TTA will differ from ground subsystem TTA by a value equal to the difference between receiver processing time and receiver time to invalidate outputs.

The Table [D-X] summarizes the time periods that contribute to the GBAS signal-in-space TTA and the range of achieved TTA that can be expected.

Table D-X

Integrity risk	Ground	Message Time-Out in	Signal-in-	Signal-in-
requirements and	subsystem TTA	Aircraft	Space TTA	Space TTA
Service Types	[<i>Note 1</i>]	[Note 5]	(nominal)	(maximum)
7.			[Note 6]	[Note 7]
B-3.6.7.1.2.1.1.1	3.0 sec	3.5 sec	3.0 sec	6.0 sec
&	[Note 2]			
B-3.6.7.1.2.2.1				
GAST A,B,C				
B-3.6.7.1.2.1.1.2	3.0 sec	3.5 sec (above 200 ft HAT)	3.0 sec	6.0 sec
&	[Notes 2 and 8]	1.5 sec (below 200 ft HAT)	3.0 sec	4.0 sec
B-3.6.7.1.2.2.1				
GAST D				
B-3.6.7.1.2.1.1.3	1.5 sec	3.5 sec (above 200 ft HAT)	1.5 sec	4.5 sec [Note
GAST D				3]
		1.5 sec (below 200 ft HAT)	1.5 sec	2.5 sec [Note
				3]
B-3.6.7.3.3	1.5 sec [Note 9]	3.5 sec (above 200 ft HAT)	1.5 sec	4.5 sec [Note
GAST D				4]
		1.5 sec (below 200 ft HAT)	1.5 sec	2.5 sec [Note
				4]

- Note 1: These ground subsystem TTA requirements apply to a ground subsystem transmitting Type 1 messages. Ground subsystems transmitting Type 101 messages have a 5.5 second TTA as standardized in Appendix B section 3.6.7.1.2.1.2.1.2.
- Note 2: These times apply to excluding all ranging sources, marking all ranging sources as invalid in Message Type 1 or the cessation of VDB transmission. When a single ranging source is marked invalid or excluded, it may or may not cause the aircraft receiver to generate an alert, depending on the role of that ranging source in the aircraft's position solution.
- Note 3: This design requirement applies to the integrity of internal ground subsystem functions (excluding single reference receiver failures). This includes the ground subsystem ranging source monitoring capability. The table illustrates the exposure time for ground equipment failures that result in the transmission of non-compliant information and that are enunciated to the aircraft using the VDB transmission.
- Note 4: These requirements apply to the integrity monitoring for GNSS ranging sources . When a single ranging source is marked invalid or excluded, it may or may not cause the aircraft receiver to generate an alert, depending on the role of that ranging source in the aircraft's position solution. The times listed in the table assume the ranging source was critical to determining the position solution.
- Note 5: The missed message time-out allocation starts with the last received message and not with the first missed message, so is 0.5 seconds longer than time added to the SIS time-to-alert.
- Note 6: If transmissions continue and there are no missed messages, the "nominal" column is relevant. This value includes the maximum ground subsystem contribution
- Note 7: The maximum SIS TTA includes the maximum ground subsystem contribution and the possible temporary loss of message reception. When VDB transmissions cease, the maximum SIS TTA is relevant. This time is computed by adding the ground subsystem TTA and the airborne message time out minus 0.5 seconds (see note 5).

Note 8: Although these sections are related to FAST D and the maximum TTA values are larger than those historically associated with Category II/III operations, these TTA values in this line are not relevant for integrity to support Category II/III. These TTA values apply to the bounding conditions (see section 7.5.3.1) and therefore are related to the total risk of fault free error sources and faults exceeding the protection levels. For GAST D, the effects of malfunctions are addressed by the additional requirements in Appendix B section 3.6.7.1.2.1.1.3, Appendix B section 3.6.7.3.3 and additional airborne requirements as provided in RTCA DO-253C, for example the reference receiver fault monitor. These additional requirements are more constraining and enforce a shorter TTA that is appropriate for Category II/III operations. The existence of the longer TTA values in this line should not be interpreted to imply that errors near or exceeding the alert limit for up to these longer exposure times can occur with a probability greater than $1x10^{-9}$ in any landing

Note 9: This is "time to detect and broadcast"; the other ground system requirements apply in addition.

Figure [D-X] illustrates the nominal case with no missed messages and Figure [D-Y] illustrates the effect of missed messages for GAST D below 200ft. Above 200ft, the situation is similar, but the aircraft has a longer missed message allocation, as described above.

The figure illustrates the effect on the SIS time-to-alert due to missed messages (upper half) and VDB termination (lower half) using the example of GAST D requirements below 200 feet. The upper time-line shows just two messages being missed, but the third is received, so operations can continue, unless the third message is indicating a fault condition that results in an alert from the receiver. The lower time-line shows the effect of the VDB terminating. The aircraft receiver invalidates its outputs after three messages are missed. The SIS time-to-alert combines the ground time-to-alert and the missed message allocation (See Table D-X), but it is now displaced by the aircraft receiver processing time. Above 200ft, the situation is similar, but the aircraft has a longer allocation, as described in RTCA DO-253C.

For SIS integrity, the diagram indicates that the SIS time-to-alert starting point is where the fault-free airborne receiver outputs out-of-tolerance data. The SIS time-to-alert end event is also at the output of the airborne receiver.

The start event of the ground subsystem's time-to-alert or time-to-detect and broadcast is the last bit of the first message (Type 1 and Type 11 message pair for GAST D) including the out-of-tolerance data. For ground equipment failures or termination of the VDB signal, this is the first message the ground subsystem broadcasts containing correction, integrity or path information that does not conform to the applicable integrity requirement (e.g. SIS integrity, Ground Subsystem integrity). For satellite failures, the requirements are out-of-tolerance once differential pseudorange errors exceed the performance metrics detailed within a certain requirement (e.g. Ranging Source Monitoring). Their end event is the last bit of the first message (message pair for GAST D) removing the out-of-tolerance data or flagging it invalid.

It should be noted that, while the Figure D-X indicates that the SIS and ground subsystem TTAs reference different start and end points in time, an ANSP may assume that they are the same. A ground subsystem should be evaluated and certified with no credit or penalty for airborne receiver variations due to a specific, approved aircraft implementation. From the ground subsystem perspective, all received message are assumed to be instantaneously applied or acted upon by the airborne receiver. This effectively results in equivalent SIS and ground subsystem TTA reference points from the ground subsystem's point of view.

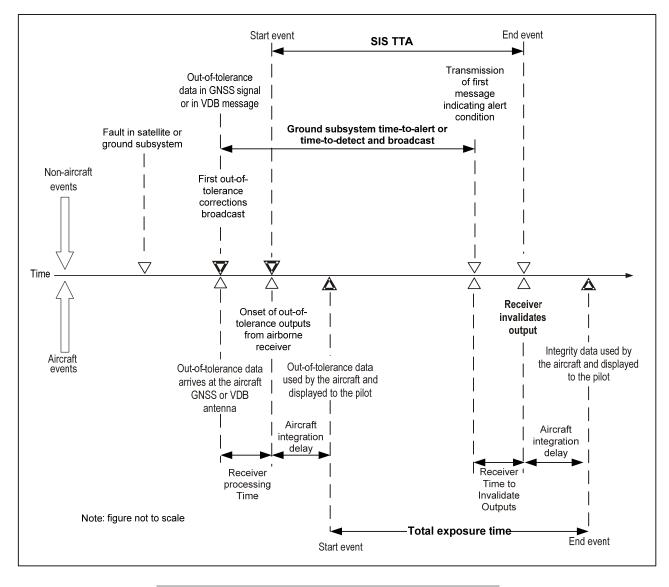


Figure D-X: Nominal GBAS Time-to-Alert Illustration

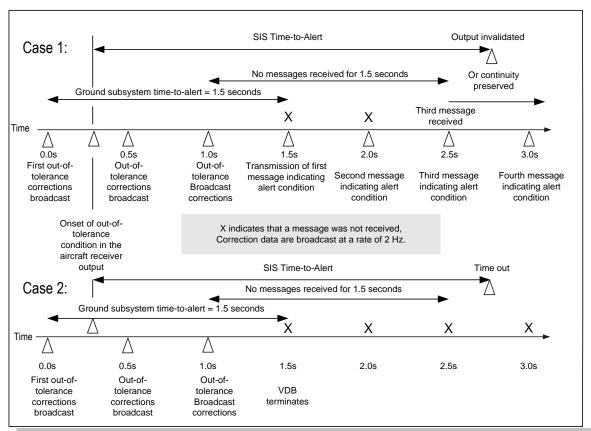


Figure D-Y: Effect of missed messages on the GAST D GBAS Time-to-Alert below 200ft Case 1 describes the situation for missed messages, Case 2 the one for VDB termination.

7.5.12.4 Ground Subsystem Integrity Risk for GAST D. Appendix B Section 3.6.7.1.2.1.1.3 specifies a new ground subsystem integrity requirement relating to failsafe design criteria. This integrity method will ensure that failures within the ground subsystem that might affect the stations functions and result in erroneous information are Extremely Improbable. The intent of this requirement is to specify the allowable risk that the ground subsystem shall internally generate and cause to be broadcast erroneous information. Other requirements specify the required performance of the ground subsystem with respect to detection and mitigation of faults originating outside the ground subsystem (such as ranging source failures). This requirement relates to the probability that the ground subsystem fails to meet the intended function. The intended function for GBAS is defined in Chapter 3, Section 3.7.3.5.2. The functions listed in that section and their associated performance requirements characterize the intended function of the system.

7.5.12.4.1 Verification of Compliance with Subsystem Integrity Risk for GAST D. Verification that a ground subsystem meets the integrity risk requirements of Appendix B section 3.6.7.1.2.1.1.3 would typically be accomplished through a combination of analysis and appropriate safety related design practices/processes. The overall process must ensure that failures within the ground subsystem that might affect the stations intended functions and result in erroneous information are Extremely Improbable. All ground subsystem component failure conditions must be shown to be sufficiently mitigated through either direct monitoring or through use of an acceptable design assurance development process (such as RTCA/DO-178 and RTCA/DO-254). The methodology should provide assurance of mitigation of component (HW, SW) failures. The integrity method of design assurance applied in conjunction with fail-safe design concepts and other assurance actions (such as those in SAE ARP 4754) to detect and remove systematic errors in the design, provides safety assurance of the GAST D ground system. Some

states have used safety assurance guidance from ICAO SMS Doc 9589, especially Chapter 4 §4.4.9 "Modern View of Causation", Chapter 12 "Safety Management System" and Chapter 13 "Safety Assessment Process".

7.6 Continuity of service

- 7.6.1 Ground GBAS continuity—and—integrity designator. The ground GBAS continuity—and integrity designator (GCID) provides an indication of the current capability—classification of GBAS ground subsystems. The ground subsystem meets the performance and functional requirements of GAST A, B or C Category I precision approach or APV—when GCID is set to 1. The ground subsystem meets the performance and functional requirements of GAST A, B, C and D when GCID is set to 2. GCID of 5, 3 and 4 are intended to support future operations with an associated service type that has requirements that are more stringent than Category I operations—GAST D. The GCID is intended to be an indication of ground subsystem status to be used when an aircraft selects an approach. It is not intended to replace or supplement an instantaneous integrity indication communicated in a Type 1 or Type 101 message. GCID does not provide any indication of the ground subsystem capability to support the GBAS positioning service.
- 7.6.2 Ground subsystem continuity of service. GBAS ground subsystems are required to meet the continuity of service specified in Appendix B to Chapter 3, section 3.6.7.1.3 in order to support GAST A, B and C. Category I precision approach and APV. GBAS ground subsystems that are also intended to support other operations through the use of the GBAS positioning service should support the minimum continuity required for terminal area operations, which is $1-10^{-4}$ /hour (Chapter 3, Table 3.7.2.4-1). When the GAST A, B or C Category I precision approach or APV required continuity (1-8 × 10⁻⁶/15 seconds) is converted to a per hour value it does not meet the $1-10^{-4}$ /hour minimum continuity requirement. Therefore, additional measures are necessary to meet the continuity required for other operations. One method of showing compliance with this requirement is to assume that airborne implementation uses both GBAS and ABAS to provide redundancy and that ABAS provides sufficient accuracy for the intended operation.
- Ground subsystem continuity of service for GAST D. A ground segment that supports GAST D must meet the signal in space continuity requirement (1-8.0 x 10⁻⁶/15 seconds) for a GAST A, B and C system but must also meet the continuity requirements specific to GAST D as defined in Appendix B section 3.6.7.1.3.2. The ground subsystem continuity is defined by two requirements. One is the continuity of the ground subsystem that includes failures of all components necessary for the VDB broadcast, including the reference receivers. It also includes loss of service due to integrity failures in the ground subsystem that result in alerts, and monitor false alerts. The other allocation is the continuity associated with monitor fault free detections. The reason for defining the ranging source monitor detections as a separate requirement is because the VDB broadcast portion includes all failures that result in the loss of the signal-in-space, whereas the monitor contribution is related only to exclusion of individual satellites from the broadcast corrections. This does not necessarily result in a loss of the signalin-space by the airborne receiver. The requirement is defined on a per ranging source basis so that the ground design does not need to account for the actual number of satellites in view or the number considered critical to the user for a specific approach. It is the responsibility of the airborne user to demonstrate the overall continuity achieved when considering the contribution of the satellites and the airborne monitors.

7.7 GBAS channel selection

7.7.1 Channel numbers are used in GBAS to facilitate an interface between aircraft equipment and the signal-in-space that is consistent with interfaces for ILS and MLS. The cockpit integration and

crew interface for GBAS may be based on entry of the 5-digit channel number. An interface based on approach selection through a flight management function similar to current practice with ILS is also possible. The GBAS channel number may be stored in an on-board navigation database as part of a named approach. The approach may be selected by name and the channel number can automatically be provided to the equipment that must select the appropriate GBAS approach data from the broadcast data. Similarly, the use of the GBAS positioning service may be based on the selection of a 5-digit channel number. This facilitates conducting operations other than the approaches defined by the FAS data. To facilitate frequency tuning, the GBAS channel numbers for neighbouring GBAS ground subsystems supporting positioning service may be provided in the Type 2 message additional data block 2.

- 7.7.2 A channel number in the range from 20 001 to 39 999 is assigned when the FAS data are broadcast in the Type 4 message. A channel number in the range from 40 000 to 99 999 is assigned when the FAS data associated with an APV are obtained from the on-board database.
- 7.7.3 Every FAS data block uplinked in a Type 4 message will be associated with a single 5 digit channel number regardless of whether or not the approach is supported by multiple approach service types. For approaches that are supported by multiple approach service types, the Approach Performance Designator field in the Type 4 message is used to indicate the most demanding approach service type supported by the ground subsystem for any specific approach.

7.8 Reference path data selector and reference station data selector

A mapping scheme provides a unique assignment of a channel number to each GBAS approach. The channel number consists of five numeric characters in the range 20 001 to 39 999. The channel number enables the GBAS airborne subsystem to tune to the correct frequency and select the final approach segment (FAS) data block that defines the desired approach. The correct FAS data block is selected by the reference path data selector (RPDS), which is included as part of the FAS definition data in a Type 4 message. Table D-6 shows examples of the relationship between the channel number, frequency and RPDS. The same mapping scheme applies to selection of the positioning service through the reference station data selector (RSDS). The RSDS is broadcast in the Type 2 message and allows the selection of a unique GBAS ground subsystem that provides the positioning service. For GBAS ground subsystems that do not provide the positioning service and broadcast the additional ephemeris data, the RSDS is coded with a value of 255. All RPDS and RSDS broadcast by a ground subsystem must be unique on the broadcast frequency within radio range of the signal. The RSDS value must not be the same as any of the broadcast RPDS values.

Table D-6. Channel assignment examples

Channel number (N)	Frequency in MHz (F)	Reference path data selector (RPDS) or Reference station data selector (RSDS)
20 001	108.025	0
20 002	108.05	0
20 003	108.075	0
20 397	117.925	0
20 398	117.95	0
20 412 (Note)	108.025	1
20 413	108.05	1
••••	••••	••••

Note.— Channels between 20 398 and 20 412 are not assignable because the channel algorithm maps them to frequencies outside the range of 108.025 MHz and 117.950 MHz. A similar "gap" in the channel assignments occurs at each RPDS transition.

7.9 Assignment of RPDS and RSDS by service provider

RPDS and RSDS assignments are to be controlled to avoid duplicate use of channel numbers within the protection region for the data broadcast frequency. Therefore, the GBAS service provider has to ensure that an RPDS and RSDS are assigned only once on a given frequency within radio range of a particular GBAS ground subsystem. Assignments of RPDS and RSDS are to be managed along with assignments of frequency and time slots for the VHF data broadcast.

7.10 GBAS identification

The GBAS identification (ID) is used to uniquely identify a GBAS ground subsystem broadcasting on a given frequency within the coverage region of the GBAS. The aircraft will navigate using data broadcast from one or more GBAS broadcast stations of a single GBAS ground subsystem (as identified by a common GBAS identification).

7.11 Final approach segment (FAS) path

- 7.11.1 FAS path is a line in space defined by the landing threshold point/fictitious threshold point (LTP/FTP), flight path alignment point (FPAP), threshold crossing height (TCH) and glide path angle (GPA). These parameters are determined from data provided in a FAS data block within a Type 4 message or in the on-board database. The relationship between these parameters and the FAS path is illustrated in Figure D-6.
- 7.11.1.1 FAS data blocks for SBAS and some GBAS approaches are held within a common onboard database supporting both SBAS and GBAS. States are responsible for providing the FAS data to support APV procedures when the Type 4 message is not broadcast. These data comprise the parameters

contained within the FAS block, the RSDS, and associated broadcast frequency. The FAS block for a particular approach procedure is described in Appendix B, 3.6.4.5.1 and Table B-66.

7.11.2 FAS path definition

- 7.11.2.1 Lateral orientation. The LTP/FTP is typically at or near the runway threshold. However, to satisfy operational needs or physical constraints, the LTP/FTP may not be at the threshold. The FPAP is used in conjunction with the LTP/FTP to define the lateral reference plane for the approach. For a straight-in approach aligned with the runway, the FPAP will be at or beyond the stop end of the runway. The FPAP is not placed before the stop end of the runway.
- 7.11.2.2 Δ Length offset. The Δ length offset defines the distance from the end of the runway to the FPAP. This parameter is provided to enable the aircraft equipment to compute the distance to the end of the runway. If the Δ length offset is not set to appropriately indicate the end of the runway relative to the FPAP, the service provider should ensure the parameter is coded as "not provided".
- 7.11.2.3 *Vertical orientation*. Local vertical for the approach is defined as normal to the WGS-84 ellipsoid at the LTP/FTP and may differ significantly from the local gravity vector. The local level plane for the approach is defined as a plane perpendicular to the local vertical passing through the LTP/FTP (i.e. tangent to the ellipsoid at the LTP/FTP). The datum crossing point (DCP) is a point at a height defined by TCH above the LTP/FTP. The FAS path is defined as a line with an angle (defined by the GPA) relative to the local level plane passing through the DCP. The GPIP is the point where the final approach path intercepts the local level plane. The GPIP may actually be above or below the runway surface depending on the curvature of the runway.
- 7.11.3 "ILS look-alike" deviation computations. For compatibility with existing aircraft designs, it is desirable for aircraft equipment to output guidance information in the form of deviations relative to a desired flight path defined by the FAS path. The Type 4 message includes parameters that support the computation of deviations that are consistent with typical ILS installations.
- 7.11.3.1 Lateral deviation definition. Figure D-6 illustrates the relationship between the FPAP and the origin of the lateral angular deviations. The course width parameter and FPAP are used to define the origin and sensitivity of the lateral deviations. By adjusting the location of the FPAP and the value of the course width, the course width and sensitivity of a GBAS can be set to the desired values. They may be set to match the course width and sensitivity of an existing ILS or MLS. This may be necessary, for example, for compatibility with existing visual landing aids.
- 7.11.3.1.1 Lateral deviation reference. The lateral deviation reference plane is the plane that includes the LTP/FTP, FPAP and a vector normal to the WGS-84 ellipsoid at the LTP/FTP. The rectilinear lateral deviation is the distance of the computed aircraft position from the lateral deviation reference plane. The angular lateral deviation is a corresponding angular displacement referenced to the GBAS azimuth reference point (GARP). The GARP is defined to be beyond the FPAP along the procedure centre line by a fixed offset value of 305 m (1 000 ft).
- 7.11.3.1.2 Lateral displacement sensitivity. The lateral displacement sensitivity is determined by the aircraft equipment from the course width provided in the FAS data block. The service provider is responsible for setting the course width parameter to a value that results in the appropriate angle for full scale deflection (i.e. 0.155 DDM or $150~\mu A$) taking into account any operational constraints.
- 7.11.3.2 *Vertical deviations*. Vertical deviations are computed by the aircraft equipment with respect to a GBAS elevation reference point (GERP). The GERP may be at the GPIP or laterally offset from the GPIP by a fixed GERP offset value of 150 m. Use of the offset GERP allows the glide path

deviations to produce the same hyperbolic effects that are normal characteristics of ILS and MLS (below 200 ft). The decision to offset the GERP or not is made by the aircraft equipment in accordance with requirements driven by compatibility with existing aircraft systems. Service providers should be aware that users may compute vertical deviations using a GERP which is placed at either location. Sensitivity of vertical deviations is set automatically in the aircraft equipment as a function of the GPA. The specified value for the relationship between GPA and the full scale deflection (FSD) of the vertical deviation sensitivity is FSD=0.25*GPA. The value 0.25 is taken from the MLS standards (Attachment G 7.4.1.2) and differs slightly from the nominal value of 0.24 recommended for ILS (chapter 3 section 3.1.5.6.2). However, the value specified for MLS is well within the tolerances recommended for ILS of 0.2 to 0.28. Therefore the resulting sensitivity is equivalent to the glide path displacement sensitivity provided by a typical ILS installation.

- 7.11.4 Approaches not aligned with the runway. Some operations may require the definition of a FAS path that is not aligned with the runway centre line as illustrated in Figure D-7. For approaches not aligned with the runway, the LTP/FTP may or may not lie on the extended runway centre line. For this type of approach Δ length offset is not meaningful and should be set to "not provided".
- 7.11.5 SBAS service provider. A common format is used for FAS data blocks to be used by both GBAS and SBAS. The SBAS service provider ID field identifies which SBAS system(s) may be used by an aircraft that is using the FAS data during an approach. The GBAS service provider may inhibit use of the FAS data in conjunction with any SBAS service. For precision approaches based on GBAS this field is not used, and it can be ignored by aircraft GBAS equipment.
- 7.11.6 Approach identifier. The service provider is responsible for assigning the approach identifier for each approach. The approach identification should be unique within a large geographical area. Approach identifications for multiple runways at a given airport should be chosen to reduce the potential for confusion and misidentification. The approach identification should appear on the published charts that describe the approach. The first letter of the approach identifier is used in the authentication protocols for GBAS. Ground subsystems that support the authentication protocols must encode the first character of the identifier for all approaches supported from the set of letters {A X Z J C V P T } as described in Appendix B, Section 3.6.7.4.1.4. This enables airborne equipment (that supports the authentication protocols) to determine which slots are assigned to the ground subsystem and therefore to subsequently ignore reception of data broadcast in slots not assigned to the selected ground subsystem. For ground subsystems that do not support the authentication protocols, the first character of the Approach identifier may be assigned any character except those in the set {A X Z J C V P T }.

7.12 Airport siting considerations

- 7.12.1 The installation of a GBAS ground subsystem involves special considerations in choosing prospective sites for the reference receiver antennas and the VDB antenna(s). In planning antenna siting, Annex 14 obstacle limitation requirements must be met.
- 7.12.2 Locating reference receiver antennas. The site should be selected in an area free of obstructions, so as to permit the reception of satellite signals at elevation angles as low as possible. In general, anything masking GNSS satellites at elevation angles higher than 5 degrees will degrade system availability.
- 7.12.2.1 The antennas for the reference receivers should be designed and sited to limit multipath signals that interfere with the desired signal. Mounting antennas close to a ground plane reduces long-delay multipath resulting from reflections below the antenna. Mounting height should be sufficient to prevent the antenna being covered by snow, or being interfered with by maintenance personnel or ground

traffic. The antenna should be sited so that any metal structures, such as air vents, pipes and other antennas are outside the near-field effects of the antenna.

- 7.12.2.2 Besides the magnitude of the multipath error at each reference receiver antenna location, the degree of correlation must also be considered. Reference receiver antennas should be located in places that provide independent multipath environments.
- 7.12.2.3 The installation of each antenna should include a mounting that will not flex in winds or under ice loads. Reference receiver antennas should be located in an area where access is controlled. Traffic may contribute to error due to multipath or obstruct view of satellites from the antennas.
- 7.12.3 Locating the VDB antenna. The VDB antenna should be located so that an unobstructed line-of-sight exists from the antenna to any point within the coverage volume for each supported FAS. Consideration should also be given to ensuring the minimum transmitter-to-receiver separation so that the maximum field strength is not exceeded. In order to provide the required coverage for multiple FASs at a given airport, and in order to allow flexibility in VBD antenna siting, the actual coverage volume around the transmitter antenna may need to be considerably larger than that required for a single FAS. The ability to provide this coverage is dependent on the VDB antenna location with respect to the runway and the height of the VDB antenna. Generally speaking, increased antenna height may be needed to provide adequate signal strength to users at low altitudes, but may also result in unacceptable multipath nulls within the desired coverage volume. A suitable antenna height trade-off must be made based on analysis, to ensure the signal strength requirements are met within the entire volume. Consideration should also be given to the effect of terrain features and buildings on the multipath environment.
- 7.12.4 Use of multiple transmit antennas to improve VDB coverage. For some GBAS installations, constraints on antenna location, local terrain or obstacles may result in ground multipath and/or signal blockage that make it difficult to provide the specified field strength at all points within the coverage area. Some GBAS ground facilities may make use of one or more additional antenna systems, sited to provide signal path diversity such that collectively they meet the coverage requirements.
- 7.12.4.1 Whenever multiple antenna systems are used, the antenna sequence and message scheduling must be arranged to provide broadcasts at all points within the coverage area that adhere to the specified minimum and maximum data broadcast rates and field strengths, without exceeding the receiver's ability to adapt to transmission-to-transmission variations in signal strength in a given slot. To avoid receiver processing issues concerning lost or duplicated messages, all transmissions of the Type 1, Type 11 or Type 101 message, or linked pairs of Type 1, Type 11 or Type 101 messages for a given measurement type within a single frame need to provide identical data content.
- 7.12.4.2 One example of the use of multiple antennas is a facility with two antennas installed at the same location but at different heights above the ground plane. The heights of the antennas are chosen so that the pattern from one antenna fills the nulls in the pattern of the other antenna that result from reflections from the ground plane. The GBAS ground subsystem alternates broadcasts between the two antennas, using one or two assigned slots of each frame for each antenna. Type 1 or Type 101 messages are broadcast once per frame, per antenna. This allows for reception of one or two Type 1 or Type 101 messages per frame, depending on whether the user is located within the null of one of the antenna patterns. Type 2 and 4 messages are broadcast from the first antenna in one frame, then from the second antenna in the next frame. This allows for reception of one each of the Type 2 and 4 messages per one or two frames, depending on the user location.

- 7.13.1 The lateral and vertical alert limits when the active service type is C or D for Category I precision approach are computed as defined in Appendix B, Tables B-68 and B-69. In these computations the parameters D and H have the meaning shown in Figure D-8.
- 7.13.2 The vertical alert limit when the active service type is C or D for Category I precision approach is scaled from a height of 60 m (200 ft) above the LTP/FTP. For a procedure designed with a decision height of more than 60 m (200 ft), the VAL at that decision height will be larger than the broadcast FASVAL.
- 7.13.3 The lateral and vertical alert limits for APV procedures associated with channel numbers 40 001 to 99 999 are computed in the same manner as for APV procedures using SBAS as given in Attachment D, 3.2.8.

7.14 Monitoring and maintenance actions

- 7.14.1 Specific monitoring requirements or built-in tests may be necessary in addition to the monitors defined in Appendix B, section 3.6.7.3 and should be determined by individual States. Since the VDB signal is critical to the operation of the GBAS broadcast station, any failure of the VDB to successfully transmit a usable signal within the assigned slots and over the entire coverage area is to be corrected as soon as possible. Therefore, it is recommended that the following conditions be used as a guide for implementing a VDB monitor:
 - a) Power. A significant drop in power is to be detected within 3 seconds an appropriate time period.
 - b) Loss of message type. The failure to transmit any scheduled message type(s). This could be based on the failure to transmit a unique message type in succession, or a combination of different message types.
 - c) Loss of all message types. The failure to transmit any message type for an appropriate time period-equal to or greater than 3 seconds will be detected.

The appropriate time periods for these monitors depends on the FAST and on whether a backup transmitter is provided. Where a backup transmitter is provided the objective is to switch to the backup transmitter quickly enough to avoid an alert being generated in the airborne equipment. This means that the appropriate time periods are a maximum of 3 seconds for FAST C and a maximum of 1.5 seconds for FAST D ground systems in order to be consistent with the aircraft equipment message loss requirements. If longer periods than this are implemented the changeover to the backup transmitter will cause an alert and must therefore be considered to be a continuity failure. If no backup transmitter is provided the time periods for these monitors are not critical.

- 7.14.2 Upon detection of a failure, and in the absence of a backup transmitter, termination of the VDB service should be considered if the signal cannot be used reliably within the coverage area to the extent that aircraft operations could be significantly impacted. Appropriate actions in operational procedures are to be considered to mitigate the event of the signal being removed from service. These would include dispatching maintenance specialists to service the GBAS VDB or special ATC procedures. Additionally, maintenance actions should be taken when possible for all built-in test failures to prevent loss of GBAS service.
- 7.14.3 The use of a backup transmitter also applies to the VDB monitoring requirements defined in Appendix B, section 3.6.7.3.1. The time to switch over to the backup needs to be taken into account while remaining compliant with the time to detect and terminate transmissions defined in Appendix B sections 3.6.7.3.1.1, 3.6.7.3.1.2, and 3.6.7.3.1.3.

7.15 Examples of VDB messages

- 7.15.1 Examples of the coding of VDB messages are provided in Tables D-7 through D-10. The examples illustrate the coding of the various application parameters, including the cyclic redundancy check (CRC) and forward error correction (FEC) parameters, and the results of bit scrambling and D8PSK symbol coding. The engineering values for the message parameters in these tables illustrate the message coding process, but are not necessarily representative of realistic values.
- 7.15.2 Table D-7 provides an example of a Type 1 VDB message. The additional message flag field is coded to indicate that this is the first of two Type 1 messages to be broadcast within the same frame. This is done for illustration purposes; a second Type 1 message is not typically required, except to allow broadcast of more ranging source corrections than can be accommodated in a single message.
- 7.15.3 Table D-7A provides an example of a Type 101 VDB message. The additional message flag field is coded to indicate that this is the first of two Type 101 messages to be broadcast within the same frame. This is done for illustration purposes; a second Type 101 message is not typically required, except to allow broadcast of more ranging source corrections than can be accommodated in a single message.
- 7.15.4 Table D-8 provides examples of a Type 1 VDB message and a Type 2 VDB message coded within a single burst (i.e. two messages to be broadcast within a single transmission slot). The additional message flag field of the Type 1 message is coded to indicate that it is the second of two Type 1 messages to be broadcast within the same frame. The Type 2 message includes additional data block 1. Table D-8A provides an example of Type 1 and Type 2 messages with additional data blocks 1 and 2.
- 7.15.4.1 Table D-8B provides an example of Type 2 messages with additional data blocks 1, 3 and 4 coded within a single burst with a Type 3 message that is used to fill the rest of the time slot.
 - 7.15.5 Table D-9 provides an example of a Type 4 message containing two FAS data blocks.
- 7.15.6 Table D-10 provides an example of a Type 5 message. In this example, source availability durations common to all approaches are provided for two ranging sources. Additionally, source availability durations for two individual approaches are provided: the first approach has two impacted ranging sources and the second approach has one impacted ranging source. The Type 2 message includes additional data block 1.

7.15.7 Table D-10A provides an example of a Type 11 message.

7.16 GBAS survey accuracy

The standards for the survey accuracy for NAVAIDs are contained in Annex 14 — *Aerodromes*. In addition, the *Manual of the World Geodetic System 1984 (WGS-84)* (Doc 9674) provides guidance on the establishment of a network of survey control stations at each aerodrome and how to use the network to establish WGS-84 coordinates. Until specific requirements are developed for GBAS, the Annex 14 survey accuracy requirements for NAVAIDs located at the aerodrome apply to GBAS. The recommendation contained in Appendix B to Chapter 3, 3.6.7.2.3.4, for the survey accuracy of the GBAS reference point is intended to further reduce the error in the WGS-84 position calculated by an airborne user of the GBAS positioning service to a value smaller than that established by the requirements of Appendix B to Chapter

3, 3.6.7.2.4.1 and 3.6.7.2.4.2, in the GBAS standards and to enhance survey accuracy compared to that specified in Annex 14. The integrity of all aeronautical data used for GBAS is to be consistent with the integrity requirements in Chapter 3, Table 3.7.2.4-1.

7.17 Type 2 message additional data blocks

- 7.17.1 The Type 2 message contains data related to the GBAS facility such as the GBAS reference point location, the GBAS Continuity/Integrity Designator (GCID) and other pertinent configuration information. A method for adding new data to the Type 2 message has been devised to allow GBAS to evolve to support additional service types. The method is through the definition of new Additional Data Blocks that are appended to the Type 2 message. In the future, more additional data blocks may be defined. Data blocks 2 through 255 are variable length and may be appended to the message after additional data block 1 in any order.
- 7.17.2 Type 2 message additional data block 1 contains information related to spatial decorrelation of errors and information needed to support selection of the GBAS Positioning Service (when provided by a given ground subsystem)
- 7.17.3 Type 2 message additional data block 2 data may be used in GRAS to enable the GRAS airborne subsystem to switch between GBAS broadcast stations, particularly if the GBAS broadcast stations utilize different frequencies. Additional data block 2 identifies the channel numbers and locations of the GBAS broadcast station currently being received and other adjacent or nearby GBAS broadcast stations.
- 7.17.4 Type 2 message additional data block 3-is reserved for future use contains information necessary to support GAST D. All FAST D ground subsystems are required to transmit a Type 2 message with additional data block 3 properly populated so that the bounding requirements are met.
- 7.17.5 Type 2 message additional data block 4 contains information necessary for a ground subsystem that supports the authentication protocols. It includes a single parameter which indicates which slots are assigned to the to the ground subsystem for VDB transmissions. Airborne equipment that supports the authentication protocols will not use data unless it is transmitted in the slots indicated by the Slot Group Definition field in the MT 2 ADB 4.

Table D-7. Example of a Type 1 VDB message

	BITS	RANGE OF			BINARY REPRESENTATION						
DATA CONTENT DESCRIPTION	USED	VALUES	RESOLUTION	VALUES	(NOTE 1)						
BURST DATA CONTENT											
Power ramp-up and settling	15				000 0000 0000 0000						
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000						
SCRAMBLED DATA	SCRAMBLED DATA										
Station slot identifier (SSID)	3	_	_	Е	100						
Transmission length (bits)	17	0 to 1 824 bits	1 bit	536	000 0000 1000 0110 00						
Training sequence FEC	5	_	_	_	0000 1						
APPLICATION DATA MESSAGE BLO	CK										
Message Block (Type 1 message)											
Message Block Header	Message Block Header										
Message block identifier	8	_	_	Normal	1010 1010						
GBAS ID	24	_	_	BELL	0000 1000 0101 0011 0000 1100						

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	61	0011 1101
Message (Type 1 example)					
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	1st of pair	01
Number of measurements	5	0 to 18	1	4	0 0100
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10 ⁻³ m/m	5 × 10-6m/m	1 × 10-4	0001 0100
Ephemeris CRC	16	_	_	_	0000 0000 0000 0000
Source availability duration	8	0 to 2 540 s	10 s	Not provided	1111 1111
Measurement Block 1			l		
Ranging source ID	8	1 to 255	1	2	0000 0010
Issue of data (IOD)	8	0 to 255	1	255	1111 1111
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.0 m	0000 0000 0110 0100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	-0.2 m/s	1111 1111 0011 1000
- σpr_gnd	8	0 to 5.08 m	0.02 m	0.98 m	0011 0001
B ₁	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B ₂	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B ₃	8	±6.35 m	0.05 m	-0.25 m	1111 1011
B ₄	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Issue of data (IOD)	8	0 to 255	1	126	0111 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	–1.0 m	1111 1111 1001 1100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	+0.2 m/s	0000 0000 1100 1000
σ _{pr_gnd}	8	0 to 5.08 m	0.02 m	0.34 m	0001 0001
B ₁	8	±6.35 m	0.05 m	+0.20 m	0000 0100
B ₂	8	±6.35 m	0.05 m	+0.30 m	0000 0110
B ₃	8	±6.35 m	0.05 m	-0.50 m	1111 0110
B ₄	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 3	U	±0.55 III	0.00111	Not used	1000 0000
Ranging source ID	8	1 to 255	1	12	0000 1100
Issue of data (IOD)	8	0 to 255	1	222	1101 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.11 m	0000 0000 0110 1111
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	-0.2 m/s	1111 1111 0011 1000
, ,	8	0 to 5.08 m	0.001 m/s	1.02 m	0011 0011
σρr_gnd B ₁	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B ₂	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B ₃	8	±6.35 m	0.05 m	-0.25 m	1111 1011
B ₄	8	±6.35 m	0.05 m	Not used	1000 0000
Measurement Block 4	O	±0.55 III	0.03 111	Not useu	1000 0000
Ranging source ID	8	1 to 255	1	23	0001 0111
Issue of data (IOD)	8	0 to 255	1	80	0101 0000
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	–2.41 m	1111 1111 0000 1111
. , ,			0.01 m/s	-2.41 m -0.96 m/s	1111 1110 0100 0111
Range rate correction (RRC)	16 8	±32.767 m			0000 1000
O pr_gnd	8	0 to 5.08 m	0.02 m	0.16 m +0.20 m	
B ₁		±6.35 m	0.05 m		0000 0100
B ₂	8	±6.35 m	0.05 m	+0.30 m	0000 0110

	BITS	RANGE OF			BINARY REPRESENTATION		
DATA CONTENT DESCRIPTION	USED	VALUES	RESOLUTION	VALUES	(NOTE 1)		
B ₃	8	±6.35 m	0.05 m	–0.50 m	1111 0110		
B ₄	8	±6.35 m	0.05 m	Not used	1000 0000		
Message Block CRC	32		_	_	1100 0010 1111 0011 0000 1011 1100 1010		
APPLICATION FEC	48		_	_	0110 0011 1110 1001 1110 0000 1110 1101 0010 1001 0111 0101		
Input to the bit scrambling	0 46 10	0 46 10 10 55 30 CA 10 80 BC 17 C2 20 28 00 00 FF 40 FF 26 00 1C FF 8C 40 C0 DF 01 20 7E 39 FF 13 00 88 20 60 6F 01 30 7					
(Note 2)			F6 00 1C	FF CC 40 A0 DF	F 01 E8 0A F0 FF 02 3F 10 20 60 6F 01 53 D0 CF 43 AE 94 B7 07 97 C6		
Output from the bit scrambling	0 60	0 60 27 98 1F 2F D2 3B 5F 26 C2 1B 12 F4 46 D0 09 81 B6 25 1C 18 D0 7C 2A 7F B9 55 A8 B0 27 17 3A 60 EB 5F 1B 3B A5					
(Note 3)		FE	RESOLUTION VALUES 0.05 m		3 4E D7 79 D2 E1 AD 95 E6 6D 67 12 B3 EA 4F 1A 51 B6 1C 81 F2 31		
Fill bits	0 to 2	_	_	0			
Power ramp-down	9	_	_	_	000 000 000		
D8PSK Symbols (Note 4)					35772 26234621 45311123 22460075 52232477 16617052 04750422 71513 51047466 13171745 10622642 17157064 67345046 36541025 07135576 55745512 222		

- Notes.— 1. Th The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in
- This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit. In this example fill bits are not scrambled. 2. 3. 4.
- This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of 5 $\pi/4$ radians), relative to the phase of the first symbol.

Table D-7A. Example of a Type 101 VDB message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3			Е	100
Transmission length (bits)	17	0 to 1824 bits	1 bit	416	0000000110100000
Training sequence FEC	5				11011
APPLICATION DATA MESSAGE BLO	CK				
Message Block (Type 101 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8,101	1	101	0110 0101
Message length	8	10 to 222 bytes	1 byte	46	0010 1110
Message (Type 101 example)					
Modified Z-count	14	0 to 1199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	1st of pair	01
Number of measurements	5	0 to 18	1	4	0 0100
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation Parameter (P)	8	0 to 1.275 × 10 ⁻³ m/m	5 × 10 ⁻⁶ m/m	0.115 × 10 ⁻³ m/m	0001 0111
Ephemeris CRC	16			0	0000 0000 0000 0000
Source availability duration	8	0 to 2540 s	10 s	Not provided	1111 1111
Number of B parameters	1	0 to 1	1	0	0
Spare	7			0	000 0000
Measurement Block 1					
Ranging source ID	8	1 to 255	1	2	0000 0010
Issue of data (IOD)	8	0 to 255	1	255	1111 1111
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+3.56 m	0000 0001 0110 0100
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.011 m/s	1111 1111 1111 0101
$\sigma_{ m pr_gnd}$	8	0 to 50.8 m	0.2 m	9.8 m	0011 0001
Measurement Block 2					
Ranging source ID	8	1 to 255	1	4	0000 0100
Issue of data (IOD)	8	0 to 255	1	126	0111 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	-1.0 m	1111 1111 1001 1100
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	+0.002 m/s	0000 0000 0000 0010
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	3.4 m	0001 0001
Measurement Block 3					
Ranging source ID	8	1 to 255	1	12	0000 1100
Issue of data (IOD)	8	0 to 255	1	222	1101 1110
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+4.11 m	0000 0001 1001 1011
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.029 m/s	1111 1111 1110 0011
$\sigma_{\mathrm{pr_gnd}}$	8	0 to 50.8 m	0.2 m	10.2 m	0011 0011
Measurement Block 4					
Ranging source ID	8	1 to 255	1	23	0001 0111

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)			
Issue of data (IOD)	8	0 to 255	1	80	0101 0000			
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	-2.41 m	1111 1111 0000 1111			
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.096 m/s	1111 1111 1010 0000			
σ_{pr_gnd}	8	0 to 50.8 m	0.2 m	1.6 m	0000 1000			
Message Block CRC	32				1000 1000 1001 1111 0111 1000 0000 0100			
APPLICATION FEC	48				1100 1100 1110 0110 1111 0110 1100 1110 1101 0110 0110 0010			
Input to the bit scrambling (Note 2)	0 41 60	0 41 60 1B 55 73 A4 A8 A6 74 17 C2 20 E8 00 00 FF 00 40 FF 26 80 AF FF 8C 20 7E 39 FF 40 00 88 30 7B D9 80 C7 FF CC E8 0A F0 FF 05 FF 10 20 1E F9 11 46 6B 73 6F 67 33						
Output from the bit scrambling (Note 3)	0 67 5	0 67 57 93 1F 6C BC 83 79 EE C2 1B 12 34 46 D0 09 C1 09 FC 3A 84 80 0F E6 9F 18 6D 77 8E 1E 60 19 1B BA FF BC AB 6 26 7B E7 BC CE FA 0B D3 C4 43 C8 E0 B6 FA 42 84 A						
Fill bits	0 to 2			0				
Power ramp-down	9				000 000 000			
D8PSK Symbols (Note 4)	00000	00000035 11204546 31650105 06345463 57026113 51374661 15123376 12066670 44776307 04225000 02735027 73373152 13230100 04706272 74137202 47724524 12715704 15442724 01101677 44571303 66447212 222						

- 1. The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.
- 2. This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.
- 3. In this example, fill bits are not scrambled.
- 4. This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of $5\pi/4$ radians), relative to the phase of the first symbol.

Table D-8. Example of Type 1 and Type 2 VDB messages in a single burst

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	_	_	Е	10 0
Transmission length (bits)	17	0 to 1 824 bits	1 bit	544	000 0000 1000 1000 00
Training sequence FEC	5	_	_	_	0000 0
APPLICATION DATA					
Message Block 1 (Type 1 message)					
Message Block Header					
Message block identifier	8	_	_	Normal	1010 1010
GBAS ID	24	_	_	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 1 example)			. 2,10		00011100
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	2nd of pair	11
Number of measurements	5	0 to 18	1	1	0 0001
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation	0	0 to 1.275 ×	1	OIALI	000
Parameter (P)	8	10 ⁻³ m/m	5 × 10 ⁻⁶ m/m	0 (SBAS)	0000 0000
Ephemeris CRC	16	_	_	0	0000 0000 0000 0000
Source availability duration	8	0 to 2 540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	122	0111 1010
Issue of data (IOD)	8	0 to 255	1	2	0000 0010
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+1.0 m	0000 0000 0110 0100
Range rate correction (RRC)	16	±32.767 m	0.001 m/s	–0.2 m/s	1111 1111 0011 1000
$\sigma_{\text{pr_gnd}}$	8	0 to 5.08 m	0.02 m	1.96 m	0110 0010
B ₁	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B ₂	8	±6.35 m	0.05 m	+0.15 m	0000 0011
B ₃	8	±6.35 m	0.05 m	–0.25 m	1111 1011
B ₄	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block 1 CRC	32	_	_	-	1011 0101 1101 0000 1011 1100 0101 0010
Message Block 2 (Type 2 message)					
Message Block Header					
Message block identifier	8	_	_	Normal	1010 1010
GBAS ID	24	_	_	BELL	0000 1000 0101 0011 0000 1100
Message type identifier	8	1 to 8	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	34	0010 0010
Message (Type 2 example)			ıt.		
GBAS reference receivers	2	2 to 4	1	3	01
Ground accuracy designator letter	2	_	_	В	01
Spare	1	_	_	0	0
GBAS continuity/integrity designator	3	0 to 7	1	1	001
Local magnetic variation	11	±180°	0.25°	58° E	000 1110 1000

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
Spare	5	- VALUE	—	0	0000 0
Overt_iono_gradient	8	0 to 25.5 × 10-6 m/m	0.1 × 10 ⁻⁶ m/m	0	0000 0000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 to 255	1	20	0001 0100
Latitude	32	±90.0°	0.0005 arcsec	45°40'32" N	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	±180.0°	0.0005 arcsec	93°25'13''W	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference Station Data Selector	8	0 to 48	1	5	0000 0101
Maximum Use Distance (D _{max})	8	2 to 510 km	2 km	50 km	0001 1001
K _{md_e_POS,GPS}	8	0 to 12.75	0.05	6	0111 1000
K _{md_e,GPS}	8	0 to 12.75	0.05	5	0110 0100
K _{md_e_POS,GLONASS}	8	0 to 12.75	0.05	0	0000 0000
K _{md_e,GLONASS}	8	0 to 12.75	0.05	0	0000 0000
Message Block 2 CRC	32	_	_	_	0101 1101 0111 0110 0010 0011 0001 1110
Application FEC	48				1110 1000 0100 0101 0011 1011 0011 1011 0100 0001 0101 0010
Input to the bit scrambling (Note 2)	0 41 10) 26 00 1C FF 46 40 C0 DF 01 4A 3D 0B AD 55 30 CA 10 40 44 A4 17 17 EB E5 3A 80 A0 98 1E 26 00 00 78 C4 6E BA 4A 82 DC DC A2 17
Output from the bit scrambling (Note 3)	0 67 2				F 09 25 1C 18 D0 B6 2A 7F B9 55 C2 F3 15 45 7C 50 A9 6F 3B 10 00 F7 CA 62 C8 D9 12 25 5E 13 2E 13 E0 42 44 37 45 68 29 5A B9 55 65
Fill bits	0 to 2	_	_	1	0
Power ramp-down	9	_	_	_	000 000 000
D8PSK Symbols (Note 4)					01336 62023576 12066670 74007653 30010255 31031274 26172772 42057 66270254 17431214 03421036 70316613 46567433 66547730 34732201 40607506 014444

- The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.

 This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.
- In this example fill bits are not scrambled.
- This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of 5 $\pi/4$ radians), relative to the phase of the first symbol.

Table D-8A. Example of Type 1 and Type 2 VDB messages with additional data blocks 1 and 2

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3			Е	100
Transmission length (bits)	17	0 to 1824 bits	1 bit	592	0000001001010000
Training sequence FEC	5				10110
APPLICATION DATA					
Message Block 1 (Type 1 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8	1	1	0000 0001
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 1 example)	•	.,	,	-	
Modified Z-count	14	0 to 1199.9 s	0.1 s	100 s	00 0011 1110 1000
Additional message flag	2	0 to 3	1	2nd of pair	11
Number of measurements	5	0 to 18	1	1	0 0001
Measurement type	3	0 to 7	1	C/A L1	000
Ephemeris Decorrelation	<u> </u>	0 to			
Parameter (P)	8	1.275 × 10 ⁻³ m/m	5 × 10 ⁻⁶ m/m	0 (SBAS)	0000 0000
Ephemeris CRC	16			0	0000 0000 0000 0000
Source availability duration	8	0 to 2540 s	10 s	Not provided	1111 1111
Measurement Block 1					
Ranging source ID	8	1 to 255	1	122	0111 1010
Issue of data (IOD)	8	0 to 255	1	2	0000 0010
Pseudo-range correction (PRC)	16	±327.67 m	0.01 m	+2.09 m	0000 0000 1101 0001
Range rate correction (RRC)	16	±32.767 m/s	0.001 m/s	-0.2 m/s	1111 1111 0011 1000
$\sigma_{\text{pr_gnd}}$	8	0 to 5.08 m	0.02 m	1.96 m	0110 0010
B1	8	±6.35 m	0.05 m	+0.10 m	0000 0010
B2	8	±6.35 m	0.05 m	+0.15 m	0000 0011
В3	8	±6.35 m	0.05 m	−0.25 m	1111 1011
B4	8	±6.35 m	0.05 m	Not used	1000 0000
Message Block 1 CRC	32				00110010 10100100 11001011 00110000
Message Block 2 (Type 2 message)					
Message Block Header					
Message block identifier	8			Normal	1010 1010
GBAS ID	24			ERWN	00010101 00100101 11001110
Message type identifier	8	1 to 8	1	2	0000 0010
Message length	8	10 to 222 bytes	1 byte	40	0010 1000
Message (Type 2 example)		-			
GBAS reference receivers	2	2 to 4	1	3	01
Ground accuracy designator letter	2			В	01
Spare	1			0	0
GBAS continuity/integrity designator	3	0 to 7	1	1	001
,,		-			1

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)		
Spare	5			0	0000 0		
Overt_iono_gradient	8	0 to 25.5 × 10 ⁻⁶ m/m	0.1 × 10-6m/m	0	0000 0000		
Refractivity index	8	16 to 781	3	379	1111 1001		
Scale height	8	0 to 25 500 m	100 m	100 m	0000 0001		
Refractivity uncertainty	8	0 to 255	1	20	0001 0100		
Latitude	32	±90.0°	0.0005 arcsec	45°40'32" N	0001 0011 1001 1010 0001 0001 0000 0000		
Longitude	32	±180.0°	0.0005 arcsec	93°25'13" W	1101 0111 1110 1000 1000 1010 1011 0000		
Ellipsoid height	24	±83 886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111		
Additional Data Block 1							
Reference Station Data Selector	8	0 to 48	1	5	0000 0101		
Maximum Use Distance (Dmax)	8	2 to 510 km	2 km	50 km	0001 1001		
K _{md_e_POS,GPS}	8	0 to 12.75	0.05	6	0111 1000		
K _{md_e,GPS}	8	0 to 12.75	0.05	5	0110 0100		
K _{md_e_POS,GLONASS}	8	0 to 12.75	0.05	0	0000 0000		
K _{md_e,GLONASS}	8	0 to 12.75	0.05	0	0000 0000		
Additional Data Blocks							
Additional Data Block Length	8	2 to 255	1	6	0000 0110		
Additional Data Block Number	8	2 to 255	1	2	0000 0010		
Additional Data Block 2							
Channel Number	16	20001 to 39999	1	25001	0110 0001 1010 1001		
ΔLatitude	8	±25.4°	0.2°	5.2	0001 1010		
ΔLongitude	8	±25.4°	0.2°	-3.4	1110 1111		
Message Block 2 CRC	32				11100000 01110010 00011101 00100100		
Application FEC	48				1110 0010 0101 1100 0000 1111 1010 1011 0011 0100 0100 0000		
Input to the bit scrambling (Note 2)					D FF 5E 40 8B 00 1C FF 46 40 C0 DF 01 0C D3 25 4C 55 73 A4 A8 40 EB E5 3A 80 A0 98 1E 26 00 00 60 40 95 86 58 F7 24 B8 4E 07 02 2C D5 F0 3A 47		
Output from the bit scrambling (Note 3)		0 64 A7 85 1F 6C BC 83 5F A2 C2 1A B2 DC 46 D0 09 9F 09 88 1C 18 D0 B6 2A 7F B9 55 84 1D 3B A4 7C 13 C7 D7 3B 40 00 D9 71 17 DC 4B 2D 1B 7B 83 72 D4 F7 CA 62 C8 D9 12 25 5E 13 2E 13 E0 5A C0 CC 79 7A 5C A2 DD B9 75 B6 95 64 52 78 3F					
Fill bits	0 to 2			1	0		
Power ramp-down	9				000 000 000		
D8PSK Symbols (Note 4)			00000035 11204546 31650107 56336574 60137224 74145772 26467132 56422234 30443700 05565722 06506741 73647332 27242654 63345227 31575333 33421734 42751235 60342057 66270254 17431214 03421036 70316613 46567433 62077121 37275607 55315167 17135031 34423411 274444				

- 1. The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table
- 2. This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.
- 3. In this example, fill bits are not scrambled.
- 4. This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of $5\pi/4$ radians), relative to the phase of the first symbol.

Table D-8B Example of Type 2 Message Containing Data Blocks 1, 3 and 4

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)				
BURST DATA CONTENT									
Power ramp-up and settling	15	-	-	-	000 0000 0000 0000				

	BITS	RANGE OF			BINARY REPRESENTATION
DATA CONTENT DESCRIPTION	USED	VALUES	RESOLUTION	VALUES	(NOTE 1)
	48	-	-	-	0100 0111 1101 1111 1000 1100
Synchronization and ambiguity resolution					0111 0110 0000 0111 1001 0000
SCRAMBLED DATA	1		 		100
Station Slot Identifier	3 17	- 1004 bits		E 1704	100 0 0000 0110 1010 1000
Transmission Length Training Sequence FEC	5	0 – 1824 bits	1 bit -	1704	01000 0110 1010 1000
APPLICATION DATA	J	-	-		01000
Message Block 1 (Type 2 Message)					
Message Block Header					
Message Block Identifier	8	-	-	Normal	1010 1010
GBAS ID	24	-	-	BELL	000010 000101 001100 001100
Message Type Identifier	8	1 – 101	1	2	0000 0010
Message Length	8	10 – 222 bytes	1 byte	37 43	0010 0101 0010 1011
Message (Type 2 Example)	1 0	0.4			0.4
GBAS reference receivers	2	2 - 4	1	3 B	01
Ground accuracy designator letter Spare	1	-	-	- B	01
GBAS continuity/integrity designator	3	0 – 7	1	2	010
Local magnetic variation	11	± 180°	0.25°	E58.0°	000 1110 1000
Spare	5	± 100	-	-	0000 0
Overt_iono_gradient	8	0 - 25.5 x10-6 m/m	0.1 x10-6 m/m	4x10-6	0010 1000
Refractivity index	8	16 to 781	3	379	1111 1001
Scale height	8	0 – 25,500 m	100 m	100 m	0000 0001
Refractivity uncertainty	8	0 – 255	1	20	0001 0100
Latitude	32	± 90.0°	0.0005 arcsec	N45° 40' 32" (+164432")	0001 0011 1001 1010 0001 0001 0000 0000
Longitude	32	± 180.0°	0.0005 arcsec	W93° 25' 13" (-336313")	1101 0111 1110 1000 1000 1010 1011 0000
Ellipsoid height	24	± 83,886.07 m	0.01 m	892.55 m	0000 0001 0101 1100 1010 0111
Additional Data Block 1					
Reference Station Data Selector	8	0 – 48	1	5	0000 0101
Maximum Use Distance (D _{max})	8 8	2 – 510 km	2 km	50 km	0001 1001
K _{md_e_POS,GPS} K _{md_e_C,GPS}	8	0 – 12.75 0 – 12.75	0.05 0.05	<u>6</u> 5	0111 1000 0110 0100
Kmd_e C,GPS Kmd e POS,GLONASS	8	0 - 12.75	0.05	0	0000 0000
K _{md e C,GLONASS}	8	0 – 12.75	0.05	0	0000 0000
Additional Data Block 4		0 120	0.00	<u> </u>	3333 3333
Additional Data Block Length	8	3	1 byte	3	0000 0011
Additional Data Block Number	8	4	1	4	0000 0100
Slot Group Definition	8	-	-	EF	0011 0000
Additional Data Block 3					
Additional Data Block Length	8	6	1 byte	6	0000 0110
Additional Data Block Number	8	3	1	3	0000 0011
K _{md_e_D,GPS}	8	0 to 12.75 0 to 12.75	0.05 0.05	5.55 0	0110 1111 0000 0000
K _{md_e_D,GLONASS} o vert_iono_gradient_D	8	0 – 25.5 x 10-6	0.05 0.1 x 10 ⁻⁶ m/m	4 x 10-6	0010 1000
Over_iono_gradieni_b	_	m/m	2.1 X 13 11/111	1 1 10 0	55.15.1666
Spare	8	Ŧ		ŀ	0000 0000
Message Block 1 CRC	32	-	-	-	1100 0101 1110 0000 0010 0110 1100 10110000 0010 0111 0000 1111 1111 1111 0011
Message Block 2 (Type 3 Message)					
Message Block Header					
Message block identifier	8	-	-	Normal	1010 1010
GBAS ID	24	- 4 404	-	BELL	000010 000101 001100 001100
Message type identifier Message length	8	1 - 101 N/A	1 1 buto	3 170 164	0000 0011 1010 1010 1010 0100
Message (Type 3 example)	ŏ	IN/A	1 byte	170 104	1010 1010 1010
Filler	1280 1232	-	_	-	1010 1010 1010 1010
Message Block 2 CRC	32	-	-	-	1001 0000 1110 1100 1101 1001 1011 1010 0110 1101 1011 1001 1110 0100 1110 0100
Application FEC	48	-	-	-	0000 1000 0010 0011 1100 1011 1101 0000 1101 0110 1011 0101 1101 0010 1001 0000 1111 0000 1011 1010 1000 1111 0110 0010

	BITS	RANGE OF			BINARY REPRESENTATION				
DATA CONTENT DESCRIPTION	USED	VALUES	RESOLUTION	VALUES	(NOTE 1)				
Input to Bit Scrambling (Note 2)	0 45 58 02 55 30 CA 10 40 A4 A2 17 00 14 9F 80 28 00 88 59 C8 0D 51 17 EB E5 3A 80 A0 98 1E 26 00 00								
	CO 20 OC D3 64 07 A3 55 30 CA 10 CO 55 55 55 55 55 55 55 55 55 55 55 55 55								
	55 55 55 5		55 55 55 55 55 55 5	55 55 55 55 55 55 55 55 55 55 55 55 55 	55 55 55 55 55 55 55 55 55 55 55				
	00 00 00 0	5 55 55 55 55 55 55	55 55 55 55 55 55 5	55 55 55 55 55 55 55 55 55 55 5	55 55 55 55 55 55 55 55 55 55 55				
	55 55 55 55 55 55 55 55 55 55 55 55 55								
					55 55 55 55 55 55 55 55 55 55 5D				
					4 9F 80 28 00 88 59 C8 0D 51 17 EB				
					55 30 CA 10 C0 25 55 55 55 55 55 55				
					55 55 55 55 55 55 55 55 55 55 55				
					55 55 55 55 55 55 55 55 55 55 55				
					55 55 55 55 55 55 55 55 55 55 55				
					55 55 55 55 55 55 55 55 55 55 55				
		5 55 55 55 55 27 27			=======================================				
Output from the bit scrambling	0 00 0. 0.		02 02 00 20 00	DE C1 C1 5A D4 09					
(Note 3)	007.00.	1 01 00 00 BE IE 10	001 10 00 710 01 2		C7 D0 93 58 5D 46 B5 6F D5 0C AA				
		0 1 1 L 1 L 0 L 7 1	7 17 2D AD F4 0B	20 02 04 01 00 24 00	E9 58 FA B8 CU 38 99 C/ BB 6C 3D				
					NB2 FF DF 33 4D DD 74 B5 28 2A 06				
	0.0.027			00 02 / 8 / 20 00 00 0	66 2E EE OF OE 72 71 21 25 E5 EB 14				
	FD A8 CB F8 83 38 62 39 1E 3A 4E 3E 8E 30 71 D9 24 BA 17 C1 AC 9B F7 BC D3 C8 A3 78 1D 39 B5 C4 2B								
	69 FD 04 CA 68 81 07 9A 64 8F 6B 39 7D 2A 34 D0 6F EA0 63 6F 8A 1F 2F D2 3B 9F 4E 77 CE 32 C8 D9 50								
	DE C1 C1 5A D4 09 7E E7 81 5A 5C D4 28 56 00 CE 29 60 A3 5F 77 34 64 38 71 03 43 04 FA 15 B3 8F 8A								
	13 B6 1D AC 78 B6 C7 D0 93 58 5D 46 B5 6F D5 0C AA 77 FE D3 30 A2 27 E1 EC E4 F7 17 2D AD F4 0B 29								
	82 04 61 96 E4 50 E9 58 FA B8 C0 38 99 C7 BB 6C 3D 09 CA 7B 7E C2 CF 60 8D 18 75 B9 2B C5 FC 94 C8								
	57 79 52 C5 5F 6A B2 FF DF 33 4D DD 74 B5 28 2A 06 01 91 9B A4 43 E9 63 05 1D 95 B4 54 29 56 05 51 95								
	5B AA BC 00 36 66 2E EE 0F 0E 72 71 21 25 E5 EB 14 FD A8 CB F8 83 38 62 39 1E 3A 4E 3E 8E 30 71 D9								
	24 BA 17 C1 AC 9B F7 BC D3 C8 A3 78 1D 39 B5 C4 2B 69 FD 04 CA 68 81 07 9A 1E 33 C1 86 96 B0 62 0C A2 B1								
Fill Bits	0 to 2	_	I .	21	00				
Power ramp-down	9	_	_		000 000 000				
D8PSK Symbols (Note 4)	•	I 11204546 31650102	1 46331130 130677/	I 16 52605627 35/16712	22 62533573 77100603 75554273				
Dor SK Symbols (Note 4)	01666461	/1204040 01000102 /1203311 /21113/0	1/733657 2730266	33 77076361 <i>44</i> 30100	11 17175104 35263707 43007132				
	40135774	<u> 170120077 42777040</u> <u>17012022 52546153</u>	57/25/5/ 25/130	50 77070007 4400700 51 54022547 0162275	77 17 17 0 10 1 00 2 00 10 1 10 00 1 10 2				
	56622615	23311312 51275055	01 120101 201 1000	S5 63665236 0405244	7 35155017 73303745 61650521				
	000220.0.		TITOLOTO TOL TLOS	000000000000000000000000000000000000000	1 00100011 100001 10 01000021				
	06765616 04756006 16264736 30530735 02426407 53610061 12111501 04147002 72512117 74672621 42254251 12533720 37475054 44460104 57516674 46523401 22503075 25125742 03431633 22607072								
	42254251 12533720 37475054 44450104 57515674 46523401 22503075 25125742 03431633 22507072 37230050 35463673 43300570 12353363 77140357 42715724 03470633 30354042 67720645 27225703								
	37230050 35453673 43300570 12353363 77140357 42715724 03470633 30354042 67720645 27225703 50111005 40736127 14021742 36572477 13042222 2 16750066 17666015 61400324 74057621 34465623								
					06 02750707 50746304 07355072				
					0 44465023 70575310 16110561				
					61 63063260 35751732 06143314				
					7 77713437 02041127 71056734				
					23 45606616 22473602 75240257				
					0 65512232 00600777 7				

- The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the
- order specified in the table.

 This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.
- In this example, fill bits are not scrambled. This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of $5\pi/4$ radians), relative to the phase of the first symbol.

Table D-9. Example of a Type 4 message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)		
BURST DATA CONTENT	BURST DATA CONTENT						
Power ramp-up and settling	15				000 0000 0000 0000		
Synchronization and ambiguity resolution	48				010 0011 1110 1111 1100 0110 0011 1011 0000 0011 1100 1000 0		
SCRAMBLED DATA							
Station slot identifier (SSID)	3	_	_	D	01 1		
Transmission length (bits)	17	0 to 1 824 bits	1 bit	784	000 0000 1100 0100 00		
Training sequence FEC	5	_	_	_	0000 0		

APPLICATION DATA MESSAGE BLOC	CK				
Message Block (Type 4 message)					
Message Block Header					
Message block identifier	8	_	_	Normal	1010 1010
GBAS ID	24	_	_	CMJ	0000 1100 1101 0010 1010 0000
Message type identifier	8	1 to 8	1	4	0000 0100
Message length	8	10 to 222 bytes	1 byte	92	0101 1100
Message (Type 4 example)	U	10 to 222 bytes	1 byte	32	01011100
FAS Data Set 1					
Data set length	8	2 to 212	1 byte	41	0010 1001
FAS Data Block 1		2 10 2 12	1 byte	71	0010 1001
Operation type	4	0 to 15	1	0	0000
	4	0 to 15	1	15	1111
SBAS service provider	32	0 10 15	l l	LFBO	0000 1100 0000 0110 0000 0010 0000 1111
Airport ID		-	_		
Runway number	6	0 to 36	1	15	00 1111
Runway letter	2			R	01
Approach performance designator	3	0 to 7	1	CAT 1	001
Route indicator	5	_	_	С	00011
Reference path data selector (RPDS)	8	0 to 48	1	3	0000 0011
Reference path identifier	32	_	_	GTBS	0000 0111 0001 0100 0000 0010 0001 0011
LTP/FTP latitude	32	±90.0°	0.0005 arcsec	43.6441075°N	0001 0010 1011 1010 1110 0010 1000 0110
LTP/FTP longitude	32	±180.0°	0.0005 arcsec	1.345940°E	0000 0000 1001 0011 1101 1110 1001 0000
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m	197.3	0001 1011 1011 0101
Δ FPAP latitude	24	±1°	0.0005 arcsec	-0.025145°	1111 1101 0011 1100 1100 1100
Δ FPAP longitude	24	±1°	0.0005 arcsec	0.026175°	0000 0010 1110 0000 0010 1100
Approach threshold crossing height (TCH)	15	0 to 1 638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)	17.05 m	000 0001 0101 0101
Approach TCH units selector	1	0 = ft; 1 = m	_	metres	1
Glide path angle (GPA)	16	0 to 90°	0.01°	3°	0000 0001 0010 1100
Course width	8	80.0 to 143.75 m	0.25 m	105	0110 0100
Δ Length offset	8	0 to 2 032 m	8 m	0	0000 0000
FAS Data Block 1 CRC	32	_	_	_	1010 0010 1010 0101 1010 1000 0100 1101
FASVAL/Approach status	8	0 to 25.4	0.1 m	10	0110 0100
FASLAL/Approach status	8	0 to 50.8	0.2 m	40	1100 1000
FAS Data Set 2					
Data set length	8	2 to 212	1 byte	41	0010 1001
FAS Data Block 2		2.02.12	. 2)10		
Operation type	4	0 to 15	1	0	0000
SBAS service provider	4	0 to 15	1	01	0000
Airport ID	32	0 10 10	1	LFBO	0000 1100 0000 0110 0000 0010 0000 1111
· · · · · · · · · · · · · · · · · · ·		-	_		
Runway number	6	0 to 36	1	33	10 0001
Runway letter	2		_	R	01
Approach performance designator	3	0 to 7	1	CAT 1	001
Route indicator	5	_		A	0000 1
Reference path data selector (RPDS)	8	0 to 48	1	21	0001 0101
Reference path identifier	32	_	_	GTN	0000 0111 0001 0100 0000 1110 0010 0000
LTP/FTP latitude	32	±90.0°	0.0005 arcsec	43.6156350°N	0001 0010 1011 0111 1100 0001 1011 1100
LTP/FTP longitude	32	±180.0°	0.0005 arcsec	1.3802350°E	0000 0000 1001 0111 1010 0011 0001 1100
LTP/FTP height	16	–512.0 to 6 041.5 m	0.1 m	200.2 m	0001 1011 1101 0010

∆FPAP latitude	24	±1°	0.0005 arcsec	0.02172375°	0000 0010 0110 0010 1111 1011	
ΔFPAP longitude	24	±1°	0.0005 arcsec	-0.0226050°	1111 1101 1000 0100 0111 1100	
Approach threshold crossing height (TCH)	15	0 to 1 638.35 m (0 to 3 276.7 ft)	0.05 m (0.1 ft)	15.25 m	000 0001 0011 0001	
Approach TCH units selector	1	0 = ft; 1 = m	_	metres	1	
Glide path angle (GPA)	16	0 to 90°	0.01°	3.01°	0000 0001 0010 1101	
Course width	8	80.0 to 143.75 m	0.25 m	105	0110 0100	
Δ Length offset	8	0 to 2 032 m	8 m	0	0000 0000	
FAS data block 2 CRC	32	_	_	_	1010 1111 0100 1101 1010 0000 1101 0111	
FASVAL/Approach status	8	0 to 25.4	0.1 m	10	0110 0100	
FASLAL /Approach status	8	0 to 50.8	0.2 m	40	1100 1000	
Message Block CRC	32	_	_	_	0101 0111 0000 0011 1111 1110 1001 1011	
APPLICATION FEC	48	_	_	_	0001 1011 1001 0001 0010 1010 1011 1100 0010 0101 1000 0101	
Input to the bit scrambling (Note 2)				0 40 60 30 86 90	0 C8 40 28 E0 61 47 5D 48 09 7B C9 00 AD D8 33 3C BF 34 07 40 AA 0 A8 04 70 28 E0 3D 83 ED 48 38 C5 E9 00 4B D8 DF 46 40 3C 21 BF 0 81 B4 80 26 00 EB 05 B2 F5 26 13 D9 7F C0 EA A1 A4 3D 54 89 D8	
Output from the bit scrambling (Note 3)				81 DD A3 F2 B5	89 CB 5C 2C CF 91 2D E2 2E 5D F3 07 1E 45 F1 53 5F C0 4F 53 E4 5 40 9D A0 17 90 12 60 64 7C CF E3 BE A0 1E 72 FF 61 6E E4 02 44 2 FD 63 D1 12 C3 5A 00 0E F8 89 FE 4C 12 0C 78 4F 9D 55 08 16 F6	
Fill bits	0 to 2	_	_	1	0	
Power ramp down	9	_	_	_	000 000 000	
D8PSK Symbols (Note 4)		0000003511204546316504322300771662170713052556673176724345377776157763461661570543615214576405133401677 5214231304443061301150266774341755603276241630527536540015247051420322575333462555437707605652760631444 6243163101353722250120760407526435103457714077770415665273600122324007402031443362754444				

- The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order

- This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit. In this example, fill bits are not scrambled.

 This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of $5\pi/4$ radians), relative to the phase of the first symbol.

Table D-10. Example of a Type 5 message

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)
BURST DATA CONTENT					
Power ramp-up and settling	15				000 0000 0000 0000
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000
SCRAMBLED DATA					
Station slot identifier (SSID)	3	_	_	D	01 1
Transmission length (bits)	17	0 to 1 824 bits	1 bit	272	000 0000 0100 0100 00
Training sequence FEC	5	_	_	_	0001 1
APPLICATION DATA MESSAGE BLO	OCK				
Message Block (Type 5 message)					
Message Block Header					
Message block identifier	8	_	_	Normal	1010 1010
GBAS ID	24	_	_	CMJ	0000 1100 1101 0010 1010 0000
Message type identifier	8	1 to 8	1	5	0000 0101
Message length	8	10 to 222 bytes	1 byte	28	0001 1100
Message (Type 5 example)			,		
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000
Spare	2	_	_	_	00
Number of impacted sources (N)	8	0 to 31	1	2	0000 0010
First impacted source					
Ranging source ID	8	1 to 255	1	4	0000 0100
Source availability sense	1		_	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	50 s	0000 101
Second impacted source	•	0.0.2.00			3000 101
Ranging source ID	8	1 to 255	1	3	0000 0011
Source availability sense	1	_	_	Will start	1
Source availability duration	7	0 to 1 270 s	10 s	200 s	0010 100
Number of obstructed approaches (A)	8	0 to 255	1	2	0000 0010
First obstructed approach		0 10 200	,		0000000
Reference path data selector (RPDS)	8	0 to 48	1	21	0001 0101
Number of impacted sources for first	8	1 to 31	1	2	0000 0010
obstructed approach (N _A)		1 10 01	1	2	0000 00 10
First impacted ranging source of first obstructed approach					
Ranging source ID	8	1 to 255	1	12	0000 1100
Source availability sense	1	_	_	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	250 s	0011 001
Second impacted ranging source of first obstructed approach					
Ranging source ID	8	1 to 255	1	14	0000 1110
Source availability sense	1	_	_	Will cease	0
Source availability duration	7	0 to 1 270 s	10 s	1 000 s	1100 100
Second obstructed approach	1				
Reference path data selector (RPDS)	8	0 to 48	1	14	0000 1110
Number of impacted sources for second obstructed approach (N _A)	8	1 to 31	1	1	0000 0001
First impacted ranging source of second obstructed approach	1				

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)	
DATA CONTENT DESCRIPTION	USED	VALUES	RESOLUTION	VALUES	(NOTE I)	
Ranging source ID	8	1 to 255	1	12	0000 1100	
Source availability sense	1		_	Will cease	0	
Source availability duration	7	0 to 1 270 s	10 s	220 s	0010 110	
Message Block CRC	32	_	_	-	1101 1011 0010 1111 0001 0010 0000 1001	
APPLICATION FEC	48	_	_	_	0011 1110 1011 1010 0001 1110 0101 0110 1100 1011 0101 1011	
Ihput to the bit scrambling (Note 2)		1 82 20 18 55 05 4B 30 A0 38 17 C0 40 20 50 C0 94 40 A8 40 30 4C 70 13 70 80 30 34 90 48 F4 DB DA D3 6A 78 5D 7C				
Output from the bit scrambling		1 A4 17 90 1F 1A 53 1B 7F A2 C2 19 72 FC 16 10 62 81 E1 43 2C 48 5F E3 1A 3F 56 60 18 86 EA 33 F3 B3 09 07 26 28				
Fill bits	0 to 2	-	_	0		
Power ramp-down	9				000 000 000	
D8PSK Symbols (Note 3)	000000	0000003511204546316504322056660551067602416124477363463220700103224006601332124166231163643777110173115 74302323445146644444				

- 1. The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in the table.
- This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit.
 Symbols are represented by their differential phase with respect to the first symbol of the message, in units of π/4 (e.g. a value of 5 rep
- Symbols are represented by their differential phase with respect to the first symbol of the message, in units of π/4 (e.g. a value of 5 represents a phase of 5π/4 radians) relative to the first symbol.

Table D-10B. Example of a Type 11 VDB message

	DITO	DANIOE OF			DIMARY DEPRESENTATION	
DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)	
BURST DATA CONTENT						
Power ramp-up and settling	15				000 0000 0000 0000	
Synchronization and ambiguity resolution	48				0100 0111 1101 1111 1000 1100 0111 0110 0000 0111 1001 0000	
SCRAMBLED DATA						
Station slot identifier (SSID)	3	=		E	100	
Transmission length (bits)	17	0 to 1 824 bits	1 bit	440	0 0000 0001 1011 1000	
Training sequence FEC	5			+	0 1011	
APPLICATION DATA MESSAGE BLOG	CK					
Message Block 1 (Type 11 message)						
Message Block Header						
Message block identifier	8			Normal	1010 1010	
GBAS ID	24			BELL	0000 1000 0101 0011 0000 1100	
Message type identifier	8	1 to 101	1	11	0000 1011	
Message length	8	10 to 222 bytes	1 byte	49	0011 0001	
Message (Type 11 example)						
Modified Z-count	14	0 to 1 199.9 s	0.1 s	100 s	00 0011 1110 1000	
Additional message flag	2	0 to 3	1	0	00	
Number of measurements	5	0 to 18	1	5	0 0101	
Measurement type	3	0 to 7	1	C/A L1	000	
Ephemeris Decorrelation Parameter (PD)	8	0 to 1.275 × 10 ⁻³ m/m	5 × 10-6m/m	1 × 10 ⁻⁴	0001 0100	
Measurement Block 1						
Ranging source ID	8	1 to 255	1	12	0000 1100	
Pseudo-range correction (PRC ₃₀)	16	±327.67 m	0.01 m	+1.04 m	0000 0000 0110 1000	

DATA CONTENT DESCRIPTION	BITS USED	RANGE OF VALUES	RESOLUTION	VALUES	BINARY REPRESENTATION (NOTE 1)		
Range rate correction (RRC ₃₀)	16	±32.767 m	0.001 m/s	-0.18 m/s	1111 1111 0100 1100		
σ pr gnd,100	8	0 to 5.08 m	0.02 m	0.96 m	0011 0000		
Opr gnd,30	8	0 to 5.08 m	0.02 m	1.00 m	0011 0010		
Measurement Block 2							
Ranging source ID	8	1 to 255	1	4	0000 0100		
Pseudo-range correction (PRC ₃₀)	16	±327.67 m	0.01 m	–1.08 m	1111 1111 1001 0100		
Range rate correction (RRC ₃₀)	16	±32.767 m	0.001 m/s	+0.18 m/s	0000 0000 1011 0100		
σ pr_gnd,100	8	0 to 5.08 m	0.02 m	0.24 m	0000 1100		
σpr_gnd,30	8	0 to 5.08 m	0.02 m	0.6 m	0001 1110		
Measurement Block 3							
Ranging source ID	8	1 to 255	1	2	0000 0010		
Pseudo-range correction (PRC ₃₀)	16	±327.67 m	0.01 m	+1.2 m	0000 0000 0111 1000		
Range rate correction (RRC ₃₀)	16	±32.767 m	0.001 m/s	0.3 m/s	0000 0001 0010 1100		
σ _{pr_gnd} ,100	8	0 to 5.08 m	0.02 m	0.64 m	0010 0000		
σpr_gnd,30	8	0 to 5.08 m	0.02 m	0.74 m	0010 0101		
Measurement Block 4	Measurement Block 4						
Ranging source ID	8	1 to 255	1	23	0001 0111		
Pseudo-range correction (PRC ₃₀)	16	±327.67 m	0.01 m	–2.64 m	1111 1110 1111 1000		
Range rate correction (RRC ₃₀)	16	±32.767 m	0.001 m/s	-0.51 m/s	1111 1110 0000 0010		
$\sigma_{\text{pr_gnd,100}}$	8	0 to 5.08 m	0.02 m	0.08 m	0000 0100		
σpr_gnd,30	8	0 to 5.08 m	0.02 m	0.14 m	0000 0111		
Measurement Block 5							
Ranging source ID	8	1 to 255	1	122	0111 1010		
Pseudo-range correction (PRC ₃₀)	16	±327.67 m	0.01 m	+0.8 m	0000 0000 0101 0000		
Range rate correction (RRC ₃₀)	16	±32.767 m	0.001 m/s	–0.25 m/s	1111 1111 0000 0110		
$\sigma_{\text{pr_gnd,100}}$	8	0 to 5.08 m	0.02 m	0.92 m	0010 1110		
σpr_gnd,30	8	0 to 5.08 m	0.02 m	1.08 m	0011 0110		
Message Block CRC	32		-	-	0010 1111 0000 0101 1101 1001 0000 1100		
APPLICATION FEC	48	-		-	1001 0011 1110 0111 1101 1100 0100 0001 0100 0101 1011 1110		
Input to the bit scrambling (Note 2)		0 47 60 1A 55 30 CA 10 D0 8C 17 C0 A0 28 30 16 00 32 FF 0C 4C 20 29 FF 2D 00 30 78 40 1E 00 34 80 04 A4 E8 1F 7F 40 7F 20 E0 5E 0A 00 60 FF 74 6C 30 9B A0 F4 7D A2 82 3B E7 C9					
Output from the bit scrambling (Note 3)	0 61	0 61 57 92 1F 2F D2 3B 0F 16 C2 19 92 F4 76 C6 F6 F3 B6 0F 50 24 06 0F 47 BF 56 2C C8 D0 1E DC A9 64 C7 97 64 2B E4 B1 51 F7 1D C1 05 7B 0C AE D6 E9 3D 7D 7D 50 41 10 BE 21 C4					
Fill bits	0 to 2			0			
Power ramp-down	9				000 000 000		
D8PSK Symbols (Note 4)	00000	00000035 11204546 31650101 42701130 13067746 60457114 40234621 31760262 76357705 07725551 13760416 17615700 43341354 25047116 53736646 34577501 64015223 34742121 71757170 16162053 65544366 41033007 777					

Notes.—

1. The rightmost bit is the LSB of the binary parameter value and is the first bit transmitted or sent to the bit scrambler. All data fields are sent in the order specified in

This field is coded in hexadecimal with the first bit to be sent to the bit scrambler as its MSB. The first character represents a single bit. In this example fill bits are not scrambled.

This field represents the phase, in units of $\pi/4$ (e.g. a value of 5 represents a phase of 5 $\pi/4$ radians), relative to the phase of the first symbol.

7.18 Type 101 message

Type 101 message is an alternative to Type 1 message developed to fit the specific needs of GRAS systems. The primary difference in the contents and application of these two message types is two-fold: (a) Type 101 message has a larger available range for σpr_gnd values and (b) ground subsystem time-to-alert is larger for a system broadcasting Type 101 messages. The first condition would typically occur in a system where a broadcast station covers a large area, such that decorrelation errors increase the upper limit of the pseudo-range correction errors. The second condition may be typical for systems where a central master station processes data from multiple receivers dispersed over a large area.

7.19 Airborne Processing for GBAS Approach Service Types

Note - In order to ensure the required performance and functional objectives for GAST D are achieved, it is necessary for the airborne equipment to meet defined performance and functional standards. The relevant minimum operational performance standards are detailed in RTCA DO-253C.

- 7.19.1 *Differential Position Solution for the GBAS Positioning Service*. The position solution used to provide position, velocity and time outputs is based on 100 second smoothed pseudoranges corrected with corrections obtained from Message Type 1 or Message Type 101.
- 7.19.2 Differential Position Solution for Approach Service GAST A, B and C. When the active Approach Service Type is A, B or C, the position solution used to generate deviations shall is based on 100 second smoothed pseudoranges corrected with corrections obtained from Message Type 1 or Message Type 101. The projection matrix, S, used to compute the position solution (Appendix B section 3.6.5.5.1.1.2) is computed based on σ_i computed using $\sigma_{pr \text{ gnd}}[i]$ from Message Type 1 or Message Type 101 and $\sigma_{iono,i}$ based on $\sigma_{vert \text{ iono gradient}}$ from Message Type 2.
- 7.19.3 Differential Position Solutions for Approach Service GAST D. When GAST D is the active Approach Service Type the airborne equipment will compute two different position solutions, one based on 30 second smoothed pseudoranges and the other based on 100 second smoothed pseudoranges. The following characterizes the standard processing required by the MOPS.
 - a) The position solution used to develop deviations is based on 30 second smoothed pseudoranges corrected with corrections obtained from Message Type 11
 - b) The projection matrix, S, used for both position solutions is computed based on σ_i computed using Sigma_PR_gnd_30s from Message Type 11 and $\sigma_{iono}[i]$ based on Sigma vert iono gradient D from Message Type 2 Additional Data Block 3.
 - c) A second position solution is computed using the projection matrix from b) and the 100 second smoothed pseudoranges corrected with corrections obtained from Message Type 1.
 - d) Both position solutions are based on the same set of satellites as used for the position solution defined in a), above.

Additional information regarding the intended use of these dual position solutions is given in section 7.5.6.1 of this attachment.

7.20 Type 11 message

Type 11 message is required for FAST D ground subsystems. The Type 11 message contains differential corrections derived from pseudorange data that has been carrier smoothed with a time constant of 30 seconds. The Type 11 message also includes alternative parameters for integrity bounding and for optimal weighting of measurements. Additional information regarding the standard processing of parameters in the Type 11 message is given in Section 7.19.

8. Signal quality monitor (SQM) design

8.1 The objective of the signal quality monitor (SQM) is to detect satellite signal anomalies in order to prevent aircraft receivers from using misleading information (MI). MI is an undetected aircraft pseudo-range differential error greater than the maximum error (MERR) that can be tolerated. For GAST D equipment additional requirements are in place to assure detection before the differential pseudorange error reaches a specified value (see Appendix B section 3.6.7.3.3). These large pseudorange errors are due to C/A code correlation peak distortion caused by satellite payload failures. If the reference receiver used to create the differential corrections and the aircraft receiver have different measurement mechanizations (i.e. receiver bandwidth and tracking loop correlator spacing), the signal distortion affects them differently. The SQM must protect the aircraft receivers in cases when mechanizations are not similar. SQM performance is further defined by the probability of detecting a satellite failure and the probability of incorrectly annunciating a satellite failure.

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- 8.11.4 For aircraft receivers using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11.
- 8.11.4.1 For GBAS Airborne Equipment Class D (GAEC D) receivers using early-late correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-11, regions 2, 3 or 4 only.
- 8.11.5 For aircraft receivers using early-late correlators and tracking GLONASS satellites, the precorrelation bandwidth of the installation, the correlator spacing, and the differential group delay are within the ranges as defined in Table D-12.
- 8.11.5.1 For GBAS Airborne Equipment Class D (GAEC D) aircraft receivers using early-late correlators and tracking GLONASS satellites, the precorrelation bandwidth of the installation, the correlator spacing, and the differential group delay are within the ranges as defined in Table D-12 regions 2 and 3 only.
- 8.11.6 For aircraft receivers using double-delta correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Tables D-13A and D-13B.
- 8.11.6.1 For GBAS Airborne Equipment Class D (GAEC D) receivers using double-delta correlators and tracking GPS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-13 regions 2 and 3 only.
- 8.11.7 For aircraft receivers using the early-late or double-delta correlators and tracking SBAS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-14.
- 8.11.7.1 For GBAS Airborne Equipment Class D (GAEC D) receivers using the early-late or double-delta correlators and tracking SBAS satellites, the precorrelation bandwidth of the installation, the correlator spacing and the differential group delay are within the ranges defined in Table D-14 region 2 only.

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14. Modelling of residual errors

- 14.1 Application of the integrity requirements for SBAS and GBAS requires that a model distribution be used to characterize the error characteristics in the pseudo-range. The HPL/LPL and VPL models (see 7.5.3) are constructed based on models of the individual error components (in the pseudorange domain) that are independent, zero-mean, normal distributions. The relationship between this model and the true error distribution must be defined.
- 14.2 One method of ensuring that the protection level risk requirements are met is to define the model variance (σ^2), such that the cumulative error distribution satisfies the conditions:

$$\int\limits_{v}^{\infty}f(x)dx\leq Q\bigg(\frac{y}{\sigma}\bigg) \ \text{for all} \ \bigg(\frac{y}{\sigma}\bigg) \ \geq 0 \ \text{and}$$

$$\int_{-\infty}^{y} f(x) dx \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \left(\frac{y}{\sigma}\right) \ge 0 \text{ and }$$

where

f(x) = probability density function of the residual aircraft pseudo-range error component; and

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{t^2}{2}} dt.$$

- 14.3 This method can be directly applied when the error components have zero-mean, symmetrical and unimodal probability density functions. This is the case for the receiver contribution to corrected pseudo-range error, since the aircraft element is not subjected to low-frequency residual multipath errors.
- 14.4 This method can be extended to address non-zero-mean, residual errors by inflating the model variance to compensate for the possible effect of the mean in the position domain.
- 14.5 Verification of the pseudo-range error models must consider a number of factors including:
 - a) the nature of the error components;
 - b) the sample size required for confidence in the data collection and estimation of each distribution;
 - c) the correlation time of the errors; and
 - d) the sensitivity of each distribution to geographic location and time.

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Conceptual Framework for the Proposal for GBAS to Support CAT III Operations

(Attachment H to the report of the 10-20 November 2009 meeting of the Navigation Systems Panel (NSP) Working Group of the Whole (WGW))

Navigation Systems Panel (NSP)

Working Group 1 meetings

(Montreal, November 10 – 20, 2009)

Agenda Item 3: SARPs for GNSS elements and signals (GBAS)

Conceptual Framework for the Proposal for GBAS to Support CAT III Operations

DRAFT VERSION 6.5

Presented by CSG Rapporteur)
Prepared by

Jason Burns (FAA), Barbara Clark (FAA), Rick Cassell (ERA), Curtis Shively (MITRE), Tim Murphy (ICCAIA), Matt Harris (ICCAIA) ... and many more

SUMMARY

This paper provides a description of a proposed Technical Concept for new GBAS Annex 10 requirements to support CAT III operations. It begins with an overview of the concept and a comparison with the current GBAS SARPS requirements. The new proposal includes some reallocation of requirements between the ground subsystem and the airborne subsystem. The main body of this paper also outlines a number of the key feature of this proposal including new airborne monitoring and ground subsystem requirements. Additional details describing some of these features and guidance for developing system designs are provided in a series of Appendices. Where necessary, airworthiness and operational certification criteria are discussed, so the reader may better understand how the SARPS requirements relate to performance in the context of the intended operations.

The concept described in this paper is the basis for the draft Annex 10 modifications that have been under consideration by Navigation System Panel (NSP) and its Category III subgroup (CSG). The concept is also the basis for the revised airborne equipment MOPS RTCA/DO-253C and ICD RTCA/DO-246D published on December 16, 2008. These documents will be used to support international development efforts and ultimately finalize the standards.

1. Background

This paper describes the concept underlying the proposed SARPs amendment to allow GBAS to support CAT II/III approach and landing operations using GPS L1. Much of this material has been presented before. However, this paper attempts to draw together into a single reference the description of the concepts that underlie the proposed SARPs revisions that have been developed

[1, 2, 3] and are currently being refined by the NSP CSG. The concept is also the basis for the revised RTCA airborne equipment MOPS [4] and ICD [5].

A version of this paper was presented to CSG as WP 11 to this meeting. WP 11 was reviewed and revised during the CSG meeting held 11/10 - 11/13 2009. A number of changes were made to the document to increase clarity, eliminate errors and insure consistent terminology is used throughout the document. This Flimsy represents the resultant current draft of the concept paper as of the end of this NSP meeting.

2. Recommendations

The group is invited to:

- 1) Note the concept presented in this paper
- 2) Consider this concept in the development and validation of baseline Annex 10 requirements

Conceptual Framework for the Proposal for GBAS to Support CAT III Operations

3. Introduction

This paper describes the conceptual framework behind the current proposal for GBAS standards modifications to support application of GBAS to CAT III operations. The paper includes a high level conceptual overview of the requirements allocation followed by a more detailed discussion of ground subsystem (service providers) requirements, airborne requirements and implications on airworthiness certification activities.

3.1 Requirements Philosophy

The current standards for the GBAS signal-in-space defined in Annex 10 (through amendment 77) are written in terms of the performance that can be expected at the output of an airborne, fault-free GBAS receiver. The fundamental ground subsystem requirements for integrity and continuity in Annex 10 are defined at the output of this airborne receiver. This requirement strategy was adopted for several reasons, including: to define a high-level performance standard rather than a detailed design standard; to simplify the approval process for aircraft equipment and its installation; and to complete the ground and aircraft allocation of requirements for navigation system error while deferring some implementation details (such as error bounding). This requirements methodology, while expedient from a standards development point of view has proven to be limiting as detailed implementation programs have uncovered issues and difficulties not originally envisioned. Defining the signal-in-space performance in this manner places a burden on the augmentation system to account for the performance of all possible users that comply with the airborne specifications given any combination of satellites that they might be using. Furthermore, experience with the spatial decorrelation of ionospheric errors has shown that a different means for mitigation of those errors is needed [6].

Although the signal-in-space performance as currently defined is sufficient to support the current applications, extension of the standards to support more demanding applications requires some new concepts when using a single GPS frequency. The concepts that have been developed to support this extension of the standards include:

- A requirements allocation that builds on the current GBAS standards with additions based on a more traditional approach to ground subsystem performance definition
- Introduction of multiple service types that may be supported by airborne and ground equipment.
- A classification scheme for airborne and ground equipment

Some discussion of each of these areas is included below.

3.2 Requirements Allocation

In allocating the GBAS requirements to support lower visibility operations, a different concept for allocating requirements has emerged [7, 8]. This concept has developed over the course of several years now and is the basis for a proposed SARPS change for GBAS which is under development by the NSP Cat II/III Subgroup (CSG) [1, 9, 10, 2, 3]. The concept has evolved over time and many of the references sited above are now somewhat out of date. This paper will attempt to layout the entire concept as it relates to the proposed draft standards change.

The overall strategy for the definition of requirements under this concept is illustrated in Figure 1 below. Note that these requirements support the airworthiness and operational requirements defined by individual States.

Among the "airworthiness and operational requirements" to be met are requirements on the aircraft's normal performance, performance with a malfunction, and limit case/ most critical value performance. Although these requirements are not all currently explicitly applied to the ILS signal-in-space they are used in this GBAS concept to provide success criteria for a safe landing. The primary measure of performance in this context is the total system error (TSE) of an airplane system during a landing operation. TSE is defined as the difference between where the aircraft is relative to where it was intended to be. TSE comprises two components: the navigation system error (NSE), how well the aircraft "knows" where it is, and flight technical error (FTE), how well the aircraft can adhere to the intended path.

The TSE for touchdown performance is dominated by FTE. FTE is aircraft unique and determined by the aircraft's engine performance, airframe characteristics, environmental conditions (e.g. winds) and the flight dynamics and control system characteristics (including the pilot). Given specific FTE performance, and a definition of success criteria, the required NSE to support an operation can be determined. The navigation system may consist solely of the radio navigation system, or it may also include other aircraft sensors. For CAT III operations, navigation is typically provided by a combination of the radio-navaid receiver, the radar altimeter, and an inertial navigation system. The allocation of required performance from each of these sensors depends upon the aircraft and its integration. Further information on the use of the airworthiness requirements is given in Appendix B.

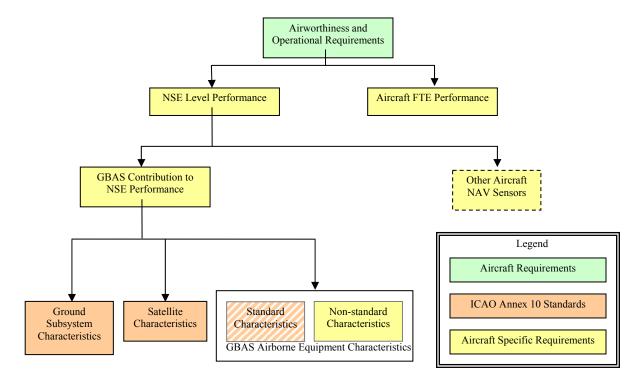


Figure 1 GBAS Standards to Support CAT III Approach and Landing Operations

In the current GBAS SARPs a standard set of performance parameters are defined at the "GBAS Contribution to NSE Performance" level in the figure. However, CAT II and III operations are unique in that the aircraft and operational approval includes comprehensive total-system error evaluations. Where a common level of performance was useful in standardizing CAT I operations, it may not be feasible given the complexity and range of aircraft implementations. Different aircraft designs have a different dependence upon and sensitivity to GBAS errors. For example, the position domain navigation system accuracy required for a given aircraft depends upon the aircraft's touchdown performance due to all other factors except the navigation system. The closer this touchdown performance is to the required limits, the better the navigation accuracy needs to be.

For the current development, the strategy for new requirements is to fix and standardize the ground and satellite component performance. Those elements of the aircraft equipment performance which affect State implementation are also standardized and are contained in the set referred to as "standard characteristics" in Figure 1. Simple examples of standard characteristics would be VDB receiver sensitivity, co-channel and adjacent channel rejection, and out-of-band signal rejection. These characteristics are required by service providers for frequency planning and spectrum management. Additional standard characteristics are required to completely define the set of requirements common to all airborne equipment and to achieve interoperability with the ground subsystem. Examples include the use of broadcast data and message time-out requirements. The remaining characteristics depend on the specific aircraft integration and therefore cannot be standardized.

The ground subsystem characteristics, satellite characteristics and the subset of airborne standard characteristics that directly support service provider functions are proposed to be included in Annex 10. Aircraft standard characteristics that do not affect State responsibilities under Annex 10 will be captured in appropriate State documents, such as airborne TSOs. Where different characteristics are required due to differences in aircraft performance or architecture, appropriate airworthiness and operational approval criteria will be applied as needed. In some cases, new approval criteria may need to be developed.

The CAT II/III development builds on the original CAT I GBAS developments. This is accomplished by introducing the concept of service types. Service Types are matched sets of airborne and ground performance and functional requirements that, when used in concert result in quantifiable NSE performance at the output of the airborne receiver. Two general classes of service are defined, Approach Services and the GBAS Positioning Service. A detailed discussion of service types can be found in reference [11]. GBAS approach services are further differentiated into multiple types referred to as GBAS Approach Service Types (GAST). A GAST is defined as the matched set of airborne and ground performance and functional requirements that are intended to be used in concert in order to provide approach guidance with quantifiable performance. Four types of approach service; GAST A, GAST B, GAST C and GAST D are currently proposed.

The current GBAS SARPS contain the requirements that make up GBAS Approach Service Types A, B and C. These correspond to the requirements which are currently labeled with the operational terms, "APV I", "APV II" and "CAT I" Respectively in the current SARPs. The additional requirements intended to support CAT II/III operations with GPS/L1 are included as part of GAST D. GAST D can be viewed as an extension of GAST C, since a ground subsystem that supports GAST D service must also meet the requirements necessary to support GAST C.

Each Approach Service Type includes a performance definition. For GAST A, B and C, that performance definition is in terms of signal-in-space performance defined as the Accuracy,

Integrity and Continuity of service in the position domain at the output of a fault free airborne GAST D includes all the requirements for GAST C and includes additional requirements necessary to support the use of GBAS in CAT II/III operations. Some of the new GAST D requirements are not necessarily more constraining than what may be achieved by a particular FAST C ground subsystem design. These requirements were simply not specified in the SARPS for GAST C. Contrarily to GAST C, GAST D requirements are now detailed at a sufficiently low level for characterizing the likelihoods and effects of all failures. additional requirements include performance requirements for monitoring performance for specific fault modes in the pseudorange domain. Also, specific monitoring requirements for the airborne equipment to address certain potential error sources are included. A key element to this notion of a matched set of performance and functional allocations is the idea of ground and airborne equipment classifications. This proposed SARPs amendment includes a classification scheme that relates GBAS Approach Service Types (GASTs), GBAS Facility Classification (GFC), Approach Facility Designation (AFD) and GBAS Airborne Equipment Classifications (GAEC). All four types of classifications are needed to describe some aspect of a GBAS. A discussion of equipment classifications is included in the draft guidance material [12]. More discussion of service types and ground subsystem classifications can be found in references [13, 14, 15]. Part of the classification scheme for both the air and the ground is an indication of which Approach Service Type(s) the equipment is designed to support. For the ground subsystem this designation is the Facility Approach Service Type (FAST). (The FAST is one element of the Ground Facility Classification (GFC) for a ground subsystem.) For Airborne equipment, this designation is the Airborne Approach Service Type (AAST). For example a ground subsystem classified as "FAST C" indicates the ground subsystem meets the performance and functional requirements for a ground subsystem to support GAST C service. A "FAST D" ground subsystem will by definition support GAST C type service as well as GAST D type service. GAST A and B are separate service levels not considered further in this document.

The approach service type dependent allocation of performance and functional requirements allows for a clear delineation of responsibility between the air and ground subsystems.

3.3 High Level Performance Requirements for GAST D

A GFC D station is required to meet both legacy FAST C and new FAST D performance requirements. FAST D includes traditional signal-in-space requirements also referred to as position domain requirements. These requirements are similar to those for FAST C with the same safety objectives (e.g. 2.0x10-7 for total loss of integrity probability).

Additional low level monitor requirements have also been included under FAST D to support CAT II/III autoland operations. These requirements are primarily specified in the range domain to allow the aircraft integrator to assess each hazard effect based on their specific design choices (e.g. monitor thresholds, geometry selection logic). Also, new airborne functions were defined. These functions provide additional mitigation of failure and environmental conditions which could affect the operational intended function. In combination with these airborne functions, the new low level ground subsystem requirements allow aircraft manufacturers to assess the total residual risk posed by each hazard condition. When assessed during airworthiness for CAT III operational segments below 200 ft, these features should enable CAT III operations when assessed in conjunction with signal-in-space requirements (i.e. applicable to precision approach integrity above 200 ft).

The following discussion illustrates, at high level, how the ground subsystem and airborne NSE performance requirements can be combined to support the TSE based airworthiness/operational requirements. State documents (e.g. advisory circulars, TSO, ground equipment specifications)

should include compliance information that can be used by ANSPs to better understand the role of the ground subsystem and can be used by aircraft manufacturers in obtaining approval for low-visibility GBAS operations.

To develop the allocated performance requirements, an analysis based on a simplified example allocation of NSE and FTE was used. The result of the analysis defined ground subsystem performance requirements for errors at the post corrected pseudorange level (see Figure 2) for both fault free errors and specific fault modes. A detailed discussion of this analysis is included in Appendix C.

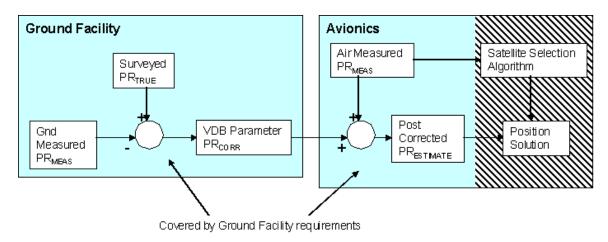


Figure 2: Ground and airborne subsystem Range Domain Integrity Responsibilities

An example application of the proposed ground subsystem standards with example aircraft requirements can be shown to meet the airworthiness and operational requirements based, again, on a simplified allocation of NSE and FTE. While such a simplified example allocation assists us with assessing the feasibility of our range domain requirements, these assumptions are too simple to be used in actual approvals. In order to obtain airworthiness and operational approval, the aircraft manufacturer would use high fidelity models of NSE and FTE to show compliance to the requirements. The existing aircraft approval processes for ILS typically employ non-linear, six degree of freedom models and simulations of aircraft dynamics which include detailed representations of the engine, airframe, guidance and control systems, weight and balance, and wind and turbulence.

3.3.1 Intended Function and Erroneous Information

A navigation system's intended function is to provide guidance information with the required performance (i.e. integrity, continuity, accuracy and availability) to support the intended operation. In the case of GAST C, CAT I precision approach represents the most stringent operation being supported and CAT III precision approaches in the GAST D case.

In both cases, the ground and airborne subsystems support GAST C and D through the broadcast and application of information via a VHF datalink. This information and the assurance of that information provide a more precise definition of the system's intended function. Annex 10 Chapter 3, Section 3.7.3.5.2 provides a list (reproduced below) of GBAS functions which can support the operational intended function. We may use this list and their associated performance

NSP WGW November 2009 Report – Attachment H (was Nov09 WGW Flimsy 6)

requirements as a means for characterizing the system's intended function. Annex 10, Appendix B Section 3.6.7.2 describes these functional requirements in further detail.

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

- a) provide locally relevant pseudo-range corrections;
- b) provide GBAS-related data;
- c) provide final approach segment data when supporting precision approach;
- d) provide predicted ranging source availability data; and
- e) provide integrity monitoring for GNSS ranging sources.

To support multiple service types, additional information is required to distinguish between the ground subsystem type, and what maximum GAST a runway end supports. The current Annex 10 change proposal specifies these changes under the functions (b) and (c) above.

Erroneous information can be defined as information which does not conform to the performance requirements associated with the functions (a) through (e), since the broadcast information no longer would be consistent with standardized requirements necessary to prevent hazardous outcomes.

Both approach service types support the same general functions above. Each requires the ground subsystem to broadcast correction and integrity information to meet certain standardized performance requirements. It is these performance requirements where they differ, and those differences that enable GAST D systems to be used for CAT III autoland operations.

GAST D requirements are a superset of GAST C requirements. The ground subsystem is required to meet both FAST C and FAST D requirements to support legacy GAEC C and new GAEC D equipment. GAEC D equipment must meet the same signal-in-space performance requirements as GAEC C equipment, however in some cases it achieves this using new information from the ground subsystem in combination with new airborne defined algorithms and responsibilities. The new broadcast parameters, airborne functions and allocations of responsibilities are sufficiently defined in the draft Annex 10 standards to allow ground manufacturers to develop equipment and perform safety analysis for certification.

In the Annex 10 draft standards, new performance requirements are defined primarily from the ground subsystem perspective. This is an inherent necessity of the concept to shift certain aspects of integrity responsibility to the airborne subsystem and the aircraft certification as whole. The following excerpts from Section 4 are the new relevant performance requirements to support GAST D functions.

The "Integrity Monitoring for Ranging Source Failures" performance requirement (see Appendix A) supports function (e) above for GAST D. The airborne subsystem and ultimately the aircraft manufacturer is responsible for applying this performance information in an airworthiness analysis to prove it can support CAT III operations.

GAEC D equipment has the new requirement to perform airborne monitoring to detect anomalous ionosphere errors outside the system's normal levels. To support this, Annex 10 defines new broadcast corrections using a 30 second smoothing time which the ground subsystem must generate and broadcast as a part of function (a).

The concept also specifies a new airborne responsibility which requires it to monitor the magnitude of the broadcast B-values in combination with its selected geometry and ensure single RR failures are not large enough to violate airworthiness criteria. The airborne Reference Receiver Failure Monitor (RRFM) makes use of the legacy B-values broadcast parameters. Additionally, new FAST D requirements have been included in the draft Annex 10 standards to limit the reference receiver failure rate, so manufacturers can leverage it during a airworthiness evaluation.

3.3.2 Signal-in-Space (SIS) Time-to-alert (TTA)

The GBAS SIS TTA is the maximum allowable time elapsed from the onset of an out-of-tolerance condition at the output of the fault-free aircraft GBAS receiver until the aircraft GBAS receiver annunciates the alert. This time is a never to be exceeded limit and is intended to protect the aircraft against prolonged periods of guidance outside the lateral or vertical alert limits.

Additional time limits are defined for new FAST D integrity and monitoring requirements similar to the ground subsystem TTA. In contrast to GAST C, the ground subsystem is allocated only 1.5 seconds to detect a condition producing out-of-tolerance errors in 30 second corrected pseudoranges and to either exclude the ranging source measurements from the broadcast or mark them as invalid. This time-to-detect and broadcast is similar in definition, but not equivalent in function to the ground subsystem TTA, as an out-of-tolerance condition in a single ranging source does not necessarily lead to out-of-tolerance guidance information. Guidance on signal-in-space TTA, ground subsystem TTA and monitor time-to-detect and broadcast limits is provided in the draft standard Attachment D, Section 7.5.12.3 [34].

3.4 Annex 10 Ground Subsystem Standards

The proposed SARPs amendment defines the set of additional GBAS Ground Subsystem standards in a new way. Table 1 below compares and contrasts the basic requirements in the existing standards for "CAT I" to the proposed amendment to support "CAT III". This table is not a comprehensive summary of the requirements and not meant to rigorously duplicate the intricacies of the standards; it is intended to illustrate some key differences in the requirement strategies.

In this concept, the new ground subsystem requirements are not written at the output of the airborne receiver, but primarily written in terms of the information the ground subsystem provides to the airborne receiver. This is more than a semantics difference, because along with changing the definition of "where" the ground requirements apply, the requirements themselves change and are re-allocated in the ground-air-space segmented system we collectively refer to as GBAS.

Consider a fundamental attribute contributed by the ground subsystem – a judgment of the integrity of the satellite ranging signals and suitability determination for their use. In the current standards concept, the ground system is responsible for the integrity of the position solution determined by the fault-free airborne receiver (Annex 10 Section 3.6.7.1.2.1.1). By contrast, under the new concept the ground is responsible for monitoring of the satellite ranging signals in the pseudorange domain and the aircraft is responsible for determining if its resulting performance is adequate. The major requirements shift here is the responsibility for the satellite geometry from the ground to the airborne equipment. It allows the user to make determinations based on meeting the operational level safety requirements such as those codified by the malfunction and limit risk/most critical value performance requirements. Airplane compliance is determined based on the pseudorange performance of the ground subsystem differential range

NSP WGW November 2009 Report – Attachment H (was Nov09 WGW Flimsy 6)

fault monitoring (to be specified in Annex 10), combined with the geometry screening and satellites selected by the airborne receiver to achieve a certain level of position domain performance, integrated with the rest of the aircraft functions, and assessed against the required touchdown requirements under the hypothesis of the failure of the ground subsystem to detect the satellite failure. The proposed amendment to Annex 10 contains sufficient details to develop a representative GAST D NSE models. Such models will be used during airworthiness certification to assess the residual NSE effects on a safe landing.

A more detailed discussion of the ground subsystem responsibilities for integrity and continuity is given in Appendix A.

Table 1 Comparison of Ground Subsystem Annex 10 Standards under the Current and Proposed SARPS

Requirement Type	Existing Ground Subsystem Standard (FAST C – Intended to	New Concept Ground Subsystem Standard (FAST D –
	support CAT I Operations)	Intended to Support CAT III Operations) ¹
Positioning	(1) Horizontal (lateral) and vertical position domain accuracy	FAST C requirements plus :
accuracy	when combined with any fault-free receiver executing the	Accuracy of pseudorange corrections (higher accuracy
	protocols	subset of existing configuration options, e.g. GAD C3 as
	(2) Ground subsystem pseudorange accuracy	a minimum)
Integrity risk	(1) Integrity risk applied to any fault-free airborne receiver	FAST C requirements plus :
	executing the protocols	(1) Specified performance requirements for range source
	(2) Broadcast integrity parameters for use by the aircraft (when	monitoring in the differential pseudorange domain
	executing the protocols) such that the risk above is satisfied	(2) Specified performance requirements for monitoring
	(3) Satellite signal integrity monitoring to detect improper	for anomalous ionosphere effects, plus one siting
	operation of differential processing for any fault-free receiver	requirement needed to limit the size of an error not
	executing the protocols and complying with signal tracking	detected by either the ground or airborne monitoring.
	constraints	(3) Specified performance requirements for σ_{vert} and σ_{lat}
		parameter
		(4) Specified likelihood probability for ground
		subsystem components (including complex hardware
		and software) that could have Catastrophic
		results/effects when failures occur.
Continuity risk	(1) Continuity risk applied to any fault-free airborne receiver	FAST C requirements plus ² :
	executing the protocols	(1) Continuity risk requirements defined as a function of
	(2) Continuity of service defined as a function the transmission	only the ground subsystem failures or false alerts (e.g.
	of data in tolerance, compliance with the VDB field strength,	VDB transmission, reference receiver failure, processor
	and the aircraft's achieved position domain error bounding for	failures, monitor false alert for message type parameter)
	any fault-free receiver executing the protocols unless	(2) Additional requirement on the fault-free detection
	configuration changes occur to the space segment	("false alert rate") of the ranging source fault monitoring
		functions at the pseudorange level

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¹ In addition to requirements indicated under the new concept, all FAST C (i.e. CAT I) requirements will be met by GFC-D stations for use during CAT III operations as well as to support CAT I capable equipment to CAT I minima.

Requirement Type	Existing Ground Subsystem Standard (FAST C – Intended to	New Concept Ground Subsystem Standard (FAST D –	
	support CAT I Operations)	Intended to Support CAT III Operations) ¹	
Availability	Availability defined at the output of any fault-free receiver	No new requirements. Given the flexibility in the	
	executing the protocols for above metrics defined in position	aircraft, it is not possible for ANSPs to reliably estimate	
	domain. This gives the ANSP a means to estimate the lower	operational availability based on the Annex 10 standards	
	bound of operational availability.	alone. Rather, ANSPs are primarily responsible for	
		ensuring system availability (see Section 3.6).	
VDB Messaging	RF transmission characteristics, physical layer and application	Current SARPS requirements with addition of some	
	layer definitions per current SARPS	new broadcast information	

² These additional FAST D requirements can not be applied assuming a fault-free airborne receiver. They define the minimum acceptable ground subsystem performance and must be considered in combination with the airborne subsystem performance to understand the total operational risk posed by a loss of continuity.

3.5 Annex 10 Airborne Standards

Table 3 below compares and contrasts the airborne requirements in the existing GBAS standards to the proposed amendment. Like Table 1, it is intended to illustrate the key differences in the requirement strategies. The most striking difference is the significantly lower amount of Annex 10 material which results from removing the detailed definition of a fault-free receiver from the ANSP responsibility. The second significant difference is that a complete quantification of the current high-level performance requirements (accuracy, continuity, integrity, and availability) cannot be determined from main body or technical appendix of ICAO standards, but instead would be described in the guidance material, or other referenced material.

This is more similar to the ILS standards approach than the current GBAS (GAST C) approach. For ILS, only the airborne interference immunity standards are included in the white pages. The airborne equipment requirements considered necessary to meet the operational objectives, including how the airborne equipment determines that a malfunction condition exists and generates an indication for the pilot, are in the guidance material and/or State requirements documents.

Numerous airborne equipment requirements were included in Annex 10 for the existing GBAS definition (GAST C). This was necessary because some of the ground subsystem requirements were written in terms of performance at the outputs of the airborne equipment. Such requirements could only be understood and applied in the context of defined airborne receiver processing. The segregation of ground and airborne requirements for the new service type introduced in this proposed amendment removes this need for inclusion of material in Annex 10. The community will continue to employ the airborne MOPS or equivalent to achieve the interoperability of the ground and airborne systems.

Recognizing that, for the purposes of Annex 10, the operational characteristics of a CAT III approach prior to 200' above the runway threshold are the same as a CAT I approach, and that any GBAS ground subsystem intended to support CAT III should also support CAT I operations, it is envisioned that the existing GBAS standards, (referred to as GAST C in the new paradigm) would have to be met by all systems.

A method for mitigating potential errors due to anomalous ionospheric conditions has been proposed and incorporated into the draft SARPs change proposal. The mitigation method includes a combination of monitoring in the airborne equipment and on the ground to limit the size of errors to which a user could be exposed. This mitigation method includes:

- 1. New requirements for additional information from the ground subsystem to allow the airborne equipment to mitigate the effects of the phenomena across much of the applicable threat space through monitoring. Some new requirements regarding the protocols for use of this additional data are included in the proposal.
- 2. New requirements on the ground subsystem for monitoring for ionospheric gradients.
- 3. A new siting requirement on the ground subsystem to limit the size of an error that could remain undetected by either the ground or airborne monitoring

Other "standard characteristics" such as the airborne equipment requirements to accomplish tuning from a ground subsystem that supports multiple levels of precision approach service have been standardized through the MOPS. The majority of envisioned additional airborne requirements would not be standardized in SARPS, but may require guidance material to support the states in the development of aircraft and operational approval criteria. An example is highlighted below.

NSP WGW November 2009 Report – Attachment H (was Nov09 WGW Flimsy 6)

More stringent satellite constellation geometry screening is likely to be required in order to achieve the required accuracy and integrity performance to support CAT III operations. Acceptable means of translating pseudorange accuracy to the position domain is defined in the updated MOPS RTCA/DO-253C. This may also be achieved by more effective methods of screening geometries targeted to particular failure modes. For example, screening based on the relative sizes of the geometry projection components (i.e. factors used to translate the range error contribution of an individual satellite into the position solution of a user) may be considered more effective at limiting the errors contributed by undetected, single satellite faults. Although the updated MOPS RTCA/DO-253C includes proposed standards for additional geometry screening, the threshold values for the screening are not specified as a minimum. Specific implementations may use thresholds that are more restrictive and, in fact may employ other forms of geometry screening in addition to the minimum standards in the MOPS RTCA/DO-253C. The airworthiness process is required to verify the effectiveness of any and all geometry screening.

Table 2 Comparison of Existing Annex 10 Aircraft Standards to the Proposal for Aircraft Standards in Annex 10 and State Regulations

Requirement Type	Existing Aircraft	New Concept Aircraft Standards			New Concept Aircraft Standards		
	Standard	Standard Characteristics	Non-standard Characteristics				
Positioning accuracy	(1) Pseudorange accuracy (2) Code smoothing characteristics	See section 3.5.1 Below	Additional geometry screening sufficient to support CAT III TSE requirements for aircraft and operational approval				
Integrity risk	(1) Bounding airborne receiver contribution to corrected pseudorange error (2) Requirements to execute protocols and alert limit comparison		 Additional geometry screening satisfactory to meet limit case/most critical value allocated requirements under SV fault hypotheses Additional requirements (geometry screening) to further mitigate the effects of ionosphere anomalies Additional requirement (including geometry screening) to monitor received B-value parameters for single Reference Receiver faults. 				
Continuity risk	None		Monitoring and geometry screening requirements must be consistent with operational use of the system				
Availability	None		Resulting availability of guidance must be consistent with operational use of the system				
VDB Messaging	(1) VDB receiver performance characteristics (2) Functional requirements on use of data		None.				

- 3.5.1 New Aircraft Standard Characteristics:
- (1) Retention of existing requirements including the application of the "error bounding protocols" and alert limit comparison with different parameters for GAEC D equipment that do not provide bounding of anomalous ionosphere NSE (see Section 4.5)..
- (2) New requirements related to new broadcast parameters (MT 11) and MT 2 Additional data block 3
- (3) Signal-in-space performance in the position domain at the output of a fault free receiver is equivalent to "CAT I" standards except:
- Anomalous ionospheric errors are not within scope of GAST D signal-in-space requirement
- additional ground subsystem item specific continuity requirements apply for GAST D (e.g. unscheduled internal ground failures, internal fault monitor false alerts or ranging source fault monitor false alerts)
- (4) Additional low level monitoring requirements are defined for anomalous ionospheric errors in both the ground and the airborne equipment.
- (5) A ground subsystem siting criteria to further limit the size of undetected errors due to ionospheric anomalies

3.6 Implications of Requirements Strategy Underlying the Proposal

The requirements strategy underlying the proposal should simplify the process of demonstrating ground system compliance to the standard. Furthermore the strategy takes advantage of the extensive aircraft evaluation accomplished for any CAT III airworthiness approval. It is similar to the ILS requirements, which have proven to be effective.

It is recognized that the proposed strategy also offers several challenges. These include:

- a) Non-common availability: as the proposed strategy allows aircraft to have different allocations to GBAS (as compared to the flight control system, wind limits, radar altimeter, inertial reference unit, etc), it will be more difficult to predict the operational capability of aircraft for flight planning or air traffic control. The status of the ground subsystem can still be reported (as with ILS), and the determination if the aircraft can support the operation would be the responsibility of the operator. In this manner, the only real change is that the operator would also incur the responsibility for whether or not the satellite geometry is adequate to support the operation.
- b) Complexity of aircraft and operational approval: The proposed strategy relies on the aircraft and operational approval to consider ground subsystem and satellite performance and fault characteristics. Adequate State guidance material (e.g. Advisor Circulars) will be developed to reduce the risk of this assessment. Note that this basic activity must be accomplished regardless of the strategy for defining requirements.
- c) From an ANSP point of view the commercial impacts of operational availability and continuity need to be considered, but are not covered in the airborne certification activities, which consider only the safety of an individual aircraft.

4. GBAS Approach Service Type D Overview

This section will give an overview of proposed changes to the standards to introduce GAST D. The following elements are currently included in the proposed SARPs Amendment to support GAST D, or are included in the updated MOPS RTCA/DO-253C.

- Addition of low level monitor performance requirements for the ground subsystem
- Addition of Ionospheric monitoring and use of 30 sec corrections in the airborne equipment supported by additional information from the ground subsystem
- Additional ionosphere monitoring required by the ground subsystem
- An additional siting requirement (restriction) for the ground subsystem to limit the maximum baseline between the threshold of a runway supporting GAST D and the ground subsystem.
- Addition of B-value monitoring in the airborne equipment to address residual risk not bounded by the H1 hypothesis Protection Level integrity equation or detected by the GF.
- Additional airborne geometry screening requirements
- Additional protection level parameters that are based on overbounding without
 consideration for rare anomalous ionospheric conditions which are covered by airborne
 monitoring. This may allow AEC D equipment to recover some system availability that
 could be lost if uplinked integrity parameters are inflated or otherwise manipulated to
 address the ionospheric anomalies.
- Changes to the ground and airborne standards to allow multiple service types to be supported while retaining interoperability with legacy equipment
- Addition of a ground subsystem design integrity risk requirement.

4.1 Low level monitor performance requirement for the ground subsystem.

Detailed discussion of the monitor requirements is given in Appendix A and Appendix C. The need for such requirements as well as potential forms for such requirements has been discussed in a number of previous papers [16, 17, 18, 7]. A proposed form for these new requirements is included in the current draft SARPs amendment. These requirements take the form of a constraint on acceptable probability of missed detection performance applicable to specific fault modes expressed in the pseudorange domain. Given these constraints, the end user can determine the resultant performance in the position domain for any given instantaneous geometry given knowledge of how the receiver forms the position solution and also taking into account geometry screening done by the receiver. This allows the end user to characterize the NSE performance in the presence of faults.

4.2 Addition of lonospheric mitigation measures in the ground subsystem and airborne equipment

The existence of large gradients or anomalies in the ionosphere during ionospheric storms has received much attention in the last few years [19, 20, 21, 22, 23]. Steep gradients in the ionosphere can result in a non-differentially correctable error in the position determination. Anomalous ionosphere conditions are defined as those conditions which an ANSP considers to be not part of GBAS normal performance. Under GAST D sufficient mitigation of differential errors under these conditions is achieved through a combination of monitoring in the ground

subsystem, monitoring in the airborne equipment, use of 30-sec smoothed corrected pseudorange corrections and some siting restrictions on the ground subsystem. Detection and mitigation of these types of phenomena has been the subject of intensive research [24, 25, 26, 27]. The RTCA LAAS MASPS included some requirements intended to address this issue for CAT II/III. However, those measures did not go far enough and subsequent research has resulted in more effective ways to address the problem. A description of the mitigation scheme can be found in reference [6].

The proposed scheme is based on ground subsystem and airborne monitors acting together as well as the introduction of pseudorange corrections from the ground subsystem that are based on 30 second carrier smoothed code phase measurements. The shorter smoothing time constant makes the system less susceptible to the buildup of ionospheric gradient induced filter lag errors. Furthermore, the simultaneous use of 30 second and 100 second smoothed pseudoranges allows for the airborne equipment to monitor for the existence of ionospheric gradients. Additionally, airborne code-carrier divergence monitors are employed at all times by GAEC D equipment (known as AAST D equipment in the context of the proposal), in order to allow detection of ionospheric gradients long before the airplane reaches the ground subsystem or starts using the differential corrections. For satellites which have not been subject to CCD monitoring for an extended period of time, RAIM type Fault Detection is applied to validate the measurements before they can be used in the position solution.

Even with these new airborne capabilities, improved ground subsystem monitoring is required to fully mitigate the ionospheric hazards in some cases. (There are cases where the ground subsystem can detect the ionospheric gradient when the airborne cannot). requirements have been added to the standards, so the aircraft can take credit for its monitoring performance. This includes a performance requirement similar to the Ranging Source Monitoring requirement, and a siting constraint (i.e. Maximum distance, 5 km, between ground subsystem reference centroid and each runway threshold crossing). The adequate performance of the combination of all the monitors (air and ground) in conjunction with the siting limitations and all other relevant mitigations has been shown for a standard threat space which is described in Guidance Material. The standard threat space chosen for the validation is believed to be large enough to cover the ionospheric environment of any location in the world. The threat space accounts for simple gradient type anomalies as well as the "plasma bubble" type anomalies which are know to manifest in geomagnetic equatorial regions. This standard threat space has been used to simulate monitor performance and calculate the size of residual errors not detected by any of the various monitors in the system. Airworthiness approvals can now appropriately account for these maximum undetected errors. The siting constraint is necessary in order to bound the maximum error due to spatial decorrelation between the ground subsystem monitors and the threat for the most problematic corner of the threat space where the phenomena is essentially invisible to both the airborne and ground monitoring. The suitability of the airworthiness approvals is tied to the efficacy of the standard threat space. If a state believes that the ionospheric conditions in its environment are more severe than the standard threat model assumed for the validation, then additional steps must be taken to ensure that the user will not be exposed to threats outside the threat space. The service provider may elect to:

- 1. Alter the characteristics of its ground subsystems, and/or
- 2. Introduce additional monitoring (internal or external to the GBAS), and/or
- 3. Introduce other operational mitigations that limit the users exposure to the extreme ionospheric conditions.

Potential ground-system changes which could achieve this risk reduction include tighter siting constraints (see section 7.5.6.1.6, and section B 3.5.7.1.4.1) and improved ground-system monitoring performance (B 3.6.7.3.4). Another strategy for mitigation of the risk is monitoring of space weather (external to the GBAS system) in conjunction with operational limitations on the use of the system during periods of high ionospheric activity. Any and all combinations of these strategies may be used to insure the GAST D user is not subjected to ionospheric anomalies outside the standard threat space. Guidance material outlining these strategies is included in the SARPS proposal.

4.3 Airborne B-value monitoring of single Reference Receiver faults

A single reference receiver fault can affect multiple, if not all, satellite correction and integrity information. Such a "fault" can be due to actual reference receiver hardware failure or excessive multipath on one or more satellites. For GAST C, the ground subsystem is required to monitor metrics relating to the B-value estimates used to characterize reference receiver fault errors, and transmit those B-values that are accepted to the aircraft in MT-1. Also for GAST C, airborne monitoring is indirectly provided by the requirement to compute position domain protection levels (PL_{H1}) from the broadcast B-values and compare them to corresponding alert limits. While this ground and airborne monitoring is effective in detecting reference receiver faults within the GAST C protection level integrity allocations, additional airborne monitoring is needed for GAST D to mitigate single reference failure effects as defined in RTCA/DO-253C.

For GAST D, the airborne equipment must also monitor the impact single reference receiver fault errors on total GBAS NSE performance and mitigate conditions which are unacceptable given the aircraft's unique landing characteristics and the operation to be performed. Its monitor test statistic is formed by combining the vertical and lateral B-value derivations (i.e. $B_{j_Apr_vert}$ and $B_{j_Apr_lat}$) and the 30/100 sec smoothed position solutions difference (i.e. D_V and D_L). The airborne equipment's knowledge of the specific geometry being used in the final position solution allows it to be the most efficient judge of whether an apparent reference receiver failure will result in hazardous misleading information or not. Furthermore, the performance of this monitor in terms of probability of missed detection for the fault mode can be quantified and accounted for in the landing system performance assessment.

4.4 Additional airborne geometry screening requirements

To relate the low level monitor performance expressed in the pseudorange domain and basic position accuracy performance requirements, the user must have knowledge of how the position solution is done and how the errors are projected from the range domain to the position domain. Then the position domain NSE characteristics can be related to the touchdown performance of a particular airplane taking into consideration the FTE performance of the airplane. It has been discussed in several papers that one critical measure of adequate NSE performance is bias errors. Hence a means to characterize and limit the effect of bias errors from ranging source faults is needed. Airborne equipment may be required to do additional geometry screening to reject geometries that result in too heavy a dependence on a single satellite range. The updated MOPS RTCA/DO-253C includes a recommended method for such geometry screening whose parameters can be tailored to a given aircraft installation.

The specifics of the proposed new geometry screening are discussed in Appendix B.

4.5 GAST D Protection Level Parameters and Protocols

GAST D systems must be able to demonstrate equivalence with GAST C performance requirements. GAEC D equipment will achieve this using new broadcast parameters in place of

those required for GAST C. These parameters will be set by the ground subsystem to provide protection level integrity of a 100 second smoothed position solution. New airborne algorithms will in turn calculate additional errors that would be introduced in a 30 second position solution (using corrections from the Type 11 message) and apply the necessary corrections to extend protection level integrity to the 30 second position solution.

The new ground subsystem parameters do not bound anomalous ionosphere (as defined by an ANSP for a region) errors with protection level integrity as was the case in GAST C. These new parameters and their associated message type are given below:

<u>Parameter</u>	Message Type		
$K_{md_e_D,GPS}$	MT-2		
$K_{md_e_D,GLONASS}$	MT-2		
$\sigma_{\text{vig},D}$	MT-2		
P_D	MT-11		
$\sigma_{pr_gnd,100}$	MT-11		

In all other respects, these parameters are set in the same manner as GAST C protection level parameters.

GFC D stations will be required to broadcast GAST C and D protection level parameters to support both sets of airborne equipment. This achieves backward compatibility with GAEC C equipment while enabling higher operational availability for GAEC D equipment.

GAST D protection level integrity will no longer characterize anomalous ionosphere errors or the risks posed by it. New GAEC D algorithms defined in avionics specifications (e.g. DO-253) together with new ground subsystem requirements will be responsible for adequately mitigating these risks for CAT III operations.

4.6 Changes to the ground and airborne standards to allow multiple service types

When future ground subsystems support multiple types of service, some facility must be provided to let the user select the appropriate/desired type of service and determine if the desired type of service is actually available. Furthermore, legacy equipment must be able to operate normally with no knowledge at all of the 'new' types of service.

Approach selection in the presence of multiple types of service was discussed in [28]. The proposed approach has been simplified relative to that proposal presented in the previous working paper. In general, the method can be summarized as:

- The approach performance designation field of Final Approach Segment (FAS) block provided in Message Type 4 is coded to indicate the 'highest' Service Type supported for the approach.
- The airborne equipment selects the FAS block through the tuning scheme in the usual manner and determines the appropriate type of service and applies the corresponding functional requirements etc.
- The airborne equipment annunciates the status with respect to which type of service is selected and which level of service is actually used. This is referred to as the "Selected Service Type" and "Active Service Type" respectively. (In some cases, the system could

attempt to select GAST D, and for some reason, only be able to achieve GAST C. The airborne equipment must annunciate this state)

More details on the approach selection scheme are given below in the context of explaining how a GAST D capable airborne receiver will operate.

4.7 Operating Concept for GAST D

Appendix D discusses the Operating Concept for GAST D. The Operating Concept refers to how the components of the system operate, how these behaviors combine to produce the desired service. The Operating Concept also includes how equipment built in accordance with this standard will be backwards compatible with legacy equipment and how legacy equipment will operate as expected in the presence of changes to the signal specifications added to accommodate this new service level.

GAST D performance and functional requirements are intended to support approach and landing operations in low visibility conditions including CAT IIIb minimums. The requirements were derived based on a definition of acceptable performance consistent with current airworthiness certification for aircraft with autoland capabilities. Ultimately, operational approvals will determine what operations can be authorized for a given aircraft when it is using a ground subsystem that supports the performance requirements defined in the Annex 10 change proposal.

From an ANSP point of view the commercial impacts of system availability and continuity need to be considered, but are not covered in the airborne certification activities, which consider only the safety of an individual aircraft.

5. Conclusions

A new requirement allocation has been proposed to provide a type of GBAS service appropriate to support CAT IIIb precision approach operations with autoland using single frequency GBAS ground subsystem and airborne equipment. The technical concept is described in the body of this paper along with details included in the appendices. Proposed Annex 10 requirements have been drafted using the functional performance aspects outlined in the concept.

Appendix A: Ground Subsystem Requirements for Facility Approach Service Type D

A-1 Introduction

This appendix describes the responsibilities of the Ground Subsystem with regard to integrity and continuity risks for GAST D. A GBAS Ground Subsystem that supports GAST D is referred to as a Facility Approach Service Type D (FAST D) Ground Subsystem. The requirements below are intended to characterize a sufficient level of safety performance to support an airworthiness case for use in CAT III operations.

A-2 FAST D Ground Subsystem Integrity Responsibility

A FAST D ground subsystem is required to meet both legacy FAST C and new FAST D performance requirements. FAST D includes traditional signal-in-space requirements also referred to as position domain requirements. These requirements are similar to those for FAST C with the same safety objectives (e.g. 2.0x10-7 for total loss of integrity probability).

Additional low level monitor requirements have also been included under FAST D to support CAT II/III autoland operations. These requirements are primarily specified in the range domain to allow the aircraft integrator to assess each hazard effect based on their specific design choices (e.g. monitor thresholds, geometry selection logic). FAST D range domain integrity is not assured at the output of a fault-free airborne subsystem as is the case for position domain integrity. These types of requirements only apply at the point inside the airborne receiver immediately after the broadcast corrections are applied to the airborne receiver's own pseudorange measurements. This requires that the GF to still consider standardized airborne characteristics (i.e. correlator design effects on signal deformation). See Figure 1 for a high level illustration of the responsibility separation of the ground and airborne subsystems for range domain requirements.

All monitors and other ground subsystem functions that support the CAT II/III portion of the precision approach operation, the aircraft autoland or rollout functions can have catastrophic consequences if an integrity failure occurs. Such failures must be extremely improbable and are generally assigned a safety objective 1×10^{-9} (i.e. probability of occurrence without detection and appropriate alert must be less then 1×10^{-9} for each cause analyzed during airworthiness process). Note that FAST D signal-in-space requirements cannot (without additional analysis) be leveraged as mitigation of hazards effects for portion of CAT II/III operations below 200 ft.

A-2.1 Integrity Coverage

This section describes integrity and monitoring methods that can be used by the ground subsystem to demonstrate coverage over a range of GBAS fault-free, faulted and environmental NSE. These methods are implemented as requirements in App. B, Sections 3.6.7.1.2, 3.6.7.1.4, 3.6.7.3.3, and 3.6.7.3.4 of the current Annex 10 change proposal and can be grouped into the following categories [1]:

A-2.1.1 GAST D Integrity Requirements

Ground Subsystem Signal-in-Space Integrity Risk for GAST D

Section 3.6.1.2.1.1.2 specifies a signal-in-space risk allocation for NSE conditions not addressed by protection level integrity. This requirement is similar to the legacy CAT I and APV requirements with the exception that risks due to anomalous ionosphere conditions are not included.

Ground Subsystem Integrity Risk for GAST D

Section 3.6.7.1.2.1.1.3 specifies a new ground subsystem integrity requirement relating to failsafe design criteria. This integrity method will ensure that failures within the ground subsystem that might affect the ground subsystem's functions and result in erroneous information are Extremely Improbable.

Protection Level Integrity for GAST C and D

Section 3.6.7.1.2.2 is also a legacy GAST C requirement which has only been revised to apply to both FAST C and D. The specified integrity risk for the protection level protocol is the same for both service types. Only their algorithms and the broadcast parameters used in the implementation of the protocols differ.

Integrity Monitoring for Ranging Source Failures

Section 3.6.7.3.3 specifies a new monitoring requirement for ranging source failure. This requirement standardizes the low level monitoring performance of the ground subsystem using a constraint region defined by the probability of missed detection versus a maximum differential pseudorange error magnitude, $|E_{\rm r}|$.

<u>Ionospheric Gradient Monitoring and Siting Restriction</u>

Section 3.6.7.3.4 specifies a new ground subsystem monitoring requirement for environmental ionospheric errors not bounded by applicable *residual ionosphere uncertainty*. The ground subsystem monitor is allocated a probability of missed detection of $1x10^{-9}$ and maximum differential range error limit equal to 1.5 m. The achieved differential range error limit is dependent on the gradient size, G, and the horizontal distance, D, between the reference point of the ground subsystem and the threshold of the approach. The maximum value of G with acceptable differential range error is determined based on the relationship $G \times D < 1.5$ m. Section 3.6.7.1.4 limits D to 5 km when applying the threat model from Attachment D, Section 7.5.6.1. Note that the probability of missed detection of $1x10^{-9}$ is specified for this monitor so that no prior probability of an ionospheric gradient need be assumed.

Aircraft Monitoring

These integrity methods are discussed further at the end of this appendix. Note that "Aircraft Monitoring" is not standardized in Annex 10, however it is necessary to discuss these airborne functions to understand how GAST D provides coverage for a fault-free and faulted NSE conditions.

A-2.1.2 Navigation Sensor Error (NSE) Sources

Table A-1 presents a list of fault-free and faulted error conditions that could affect system integrity. Each of the high-level NSE sources listed in the table is briefly explained below. Note that these threats and descriptions are for example purposes only and have not been provided as part of validation. Each State is responsible for validating a full range of threats during system certification.

Fault-free

Fault-free are errors that an ANSP anticipates from GBAS while the system is operating normally. The GF should be operating in "normal" mode with no integrity violations.

• Multipath – Errors from direct and diffuse (i.e. scattered) reflections from a given satellite.

- Noise Errors within the ground subsystem whose behavior is modeled to be noise-like and not captured in any other fault-free error source.
- RFI below the mask Errors in system performance due to elevated RFI but which do not violate the predefined RFI mask.

Ground Subsystem Faulted

These are errors caused by failure within the ground subsystem.

- Single RR Hardware Failure A rise in NSE due to the failure of a single RR. Both GAST C and D allow for single RR failures to occur as part of normal performance. Ground subsystem may include 2-4 RRs as part of their standard design configurations.
- Multiple RR Hardware Failures A rise in NSE due to failure of more then one RR. It is asserted that the H1 protection level equation does not protect the aircraft from erroneous information when multiple RR failures occur.
- VDB Failure A failure of the VDB hardware or software to broadcast the message types with integrity and continuity.
- Correction Processor Failure(s) A failure of the processor hardware or software. Error models could vary depending on the architecture used.
- Complex Hardware and Software Failures All GF component failures must be shown to be sufficiently mitigated using the relevant complex hardware and software design assurance procedures (e.g. RTCA/DO-178 and RTCA/DO-254). These processes should be used in conjunction with fail-safe design concepts.
- Correlated Multipath Affecting a Single RR (Multi-satellite) Direct reflections from multiple satellites causing a correlated position error in the same direction (i.e. cumulative error).
- Correlated Multipath Affecting Multiple RRs Direct reflections from single or multiple satellites which affects multiple RRs.

Environmental

These are errors due to the atmospheric affects outside the ground subsystem, airborne subsystem or the ranging sources which introduce errors directly into the RF ranging signal by delaying its transition through the atmosphere in an unpredictable fashion (i.e. the delay can not be sufficiently modeled, calculated and removed).

- Nominal Ionosphere Errors GBAS can incur as part of normal operation (not region dependent).
- Anomalous Ionosphere Errors not considered part of normal performance which can result in erroneous information if they occur. These are extreme regional events which are not considered part of Nominal Ionosphere. Given its regional nature, their characterization should be agreed upon between the applicant and State certification authorities. Airworthiness approvals will take into account the worst case errors that can exist after all the monitors in the system have acted given a standard threat space and assuming the anomaly may effect more than one satellite. If a state believes their environment is more severe than the limits of the standard threat space, additional mitigations outside the GBAS system may be required to ensure the user is not exposed to anomalous conditions outside the threat space.

- Nominal Troposphere Errors GBAS can incur as part of normal operation (not region dependent). For this error source, the ground subsystem is allocated sole responsibility for characterizing normal performance (via broadcast parameters and standard airborne functions).
- Anomalous Troposphere Errors GBAS incurs rarely, but occur often enough and whose NSE impacts are small enough (i.e. do not violate protection level integrity) to be tolerated as part of normal operation (may be region dependent). For this error source, the ground subsystem is allocated sole responsibility for characterizing normal performance (via broadcast parameters and standard airborne functions).
- RFI Above the Mask Rare events which ANSPs desire some robustness to in the event the local interference environment changes for short periods of time.

Ranging Source Fault-free

These are errors within the ranging source (e.g. satellite) which occur as part of normal performance of the ranging source and must be tolerated by GBAS as part of its normal performance.

• Nominal Ranging Source Errors – Errors due to any condition within the satellite which occur often enough to be considered part of normal performance.

Ranging Source Faulted

These are errors due to faults on the ranging sources vehicles.

- Signal Deformation Errors resulting from distortion of ranging source signals. Errors are quantified by evaluation the affects of such distortions on the ground and airborne subsystem correlators and tracking designs. This requires some standardization of the airborne equipment to ensure the threat space boundaries can be quantified for ground subsystems.
- Code Carrier Divergence (due to satellite only) Errors due to the divergence of the code and carrier signals caused by a fault on the satellite.
- Excessive Acceleration Errors due to slow or fast drifting of the ranging signal caused by a fault on the satellite.
- Erroneous GNSS Navigation Data Errors due to incorrect navigation data transmitted by the satellite which can result in erroneous information. These errors can be caused by failure on the ranging source or within the control segment responsible for generating the navigation data (if applicable).
- Low Power Condition reduction in satellite power below minimum specified performance.
- Multiple Ranging Source Faults Errors due ranging source failures (mentioned above) on ranging sources. In the cases where these combination of failures are not sufficiently improbable for the given service and function,

A-2.1.3 Integrity Coverage of NSE Sources

Each NSE source in Table A-1 is cross referenced with proposed integrity requirements to mitigate possible hazardous effects. Each mitigation is identified by placing its corresponding letter (defined below) in the NSE source row and the corresponding requirement column. Note

that the error list below contains all NSE source categories identified assuming the GBAS architecture as standardized in Annex 10. ANSPs, manufacturers and certification authorities will need to develop their own detailed list of causes for hazardous effects (e.g. Functional Hazard Assessments). However, it is expected that each lower level cause can be traceable to Table A-1.

During concept and system development, appropriate mitigation(s) are derived based on the impact of each hazard. A hazard may have multiple causes and resulting operational effects. The severity of these effects on airspace operations depends on the type of operation being supported, state of the overall system (e.g. phase of flight, visual/instrument flight rules, other environmental or operational constraints) and possible mitigations external to the system (e.g. existing procedures, ATC monitoring, etc). RTCA/DO-264 provides guidance on deriving safety objectives for each hazard severity [29]. Safety objectives are used to define high level safety requirements for mitigations necessary to meet the objectives (e.g. Annex 10 integrity performance requirements, target design probabilities). For example in a CAT III precision approach, an independent failure (or combination of dependent failures) resulting in misleading guidance information resulting in a short landing with hull loss (i.e. controlled flight into terrain) would be classified as a catastrophic consequence/severity of that failure. AMJ 25.1309 states that the occurrence of such failures be sufficiently, "...unlikely that they are not anticipated to occur during the entire operational life of all airplanes of one type." For a single aircraft navigation source, such as GBAS, this has been interpreted to mean that the system design should include sufficient mitigations such that the probability of the failure occurring without appropriate detection and annunciation be less than 1x10⁻⁹.

For GAST C, a safety objective commensurate with ILS was assigned for the system to support CAT I precision approach operations. Generally, service providers and manufacturers choose to allocate the high level objective and target mitigation probability to the different failure modes of the system (i.e. H0, H1 and H2 failure modes) using standard fault tree analysis methods. The intent was to capture each system failure mode under one fault tree.

For GAST D, new safety objectives are necessary to support CAT III precision approach, autoland and rollout operations. The primary concern to Annex 10 is the ground allocation of each safety objective, and what new requirements are necessary to ensure service providers and manufacturers can develop adequate mitigations to support them. Some of the new GAST D requirements are not necessarily more constraining than what may be achieved by a particular FAST C ground subsystem design. These requirements were simply not specified in the SARPS for GAST C. Contrarily to GAST C, GAST D requirements are now detailed at a sufficiently low level for characterizing the likelihoods and effects of all failures. The integrity requirements listed previously are examples of high level system requirements specified to support safety objectives linked to certain hazards. It is important that service providers recognize the relationship between operational hazards, safety objectives and high level system requirements. During the design phase, these relationships will be used to set the design assurance level for progressively lower level system design items (e.g. central processor). SAE ARP 4754 discusses a range of safety assessment processes that can be used during development to provide analytic evidence showing compliance with specified integrity requirements: Functional Hazard Assessment (FHA), Preliminary System Safety Assessment (PSSA), System Safety Assessment (SSA) and Common Cause Analysis (CCA). These assessment processes generally make use of ...Fault Tree Analysis (FTA), Dependency Diagrams, Markov Analysis, or other analysis methods." [30]. These processes should be conducted recognizing the role an item plays and its failure could play in a system's intended function (e.g. CAT III autoland).

(A) Ground Subsystem Signal-in-Space Integrity Risk for GAST D

A risk tree can be used to allocate the risk probability of 1.5×10^{-7} to faults not addressed by protection level integrity. These faults were generally referred to as part of the H2 hypothesis under CAT I developments and do not include single RR faults. For GAST D, anomalous ionospheric conditions are excluded from the allocation.

(B) Ground Subsystem Integrity Risk for GAST D

In addition to the integrity risk tree described in method (A) above, FAST D integrity also requires the ground subsystem design to include sufficient mitigations to ensure failures of system components, monitor architecture or other design relevant faults occur with a probability less $1x10^{-9}$. Section A-2.2.3 describes the requirement for assessing a ground subsystem's design. Such an assessment must ensure that GF components/functions failures are Extremely Improbable. Fail-safe methodologies should be used to demonstrate adequate mitigations.

(C) Protection Level Integrity for GAST C and D

Protection level integrity is required for both FAST C and D performance. The ground subsystem will broadcast approach service type specific parameters which are applied by analogous algorithms in the respective airborne equipment. The result is a bound on NSE with an associated risk probability of 5×10^{-8} .

(D) Integrity Monitoring for GNSS Ranging Sources

For failures that can not be demonstrated to be Extremely Improbable by design, a Differential Range Error P_{md} Limit method will likely be required. The P_{md} Limit method will limit the worst case differential error the fault could generate given that its monitor is functioning properly (Note, normal monitoring performance is assured by the Sub-system Risk Tree). These peak errors are considered part of the Intended Function.

(E) Ionospheric Gradient Monitoring and Siting Restriction

Under these requirements, the ground subsystem must detect absolute gradients in the ionosphere such that the gradient times the baseline length is less than 1.5 meters with a probability of missed detection of $1x10^{-9}$. This requirement implies a maximum undetected gradient of 300 mm/km when the baseline is the maximum allowed by the siting criteria (i.e. 5 km). The sensitivity of the absolute gradient monitor may be traded against the baseline length (D). However the maximum baseline length is limited to 5 km irrespective of the performance of this monitor.

(F) Aircraft Monitoring

Certain NSE risks can not be mitigated solely by the ground subsystem. As a result, airborne monitoring is required. In these cases, the aircraft manufacture will use standardized ground subsystem performance (via Annex 10 changes), airborne monitoring performance and its geometry selection criteria to assess the maximum position and angular deviation impact of a specific NSE condition. This analysis is part of the airworthiness process and can not be fully captured in Annex 10.

Each error condition below was assessed against the above criteria. The letter corresponding to the criteria used is indicated in the appropriate method's column for each error condition.

Table A-1: Integrity and Monitoring Coverage of NSE Sources

NSE Sources	SIS Integrity	GF Integrity	PL Integrity	RS Monitoring ⁽¹⁾	Ionospheric Monitoring & Siting	Aircraft Monitoring
GF Fault-free		1				
Multipath			C			
Noise			С			
RFI Below the mask			C			
GF Faulted						— (2)
Single RR Hardware Failure			С			$F^{(2)}$
Multiple RR Hardware Failures	A	В				
VDB failure(s)	A	В				
Processor Architecture failure	A	В				
Complex H/W and S/W failures	A	В				
Correlated Multipath Affecting a Single RR			С			$F^{(2)}$
(Multi-satellite)						
Correlated Multipath Affecting Multiple RRs ⁽³⁾	A	В				
Environmental						
Nominal Ionosphere ⁽⁴⁾			C			
Anomalous Ionosphere ⁽⁴⁾					Е	F
Nominal Troposphere ⁽⁵⁾			С			
Anomalous Troposphere ⁽⁵⁾			С			
RFI Above the Mask ⁽⁶⁾	n/a	n/a	n/a	n/a		n/a
Ranging Source Fault - Free						
Nominal Ranging Errors ⁽⁷⁾			С			
Ranging Source Faulted						(0)
Signal Deformation	A			D		F ⁽⁸⁾
Code Carrier Divergence (due to satellite only)	Α			D		F ⁽⁸⁾
Excessive Acceleration				D		F ⁽⁸⁾
Erroneous GNSS Navigation Data				D		F ⁽⁸⁾
Low Power Condition	A			D		F ⁽⁸⁾
Multiple Ranging Source Faults	A			D		$F^{(8)}$

- (1) This P_{md} limit method applies for differential range errors incurred as a result of AEC D equipment applying the 30 sec smoothed PRCs from MT-11.
- (2) Indirect monitoring of position error estimated from broadcast B-values using PLH1 will still be performed to GAST C requirements. AEC D equipment will perform additional monitoring directly on the B-values and smoothing filter differences, D_V and D_L . GF monitoring of the B-values included in the broadcast will remain consistent with legacy GAST C assumptions and requirements. The combination of these functions and requirements will be assessed using applicable airworthiness criteria.

- (3) Multipath can affect ground reference receiver measurements in three ways nominal multipath, correlated multipath among reference receivers, and nonnominal (excessive) multipath on a single reference receiver. Nominal multipath is accounted for in the broadcast σ_{pr_gnd} that supports the fault-free performance. Correlated reference receiver multipath can be handled in two ways. Since it is difficult to ensure zero correlation of multipath between reference receivers, there should be some allocation made in the fault-free performance error budget for σ_{pr_gnd} . The allocation should be consistent with the maximum correlated multipath allowed by the ground subsystem design. A maximum level of correlation is ensured by proper siting of the reference receivers, where a key aspect is to define an obstacle clearance area that needs to be maintained around the reference receiver sites.
- (4) Nominal ionosphere events are those that are considered part of normal operation and can be tolerated as part of the system's intended function. The prior probability of anomalous ionosphere events can not be precisely quantified at this time. For this reason, a worst-case theoretical model is assumed and derived using field data and a conservative specific risk assessment methodology.
- (5) Nominal troposphere conditions are those which occur on a daily basis. Anomalous troposphere events are distinct and occur on an infrequent basis, however they are frequent enough to be considered part of normal performance. Both conditions are considered part of fault-free normal performance.
- (6) This requirement should focus on designing systems with sufficient robustness to GNSS RFI to allow normal operations during rare, unintentional GNSS band RFI events. This requirement should consider State specific operational environments and spectrum enforcement.
- (7) Normal Ranging errors are those generated by the satellite and not included in the above table, such as fault-free signal deformation and code-carrier divergence. Minimum performance characterization for these errors should be provided by GNSS service providers. When this information is not available or insufficient for the target operations, statistical data and analysis may be used where available and acceptable to local State authority.
- (8) AEC D equipment is required to monitor the position domain impact of certain geometries and only apply those which allow the aircraft to complete its intended operation given standardized ground performance.

Figure A-1 illustrates how the GAST D concept provides coverage of NSE using FAST D integrity and monitoring methods/requirements (not FAST C integrity performance) by the ground and airborne subsystems. The type of evaluations (e.g. limit case, malfunction case) made during the airworthiness analysis will depend on the type of failure, and how the failure is mitigated by the airborne subsystem.

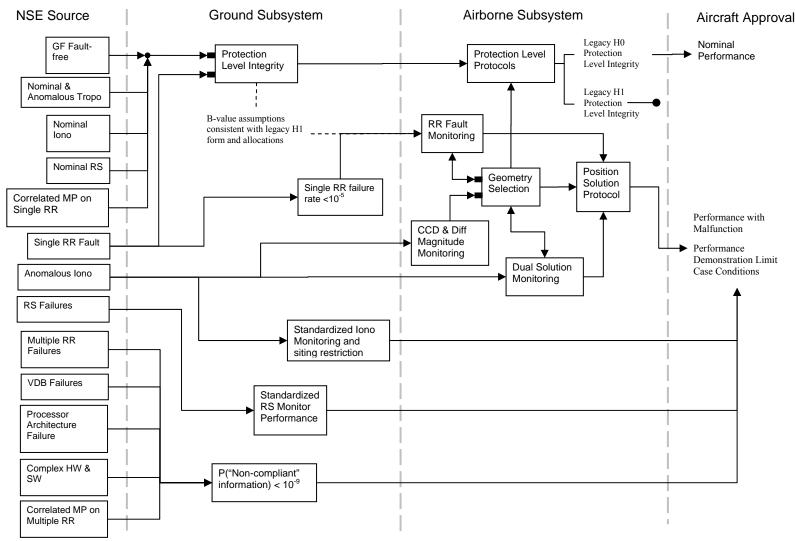


Figure A-1: FAST D Integrity Coverage of NSE Sources

A-2.2 Integrity Method Descriptions

A-2.2.1 Fault-free Performance and the W-matrix

The GF needs to communicate the normal fault-free differential error expected on each PRC provided assuming that the intended function is being satisfied. This information is used by the airborne receiver to pick the appropriate weighting (W-matrix) of the different satellite corrections in its position solution to get the best result. Under GAST C, the protection level parameters were used to provide this indication for both normal operation and fault situations. Under GAST D, it is proposed to use a different combination of parameters that better reflects its nominal error performance. The following are these parameters:

<u>Parameter</u>	Message Type
σ_{tropo}	MT-2
$\sigma_{vert_iono_gradient,D}$	MT-2
σ _{pr gnd,30}	MT-11

The Sigma Troposphere, σ_{tropo} , value is derived from a combination of transmitted parameters and aircraft information. These parameters are identical to those used for GAST C. The Sigma Vertical Ionosphere Gradient D, $\sigma_{vert_iono_gradient,D}$, parameter removes any inflation from $\sigma_{vert_iono_gradient}$ (GAST C residual ionospheric uncertainty) necessary to bound or perform geometry screening for anomalous ionosphere conditions. A new Sigma PR Ground, $\sigma_{pr_gnd,30}$, parameter was added to MT-11 for each correction. This parameter characterizes the post-correction error of the 30 second smoothed PRCs using a 1-sigma standard deviation value (i.e. 63% error bound assuming a zero mean, normal distribution). Given that it only reflects fault-free error performance, it is NOT necessary to use a specific risk methodology to derive its value. This also stipulates that it should not be used in the aircraft integrity rationale. The W-matrix serves as an indication of a satellite's normal performance and reduces the influence of those satellites with the worst performance. Since accuracy is a better indicator of normal performance, it is more practical to use the $\sigma_{pr_gnd,30}$ parameter then the $\sigma_{pr_gnd,100}$ parameter used for protection level integrity.

A-2.2.2 Ground Subsystem Signal-in-space Integrity for GAST D

Under GAST D, the ground subsystem is still required to support precision approach procedures down to 200 ft. Even for CAT III operations, it is desirable to leverage current performance standards and approvals for precision approaches down to 200 ft rather than deriving new certification criteria. A new signal-in-space integrity requirement has been defined to leverage unique features of GAST D ground and airborne equipment. New airborne monitoring capabilities are now active for the duration of the approach and allow more effective mitigation of anomalous ionospheric conditions. The aircraft has accepted responsibility for the hazardous effects of this condition, so a loss of integrity probability assignment should not be included in ground FAST D signal-in-space fault allocation. If it were included, its effects would be double counted in the overall operational safety assessment which is too conservative.

A-2.2.3 Ground Subsystem Integrity for GAST D

A GFC D manufacturer must demonstrate that their design conforms to fail-safe design criteria [31]. Among these criteria is the requirement that the system demonstrate failures of its intended

function resulting in catastrophic events are Extremely Improbable. This section will address failures of this type which are the sole responsibility of the ground subsystem.

Under GAST D, the aircraft manufacturer is responsible for showing that ranging source failures can occur and be catastrophic with a probability less then $1x10^{-9}$. While ground monitoring performance (via compliance with the Ranging Source Monitoring constraint region) is leveraged to demonstrate this, the ground subsystem is only responsible for proving that the specified ranging source monitoring performance will be met with a probability 1-10⁻⁹ in any [30] second interval.

In addition to this, the ground subsystem must ensure that all other internal components and algorithms of the system continue to operate normally with a probability of 1-10⁻⁹ in any [30] second interval.

There are many analyses and artifacts which can be used to demonstrate compliance. The methods and processes outlined in SAE ARP 4754 and 4761 are generally acceptable means for assessing fault modes [32][33]. These standards should be used at all stages of development to properly manage and document the safety risks of GF's design.

Design assurance of complex hardware components and software requires disciplined development processes. Industry standard safety assurance processes like DO-278 and DO-254 contribute to this process are not sufficient by themselves. They should be applied in consideration of other design guidance.

A-2.2.4 Protection Level Integrity for GAST C and D

Protection level integrity provides coverage of fault-free NSE, single Reference Receiver fault NSE and some environmental conditions. The ground subsystem is responsible for broadcasting parameters (when used with the appropriately matched airborne equipment class) that bounds the position domain performance at the output of a fault-free airborne receiver.

For GAST D, the following parameters will be used by the protection level protocol.

<u>Parameter</u>	Message Type
$K_{md_e_D,GPS}$	MT-2
$K_{md_e_D,GLONASS}$	MT-2
σ_{tropo}	MT-2
$\sigma_{\text{vert_iono_gradient,D}}$	MT-2
P_{D}	MT-11
$\sigma_{pr_gnd_D}$	MT-11
$\sigma_{pr_gnd,30}$	MT-11

Any inflation of the K-factors applied under GAST C for bounding or geometry screening of anomalous ionosphere errors can be removed in $K_{md_e_D,GPS}$ and $K_{md_e_D,GLONASS}$. The Sigma Troposphere, σ_{tropo} , value is derived from a combination of transmitted parameters and aircraft information. These parameters are identical to those used for GAST C. The Sigma Vertical Ionosphere Gradient D, $\sigma_{vert_iono_gradient,D}$, parameter removes any inflation from $\sigma_{vert_iono_gradient}$ (GAST C residual ionospheric uncertainty) necessary to bound or perform geometry screening for anomalous ionosphere conditions. The Sigma PR Ground, $\sigma_{pr_gnd_D}$, and Ephemeris Decorrelation parameter, P_D , for the GAST D 100 second smoothed PRCs remove from σ_{pr_gnd} and P (in MT-1),

respectively, any inflation necessary for GAST C to bound or perform geometry screening for anomalous ionosphere conditions. Sigma PR Ground for the GAST D 30 second smoothed PRCs, $\sigma_{pr_gnd,30}$, characterizes the accuracy of the GF's differential range error contributions to the airborne equipment's position solution via the weighting matrix, W (see Appendix B, Section 0).

Note that a GFC D station will still have to comply with all GAST C requirements to provide service to AEC C equipment. This includes showing compliance with the FAST C (i.e. CAT I traditional) integrity risk tree for H0, H1, H2 conditions.

A-2.2.5 Integrity Monitoring for GNSS Ranging Sources

Ranging source monitoring is a key GBAS function. FAST C standards specify high level signal-in-space integrity performance allocations that a service provider allocates to these monitors. This provides ground subsystem design flexibility, but it requires the service provider to make conservative assumptions with respect to airborne receiver designs and ultimately leads to a reduction in system efficiency. The GAST D concept proposes two new requirements to standardize minimum ranging source monitor performance, so aircraft manufacturers may leverage that performance in their system safety analysis. GAEC D equipment will use the 30 second differential corrections to form the position solution used for deviation guidance. Therefore, in both cases, the requirement applies to the probability of missed detection as a function of the size of an error due to failure in the 30 s smoothed pseudorange after the correction is applied.

The first requirement constrains the Pmd performance of the specified ranging source failures without regard for the a priori probability of the ranging source failure. The bound for a ground subsystem's monitor performance defined in draft Annex 10 Appendix B Section 3.6.7.3.3.2 is expressed in Table A-2 and illustrated in Figure A-2 [1]. Table A-2 defines the values for this performance region. The limits of the constraint region define the minimum P_{md} that the ground subsystem must ensure for any single ranging source failure condition.

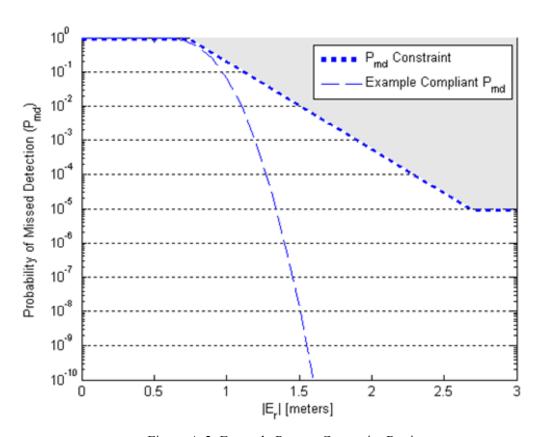


Figure A-2. Example P_{md limit} Constraint Region

Note: The example compliant P_{md} in Figure XX-1 is based on a hypothetical monitor with a threshold set to 0.8 meters and monitor noise of 0.123 meters. The curve is for illustration purposes only and does not represent the performance of any specific monitor design.

Table A-2 P_{md limit} Parameters

Probability of Missed Detection	Pseudorange Error (meters)		
$P_{md_limit} \le 1$	$0 \le E_r < 0.75$		
$P_{md_limit} \leq 10^{(-2.56x Er + 1.92)}$	$0.75 \leq E_r \leq 2.7$		
$P_{md_limit} \leq 10^{-5}$	$2.7 \leq E_r < \infty$		

The second requirement constrains the conditional probability of the Pmd performance of the specified ranging source given the a-priori failure probability for the specific ranging source failure. The conditional probability bound, Pmd*Papriori, for a ground subsystem's monitor performance defined in Appendix B Section 3.6.7.3.3.3 is illustrated in Figure A-3. The a-priori probability of each ranging source failure (Papriori), used to evaluate compliance, should be the same value used in the analysis to show compliance with the bounding requirements for FAST C and D (see Attachment D Section 7.5.3.1).

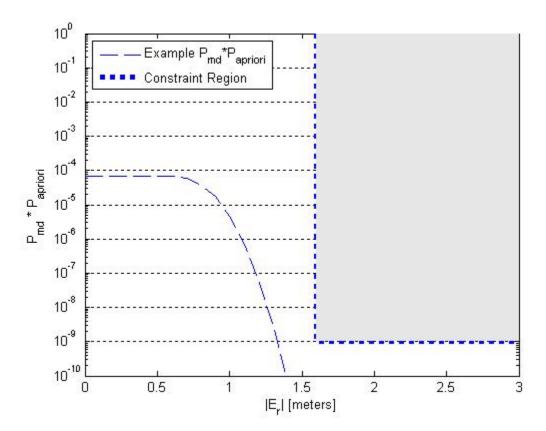


Figure A-3. Example P_{md limit} Constraint with A Priori Probability

Note: $P_{apriori}$ is assumed to be $7x10^{-5}$ for this example illustration of Figure XX-2.

Appendix C provides background on how these performance limits were derived and determined to be feasible with the GAST D intended function.

Monitor detections can be reflected in the Type 1 and 11 messages by:

- a) removing the correction for the associated satellite from both Messages, or
- b) marking the satellite as invalid using the coding of opr gnd

If more then one monitor is needed to detect a particular failure, it is possible to derive a single P_{md} performance curve to compare against the above minimum requirement considering the ability of both monitors. For multiple failures, an analysis (see Appendix C) has shown that specifying the ground monitor performance for only single faults is sufficient, because it is more constraining than the dual fault-case given anticipated geometry screening in the aircraft associated with ionospheric anomaly protection. See Table A-1 for the errors sources the must be evaluated for this requirement. See Appendix C for further guidance on the rationale for defining this region and guidance for GF mfg. compliance with the constraint region.

A-2.2.6 Ionospheric Gradient Monitoring and Siting Restriction

Nominal ionosphere errors can continue to be characterized using the GAST D residual ionospheric uncertainty parameter, $\sigma_{\text{vert iono gradient,D}}$, and anomalous ionospheric errors will

continue to be monitored by the ground subsystem. However, the safety mitigation responsibility for anomalous ionosphere conditions has been reallocated to the aircraft. GAEC D equipment will now also monitor this environmental condition and perform checks during certain phases of flight to minimize the likelihood of generating hazardous guidance information to the aircraft. To leverage the combined ground and airborne monitoring functions, additional constraints are necessary to demonstrate sufficient mitigation of this hazard. An airworthiness analysis must show how likely each part of the threat space will be detected by the monitor combination. The differential effects of the ionosphere errors vary widely with spatial separation between the ground subsystem reference point and the aircraft position. For some parts of the threat space, the error that persists after monitoring is directly a function of the baseline length. For this reason the distance from the ground subsystem reference point to the threshold must be limited. This limit has been set to 5 km in the current draft standards.

A-2.2.6.1 Ground Subsystem Ionospheric Monitoring

The standards do not specify a specific monitor performance for the ground subsystem. Rather a standard performance limit is given in terms of the product of the sensitivity of the monitor and the baseline distance between the ground subsystem and the threshold of the runway providing GAST D service. The combination of the two allows the aircraft to calculate the maximum size of gradient the ground subsystem will not detect [34].

The aircraft manufacturer will perform an analysis as part of the airworthiness approval process to demonstrate that the largest errors which may persist after all error mitigations have been applied will not result in an unsafe landing. These largest errors will be determined through simulation of the standardized ground and airborne monitors for all possible ionospheric gradients defined by a standard threat space. This analysis demonstrates sufficient mitigation of the threat considering credible operational scenarios, combined ground and airborne monitoring performance and siting constraints. The maximum size of errors post monitoring are expressed in the pseudorange (PR) domain. An airframe manufacturer translates these largest possible PR errors into the position domain in accordance with limits set on acceptable geometry screening done by the airborne subsystem. Selective geometry screening maybe used by the aircraft in order to limit size of errors in the position domain that may exist with a probability of greater than 10^{-9} . The largest errors that will persist after the combinations of all the monitoring are determined based on an assumed standard threat space. This threat space is described in the guidance material. ANSPs are responsible for ensuring the airborne users are not exposed to ionospheric gradients outside the limits of the standard threat model.

ANSPs offering GAST D service in threat environments which are believed to exceed the standard threat space limits must take additional steps to ensure that the user will not be exposed to threats outside the threat space. Strategies that may be employed are discussed in section 4.2 of this document as well as the guidance material (section D.7.5.6.1.7). In general a service provider may elect to:

- 1. alter the characteristics of its ground subsystem, and/or
- 2. introduce additional monitoring (internal or external to the GBAS), and/or
- 3. Introduce other operational mitigations that limit the users exposure to the extreme ionospheric conditions.

Potential ground-system changes which could achieve this risk reduction include tighter siting constraints (see section 7.5.6.1.6, and section B 3.5.7.1.4.1) and improved ground-system monitoring performance (B 3.6.7.3.4). Another strategy for mitigation of the risk is monitoring

of space weather (external to the GBAS system) in conjunction with operational limitations on the use of the system during periods of high ionospheric activity. Any and all combinations of these strategies may be used to insure the GAST D user is not subjected to ionospheric anomalies outside the standard threat space. Reference [35] provides additional discussion of the validation of the monitor performance and how trade-offs between siting and monitor performance may be used to address threats outside the standard threat space.

A-2.2.6.2 Siting Restrictions

The GAST D SARPS proposal includes a new siting restriction such that the distance between the ground subsystem and the threshold of any runway supporting GAST D must be less than or equal to 5 km. This siting limitation is required to address a very specific corner of the threat space where neither the airborne or ground monitoring can effectively limit the worst case error. (Details regarding this corner of the threat space may be found in [35]).

Although 5 km is the maximum baseline length, it is possible that a service provider would choose to further restrict the baseline length between the ground subsystem and the threshold. Further restricting this difference will allow for lower sensitivity on the gradient detection monitor in the ground subsystem. Also, reducing this baseline might be part of the strategy employed to assure that users are not subjected ionospheric anomalies outside the standard threat space.

A-2.2.7 Aircraft Monitoring

A number of new airborne monitoring functions are used in combination with ground monitoring performance, nominal error bounds, and broadcast parameters to fully mitigate certain threats. Generally, new ground requirements have been added to the standards, so the aircraft mfg. knows with what probability and to what magnitude each NSE source has been limited by the ground subsystem alone. The airborne equipment can then be designed to mitigate the residual risk. The key feature of this concept is the shift of signal-in-space integrity responsibility to the aircraft for certain failures common to the ground and airborne (e.g. ranging source failures). As a result, the new standard ground requirements are defined in terms of differential range error, and the aircraft selectively restricts those geometries that do not meet the necessary position domain performance given those differential range error limits. Additional information on these functions and their relation to airworthiness can be found in Appendix B.

A-3 Continuity Hazard

A-3.1 Background

As part of the GAST D concept, the CSG has attempted to derive an acceptable probability loss of GBAS precision approach service under Category III weather conditions. Previous papers have given us insight into analogous ILS continuity of service numbers, and how they were established [36]. Subsequent discussions concluded that applying these values directly to GBAS was possibly conservative given typical aircraft equipage for CAT III operations, current certification criteria and their application in aircraft approvals.

Efforts are ongoing to develop an operationally relevant continuity risk allocation to the navigation system. The All Weather Operations Harmonization Working Group (AWOHWG) is currently discussing how to best address GBAS loss of continuity during landing and rollout under CAT III weather conditions. This hazard should be evaluated for its effects on aircraft operations, the air crew and occupants. Additionally, service providers must assess the effects this hazard will have on other terminal area operations and enroute traffic. This paper summarizes previous discussions and incorporates safety assessment concepts for Air traffic Services [37].

A-3.2 Operation Service Description

GBAS provides differential corrections and integrity information to augment GNSS ranging and navigation data. Current, standards define functions to support Category I precision approach and non-precision approach procedures. New requirements, referred to as GAST D, seek to add GBAS precision approach services down to Category III weather minima with autoland.

Autoland capabilities can vary according to aircraft. FAA Advisory Circular 120.28D and EASA CS-AWO Decision No. 2003/6/RM discuss a number of these systems and provides guidance for their approval [38][39]. Although, the AC does not contain direct guidance on appropriate aircraft navigation system continuity risk allocation. However, certain information can help us determine if our requirements are an operationally relevant allocation. For example, an aircraft is required to be"... shown to be capable of safely completing an approach, touchdown, and rollout and permitting a safe go-around from any altitude to touchdown following any failure condition not shown to be extremely improbable." [38, Section 4.3.1].

A-3.4 Loss of Continuity Effects

A-3.4.1 Operation, Air Crew and Occupants

Ed Note: The primary purpose of the AWOHWG activity is to establish FAA and EASA criteria to be used for airworthiness certification and obtain or maintain approval for Category II and III GBAS operations. These criteria are expected to include a demonstration of the acceptability of the GBAS continuity (as specified in ICAO Annex 10) for the subject aircraft. Safety effects on a single CAT III operation will be covered by the AWOHWG activity. Conclusions or guidance from that group will be include here once available.

A-3.4.2 ATC Services

This section looks at the possible safety effects a loss of continuity could have on air traffic control (ATC) services. It assumes sufficiently equipped aircraft and crew training to safely complete a landing or execute a go-around during a loss of GAST D service below 50 ft.

A loss of continuity which results in safe landing completed by the aircraft autoland system or manually by the pilot is transparent to ATC and will not affect other departure or arrival operations. A loss of continuity resulting in a missed approach requires ATC to monitor the aircraft during the missed approach, and after the missed approach is completed, vector the aircraft initially away from other aircraft and then reintegrate that aircraft back into the traffic flow if appropriate. Without sufficient mitigation, errors during missed approaches could result in loss of separation between multiple aircraft on approach or in the terminal area.

A single missed approach, even under CAT III weather conditions, is considered a safe and normal operation. For airports that utilize multiple approach operations at the same time, a loss of the broadcast signal or other interruption to normal services could affect multiple aircraft at various stages of approach and landing. However, each procedure is designed assuming go-arounds could occur for all approaches at the same time. ATC surveillance ensures separation is maintained during the critical phase of the missed approach, and usually air traffic configurations require more than one approach controller for multiple approaches [40, Section 6.7]. Separation should be monitored and maintained during this period (~1 NM past departure end of runway). Given this, multiple missed approaches may increase ATC work load resulting in a slight reduction in ATC services. However, it will likely not result in a loss of aircraft separation. Thus, a loss of continuity for multiple missed approaches under CAT III conditions could be classified as a **Minor** severity.

If multiple aircraft must conduct a missed approach and other aircraft must be vectored to alternative approaches or airports, this will further burden ATC to maintain proper separation of enroute and terminal airspace, however this workload would be spread over multiple approach controllers. This would also equate to a slight increase in ATC workload and a **Minor** severity.

These assertions need to be reviewed as part of a full operational safety assessment. ANSPs should solicit inputs from their ATC stakeholders and validate the assumptions and conclusion made above.

A-3.5 Ground Subsystem Continuity

A-3.5.1 Background

The generic definition of continuity is the "capability of the system to perform its function without unscheduled interruptions during the intended operation" [Annex 10, Attachment D, 3.4.1]. The definition for approach and landing is "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, 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. In this case, the continuity requirement is stated as a probability for a short exposure time" [Annex 10, Attachment D, 3.4.3.1].

The following is the current GBAS CAT I (GAST C) SARPs requirement, as revised in Annex 10 amendment 83 [41].

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 $1-8.0~\mathrm{x}$ 10^{-6} per 15 seconds.

Note 1.— 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.

This requirement has been revised to incorporate a average risk assessment methodology. The NSP has determined that CAT I safety hazards do not warrant using more restrictive specific risk methods. CAT III safety hazards require use of specific risk assessment methods. Therefore, GAST D continuity requirements must be assessed using specific risk.

For GAST D, it is not appropriate to define a single SIS continuity requirement (i.e. probability with exposure time) as we did for CAT I. GAST D SIS performance is reliant on the combination of ground and airborne subsystem designs. The draft Annex 10 standards include the maximum likelihood of a continuity hazard caused by the ground subsystem, and that can be combined with an aircraft analysis to determine the total operational risk. Given the depth of analysis required to certify aircraft for CAT III operations, this level of assessment is feasible. This methodology is similar to that used for GAST D integrity risk allocation.

A.3-5.2 Proposed Allocation of the Ground System Requirements

The GAST D continuity requirements were conceived with three primary goals in mind:

- 1) Segregate the ground system requirements from assumptions about avionics and aircraft performance as much as possible.
- 2) Standardize the ground subsystem continuity independent of the satellite constellation performance, while specifying the constellation assumptions well enough to support the aircraft's estimation of continuity of service.
- 3) The ground system should support the full range of CAT II/III operations with autoland and rollout.

The first goal is similar to the motivation for defining the ground integrity monitoring requirement independent of airborne avionics performance. Having to make assumptions about airborne implementation and performance can lead to overly conservative values and significantly complicate the ground's safety assessment process. Similarly the second goal is to define the requirements independent of the actual satellite constellation, such as the number of critical satellites. Ideally showing compliance with the ground system requirements would not be dependent upon assumptions about the airborne equipment or the satellite constellation being used in the aircraft position solution. The third goal is to enable the ground system to support the most demanding approach and landing operations. Sufficient operational continuity for CAT II/III precision approaches can be achieved through a combination of specific ground subsystem continuity requirements and airworthiness criteria consistent with these operations.

The following defines two probability and exposure time requirements for a GFC D station's faulted and fault-free conditions (the yellow portion indicates change made from the original proposal).

3.6.7.1.3.2 Additional continuity of service requirements for FAST D. The probability of a GBAS ground subsystem failure or false alert, excluding ranging source monitoring, not causing an unscheduled interruption of service for a period equal to or greater than 1.5 seconds shall be greater than 1-2.0x10⁻⁶ during any 15 second interval. The probability that the ground subsystem excludes any individual

fault-free ranging source from the Type 1 or Type 11 corrections due to a false detection by the ground integrity monitors shall not exceed 2.0x10⁻⁷ during any 15 second interval.

Note 1.- Loss of service includes failures resulting in loss of the VHF data broadcast, failure to meet the VHF data broadcast field strength, failures resulting in transmission of out of tolerance VHF broadcast data, and alert due to an integrity failure. Guidance material on the potential causes of loss of service and monitor false detections are contained in Attachment D, section 7.6.2.2.

Note 2. – Continuity for FAST D is defined as the probability that the ground subsystem continues to provide the services associated with the intended ground subsystem functions. Ultimate continuity of navigation system performance in the position domain must be evaluated in the context of a specific satellite geometry and airplane integration. Evaluation of position domain navigation service continuity is the responsibility of the airborne user for GAST D. Additional information regarding continuity is given in Attachment D section 7.6.2.1.

The ground subsystem continuity is defined by two requirements. One is the continuity of the ground subsystem that includes failures of all components necessary to successfully broadcast the required VDB message types and comply with all related requirements (e.g. reference receiver, VDB transmitter). It also includes loss of service due to integrity failures in the ground subsystem that result in ground subsystem alerts. The other requirement is the continuity associated with ranging source monitor fault free detections. False detections of this type are defined separately, because the monitor contribution is related only to exclusion of individual satellites from the broadcast corrections. This does not necessarily result in a loss of the SIS by the airborne receiver. The aircraft will combine the ground false detection probability with its own hazard conditions to determine the total SIS loss of continuity hazard risk

The requirement is defined on a per ranging source basis. The reason for that is the ground design then does not need to account for the actual number of satellites in view or the number considered critical to the user for a specific approach.

A 15 second exposure interval is defined for the GAST D continuity requirement. This value is somewhat arbitrary, but does correspond to CAT II/IIIA operations (see Figure D-1). Autoland and rollout hazard effects are highly dependent on the aircraft integration and any mitigations it may or may not include. For this reason, the exposure interval is kept generic. Each aircraft manufacturer must derive their applicable exposure interval based on their proposed design and the intended operation. The manufacturer can then calculate the corresponding continuity risk probability taking into account the required ground subsystem performance in addition to the aircraft design.

Figure A-4 shows a possible method of allocating the SIS continuity for GAST D. The two "shall" requirements above correspond to the boxes "Subsystem Failure or False Alert" and "Ranging Source Monitoring" in the figure. The "Total GBAS SIS Continuity" box corresponds to the "GBAS Contribution to NSE Performance" from Figure 1 in the main body where the combination of ground and airborne subsystem causes must all be considered to derive a operationally relevant loss of continuity likelihood.

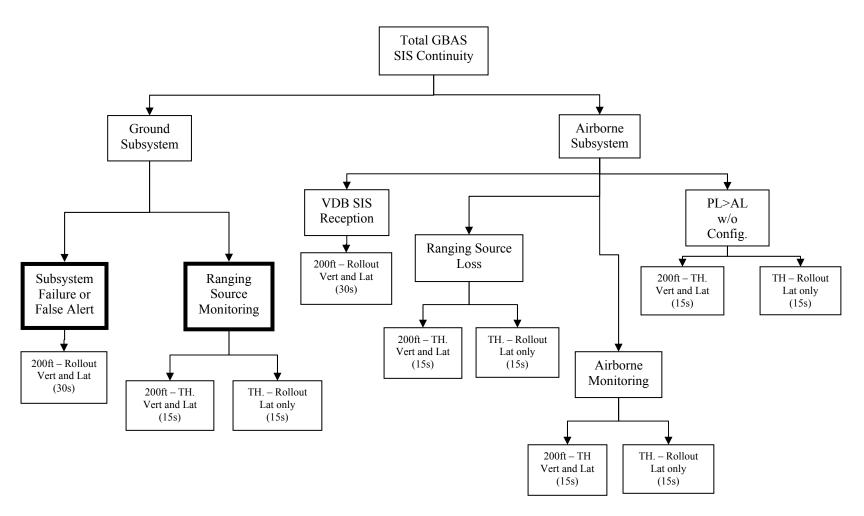


Figure A-4. Example GAST D SIS Continuity Allocations

The above "Ranging Source Loss" condition can occur in a number of ways. Some possible examples are loss of satellite tracking (e.g. due to aircraft maneuvers, antenna gain patterns or other aircraft specific causes), unscheduled satellite maneuver or the satellite is set unhealthy due for reasons internal to the GNSS Ranging Source provider. These causes are external to the airborne subsystem, and minimum performance requirements are usually available which define the likelihood of these kinds of conditions.

Below are example probability allocations based on Figure A-4, it is assumed the initial part of the CAT III operation is the 15 seconds prior to threshold. During that phase continuity is required for both the vertical and lateral guidance. It is also assumed that the landing (including flare maneuver) and rollout phase of the operation is another 15 second period where only the lateral guidance continuity is required. Note, this concept is inconsistent with DO-253C MOPS, which requires both vertical and lateral during the entire operation. This inconsistency has been logged as a maintenance action for RTCA working group four and will be discussed during their February 2010 meeting.

To separate continuity risk between approach and landing phases, the airborne equipment must separate lateral and vertical guidance. The evaluation is done over a total exposure of 30 seconds. Table A-2 is a set of continuity risk allocations based on this example. Some are requirements specified in the standards (e.g. Annex 10 ground subsystem continuity), while others are estimated allocations that are not defined in the standards (e.g. airborne monitors). Some of the assumptions included in this example are that there are a maximum of 6 critical satellites for vertical and 3 critical satellites for lateral (these values are based on a specific risk). The estimated total SIS continuity is 1.01×10^{-5} per operation (30 sec). This probability is consistent with ongoing AWOHWG discussions which state that the likelihood of GBAS loss of continuity should be "on the order of" 1.0×10^{-5} .

Table A-2. Example GAST D SIS Continuity Allocations

Allocation	Exposure (sec)	Risk	Reference / Rationale
Ground Subsystem	30	5.8x10-6	n/a
Ground Subsystem Failure: 200 ft through Rollout	30	4x10 ⁻⁶	Consensus
Ground RS Monitoring	30	1.8x10 ⁻⁶	n/a
Ground RS Monitoring: 200 ft to Threshold	15	$1.2x10^{-6}$	Consensus
Ground RS Monitoring: Threshold through Rollout	15	$6.0x10^{-7}$	Consensus
Airborne Subsystem	30	4.26x10 ⁻⁶	n/a
Ranging Source (RS) Loss	30	3.85x10 ⁻⁶	n/a
RS Loss: 200 ft to Threshold	15	2.57x10 ⁻⁶	DO-245A, Table D-8 WP, ICAO/NSP,
RS Loss: Threshold through Rollout	15	1.28x10 ⁻⁶	DO-245A, Table D-8

Allocation	Exposure (sec)	Risk	Reference / Rationale
VDB SIS Reception	30	6x10 ⁻⁸	DO-245A, Table D-8
PL>AL Without Configuration Change	30	4.5x10 ⁻⁸	n/a
PL>AL: 200 ft to Threshold	15	4x10 ⁻⁸	DO-245A, Table D-8
PL>AL: Threshold through Rollout	15	$0.5x10^{-8}$	DO-245A, Table D-8
Airborne Monitoring	30	3x10 ⁻⁷	n/a
Monitoring: 200 ft to Threshold	15	$1.5x10^{-7}$	Consensus
Monitoring: Threshold through Rollout	15	$1.5x10^{-7}$	Consensus
Total SIS Continuity	30	1.01x10 ⁻⁵	n/a

The last column includes References/Rationales for each column's target probability. The term "Consensus" means that the value was determined to be feasible, by the CSG, per manufacturer and ANSP input. The airborne monitoring probability, $3x10^{-7}$, was derived from the overall loss of continuity safety objective minus the allocations to other conditions. The airborne monitoring allocation is consistent with the specific monitor allocations defined in DO-253C, while assuming allocations of the same order of magnitude for monitors without defined requirements. This allocation was equally spilt between the two segments of the operation (i.e. "200 ft to Threshold" and "Threshold through Rollout").

In summary, the proposed ground continuity requirements should be able to support a range of CAT II/III operations given the currently proposed hazard effects and severity assignments. It will be up to the ground subsystem manufacturer to determine the minimum equipment configuration needed to meet the specified subsystem continuity. This includes any redundancy implemented for the VDB transmitter, corrections processors, etc. The proposed requirement for loss of continuity should allow for at least one reference receiver failure. In addition to loss of continuity, service providers may also define additional requirements to support State specific reliability and maintainability needs.

Appendix B Airborne Considerations for GAST D

B.1 Airworthiness Certification Considerations

One of the primary driving considerations behind the current GAST D proposal is to provide enough information about the performance of the service type to enable assessment of total system performance (i.e. Navigation system and airplane systems) in the context of an airworthiness certification program. Under the proposal, airplane performance in terms of allowable total system error (TSE) may be derived as a function of airborne satellite geometry screening parameters, airborne monitoring requirements (e.g., ionosphere anomalies and single reference receiver faults) and GBAS ground monitoring requirements (e.g., ranging source faults). This topic of relating airplane TSE performance to NSE based requirements has been discussed at length in a number of references [42]. A brief overview of the subject will be given here.

B.1.1 Airworthiness Requirements

Within the context of developing a new type of service for GBAS, it was necessary to have a definition of what is considered a successful landing. [43, 44, 45]. Fortunately, existing airworthiness requirements for autoland include success criteria that can be used as a definition of a safe landing [46, 47].

Three airworthiness requirements have been selected and adapted for use in the derivation of the Annex 10 ground subsystem's ranging source fault monitoring requirements. These requirements are located in the following documents:

- 1. AC 120-28D, Section 6.3.1 "Nominal Performance"
- 2. AC 120-28D, Section 6.4.1 "Performance with Malfunction"
- 3. CS AWO Subpart 1 "Performance Demonstration Limit Case Conditions"

Item (1) is applicable to GBAS as written. Items (2) and (3) have been adapted by the GBAS community and could result in new airworthiness requirements for GBAS. The requirements have been given monikers (Nominal Condition, Malfunction Condition, and Limit Condition respectively) that relate to their *original* purpose within the airworthiness documents; these names are *not* intended to be indicative of the role they play in the proposed ICAO Annex 10 material. For example, the malfunction condition does not address ground or airborne subsystem malfunctions and the limit condition does not address performance at a single extreme value.

The resulting three conditional requirements include a group of performance parameters, each with an associated maximum probability that the parameter may exceed a specified limit for that condition. The performance parameters include longitudinal and lateral gear touchdown locations, structural load, and airplane attitude at touchdown.

The nominal performance requirements are used to demonstrate that the aircraft will land in the touchdown box with the required probability under fault free conditions. These requirements are already used for ILS and take account of the nominal ILS accuracy. The proposed use of these requirements within the GBAS concept is identical to the ILS case. The performance with malfunction requirement is normally applied to aircraft system failures that have a probability greater than 10-9. It is not currently applied to the ILS signal-in-space but in the GBAS concept it is used in the derivation of the required monitor performance. Similarly the limit case requirement is normally applied to limiting environmental conditions such as maximum wind speed and it is not currently applied to the ILS NSE. In the GBAS concept it is used to define a

limit condition on the NSE as a result of a failure which is not detected by one of the monitors. In this case the limiting condition is considered to be an NSE bias caused by fault which is not detected by the monitor. Each fault condition is considered to be an independent event and the limit case requirements ensure that the aircraft will land within the touchdown box with the required probability in the presence of a fault which is not detected by the ground system monitors. These requirements and their treatment regarding GBAS requirements and airplane performance are described in more detail in the following sections.

B.1.2 Relating Ground Monitoring Requirements to Airworthiness Requirements on Landing System Performance

The additional monitor requirements to support GAST D are discussed in Appendix A. These requirements define a limit on the probability that a ranging source error induced by a fault will go undetected by monitoring (P_{md}) as a function of the size of the error due to the fault in the range domain. Table A-2, Figure A-2 and Figure A-3 describe the general form of the first of two monitor requirements from the current draft SARPs change Proposal [1] (Sections 3.6.7.3.3.2 and 3.6.7.3.3.3). These specified P_{md} limits can be related to two of the three airworthiness requirements referenced in the previous section - the limit case and the malfunction case.

The malfunction case requirement applies to all faults with a probability greater than $1x10^{-9}$. To assess the worst case malfunction, the P_{md} constraint region can be used to derive the maximum size of an error that can happen with a probability of greater than $1x10^{-9}$. The product of the prior probability of a fault and the probability of missed detection of errors due to the fault is limited to a probability smaller than 10^{-9} for range errors due to a fault that are larger than 1.6 meters. In other words, for any of the specified fault modes, the largest undetected error with a probability of greater than 10^{-9} is 1.6 meters in the pseudorange domain. This individual pseudorange error can be related to the position domain through the geometry factor for the specific satellites in use. Consequently the maximum impact of a single range error can be limited by screening the geometry used by the airborne receiver. More details are given below.

The constraint region at values smaller than 1.6 meters can be related to the limit condition by deriving the "most critical value" for a hypothetical monitor that performs at the limit of the constraint region. The most critical value can be defined as the size of an error, that when combined with a specific airplane's FTE results in the highest probability of landing outside one of the landing box limits.

The limit condition drives the shape of the ground monitor requirements at smaller values and continues to a probability of 10^{-5} , such that the probability of an unsuccessful landing for errors larger than 1.6 meters is limited to 10^{-5} .

The P_{md} constraint region limits were in fact derived based on expected Malfunction case and Limit Case conditions assuming FTE from a set of representative airplanes. More details on the derivation of the requirements are given in Appendix C. The specific limits were chosen to accommodate a broad range of airplane designs, but some designs may require additional limits on satellite geometry to ensure airworthiness compliance. Some examples of geometry screening are discussed in the next section, and their impact on airplane performance is included in the airplane performance requirements section for each of the three airworthiness conditions.

It is important to understand that even though the P_{md} constraint region limits were derived based on the FTE performance of a set of representative airplanes, the P_{md} constraint region allows for the assessment of any specific airplane's performance by allowing for a definition of a maximum error in the malfunction case and a limit case based on the 'most critical value'. In both these cases, specific characteristics of the design are invoked in order to translate the general P_{md}

constraint region into the needed parameter. In the malfunction case, the P_{md} constraint at 1.6 m is translated to a maximum error in the position domain using the geometry screening limits that relate to the translation of a single satellite failure into the position domain. For the limit case condition, the actual FTE performance of a specific airplane is used to determine the "most critical value (through computation of the error with the peak probability of putting the airplane outside the landing box, E_{peak} , as described in [42]). Also, in the limit case, the specific geometry screening types and thresholds come into play in translating E_{peak} , in the pseudorange domain into the position domain.

B.1.3 Airborne Geometry Screening

Additional airborne screening requirements are included in the current Draft MOPS proposal. These options include, but are not limited to, selection of smaller alert limits and selection of smaller maximum projection factors from the range domain to the position domain.

Selection of a smaller alert limit reduces the fault-free navigation sensor error (NSE) standard deviation that must be assumed for the worst case satellite geometry. Because of the nature of the protection level computations, the standard deviation of the NSE can be related to the alert limit. For example, in the case of the vertical, the standard deviation of NSE for the worst fault-free satellite geometry may be estimated as follows.

$$\sigma_{\mathit{ffNSE_Vert}} \leq \frac{\mathit{VAL}}{\mathit{K}_{\mathit{ffmd}}}$$
 [1]

Since geometry screening will ensure that VPL<=VAL and VPL is computed based on sigmas that are chosen to ensure error bounding in the tails to support the classical protection level computations, then an estimate like the one in eq.[1] above is a very conservative estimate of the nominal accuracy of the system. Furthermore, the estimate of the accuracy is already a limit case in that it is a limit geometry, i.e. the worst geometry that is acceptable via the VPL<VAL check.

Since the fault-free NSE is included in the total system error (TSE), along with flight technical error (FTE), the probability of a successful landing can be increased by reducing the fault-free NSE via a smaller VAL.

$$\sigma_{TSE} = \sqrt{\sigma_{FTE}^2 + \sigma_{NSE}^2}$$
 [2]

Selecting smaller limits on maximum projection factors directly limits the probability of missed detection in the position and touchdown domains. For example, in the case of the vertical, if a limit is placed on the maximum magnitude of the vertical projection from the pseudorange domain to the position domain, $S_{\text{vert,i}}$, then the following relationship is true for a single-satellite fault that dominates the position error.

$$\max(E_V) = E_R * \max(|S_{vert,i}|)$$
 [3]

Details on how these screening methods may apply to performance requirements are part of the next section.

B.2. Airplane Performance Requirements

In this section the general equations for touchdown performance are examined and their applicability to the three assumed airworthiness requirements is shown. First, equations for the airplane touchdown distribution are defined as a function of error and geometry screening, and

then they are applied to the three airworthiness criteria. Note that this same technique may be used to show airworthiness for the lateral touchdown and other performance parameters.

B.2.1 Unsuccessful Landing

Longitudinal touchdown distribution is a driving requirement in terms of airplane performance and airworthiness; however, it is not the only requirement. Methods similar to those discussed in this appendix may be applied in order to determine compliance with the other dimensions of the airworthiness requirements, such as lateral touchdown, bank angle, and more, in as much as they are dependent on the NSE (both fault-free and faulted). For the remainder of this appendix, the longitudinal touchdown case will be described.

Let the following equation describe a probability density function for the location of the touchdown point on the longitudinal axis, x, of the runway for the nominal, fault-free condition. This distribution is typically determined by performing a high-fidelity landing simulation for a particular airplane and autopilot design using a standard GBAS signal model to represent the fault-free NSE for the receiver being used. For each airworthiness requirement this distribution may be defined differently.

$$p_{TSE-LON}(x)$$
 [4]

Then, the generalized probability that a landing is unsuccessful, P_{UL} , is the integral of the touchdown distribution about the region defined as unsuccessful for the particular airworthiness condition.

$$P_{UL} = \int_{UNSUCCESSFUL} p_{TSE_LON}(x)$$
 [5]

As explained in the next three sections, the unsuccessful region and the touchdown distribution are treated differently for each airworthiness requirement. Next, the regions of success and treatments of TSE for each of the three airworthiness criteria are discussed. Also, the effect of geometry screening on the required airplane performance is discussed for each of the three criteria.

B.2.2 Nominal Condition

The nominal condition for the longitudinal touchdown case requires that

$$P_{III} < 10^{-6}$$
 [6]

for a land short limit of 200 feet and, separately, for a land long limit of 2700 feet. The touchdown distribution used to form P_{UL} for the nominal condition is required to include the effect of all influencing parameters varied according to their expected distributions. The unsuccessful region would be from negative infinity to 200 feet for the land short requirement, and the unsuccessful region for the land long requirement is from 2700 feet to infinity.

Geometry screening may be applied to reduce the effect of fault-free NSE on the touchdown distribution through the use of a smaller VAL if the unsuccessful landing probability does not meet the requirement. This is possible since the worst case NSE may be expressed as a function of VAL as in Equation (1).

Similarly, the variable of interest for each parameter specified in the nominal condition requirements, such as lateral touchdown point, or bank angle at touchdown, must be expressed as a probability density and integrated over the unsuccessful values for the parameter. The result of the integration must be smaller than the requirement for each parameter.

This condition is no change from its treatment for other landing systems, such as ILS. The only difference is that the NSE is described by GBAS NSE that is limited by geometry screening. The treatment of errors for the limit and malfunction conditions, discussed next, are specific to the GBAS design.

B.2.3 Limit Condition

Assume that the limit condition for the longitudinal touchdown case requires that the following be demonstrated: Given that a particular fault generates an error, E, at the most critical value for that fault, the probability that the airplane lands shorter than 200 feet from the threshold must be smaller than 10^{-5} , and the probability that the airplane lands longer than 3000 feet from the threshold must also be 10^{-5} with all other effects varying in their expected manner.

The probability of an unsuccessful landing for each monitored fault is the joint probability that the monitor will not detect the fault that causes an error, E, and that the landing will be unsuccessful given an error, E:

$$P_{UL}(E) = P_{UL|E}(E) * P_{md}(E)$$
[7]

The most critical value of E for a particular fault is defined as the E at which $P_{UL}(E)$ is maximized.

To form the conditional unsuccessful landing probability, $P_{UL/E}(E)$, a conditional touchdown distribution must be used that would result from a constant bias error in addition to the fault-free NSE and FTE distributions. This must be done for a range of error sizes to form the total conditional probability of an unsuccessful landing as a function of the error. The conditional unsuccessful landing probability is expressed as follows for the land short and land long cases:

Land Short
$$P_{UL|E}(E) = \int_{-\infty}^{200} p_{TSE_LON|E}(x, E) dx$$
, and

Land Long
$$P_{UL|E}(E) = \int_{3000}^{\infty} p_{TSE_LON|E}(x, E) dx$$
 [8]

This conditional probability is also a function of glide path angle and fault-free NSE. The probability as a function of error size may be reduced through the use of smaller alert limits, which limits fault-free NSE.

A bound on $P_{md}(E)$ may be derived from the proposed Annex 10 material, since it requires a maximum missed detection probability as a function of range errors, $P_{md_limit}(|E_R|)$. For example, in the case of the longitudinal touchdown requirement, the vertical position error has the largest effect on the touchdown location. The worst case projection of a range error into vertical error, $max(|S_{vert,i}|)$, may be used to determine the resulting limit on $P_{md}(E_v)$ by substituting E_R with $E_v/max(|S_{vert,i}|)$ in Equation 3.

$$P_{md}(E_{v}) = P_{md_\lim it} \left(\frac{E_{v}}{\max(|S_{vert,i}|)} \right)$$
 [9]

As part of the airborne design, a limit may be imposed on $|S_{vert,i}|$ to reduce the probability that a vertical error will go undetected.

Airplane design and/or geometry screening should also take into account the glidepath angles that are intended for use since the touchdown distribution will also be a function of glide path angle.

Smaller glide path angles will change the touchdown dispersion and may cause the P_{UL} to increase. The effect is that the limit condition (and other conditions) will be exceeded for some critical glide path angle. The design should accommodate all glide path angles that will be used in operation.

Both types of airborne geometry screening - alert limits and projection factor limits - may be useful as means for meeting the limit case requirement since smaller alert limits will effectively reduce the fault-free NSE that contributes to P_{UL} , and limits on projection factors can reduce the impact of a ranging error in the position domain axis of most concern. For this example, a limit may be imposed on the projection, $|S_{Apr_vert,i}|$, from the range to vertical position domain in order to reduce the probability that a vertical error will go undetected.

Figure B-1 notionally illustrates one method to determine geometry screening parameters based on the longitudinal land short case. For this example lateral errors are assumed to have no impact on the longitudinal touchdown distribution for this airplane design. Example unsuccessful landing probability curves are shown to have been derived using two different assumptions for nominal NSE, VAL=10, 8, and 6. These curves are purposefully chosen to be based on no particular assumptions on touchdown distribution to help illustrate the point that they will be determined for an airplane design based on whatever the airplane response is to NSE errors. Another set of curves represents limits on unsuccessful landing probability, $\max_{UL}(|E_V|)$ from equation (8), divided by the 10^{-5} limit condition requirement for the land short condition using various choices for $\max_{VL}(|E_V|)$. Any combination that results in $P_{UL}(|E_V|) < \max_{VL}(|E_V|)$ will satisfy the requirement; however, the combination that provides the highest system availability may be the preferred choice.

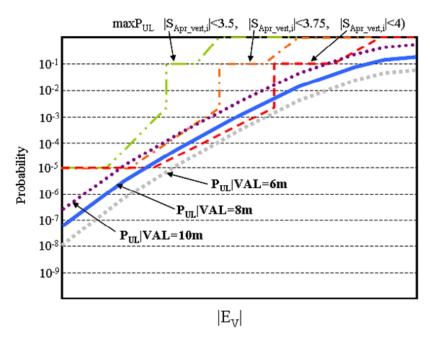


Figure B-1: Notional examples of unsuccessful landing probability for a particular airplane design as a function of three alert limit choices compared with maximum unsuccessful landing probability based on ground monitor P_{md} requirement scaled by three choices for projection factor screening.

Airplane design and/or geometry screening should also take into account the glidepath angles that are intended for use since the touchdown distribution will also be a function of glide path angle. Smaller glide path angles will change the touchdown dispersion and may cause the P_{UL} to increase. An effect of glide path angle may be that the limit condition (and other conditions) requirement is exceeded for some critical glide path angle. In this case the design should accommodate all glide path angles that are desired for operational approval.

B.2.4 Malfunction Condition

Assume the malfunction condition, briefly summarized, requires the following: Given any error, resulting from a malfunction, that is more probable than 10⁻⁹, and all other varying parameters are at their nominal value, including fault free NSE, the probability of landing in the touchdown box must be one. Consistent with current practice, the definition of "nominal value" should be determined as part of the airworthiness approval process for a particular airplane design.

For the malfunction condition, the Annex 10 derivation requires that all ranging source malfunctions that cause range errors greater than [1.6 m] be less probable than 10⁻⁹ after monitoring, when combined with the prior probability of that fault.

For the malfunction case the airborne design may include geometry screening in order to meet this requirement. A limit on the projection of the maximum range error into the position domain, $max(|S_{vert,i}|)$, would result in more margin for fault-free NSE and FTE. Also, a reduction in VAL could be used to help an airborne design meet this condition since the fault free NSE must be considered. By choosing a smaller VAL, the nominal TSE may be reduced to accommodate larger errors that are more probable than 10^{-9} .

Airplane design and/or geometry screening should consider the glidepath angles that are intended for use since the touchdown distribution will also be a function of glidepath angle. Smaller glide path angles will change the touchdown dispersion and may cause the P_{UL} to increase, which will cause the limit condition (and other conditions) to be exceeded for some critical glide path angle.

Note that anomalous ionospheric events may be considered an environmental effect. However, since there are monitors and other mitigations built into the system that are attempting to limit or eliminate errors produced by these effects, large *undetected* ionosphere induced errors should be viewed as a malfunction case and should not go undetected with a probability of greater than 1×10^{-9} . Therefore these errors should be addressed in a manner consistent with the malfunction conditions. The airplane manufacturer will need to demonstrate that the worst case errors due to anomalous ionosphere events that remain undetected will still allow the airplane to land in the safe landing box with all other variables in the system set to nominal.

B.3 Airborne Requirements for GAST D

This section discusses the airborne functional and performance requirements necessary to support GAST D service. As mentioned in the main body of this paper, the previously defined service types for GBAS (GAST A, B and C), were defined in terms of the "Signal in Space" which was then defined to be the performance at the output of fault free user equipment. To support that type of definition, standard user equipment processing (or protocols for the application of data) had to be defined. GAST D type service is not all that dissimilar for two reasons.

1. The position domain SIS requirements for GAST C still apply to support operations to the CAT I DH. Hence, the standard protocols are still used and the accuracy, integrity and Continuity of the SIS is still provided to the same levels defined for GAST C

2. Additional pseudorange domain requirements on monitoring performance are introduced. However, as discussed in Appendix A, the definition of performance for these monitors is referenced to the point in the processing after the differential correction has been applied to a pseudorange measurement. Therefore the basic idea of fault free user equipment still applies albeit at the pseudorange domain level.

Consequently, for GAST D the airborne equipment must still comply with functional and performance requirements in order to ensure that the level of performance (accuracy, integrity, and continuity) is achieved. Beyond the functional and performance requirements for GAST C (already in the current SARPS and MOPS), GAST D introduces:

- Additional receiver design constraints on correlator spacings and receiver bandwidth.
- Additional geometry screening checks
- Functional requirements (including geometry screening) and monitors intended to detect or mitigate the effects of ionospheric anomalies.
- A functional requirement (including geometry screening) for a B-value monitor to protect against correlated faults due to a reference receiver failure.
- Functional requirements to allow airborne equipment to determine when GAST D could be used and should be used.

B.3.1 Receiver design constraints.

As mentioned in Appendix A, avionics implementation characteristics can influence the magnitude of errors induced by certain fault modes after the application of the GF transmitted PRC.

The following avionics design implementations must be considered

Receiver Characteristics	Fault Mode Performance that May be Affected
Tracking Loop Design	Signal Deformation Monitoring
RF filter design (RFI/low power)	Signal Deformation Monitoring RFI/Low Power monitoring

APPENDIX C DERIVATION OF GROUND MONITOR RANGE DOMAIN PMD LIMITS AND GUIDANCE FOR DEMONSTRATING COMPLIANCE

Curtis A. Shively

C.1 Derivation of Ground Monitor Range Domain P_{md} Limits

C.1.1 Introduction

This appendix derives constraints on the ground monitor probability of missed detection (P_{md}) of a range domain error due to a failure. These constraints are the union of two separate regions. Each region is derived from an overall requirement associated with safe landing of the aircraft (rather than integrity of Navigation Sensor Error (NSE)). Safe landing is characterized by touchdown point of the aircraft on the runway. The derivation is based on the longitudinal touchdown point as affected by vertical NSE (NSE_V) since that case produces a more stringent requirement than does consideration of the lateral dimension. The two forms of the requirement are: 1) limit case faulted NSE_V and 2) malfunction case faulted NSE_V .

The limit case requirement stipulates that the probability of unsafe landing cannot exceed 10^{-5} "when one parameter is at its most critical value and the others vary in their usual manner" [48]. For the limit case, the most critical value is loosely interpreted as the bias in NSE_V due to undetected fault. Two alternatives for basing monitor requirements on the limit case were initially described in [17]. Refinements and analyses of monitor requirements based on the limit case requirement were subsequently presented in [49,50,51,52]. The derivation here is based on [52]. The malfunction case refers to the requirement that the landing must be safe with complete certainty for any value of faulted NSE_V that is more likely than a specified probability (10^{-9}). Monitor requirements based on malfunction case NSE_V were also previously described in [49,50,52]. The derivation here is based on [52].

C.1.2 Philosophy

In order to derive requirements for ground monitor performance in detecting range domain NSE faults, assumptions must be made about other factors that determine the probability of an unsafe landing. These include: fault-free NSE characteristics, conversion of range errors to vertical position errors, conversion of vertical position errors to longitudinal touchdown point, nominal aircraft landing performance and nominal glide path angle of the approach. Assumptions for these factors are described below in Section C.1.3. These assumptions were carefully chosen to be conservative and represent the most extreme cases that could reasonably be accommodated. In practice, with the ground monitor performance specified, the airframe manufacturer must determine the actual detailed performance of the airborne navigation equipment (such as satellite geometry limiting) needed in conjunction with the particular aircraft landing performance to achieve the overall landing safety requirements. It is believed that the assumptions made herein for determining the ground monitor performance will accommodate nearly all (if not all) candidate aircraft and airborne equipment that is compliant with the CAT III LAAS MOPS.

C.1.3 Assumptions

The vertical *NSE* is assumed to be composed of a component due to the fault (E_V) and a fault-free component ($NSE_{ff,V}$)

$$NSE_{V} = E_{V} + NSE_{ff,V} \tag{C-1}$$

 $NSE_{\rm ff,V}$ is assumed to be Gaussian distributed with zero mean and standard deviation $\sigma_{\rm NSEff,V}$. The derivation assumes $\sigma_{\rm NSEff,V}$ takes on the largest value allowed by $VPL_{\rm H0}$

$$VPL_{H0} = K_{ffmd} \times \sigma_{NSEff V} = VAL$$
 (C-2)

Assuming VAL = 10.0 m and $K_{\text{ffmd}} = 5.81 \text{ gives}$

$$\sigma_{\text{NSEff,V}} = \frac{VAL}{K_{\text{ffmd}}} = \frac{10}{5.81} = 1.72 \,(\text{m})$$
 (C-3)

Since a ground monitor P_{md} requirement is desired in the range domain, a relationship is needed between E_V and the corresponding range error E_R . The relationship between E_V and E_R for the ith satellite is given by

$$E_{V,i} = S_{\text{vert},i} \times E_{R,i} \tag{C-4}$$

Where $S_{\text{vert},i}$ is the well-known vertical coefficient for the ith satellite in the position solution. The derivation assumes a value of $S_{\text{vert},i} = 4.0$. Limiting $S_{\text{vert},i}$ to 4.0 would be accomplished in the airborne receiver. It should be pointed out that the P_{md} limit derived from this assumption in conjunction with actual aircraft landing characteristics might permit an $S_{\text{vert},i}$ limit larger than 4.0 to be used in the airborne equipment and still provide the overall landing safety required.

In order to compute probability of unsafe landing due to vertical *NSE* a transformation is needed from NSE_V to the corresponding error in longitudinal touchdown point of the aircraft (NSE_L). A simple transformation based on the glide path angle was proposed in [43] and is used herein

$$NSE_L(ft) = \frac{3.28 \times NSE_V(m)}{\tan(GPA)}$$
 (C-5)

From equation (C-5) it can be seen that the effect of *NSE* is more pronounced (and thus the fault missed detection requirement is more stringent) for smaller values of *GPA*. Generally, a standard

precision approach GPA is 3.0 degrees. However there are existing ILS approaches with GPAs as low as 2.5 degrees. Therefore a minimum GPA of 2.5 degrees is assumed for the derivation of the monitor requirements.

In addition to faulted and fault-free components of *NSE* the probability of unsafe landing involves the nominal aircraft landing characteristics. The aircraft is assumed to have a nominal longitudinal touchdown point (*NTDP*) and flight technical error (*FTE*) that produces a longitudinal variation of touchdown relative to *NTDP*. *FTE* is characterized by a Gaussian distribution with a zero mean and standard deviation σ_{FTE} . A value of NTDP = 1,290 ft is assumed in the derivation of the monitor requirements. Based on considerations that are proprietary to airframe manufacturers, different values of σ_{FTE} are used for deriving limit case and malfunction case P_{md} requirements. Therefore, the particular value assumed is indicated below with each derivation.

C.1.4 Monitor Requirements Derived from Limit Case Requirement

The limit case represents a requirement on the conditional risk of unsafe landing given a fault has occurred

$$Risk_{|fault} \le 10^{-5} \tag{C-6}$$

This conditional risk involves two events: 1) the fault is not detected and 2) the landing is unsafe given the fault is not detected. The random noise in the fault detection process is assumed to be independent from the random error components that contribute to the probability of an unsafe landing. Therefore, the risk may be expressed as the product of two probabilities

$$Risk_{|fault} = P_{md} \times P_{UL|fault_not_detected}$$
 (C-7)

The requirement to ensure a safe landing is most demanding when applied to the longitudinal (rather than lateral) touchdown point as affected by the vertical component of the faulted NSE. The probability the fault is not detected varies with the magnitude of the resulting vertical error. The probability the landing is unsafe varies with both the magnitude and sign of the resulting vertical error. Therefore, the risk and accompanying requirement may be expressed as

$$Risk_{|fault}(E_V) = P_{md_V}(|E_V|) \times P_{UL|EV_{not_detected}}(E_V) \le 10^{-5}$$
 (C-8)

In practice for actual monitor and aircraft landing characteristics, this risk will have a peak value for some particular value of E_V and be less than that peak risk for all other values of E_V . The value of E_V for which the peak risk occurs could be taken as the single "most critical" value for the limit case (one of the alternative concepts proposed in [51]). However, the intent here is to derive a design limit on how large the ground monitor P_{md} $V(|E_V|)$ can be as a function of $V(|E_V|)$

given an assumption for the function $P_{\text{UL}|\text{EV}_{\text{not_detected}}}(E_V)$. Therefore, the second alternative concept proposed in [51] will be used. Under that concept, the $Risk_{\text{|fault}}$ requirement will be satisfied if for every value of E_V (includes whatever value actually turns out to be "most critical" producing the peak risk) the following relationship is maintained

$$P_{\text{md_V}}(|E_V|) \le P_{\text{md_limit_V}}(|E_V|) = \min \left[1, \frac{10^{-5}}{P_{\text{UL}|\text{EV_not_detected}}(E_V)}\right]$$
(C-9)

Where it has also been recognized that $P_{\text{md V}}(|E_V|)$ cannot exceed 1.0.

Positive values of E_V correspond to landing long and negative values of E_V correspond to landing short. The landing short case will be shown since it was found to produce a more stringent $P_{\rm md}$ requirement than landing long. A short landing occurs when the touchdown point is less than 200 ft past the runway threshold. Therefore, the value of $P_{\rm UL|EV_not_detected}(E_V)$ may be expressed as

$$P_{\text{UL}|\text{EV_not_detected}}(E_V) = \text{Prob}\left\{NTDP + \frac{3.28 \times (E_V + NSE_{ff,V})}{\tan(GPA)} + FTE \le 200\right\}$$
 (C-10)

where use has been made of the conversion from vertical NSE to longitudinal NSE as given above in equation (C-5). Based on the additional assumption that FTE and $NSE_{ff,V}$ are Gaussian distributed

$$P_{\text{UL}|\text{EV_not_detected}}(|E_V|) = 1 - Q \left(\frac{200 - NTDP + \frac{3.28 \times |E_V|}{\tan(GPA)}}{\sigma_{TSE}} \right)$$
(C-11)

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{\frac{-t^2}{2}} dt$$
 (C-12)

$$\sigma_{TSE} = \sqrt{\sigma_{\text{NSEff}}^2 + \sigma_{\text{FTE}}^2}$$
 (C-13)

$$\sigma_{\text{NSEff}} = \frac{\sigma_{\text{NSEff,V}} \times 3.28}{\tan(GPA)}$$
 (C-14)

For deriving the limit case P_{md} requirement it was assumed that NTDP = 1,290 ft and σ_{FTE} = 150 ft. Figure C-1 shows the resulting $P_{md_limit_V}(|E_V|)$. The curve that rises with increasing $|E_V|$ is $P_{UL|EV_not_detected}(|E_V|)$. Note that the "knee" of the $P_{md_limt_V}(|E_V|)$ curve occurs for the value of $|E_V|$ where $P_{UL|EV_not_detected}(|E_V|)$ reaches 10^{-5} (about 3.2 m). The corresponding P_{md} requirement in the range domain $P_{md_limit_R}(|E_R|)$ is given in Figure C-2. This figure assumes the error is on a single satellite with range to vertical position error amplification by the factor S_{vert} = 4.0 as discussed in Section C.1.3. Figure C-2 also shows the straight line approximation to $P_{md_limit_R}(|E_R|)$ used for simplicity to define the P_{md} limit region. Table C-1 gives the mathematical description for this approximation.

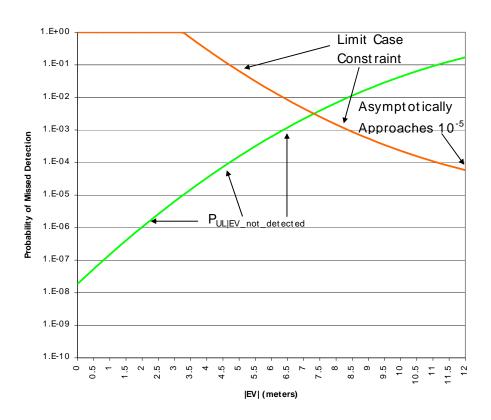


Figure C-1. P_{md limit} in Position Domain Based on Limit Case

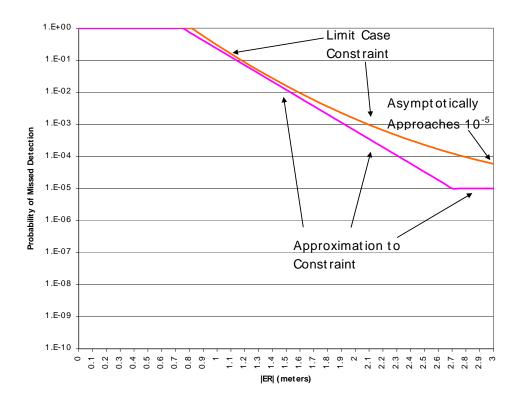


Figure C-2. P_{md limit} in Range Domain Based on Limit Case

Table C-1 Limit Case P_{md limit} Approximation

Probability of Missed Detection	Pseudorange Error (meters)
$P_{md_limit} \le 1$	$0 \leq E_r < 0.75$
$P_{md_limit} \le 10^{(-2.56x Er + 1.92)}$	$0.75 \le E_r < 2.7$
$P_{md_limit} \le 10^{-5}$	$2.7 \leq E_r < \infty$

C.1.5 Monitor Requirements Derived for Malfunction Case Faulted NSE

Similar to the limit case, the malfunction case is associated with the safety of the landing (rather than a bound on the vertical error). However, some details of the scenario and accompanying requirement differ from those in the limit case. As stated in [50]: "The aircraft must be able to execute a safe go-around or it must be able to complete a safe landing under any malfunction scenario that is not extremely improbable (probability of occurrence on the order of 10⁻⁹ per landing)". If faulted *NSE* is considered to be a "malfunction", the requirement becomes pertinent to the current monitor performance requirements derivation. Furthermore, as in [49,50] the "occurrence" of the malfunction will be interpreted more comprehensively as the situation when the fault occurs but is also not detected by monitoring. Therefore, an interpretation of this requirement as pertaining to faulted *NSE* may be stated

$$P_{\text{md_v}}(|E_v|) \times P_{\text{fault}}$$
 $> 10^{-9} \rightarrow \text{must land safely}$ $\leq 10^{-9} \rightarrow \text{don't care}$ (C-15)

Suppose for the moment that it is possible to determine the largest value of $|E_V|$ for which the aircraft lands safely (denoted $|E_{V_safe_max}|$). Then the requirement in equation (C-15) may be equivalently stated

$$P_{\text{md_V}}(|E_V|) \times P_{\text{fault}} \begin{cases} > 10^{-9} \to \text{must have } |E_V| \le |E_{\text{V_safe_max}}| \\ \le 10^{-9} \text{ don't care about } |E_V| \end{cases}$$
 (C-16)

The corresponding limit on $P_{\text{md V}}(|E_V|)$ then becomes

$$P_{\text{md_limit_V}}(|E_V|) = \begin{cases} \frac{10^{-9}}{P_{\text{fault}}}; |E_V| > |E_{\text{V_safe_max}}|, \\ 1.0; |E_V| \le |E_{\text{V_safe_max}}| \end{cases}$$
(C-17)

In general, the safety of a landing has been considered a probabilistic event due to the random nature of $NSE_{\rm ff,V}$ and FTE. However, $|E_{\rm V_safe_max}|$ is the largest $|E_{\rm V}|$ for which the aircraft lands safely with complete certainty (probability 1.0). Therefore, in order to determine $|E_{\rm V_safe_max}|$ it is necessary to chose fixed values for $NSE_{\rm ff,V}$ and FTE. Taking $NSE_{\rm ff,V}$ and FTE at their mean values (zero) is too liberal. Consequently, $NSE_{\rm ff,V}$ and FTE are both assumed to be at their 95th percentile values as illustrated in [50]. The value of $|E_{\rm V_safe_max}|$ can be determined for both landing short and landing long. However, as for the limit case, the situation of landing short gives a more restrictive $P_{\rm md}$ requirement. Therefore, assuming the worst signs for $NSE_{\rm ff,V}$ and FTE to cause a short landing, $|E_{\rm V_safe_max}|$ satisfies

$$NTDP + \frac{3.28 \times (E_{V_safe_max} - NSE_{ff,V,95\%})}{\tan(GPA)} - FTE_{95\%} = 200$$
 (C-18)

Solving equation (C-18) for $E_{V \text{ safe max}}$ gives

$$E_{\text{V_safe_max}} = \frac{\tan(GPA) \times (200 - NTDP + 1.96 \times \sigma_{\text{FTE}})}{3.28} + 1.96 \times \sigma_{\text{NSEff,V}}$$
(C-19)

For deriving the malfunction case P_{md} requirement it was assumed that NTDP = 1,290 ft and σ_{FTE} = 180 ft. Using these assumptions in equation (C-19) gives

$$\left| E_{\text{V_safe_max}} \right| = 6.44 \, \text{(m)} \tag{C-20}$$

Assuming E_V is due to a range error on a single satellite, the corresponding limit in the range domain becomes

$$P_{\text{md_limit_R}} \left(|E_R| \right) = \begin{cases} \frac{10^{-9}}{P_{\text{fault}}}; |E_R| > |E_{\text{R_safe_max}}| \\ 1.0; |E_R| \le |E_{\text{R_safe_max}}| \end{cases}$$
(C-21)

Where

$$\left| E_{\text{R_safe_max}} \right| = \frac{\left| E_{\text{V_safe_max}} \right|}{S_{\text{vert}}}$$
 (C-22)

Under the assumption that $S_{\text{vert}} = 4.0$ as per Section C.1.3

$$\left| E_{\text{R_safe_max}} \right| = \frac{6.44}{4.0} = 1.61 \text{ (m)}$$
 (C-23)

In order to fully define $\underline{P}_{md_limit_R}(|E_R|)$ a value for P_{fault} must be assumed. Based on a satellite fault rate of 10^{-4} per hour [53], an exposure time of 15 seconds and a maximum of 18 ranging sources, the value of P_{fault} is conservatively assumed to be

$$P_{\text{fault}} = \frac{10^{-4} \times 15 \times 18}{3600} = 7.5 \times 10^{-6}$$
 (C-24)

Figure C-3 shows a graph of $P_{\text{md_limit_R}}(|E_R|)$ based on the above derivation for the malfunction case of faulted *NSE*.

Figure C-3 also shows a simplified limit based on rounding of $E_{R_safe_max}$ and $10^{-9} / P_{fault}$.

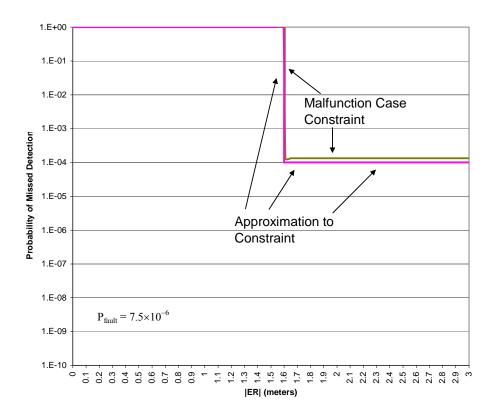


Figure C-3. $P_{md\ limit}$ in Range Domain for Malfunction Case Faulted NSE

For judging compliance of ground monitor performance it is convenient to show range domain monitoring requirements for both cases on the same graph. Figure C-4 plots P_{md_limit} for both the limit case and the malfunction case (assuming $P_{fault} = 7.5 \times 10^{-6}$) and also shows the union of the two constraint regions.

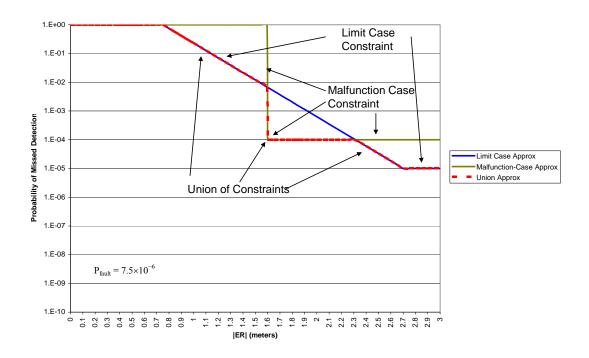


Figure C-4. Union of P_{md_limit} in Range Domain for Both Limit Case and Malfunction Case Faulted NSE

C.1.6 Consideration of Dual Faults

The above discussion has derived a $P_{\text{md_limit}}$ performance constraint based on the assumption that only a single fault occurs. This section will show that if the monitor for any single fault meets this $P_{\text{md_limit}}$ constraint, adequate safety is provided for the case of dual faults under the assumptions for aircraft performance (NTDP = 1,290 (ft) and $\sigma_{\text{FTE}} = 180$ (ft)) and largest single $|S_{\text{vert}}| \le 4.0$, with the additional assumption that the sum of the largest two $|S_{\text{vert}}|$ values does not exceed 6.0. Combinations of more than two faults have a priori probability much smaller than 10° and therefore need not be considered.

For this analysis the case of dual faults will be treated as malfunction case faulted NSE. The limit on $DualP_{md_{-}V}(|E_{V}|)$ is the same as given in equation (C-17) with $|E_{V_{-}safe_{-}max}| = 6.44$ m as derived for equation (C-20). The limit on $DualP_{md_{-}V}(|E_{V}|)$ also depends on the a priori probability of dual faults, denoted $DualP_{fault}$. For determining $DualP_{fault}$, 5 types of ranging source faults will be considered (see C.2.1 for complete list). The value of $DualP_{fault}$ will be based on all possible combinations of two faults occurring on two different satellites. The exclusion of two faults on the same satellite is justified in [54]. Under the assumption that the two faults must be on different satellites, $DualP_{fault}$ is given by

$$DualP_{\text{fault}} = [\text{Total Number of Satellite Pairs}] \times [\text{Total Probability of Fault Pairs}]$$
 (C-25)

The rationale for determining the total number of satellite pairs is as follows. Assuming a maximum of 18 satellites, the number of combinations of satellites taken in pairs is $18 \times 17 / 2 = 153$. However, this result does not consider the distinction between the case of satellite 1 failing before satellite 2 and the additional case of satellite 2 failing before satellite 1. The minimum exposure time to be considered (15 s) is somewhat longer than the time-to-alert (2 s). Therefore, it is relevant to consider the possibility that one of the dual faults is "latent", i.e., it occurred somewhat prior to the second fault and still could be undetected at the time the second fault occurs. Consequently, it will be conservatively assumed that the order of the two faults matters. The total number of satellite pairs will thus be taken as the number of distinct permutations of satellite pairs given by $18 \times 17 = 306$.

The total probability of fault pairs is based on all 25 combinations of the 5 fault types. The a priori probability of each of the 5 types of ranging source faults is denoted $P_{\rm RS_fault}$ and given by 1×10^{-4} per hour [53]. The total probability of all fault pairs is then given by

Total Probability of Fault Pairs =
$$\sum_{i=1}^{5} P_{RS_{-}fault,i} \times \frac{T_{1}}{3600} \sum_{j=1}^{5} P_{RS_{-}fault,j} \times \frac{T_{2}}{3600}$$

$$= 25 \times \frac{T_{1}}{3600} \times \frac{T_{2}}{3600} \times P_{RS_{-}fault}^{2}$$
(C-26)

where T_1 and T_2 are the exposure times associated with the first and second faults, respectively. If $T_1 = T_2 = 15$ s, the resulting total probability of fault pairs is calculated to be 4.3×10^{-12} . The corresponding a priori probability of dual faults is $DualP_{\text{fault}} = 1.3 \times 10^{-9}$. This value of $DualP_{\text{fault}}$ does exceed 10^{-9} and is therefore of interest. However, it is readily apparent that the constraint region corresponding to a value of $DualP_{\text{fault}}$ so close to 10^{-9} would present no challenge for ground monitor compliance given the single fault constraint already imposed for an a priori probability which is nearly four orders of magnitude larger than 10^{-9} (refer to Figure C-3). Therefore, to develop an even more conservative illustration it will be assumed that the exposure time for the first fault is $T_1 = 1,200$ s (20 minutes). The resulting total probability of fault pairs is calculated to be 3.5×10^{-10} and the corresponding a priori probability of dual faults is $DualP_{\text{fault}} = 1.1 \times 10^{-7}$.

Performance in comparison to the dual fault constraint region $DualP_{\rm md_V}(|E_V|)$ just derived above will be illustrated for a generic single fault monitor that barely meets the $P_{\rm md_limit}$ constraint region in Figure C-4. This monitor has Gaussian distributed noise on the test statistic with standard deviation of $\sigma_R = 0.2$ m. The monitor threshold T_R is set at $3.89 \times \sigma_R = 3.89 \times 0.2$ m = 0.778 m to give a false detection probability equal to 1.0×10^{-4} per decision. It should be realized that this false detection probability and the slow roll-off of monitor $P_{\rm md}$ with increasing $|E_R|$ are much worse than the performance of any monitor actually meeting a continuity risk allocation needed for even CAT I applications. The monitor performance in comparison to the $P_{\rm md_limit}$ region (based on single faults) is shown in Figure C-5.

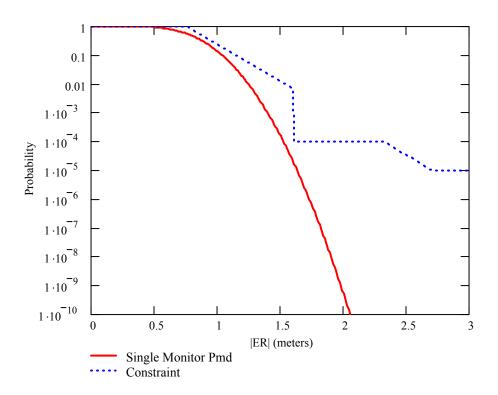


Figure C-5. P_{md} Performance of Generic Monitor Barely Meeting P_{md_Limit} Constraint

The performance of two such monitors in response to two faults is illustrated in the vertical position domain in Figure C-6. The points on the plot correspond to various combinations of the two range errors E_{R1} and E_{R2} . Under the S_{vert} assumptions stated above, the worst case is $S_{vert1} = 4.0$ and $S_{vert2} = 2.0$ (rather than $S_{vert1} = S_{vert2} = 3.0$). Therefore, the total vertical error for each point is given by $DualE_V = S_{vert1} \times E_{R1} + S_{vert2} \times E_{R2}$. $= 4.0 \times E_{R1} + 2.0 \times E_{R2}$. The monitors are assumed to be independent giving $DualP_{md_total} = P_{md}(E_{R1}) \times P_{md}(E_{R2})$. Note that even under the extremely conservative assumptions for this illustration, the points all fall beneath the constraint indicating that the safety of the landing would be assured even in the case of dual faults.

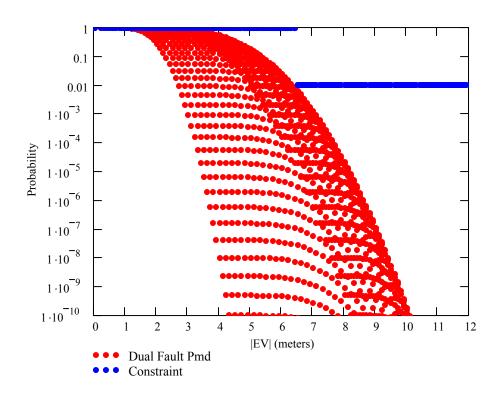


Figure C-6. Vertical Error P_{md} Performance for Dual Faults Compared to Constraint for Safe Landing

C.2 Demonstration of Compliance with Ground Monitor Requirements

C.2.1 Faults to Be Addressed

The following types of faults must be addressed:

Code-Carrier Divergence

Signal Deformation

Excessive Acceleration

Ephemeris

Low Power

C.2.2 Considerations

C.2.2.1 Monitor Detection Domain to Range Domain

In concept a fault monitor operates on a decision statistic D. The monitor $P_{\rm md}$ performance can thus be determined as a function of D, $P_{\rm md_D}(D)$. However, if the monitor does not operate directly in the range domain a transformation is needed between D and the corresponding range error $E_{\rm R}$

$$E_R = f(D) \tag{C-27}$$

So that the corresponding expression for P_{md} in the range domain may be determined as

$$P_{md} \quad {}_{R}(|E_R|) = P_{md} \quad {}_{D}(f^{-1}(|E_R|)) \tag{C-28}$$

Note that f does not necessarily represent a linear relationship.

C.2.2.2 Consideration of Ground Latency and Allowed Time to Detect and Broadcast

The ground monitor missed detection performance must take into account the allowed time-todetect and affect the broadcast (TTDABA) in comparison to the ground latency (τ_G) . The timing relationships are illustrated in Figure C-7 for the case where $\tau_G > TTDABA$. The fault onset may occur at any time. However, the aircraft guidance must be flagged as invalid within the time-toalert (2.5 s) of the time when the error first becomes large enough to potentially cause an unsafe landing. A differentially corrected pseudorange error with magnitude E_R is considered to be potentially unsafe. As shown in the figure, TTDABA is the time between when magnitude of the error in the differentially corrected pseudorange exceeds E_R and when the last bit of the integrity data must leave the VDB. The required value of TTDABA is chosen as [1.5] seconds to allow [1.0] seconds of additional margin for delay and missed messages in the airborne equipment. In determining the size of such an error (or errors) in the range domain it is assumed that the satellite geometry is the worst that meets the geometry constraints implemented in the airborne equipment. The ground latency (τ_G) is the time between when the measurement used in the decision statistic for detection is taken (t_{meas}) and when the last bit of the integrity data reflecting the detection leaves the VDB ($t_{meas} + \tau_G$). Therefore, the P_{md} corresponding to $E_R(t)$ must be calculated using the value $E_R(t_{meas})$

$$P_{md} \quad {}_{R}(E_{R}(t)) = P_{md} \quad {}_{D}(f^{-1}(E_{R}(t_{meas})))$$
(C-29)

Since t_{meas} is τ_G s before the last bit of corresponding integrity data leaves the VDB, $t_{meas} = t + TTDABA - \tau_G$ giving

$$P_{md_R}(E_R(t)) = P_{md_D}(f^{-1}(E_R(t + TTDABA - \tau_G)))$$
(C-30)

Therefore, if $\tau_G > TTDABA$, the P_{md} corresponding to $E_R(t)$ must be calculated for a time t_{meas} that is $\tau_G - TTDABA$ s earlier than time t. Consequently, for errors that grow with time, the monitor performance is worse than for constant errors, because the error is smaller at the time considered for P_{md} . On the other hand if $\tau_G < TTDABA$, for errors that grow with time, the monitor performance is better than for constant errors, because the error is larger at the time considered for P_{md} . If $\tau_G = TTDABA$, error growth is not a consideration in evaluating monitor performance compliance.

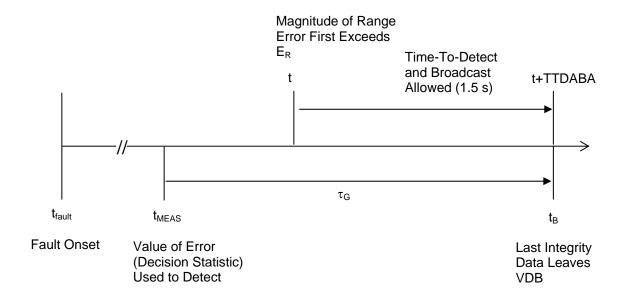


Figure C-7. Time Relationships for Monitor Performance Compliance

C.2.2.3 Probability Points to be Evaluated

Compliance is demonstrated by showing that $P_{md_R}(|E_R|)$ is smaller than $P_{md_limit_R}(|E_R|)$ given in Figure C-4 for any E_R , $0 \le |E_R|$. If $P_{md_R}(|E_R|)$ can be determined in closed form, compliance may be shown by making the comparison for a large number of values of $|E_R|$ in the desired range. However, if, $P_{md_R}(|E_R|)$ must be determined by actual or simulated monitor operation, it may be necessary to limit the comparison to a relatively small number of discrete values of $|E_R|$. As can be surmised by examining the plot of $P_{md_limit_R}(|E_R|)$, the two most critical points are the value of $|E_R|$ for which $P_{md_R}(|E_R|)$ first becomes less than 1.0 and the value of $|E_R|$ for which $P_{md_R}(|E_R|)$ is equal to 10^{-5} . Other intermediate probability values for which the corresponding value of $|E_R|$ must be determined are 0.5, 10^{-1} , 10^{-2} ., 10^{-3} and 10^{-4} . The number of independent samples should be at least 10 times the smallest probability to be characterized. Therefore, 10^6 total samples are needed. If obtaining such a large number of samples is not feasible perhaps an argument can be

made for behavior beyond the values of $|E_R|$ actually represented. For example, it is conceivable that errors beyond a certain magnitude cannot actually occur and thus $P_{md_R}(|E_R|)$ may be considered to be infinitesimally small beyond a certain value of $|E_R|$.

C.2.2.4 Multiple Monitors for Same Fault

The above discussion assumes that a particular type of fault is addressed by only a single monitor function operating on only a single decision statistic. However, in practice more than one "monitor" may contribute to the detection of the fault. In that case, the combined performance of the multiple monitors may be considered when showing compliance with the monitor performance requirement. This combined performance must account for the degree to which the multiple monitor decisions are independent. In general the multiple monitors will operate on different decision statistics and have different effective "thresholds" in the range domain. If the noise on the decision statistics is truly uncorrelated, then for a given value of $|E_R|$ the combined performance may be taken as the product of the individual monitor performance characteristics

$$P_{\text{md_multi-monitor_R}} \left(\left| E_R(t) \right| \right) = \prod_i P_{\text{md_D,i}} \left(f_i^{-1} \left(E_R(t + TTDABA - \tau_G) \right) \right)$$
 (C-31)

C.2.3 Examples

The examples assume E_R is a ramp error

$$E_R(t) = -C \times t \tag{C-32}$$

For simplicity it is also assumed that f = 1.0. Therefore, the monitor characteristics may be expressed directly in the range domain

$$P_{\text{md R}}(|E_R(t)|) = P_{\text{md D}}(|E_R(t + TTDABA - \tau_G)|)$$
(C-33)

A generic monitor is assumed with Gaussian distributed noise on the test statistic with standard deviation of $\sigma_R = 0.06$ m. The monitor threshold T_R is set at $6.11 \times \sigma_R = 6.11 \times 0.06$ m = 0.367 m to give a false detection probability equal to 10^{-9} per decision. The monitor performance is then given by

$$P_{\text{md}_{R}}(|E_{R}(t)|) = 1 - Q\left(\frac{T_{R} - |E_{R}(t + TTDABA - \tau_{G})|}{\sigma_{R}}\right)$$
(C-34)

Since $E_{\rm R}(t)$ is a ramp, from equation (C-29)

$$\left| E_R \left(t + TTA_G - \tau_G \right) \right| = \left| E_R \left(t \right) \right| + C \times \left(TTDABA - \tau_G \right) \tag{C-35}$$

For the first example, the GF latency is assumed to be $\tau_G = 2.0$ s, giving $TTDABA - \tau_G = 1.5 - 2.0$ = -0.5 s. Results for this example comparing P_{md} performance to the requirement are shown in Figure C-8 for several values of C. Note that for the 3 smallest values of C, the P_{md} performance requirement is met. However, for C = 1.5 m/s the requirement is not met. This example illustrates the concern if $\tau_G > TTDABA$. As can be seen from the P_{md_Limit} requirement, the monitor must begin to detect an error E_R when its magnitude exceeds 0.75 m. Since $\tau_G > TTDABA$, this detection must occur before the error first becomes unsafe at the aircraft (refer back to Figure C-7). However, if $|E_R|$ exceeds 0.75 m within $|TTDABA - \tau_G|$ s after fault onset, it is impossible for the monitor to meet the required performance even if the threshold can be set very close to zero (refer back to Figure C-7). To meet the allocation for TTDABA the monitor would in effect need to detect the fault before it could first be observed. The largest value of C (C_{max}) for which monitor performance might be acceptable for $\tau_G > TTDABA$ is given approximately by

$$C_{\text{max}} = \frac{0.75 - T_{\text{R}}}{\tau_G - TTDABA} \tag{C-36}$$

Thus, if $\tau_G > TTDABA$, compliance must also demonstrate that ramps with velocity larger than C_{max} are sufficiently unlikely or mitigated by other means.

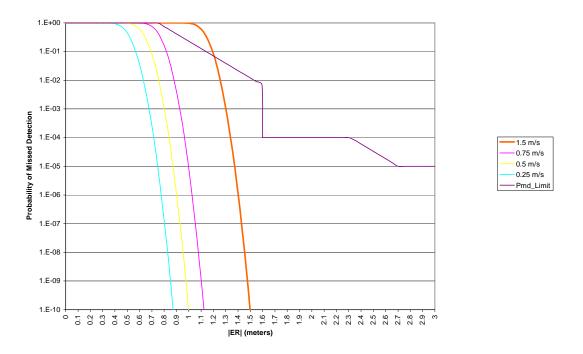


Figure C-8. Generic Monitor Performance for $\tau_G > TTDABA$, $(TTDABA - \tau_G = 1.5 - 2.0 = -0.5 \text{ s})$

Results for a second example with $\tau_G = TTDABA = 1.5$ s are shown in Figure C-9. For that case, the results do not depend on the value of C. The $P_{\rm md}$ performance is given simply by

$$P_{md}(|E_R|) = 1 - Q\left(\frac{T_R - |E_R|}{\sigma_R}\right) = 1 - Q\left(\frac{0.367 - |E_R|}{0.06}\right)$$
(C-37)

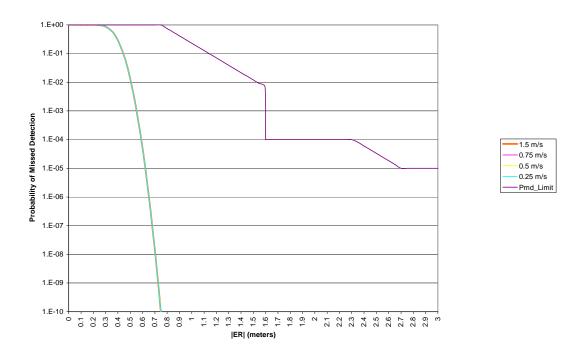


Figure C-9. Generic Monitor Performance for $TTDABA = \tau_G = 1.5 \text{ s}$

Results for a third example with $\tau_G < TTDABA$, $(TTDABA - \tau_G = 1.5 - 1.0 = 0.5 \text{ s})$ are given in Figure C-10. Note that for a given missed detection probability, the range error decreases as the slope of the ramp increases. Thus, steep ramp errors are actually less problematic than shallow ramp errors (opposite of performance trend when $\tau_G > TTDABA$ as in Figure C-8). For $\tau_G < TTDABA$ the GF can detect the error after it has first become unsafe at the aircraft. The additional growth of the error during this extra time makes it easier to detect than for the case when it must be detected before it first becomes unsafe at the aircraft $(\tau_G > TTDABA)$. Consequently, the worst missed detection performance for $\tau_G < TTDABA$ occurs for smaller values of C (least extra error growth) and is never worse than the case when $\tau_G = TTDABA$ (Figure C-9) which provides no time for extra error growth at all.

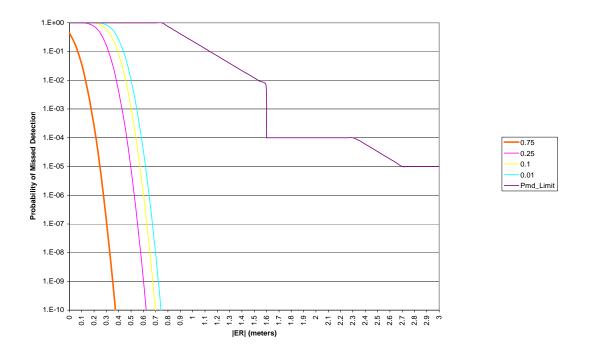
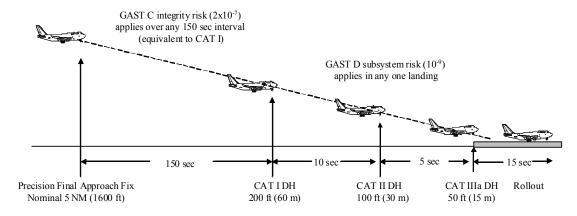


Figure C-10. Generic Monitor Performance for $\tau_G < TTDABA$, $(TTDABA - \tau_G = 1.5 - 1.0 = 0.5 \text{ s})$

Appendix D Operations Concept for GAST D

D.1 GAST D Operations Concept Overview

Figure D-1 gives an overview of the GAST D Operations Concept.



- GAST D integrity exposure applies in any one landing, which is a minimum of 15 sec, based on the time
 interval between 200 ft and 50 ft altitude. If the operation includes lateral guidance through rollout, the exposure
 time can be 30 sec for lateral.
- GAST D continuity exposure time is a minimum of 15 sec, based on the time interval between 200 ft and 50 ft altitude. If the operation includes lateral guidance through rollout, the exposure time can be 30 sec for lateral.

Figure D-1 GAST D Operations Concept Overview

The following sections describe the operation of a GAST D capable GBAS for the GAST D capable user as well as implications on a non-GAST D capable users.

D.2 Operations Concept for GAEC D User Against a GAST D capable Ground Subsystem

For GAST D capable airborne equipment (i.e. GAEC D), there are some requirements that apply at all times, even if an approach that requires (or supports) GAST D service is not currently being selected (i.e. is not the selected or active service type). For example, some of the mitigations for ionospheric gradient threats require that certain monitoring be conducted well before the airplane reaches the final approach (e.g. for CCD monitoring across speed changes as discussed in the previously mentioned reference [24]). Since an approach indicating GAST D is supported can be selected at any time, the receiver must perform such monitoring at all times in anticipation that a GAST D approach may be selected.

Two examples of requirements that would apply at all times are given below. These examples are based on the current thinking with respect to the mitigation of ionospheric gradient threats.

- At all times the airborne equipment must smooth the pseudoranges with 100 sec filters and a parallel set of filters with a 30 second time constant. This must be done at all times because the airborne equipment does not know when an approach will be selected, so it needs to be ready. The need to wait for convergence of the smoothing filters after approach selection is undesirable.
- Also, at all times the GAEC D equipment must perform airborne CCD monitoring using a standard filter. The output of the filter is compared to a pre-determined threshold and if that threshold is exceeded, the associated pseudorange is marked as unusable for a

precision approach position solution (when the aircraft is within the precision approach region) and will remain marked as unusable for 20 minutes after the detector output returns to below the threshold.

• GAEC D equipment must also perform a "RAIM like" test on each satellite when inside the precision approach region. This test can also be used to add a satellite back into the position solution following detection by the CCD monitor.

The ground subsystem also has functional and performance requirements it must meet at all times (when a GAST D level of service is supported). Examples of these requirements are given below.

- If the GAST D capable ground subsystem is currently meeting the requirements associated with GAST D, GCID should be set to 2.
- The ground subsystem must meet the low level monitoring requirements. If the low level monitoring requirements are for some reason not able to be met, then GCID should be set to 1.
- The ground subsystem must also smooth the pseudoranges at both 100 seconds and 30 seconds. The set of 100 sec smoothed pseudoranges is used to form differential corrections provided in the Type 1 message exactly as described in the SARPs today for GAST C. All other parameters in the Type 1 message are also the same as defined today. The second set of 30 second smoothed pseudoranges is used to compute a set of differential corrections which is uplinked in a new Type 11 message.

A typical scenario illustrating the operations concept for GAST D user would be as follows:

- The user "selects a channel", derives physical frequency and RPDS/RSDS
- The airborne equipment searches Type 4 messages looking for RPDS and Type 2 messages looking for RSDS
- If RSDS is found in Type 2, acquire station ID from header of Type 2 message and begin filtering messages This is the Positioning Service Only mode and is treated exactly the same as it would be with legacy equipment (i.e. in accordance with the current SARPs).
- If RPDS is found in a Type 4 acquire station ID from header and begin filtering messages from selected station
 - o Check GCID in Type 2 message, if 0 or 1 − Revert to legacy user mode above. (GCID of <=1 indicates the ground subsystem only supports legacy equipment)
 - o If GCID >1, get the Approach Performance Designator (APD) field from the selected FAS block. (GCID indicates the ground subsystem supports types of service D or higher). Multi-service type aware equipment shall evaluate the APD field.)
 - o If Service Types supported as indicated in APD field < "2" revert to legacy user operation (Only GAST A, B or C is supported on this FAS treat as legacy system with exception that airborne CCD filtering is still in force)
 - o If APD values supported > "1" determine service type to use:
 - Choose highest service type available from ground subsystem and "required" by airborne this is the Selected Service Type
 - Use the FASLAL and FASVAL associated with selected FAS data block in the Type 4 message. For GAST D, these values are considered maximums. The airborne equipment may use smaller values if necessary for geometry screening to support touchdown performance.

- Airborne equipment computes
 - o Projection matrix S based on 30 s sigmas provided in type 11 message
 - o 30 second smoothed differential solution based on corrections in Type 11 message
 - o 100 second smoothed differential solution based on corrections in Type 1 message but using the same projection matrix, S. (A common set of satellites must be used for both solutions).
 - Deviations from the path defined in the selected FAS datablock based on the current position determined using the 30 second smoothed differential pseudoranges.
- Airborne equipment compares 30 second and 100 second solutions. If the difference exceeds 2 meters³ vertical or 2 meters horizontal consider subset solutions. This is the Dual Solution Iono Gradient Monitor Algorithm (DSIGMA) test as discussed in [6].
 - o If excluding satellite (s) results in a subset with < [2 m] difference, excluded satellites must be marked as unusable for 20 mins
 - o If no solution meets this DSIGMA Test, then the airborne equipment will revert to GAST C and provide an appropriate annunciation.
- Airborne equipment Reference Receiver Fault Monitor (RRFM) computes single RR error estimates in position domain for each RR based on the B-values. The error estimate is compared to a detection threshold if exceeded revert to the next lowest service type.
- Airborne equipment performs geometry screening:
 - Compare protection levels to LAL (FASLAL,D) and VAL (FASVAL,D) if exceeded or any airborne monitors fail, revert to next lowest service type and indicate "unable GAST X using Y" FASVAL and FASLAL (and service type specific functional requirements) Apply service type specific functional requirements.
 - When the aircraft is inside the precision approach region compare the maximum value of any S_{Apr_vert} and S_{Apr_lat} with a user specified maximum limit if exceeded revert to next lowest service type or use a subset geometry that does not exceed the limit.

D.3 Operating Concept for Legacy User (GAEC C) Against a GAST D capable Ground Subsystem

Equipment built in accordance with the current SARPs must operate normally even if the ground subsystem is built to support the new GAST D. This is accomplished simply in this scheme. The airborne equipment selects a channel in the normal manner. It ignores the new message type 11. The airborne equipment will use MT 1, MT 2 and MT 4 in exactly the same way as currently defined. The ground subsystem will continue to produce those messages in accordance with the requirements of the current SARPs. The only change is in the value of GCID. For a GAST D capable ground subsystem GCID is set to 2 (when the ground subsystem is meeting all the functional and performance requirements necessary to support GAST D). Airborne equipment built to the current standards will accept a value of GCID=2, and will operate normally. Furthermore the legacy equipment is not required to check APD and thus will use all available FAS data.

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³ Thresholds for both the airborne CCD and DSIGMA tests are included in DO-253C.

There is an important point to be understood at this time. Ground subsystems built to support GAST D must also at a minimum support GAST C. Another way to look at this is that the FAST D functional requirements for the ground subsystem are a superset of the FAST C requirements.

D.3.1 Operating Concept GAST D Capable Airborne Equipment (GAEC D) against a Legacy Ground Subsystem

When GAST D capable airborne equipment encounters a legacy ground subsystem that supports only GAST C (or lower), it will be able to tell immediately by the state of GCID. If GCID=1, then the airborne equipment does not even attempt to find information about higher types of service in the APD. It simply implements the functional requirements currently defined for "CAT I" in the SARPs.

One small caveat to this interoperability of new equipment against legacy ground subsystems is the new functional requirements that must be performed at all times by GAST D capable airborne equipment as described above. Smoothing with both time constants must be done even if the second set of pseudoranges are not needed for the ground-station or approach currently selected. Again, the receiver never knows when a GAST D capable ground subsystem would be selected and an extended delay waiting for smoothing filters to converge would be unacceptable. The other new functional requirement for GAEC D equipment is more significant. The CCD monitoring that must be run at all times may have identified a large gradient threat; even if a GAST C approach is selected. Detection of a large gradient by the airborne CCD monitor would be beneficial to the GAST C user and the airborne user may decide to apply the results of the monitoring for satellite selection, even when operating as GAST C. However, use of the CCD information in satellite selection for the GAST C approach is not proposed as a minimum airborne requirement.

NSP WGW November 2009 Report – Attachment H (was Nov09 WGW Flimsy 6)

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NSP WGW November 2009 Report – Attachment H (was Nov09 WGW Flimsy 6)

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