SYSTEM OF DIFFERENTIAL CORRECTION AND MONITORING

SDCM

I N T E R F A C E
C O N T R O L
D O C U M E N T

GLONASS Satellite-Based Augmentation System. – System of Differential Correction and Monitoring L5 Band Radio Signals and Data Block Format

Edition 1.0

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APPROVED

____________________ D.O. Rogozin,
CEO, Roscosmos
"_____"_________________2020

Interface Control Document
GLONASS Satellite-Based Augmentation System –
System of Differential Correction and Monitoring
L5 Band Radio Signals and Data Block Format

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Reviewed

_______________M.N. Khailov, Assistant CEO for Space-Based Systems,
Roscosmos
"_____" _________________2020

_______________S.N. Karutin, GLONASS Chief Designer
"_____" _________________2020

Russian Space Systems

________________A.E. Tyulin, CEO, Russian Space Systems
"_____" _________________2020

Approvals

On behalf of Roscosmos

____

On behalf of Russian Space Systems

V.G. Denezhkin

V.G. Sernov

V. V. Kurshin

____

On behalf of the Central Research Institute of Machine Building

____

On behalf of the Civil Aviation Research Institute

approved (letter rf. No. 807-71-f-32161 as of 18.11.2020)

On behalf of the Air and Space Forces Central Research Institute, Russian Ministry of Defense

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1 Introduction

1.1 SDCM Purpose

1.1.1 The System of Differential Correction and Monitoring (SDCM) is a SBAS augmentation of the Global Navigation Satellite System GLONASS for enhancing accuracy and ensuring integrity of positioning for marine, airborne, terrestrial and space users of GLONASS and GPS navigation signals with open access.

This document specifies the format of the L5 signals providing the dual-frequency multi-constellation (DFMC) service of the SDCM system. The DFMC service supports any combination of GNSS or a single GNSS.

Please see [1] for the L1 SDCM signal format. The signal provides single-frequency service of the SDCM supporting GPS and GLONASS.

1.2 SDCM Hardware

1.2.1 The SDCM hardware consists of two segments:

- space-based;
- ground-based.

The space-based segment includes three operating geostationary satellites of multifunctional Space System Luch, broadcasting SDCM data to users by means of SBAS radio signals. In the future, Luch 5VM, Luch 5M, and other satellites developed under the National Space Program will also be used as part of the SDCM space segment.

The ground-based segment of the System of Differential Correction and Monitoring includes Data Processing Center, the network of Reference Stations located worldwide, ground based facilities and some Mission Uplink and Control Centers transmitting SDCM data to users.

The ground-based segment is responsible for:

- monitoring of open service radio navigation field of GLONASS, GPS, Galileo and BDS satellites;
- continuous correction of orbits and clocks of GLONASS, GPS, Galileo and BDS satellites;
- generation of differential corrections – correction data and integrity data;
- transmission of differential corrections to the user via Space Segment and ground facilities.

1.3 SDCM Interface Definition

1.3.1 This document contains the L5 Data format. The signals are L1 and L5 GLONASS/GPS/Galileo/BDS SBAS corrections with open access. Figure 1 shows the common SDCM L5 interface from the space-based segment to the end-user navigation equipment.

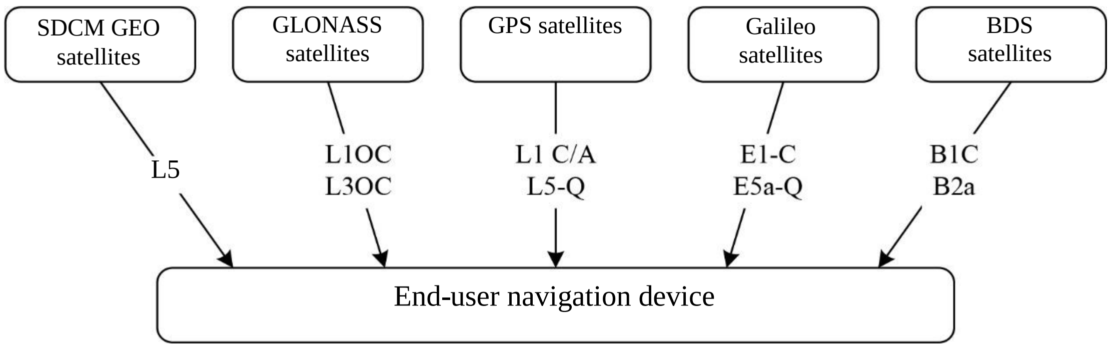

Figure 1 – SDCM L5 interface from space-based segment to the end-user navigation equipment

Interface of L1OC and L3OC signals is regulated by GLONASS ICDs [2], [3].

SDCM L5 data signal transmitted by GEO-satellites to the user contains differential corrections and GNSS integrity data.

2 General

2.1 SDCM ICD Definition

2.1.1 This Interface Control Document (ICD) complies with standards [4-7]. It defines the format of the L5 signal transmitted by the SDCM satellites.

2.2 ICD Approval/Amendment Procedure

2.2.1 The ICD is developed by the Joint Stock Company “Russian Space Systems”, the principal SDCM designer.

The Joint Stock Company “Russian Space Systems” responsibilities include the ICD development, approvals, amendments, preservation, and official distribution.

The ICD is duly approved by Roscosmos officials and becomes effective after the Roscosmos CEO approval.

Due to continuous refinement, the SDCM properties may be changed. The ICD developer secures the approvals of any amendments by all the parties, and issues a new edition if required.

Any amendments and new ICD revisions become effective after the Roscosmos CEO approval.

3 SDCM Space-Based Segment

3.1 Radiosignal is transmitted by 3 operating satellites on a geostationary orbit (GEO-satellites) from multifunctional space system Luch (see Table 1).

Table 1 – Nominal parameters of SDCM space segment

Satellite	Luch-5VM1	Luch-5VM2	Luch-5VM3
PRN code number (see section 5.2)	140	125	141
Orbital position	E95°	W16°	E167°
Orbit longitude maintenance accuracy, °	± 0.1	± 0.1	± 0.1
Eccentricity	0 to 0.0006	0 to 0.0006	0 to 0.0006
Inclination, °	0 to 5	0 to 5	0 to 5
GEO radius, km	42,164	42,164	42,164

The L5 SDCM signal power, when received by an isotropic right circular polarization terrestrial antenna, is at least minus 158 dBW power for the satellite elevation exceeding 5°. The maximum signal power received by an isotropic (0 dB gain) antenna with right circular polarization does not exceed -150.5 dBW.

The SDCM GEO-satellite coverage area is identified by the signal power (at least -158.5 dBW and elevation (at least 5°) for the worst-case scenario.

Figure 2 shows the estimated coverage areas of SDCM GEO-satellites.

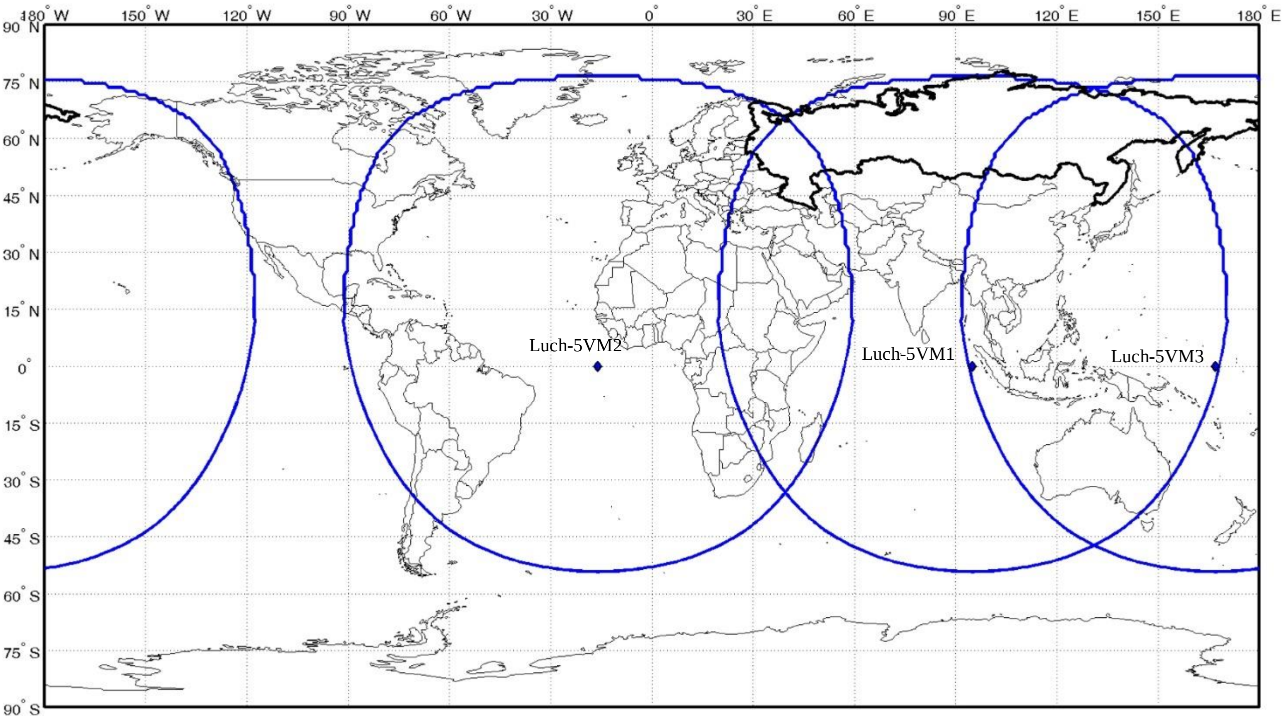

Figure 2 – SDCM GEO-satellites coverage areas

Table 2 represents the SDCM L5 signal power as received by a terrestrial isotropic antenna (gain = 1) with the right circular polarization vs. the elevation for the rated signal power. The data are valid for terrestrial users arranged longitudinally under the SDCM GEO-satellite.

Table 2 – L5 signal power as received by a terrestrial isotropic antenna (gain = 1) vs. the GEO-satellite elevation angle. The data are valid for terrestrial users arranged longitudinally under a satellite

User	Elevation, °	Signal power, dBW
Terrestrial user in the Northern latitudes	5	-157.3
	10	-157.0
	20	-156.6
	30	-156.3
	40	-156.1
	50	-155.9
	60	-155.8
	70	-155.8
	80	-155.8
	90	-156.0
Terrestrial user in the Southern latitudes	80	-156.2
	70	-156.5
	60	-156.8
	50	-157.1
	40	-157.5
	30	-157.9
	20	-158.4
	10	-158.9
	5	-159.2

4 SDCM to User Interaction Overview

4.1 Requirements for SDCM Time to alert (TTA) are shown in Appendix A (for state functions of GNSS satellites, standard differential corrections and accurate differential corrections, respectively). Figure 3 shows components of total TTA for both ground and space segments.

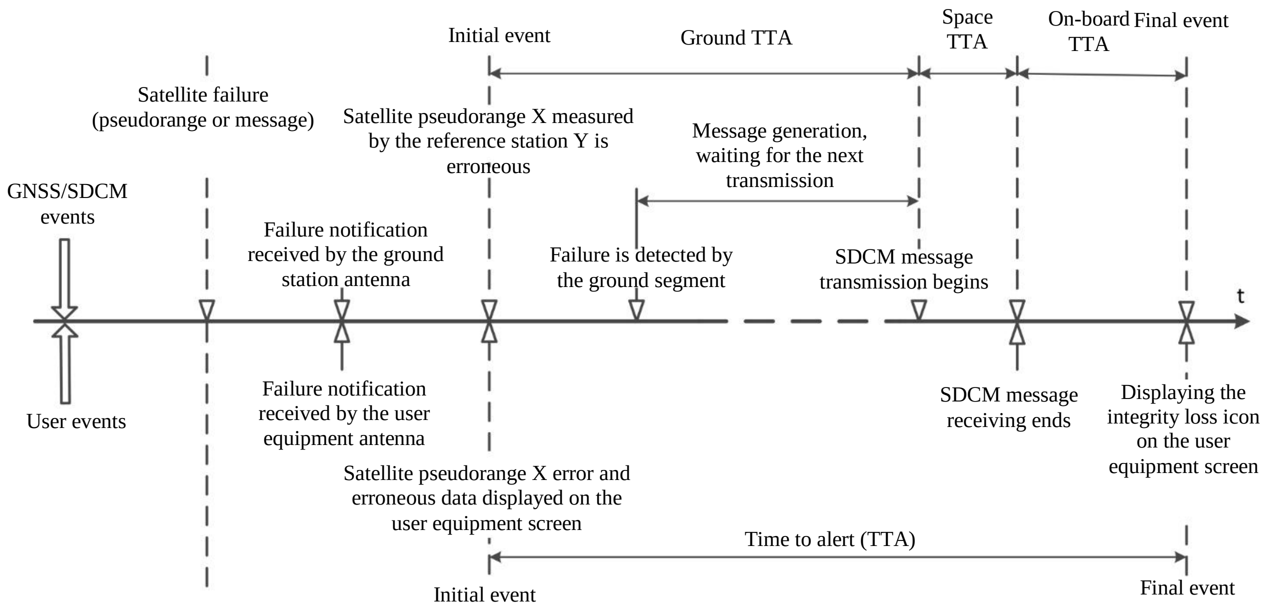

Figure 3 – SDCM Time to Alert

As shown in Figure 3, “initial event” in GNSS/SDCM and “initial event” at user equipment which mean satellite failure are considered simultaneous. That is not exactly true because of different receiver specifications. There is little difference, due to receiver processing, between the time of measured pseudorange distortion and the time when distorted data is displayed. For simplification purposes, it is not shown in the Figure.

Since tropospheric errors are local, each user estimates their specific error values. Recommended model for accurate tropospheric delay estimation is given in

Appendix B (based on [8]) nevertheless, other models can also be used at the user's choice and risk.

Multipath contribution into positioning error is considerable and affects both SDCM ground facilities and user equipment. In SDCM ground facilities multipath effect is reduced as far as it is possible or suppressed to minimize signal errors. User equipment also provides for multipath suppression features.

GPS uses the WGS84 coordinate system. Galileo and BDS use their dedicated coordinate systems similar to WGS84. GLONASS uses PZ-90. SDCM generates corrections for GPS, Galileo, and BDS satellites expressed in the latest WGS84 revision and for GLONASS satellites the latest PZ-90 revision is used.

The SDCM data for GLONASS, GPS, Galileo and BDS is transmitted nearly in real-time mode.

5 L5 SDCM Signal Structure

5.1 L5 Frequency Properties

5.1.1 Carrier frequency of L5 signal

A pseudo random noise radio signal is used at a carrier frequency of 1176.45 MHz. Code-division multiplexing of the three SDCM GEO-satellite channels is used.

5.1.2 Carrier frequency stability

Short-time L5 carrier frequency deviations at the output of the satellite transmitting antenna do not exceed 6.7×10^{-11} (averaged over 1 to 10 s periods).

5.1.3 Carrier phase noise

The spectral density of the L5 unmodulated carrier phase noise is such that the RMS carrier phase tracking error in a tracking loop with a 10 Hz one-sided noise bandwidth is 0.1 rad.

5.1.4 Spurious emissions

The spurious components of the L5 out-of-band emission at any frequency are at least 40 dB below the unmodulated carrier power.

5.1.5 Modulation

5.1.5.1 In-Phase Channel

L5 is a BPSK(10) phase-manipulated signal with 10,230 chips long pseudorandom codes (PRC). The data is continuously encoded by a 1/2 convolutional encoder. The characters generated by the convolutional encoder at a 500 bps rate are subsequently encoded by the Manchester code and added modulo 2 to the PRC characters. The generated chip stream at 10.23 Mchip/s phase modulates the carrier.

5.1.5.2 Convolutional Encoder Overview

In L5 signal transmitted by a GEO-satellite, data transmitted at a rate of 250 bps are continuously convolutional encoded at a code rate of 500 sps (Figure 4). In the first half of each bit, the output switch of the convolutional encoder occupies position 1.

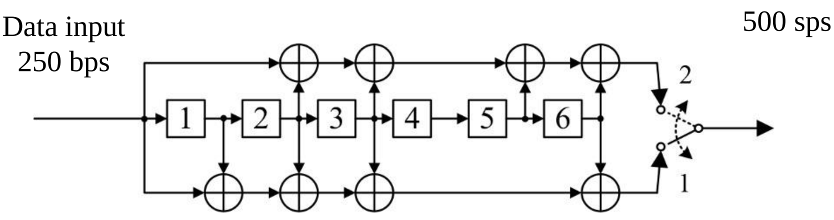

Figure 4 – Convolutional encoder

5.1.5.3 Manchester Code

The characters generated by the convolutional encoder at a 500 bps rate are subsequently encoded by the Manchester code as shown in Figure 5.

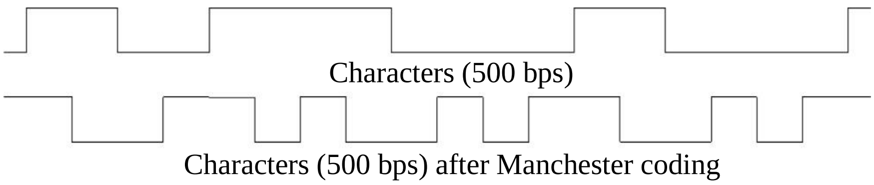

Figure 5 – Manchester Code

5.1.6 L5 Signal Bandwidth

The L5 SDCM signal bandwidth (at 3 dB) will occupy a frequency band between 20 and 24 MHz.

5.1.7 Doppler Shift

The Doppler shift of the L5 carrier transmitted by SDCM and received by a static receiver is caused by the GEO-satellite motion. In the worst case (at the end of the satellite service life) its speed would not exceed ±86 m/s relative to the user; the corresponding Doppler shift would not exceed ±337 Hz.

5.1.8 Polarization

The L5 signal transmitted by SDCM GEO-satellites uses a right-hand circular polarization. The ellipticity does not exceed 2 dB within ±9.1° from the antenna axis.

5.1.9 Correlation Loss

Correlation loss is the perfect correlator output power ratio for two cases:

- the correlator input is the received L5 signal and a perfect non-filtered pseudorandom reference signal;
- the correlator input is a perfect non-filtered pseudorandom reference signal normalized to the L5 signal power as in the first case, and a perfect non-filtered pseudorandom reference signal.

The correlation loss of the L5 signal due to imperfect modulation and filtration by the GEO satellite equipment does not exceed 1 dB.

5.1.10 Received Signal Power

The SDCM L5 signal at (43 ± 3) W when received by an isotropic right circular polarization terrestrial antenna with a 3 dB gain is at least -158 dBW power for the satellite elevation exceeding 5°. The maximum signal power received by an isotropic (0 dB gain) antenna with right circular polarization does not exceed -150.5 dBW.

5.1.11 SDCM Satellite Signal Properties

5.1.11.1 Carrier and Code Signals Coherence

For the L5 signal, the code signal drift rate with respect to the carrier does not exceed 0.5 m/s.

5.1.11.2 Maximum Signal Phase Deviation

A non-corrected phase of the L5 signal deviates from the SDCM system time by no more than $\pm 2^{-10}$ s.

5.2 SDCM L5 C/A Codes (PRC)

5.2.1 The SDCM L5 PRCs are taken from the SBAS L5 codes shown in Figure 6. The SBAS L5 codes are denoted as $XI_i(t)$.

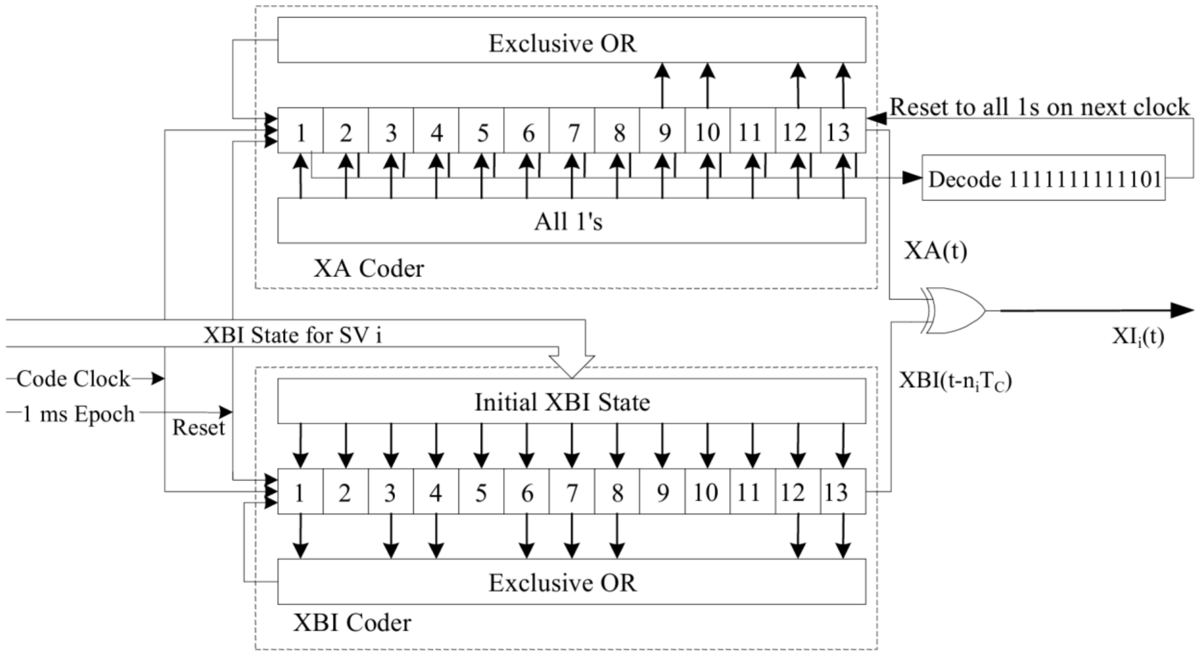

Figure 6 – SBAS L5 code generator

The $XI_i(t)$ code is generated by adding modulo 2 of two codes: XA(t) and $XBI_i(nI_i, t)$, where nI_i is the initial state of XBI_i for the satellite i. See Table 3 for the initial data used to generate $XI_i(t)$ for i from 120 to 158.

The $XI_i(t)$ code is formed by adding modulo 2 of two expanded M sequences at a 10.23 Mbit/s clock frequency (XA and XBI_i). XA is an M sequence 8,191 chips long. Its initial state is “all ones”. It is reset to the initial state before generating the last chip within the period (so the code length is 8,190), and then it is generated till 1 µm elapses since the XA period begins. As a result, the XA length is 10,230 chips. XBI_i is an M sequence 8,191 chips long. Its initial states are listed in Table 3. They are reset to the initial state after 1 µm elapses since the XBI_i period begins. As a result, the XBI_i length is 10,230 chips.

Table 3 – Initial data for the SBAS L5 PRN code generation

SBAS L5 PRN code number	XBI initial state 1)	XBI code delay, chips 2)
120	1101001100010	2,797
121	1100011001100	934
122	1000011000101	3,023
123	1111011011011	3,632
124	0000001100100	1,330
125	1101110000101	4,909
126	1100001000010	4,867
127	0001101001101	1,183
128	1010100101011	3,990
129	1111011110100	6,217
130	1111111101100	1,224
131	0000010000111	1,733
132	1111110000010	2,319
133	0011100111011	3,928
134	1101100010101	2,380
135	0101011111011	841
136	0001100011011	5,049
137	0001101110111	7,027
138	1110011110000	1,197
139	0111100011111	7,208
140	0011101110000	8,000
141	1111001001000	152
142	0001101110010	6,762
143	0101100111100	3,745
144	0010010111101	4,723
145	1101110110011	5,502
146	0011110011111	4,796
147	1001010101111	123
148	0111111101111	8,142
149	0000100100001	5,091
150	1110001101011	7,875
151	1111010010001	330
152	1011010111101	5,272
153	0001101110000	4,912
154	0000010111100	374
155	0100101111100	2,045
156	1110110111010	6,616
157	1101110101011	6,321
158	1101000110001	7,605

1) In the binary representation of the XBI initial state the LSB is the first output bit. Since the XA initial state is “all ones”, the initial states of XI are inversed XBI initial states.

2) XBI code delay is the number of XBI clock pulses elapsed since the XA was in its initial state (all ones).

The XA and XBI_i code polynomials are as follows, respectively:

$$g_{XA}(x) = 1 + x^9 + x^{10} + x^{12} + x^{13},$$

$$g_{XBI}(x) = 1 + x + x^3 + x^4 + x^6 + x^7 + x^8 + x^{12} + x^{13}.$$

Figure 7 (XA code) and Figure 8 (XBI codes) show the shift register bits mapping to the exponents of the corresponding polynomial. For the XBI codes, the shift register can be initiated by ones with a subsequent delay as indicated in Table 3, it can be initiated by the initial states listed in Table 3.

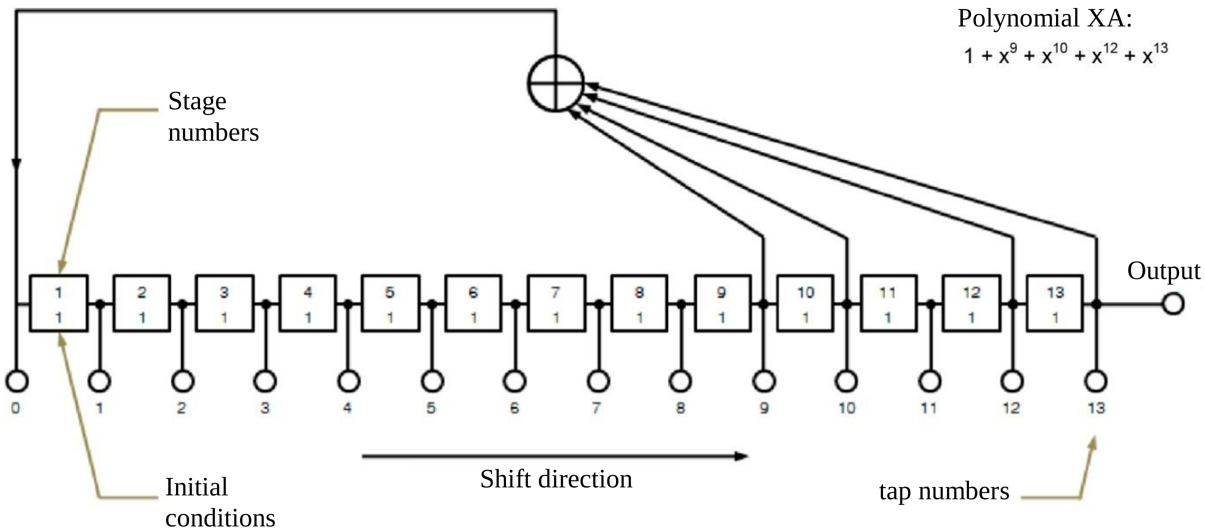

Figure 7 – XA shift register generator configuration

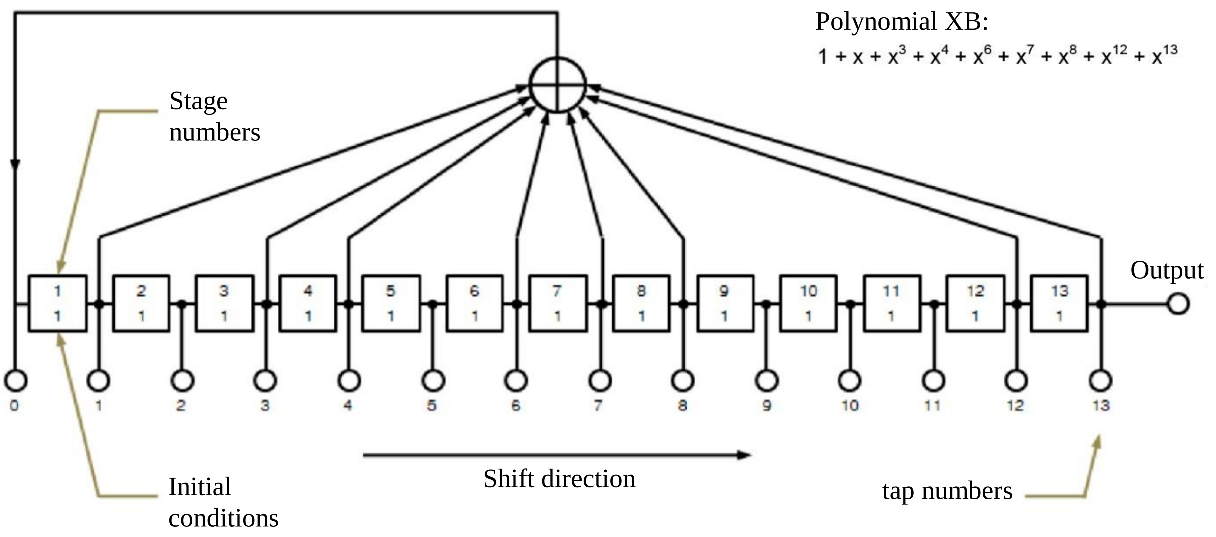

Figure 8 – XBI shift register generator configuration

6 L5 Signal Format

6.1 The following definitions are used to describe data structure of navigation L5 messages:

- bit – binary symbol of data;
- string – sequence of 250 bits;
- string field – data block containing a specific parameter or zeros;
- spare fields – the contents of such fields are not specified in this document. They are denoted as “Spare”. The user ignores the spare field contents.

The SDCM L5 data is transmitted as a sequence of 1 s-long strings of 250 bits each (Figure 9). A string contains the following fields: Preamble (4 bits), Message Type (6 bits), Data Field (216 bits), and Cyclic Redundancy Check (CRC) (24 bits).

All the fields are transmitted with most significant bits (MSBs) ahead. Transmission of a string starts with Preamble field.

In the fields which numerical values may be positive or negative, the most significant bit is the sign bit. Symbol “0” corresponds to “+” and symbol “1” corresponds to “–”.

Each string begins with the 4-bit Preamble field. For three successive data blocks, the six Preamble fields would contain 0101, 1100, 0110, 1001, 0011, 1010.

Message Type identifier consists of 6 bits and defines 64 message types (0-63), as Table 4 shows. Message Type identifier is transmitted MSBs ahead.

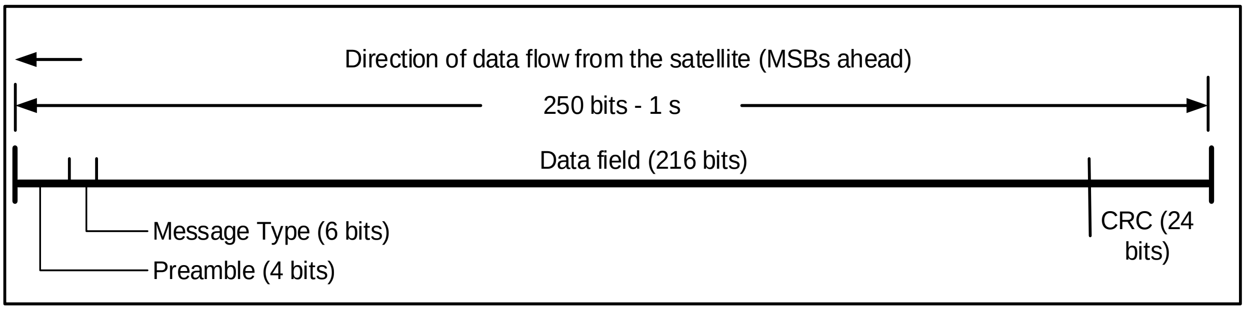

Figure 9 – Data format

Table 4 – Message types

Type	Content
0	L5 Test Message (see section 7.1)
1–30	Spare
31	PRN Mask Assignments (see section 7.2)
32	Clock-Ephemeris Corrections and Covariance Matrix (see section 7.4)
33	Spare
34, 35, 36	Integrity Data (DFREI and DFRECI) (see section 7.3)
37	OBAD Parameters and DFREI Scale Table (see section 7.6)
38	Spare
39	SDCM Satellite Ephemeris and Covariance Matrix 1 (see section 7.5)
40	SDCM Satellite Ephemeris and Covariance Matrix 2 (see section 7.5)
41	Spare
42	SDCM Time Offset (see section 7.8)
43-46	Spare
47	SDCM Satellite Almanacs (see section 7.7)
48-61	Spare
62	L5 Internal Test Message (see section 7.9)
63	Null L5 Message (see section 7.10)

Data field consists of 216 bits and contains SDCM message. These messages are transmitted with different rate depending on the data broadcast interval or on message priority. For instance, if the messages coming from a SDCM GEO-satellite are found to be invalid, a Type 0 message is transmitted immediately by the satellite. The Data field content depends on the message type. For the message types, see section 7. Appendix D represents data broadcast and time-out intervals (the time interval for which data is applicable).

The cyclic redundancy check (CRC) field. The last 24 bits of each string is the CRC field.

The CRC field value is the $R(x)$ remainder of the two polynomials division modulo 2:

$$\left\{\frac{\left[x^k M(x)\right]}{G(x)}\right\}_{\mathrm{mod}\,2} = Q(x) + R(x), \qquad (1)$$

where k is the number of the CRC field bits (24);

$M(x)$ is the binary sequence m_i generated from the Preamble (4 bits), Message Type (6 bits), and Data (216 bits) field values with the following polynomial:

$$M(x) = \sum_{i=1}^{226} m_i x^{226-i} = m_1 x^{225} + m_2 x^{224} + \ldots + m_{226} x^0; \qquad (2)$$

m_1 is the first Preamble field bit to be transmitted;

m_{226} is the 216th bit of the Data field;

$G(x)$ is the CRC generator polynomial:

$$G(x) = x^{24} + x^{23} + x^{18} + x^{17} + x^{14} + x^{11} + x^{10} + x^7 + x^6 + x^5 + x^4 + x^3 + x + 1; \qquad (3)$$

Q(x) is the quotient;

R(*x*) is the remainder (the binary characters r_i in the Data field):

$$R(x) = \sum_{i=1}^{k} r_i x^{k-i} = r_1 x^{23} + r_2 x^{22} + \ldots + r_{24} x^0, \ k = 24; \tag{4}$$

r_1 is the first Data field bit to be transmitted;

r_{24} is the last Data field bit to be transmitted.

7 SDCM L5 Data Content

7.1 Type 0 message. L5 Test Message

7.1.1 This type of message is intended for SDCM testing purposes only. It is also used if the messages coming from an SDCM GEO-satellite are found to be invalid. A Type 0 message is transmitted at least once a minute. Never use SDCM test messages for Safety of Life (SoL) operations. In SoL operations, upon receiving a Type 0 message the user stops receiving Type 31, 34, 35, 36, 32, 39, 40, 37, and 42 messages from the affected SDCM GEO-satellite to avoid possible accuracy and integrity deterioration. The test messages may be used in non-SoL operations.

For better performance, other message types can be used, e.g., Type 47 (see section 7.7). Still, the broadcast indicator bit in a Type 47 message and the SBAS service provider is considered invalid.

7.2 Type 31 message. PRN Mask Assignments

7.2.1 About Type 31 message

A Type 31 message contains a satellite mask (the Satellite Mask field). The satellite mask is a set of 214 bits such that each bit represents one specific satellite as shown in Table 5 and the value of that bit indicates whether augmentation is, or is not, provided for that satellite.

Table 5 – PRN code number assignments

PRN code number	Assignment
1-32	GPS
33-37	Reserved (GPS)
38-69	GLONASS Slot Number plus 37
70-74	Reserved (GLONASS)
75-110	Galileo Slot Number plus 74
111	Reserved (Galileo)
112-119	Spare
120-158	SBAS including SDCM
159-195	BDS Slot Number plus 158
196-214	Spare
Note 1.– SDCM can augment various core constellations to fulfil SBAS L5 and DFMC SBAS. Note 2.– “Spare” means that the slot number has not been assigned to a certain system, but is planned to be assigned.	

In this document, the following terms are used [4]:

- satellite slot number: a number representing a specific slot in the satellite mask (slots numbers range from 1 to 214) assigned to a specific satellite for which SBAS augmentation can be provided;
- satellite slot value: binary indication per satellite slot to indicate whether SBAS data are provided for the satellite. Coding: 0 = data not provided; 1 = data provided;
- augmented slot index: a 1...92 integer, a sequential number of the satellite slot.

The structure and content of Type 31 message are given in Figure 10 and Table 6, respectively.

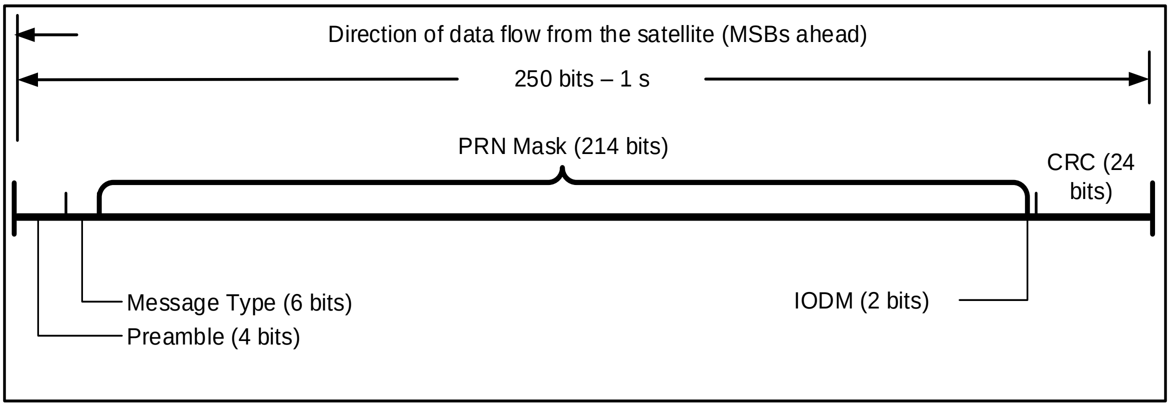

Figure 10 – Type 31 message structure. PRN mask assignments

The satellite mask can set up to 92 satellites listed in Table 5 from the 214 possible satellites available for augmentation. The reason is the SDCM data update period limitations. The satellite mask is followed by the IODM (Issue of Data Mask) field. It is an indicator provided in Type 31, 34, 35 and 36 messages that links the integrity data provided in Type 34, 35 and 36 messages with the augmented slot indexes in the Type 31 message. When there is a change in the satellite mask, the IODM modulo 4 is increased by 1.

Table 6 – Type 31 message content. PRN mask assignments

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Type	6	4	9	1	0	63	–	Message type (see section 6)
GPS mask	Satellite slot number 1	1	10	10	1	0	1	–	Bit for 1-st GPS satellite
	to Satellite Slot Number 32	1	41	41	1	0	1	–	to Bit for 32-nd GPS satellite
	Satellite slot number 33	1	42	42	1	0	1	–	GPS reserved, bit 1
	to Satellite Slot Number 37	1	46	46	1	0	1	–	to GPS reserved, bit 5
GLONASS mask	Satellite slot number 38	1	47	47	1	0	1	–	Bit for 1-st GLONASS satellite
	to Satellite Slot Number 69	1	78	78	1	0	1	–	to Bit for 32-nd GLONASS satellite
	Satellite slot number 70	1	79	79	1	0	1	–	GLONASS reserved, bit 1
	to Satellite Slot Number 74	1	83	83	1	0	1	–	to GLONASS reserved, bit 5
Galileo mask	Satellite slot number 75	1	84	84	1	0	1	–	Bit for 1-st Galileo satellite
	to Satellite Slot Number 110	1	119	119	1	0	1	–	to Bit for 36-th Galileo satellite
	Satellite Slot Number 111	1	120	120	1	0	1	–	Galileo reserved
Spare	Satellite slot number 112	1	121	121	1	0	1	–	Spare, bit 1
	to Satellite Slot Number 119	1	128	128	1	0	1	–	Spare, bit 9
SBAS mask	Satellite slot number 120	1	129	129	1	0	1	–	Bit for 1-st SBAS satellite
	to Satellite Slot Number 158	1	167	167	1	0	1	–	to Bit for 39-th SBAS satellite
BDS mask	Satellite slot number 159	1	168	168	1	0	1	–	Bit for 1-st BDS satellite
	to Satellite Slot Number 195	1	204	204	1	0	1	–	to Bit for 37-th BDS satellite
Reserved for future GNSS	Satellite slot number 196	1	205	205	1	0	1	–	Reserved, bit 1
	to Satellite Slot Number 214	1	223	223	1	0	1	–	to Reserved, bit 19
Message trailer	IODM	2	224	225	1	0	3	–	Issue of data Mask
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

7.2.2 Type 31 message parameters

The maximum number of satellites to be augmented in each GNSS is 37. Each GNSS satellite has a number from 1 to 37. It broadcasts its number. The SDCM data is not transmitted for any satellites with numbers beyond the 1...37 range.

Satellite slot numbers are assigned in the order of the GNSS satellite numbers. E.g., for a GLONASS satellite number *n* the slot number in a Type 31 message is (*n* + 37).

Figure 11 shows how the list of satellites for which the SDCM data is transmitted is formed, and the data sequence controlled by the Satellite Mask field. “Empty” means the satellite number is skipped.

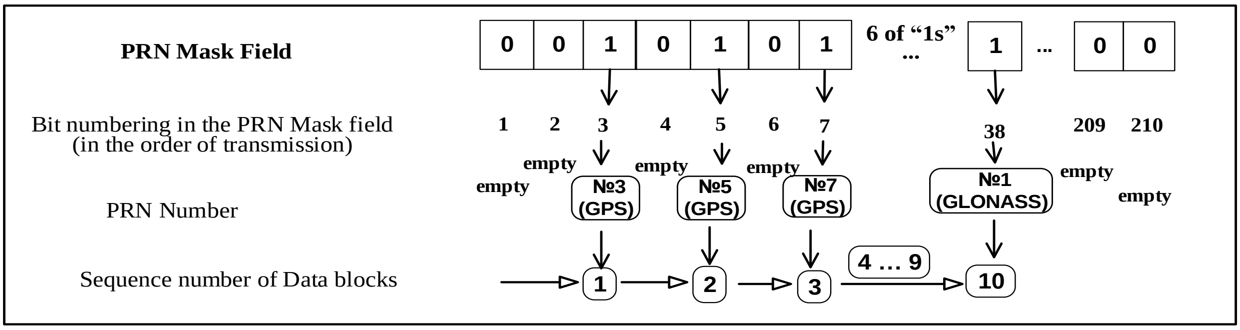

Figure 11 – Principle of forming a list of C/A codes of used satellites

7.2.3 Changing Type 31 Message Satellite Mask

If the IODM value in a Type 31 message is not equal to the IODM value in Type 34, 35, or 36 messages, do not use these Type 34, 35, or 36 messages until receiving the satellite mask in a Type 31 message with the valid IODM value.

After receiving a Type 31 message with a new IODM value the user equipment:

- continues using the old satellite mask (for its validity interval specified in Table D.1) until other messages with a new IODM value are received;
- stores the new satellite mask to avoid service interruptions when switching to a new mask.

When switching to a new mask, the user equipment may still use some data associated with the old satellite mask, and some data associated with the new one. However, do not use the messages with the new IODM value until a new satellite mask is received.

SDCM guarantees that at any given epoch there are no more than two active satellite masks with different IODM values. A satellite mask is active if there is a transmitted Type 31 message and its validity interval has not yet timed out.

7.3 Type 34, 35, 36 Messages. Integrity Data (DFREI and DFRECI)

7.3.1 Type 34 Message

The message contains integrity data as DFRECI parameters for each index of the augmented slot, and as DFREI parameters for the first 7 indexes of the augmented slot. See Table 7 for the Type 34 message contents.

Dual Frequency Range Error Change Indicator (DFRECI) is a 2-bit indicator showing the integrity status of the satellite specified as its augmented slot index. Dual Frequency Range Error Indicator (DFREI) is a 4-bit indicator showing the dual-frequency range error (DFRE).

Table 7 – Type 34 message contents. Integrity data

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Message Type	6	4	9	1	0	63	–	Message Type (see section 6)
DFRECI	DFRECI 1	2	10	11	1	0	3	–	DFRE change indicator for augmented slot index 1
	to DFRECI 92	2	192	193	1	0	3	–	to DFRE change indicator for augmented slot index 92
DFREI	DFREI 1	4	194	197	1	0	15	–	DFRE indicator 1
	to DFREI 7	4	218	221	1	0	15	–	to DFRE indicator 7
Reserved	Reserved	2	222	223	–	–	–	–	–
IOD	IODM	2	224	225	1	0	3	-	Issue of Data Mask
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

The DFRECI values are transmitted for each augmented slot index, i.e., for each satellite slot value of wich has been set to one within the satellite mask (see section 7.2). Each DFRECI field can take the following values:

- 0 (00_2): the DFREI value has not changed and is still in the 0...14 range;
- 1 (01_2): the DFREI value has been changed. The new value is within the 0...14 range and is transmitted in a message;
- 2 (10_2): the DFREI value has been increased by 1 (if the current DFREI value is 15, after incrementing the value will still be 15);
- 3 (11_2): the satellite status is “SBAS skip”.

“0” and “2” DFRECI values for a satellite are always applicable to the last valid DFREI value for this satellite (an active value validity interval has not yet timed out). If DFRECI = 2, it means that the current DFREI value is 1 greater than the value contained in the message.

A DFRECI value is transmitted in a Type 34 message for a specific satellite overrides any DFRECI values already existing for this satellite and restarts the DFREI validity interval. DFRECI values are transmitted for satellites where DFRECI=1 in the order of their sequence in the DFREI field.

The DFREI range is from 0 to 15, with a value of 15 corresponds to “Do Not Use for SBAS”. For other values (from 0 to 14), the DFREI table defining the correspondence between the DFRE Indicator (DFREI) values and the standard deviation (σ_{DFRE}, in meters). The DFREI table is transmitted in the Type 37 message (see section 7.6). SDCM evaluates the standard deviation values (within the acceptable ranges).

A DFRECI value is transmitted in a Type 34 message for each satellite replaces any DFRECI values already existing for this satellite (in Type 34, 35, 36, 32, or 40 messages), and resets the DFREI timeout interval.

A Type 34 message contains the IODM 2-bit field associated with the satellite mask (see section 7.2).

7.3.2 Type 35 Message

The message contains integrity data as DFREI parameters augmented slot indexes from 1 to 53. See Table 8 for the message contents.

Table 8 – Type 35 message contents. Integrity data

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Message Type	6	4	9	1	0	63	–	Message Type (see section 6)
DFREI	DFREI 1	4	10	13	1	0	15	–	DFRE indicator for augmented slot 1
	to DFREI 53	4	218	221	1	0	15	–	to DFRE indicator for augmented slot index 53
Reserved	Reserved	2	222	223	–	–	–	–	Reserved
IOD	IODM	2	224	225	1	0	3	–	Issue of Data
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

For the DFREI parameters and the IODM fields see section 7.3.1.

7.3.3 Type 36 Message

The message contains integrity data as DFREI parameters augmented slot indexes from 54 to 92. See Table 9 for the message contents.

Table 9 – Type 36 message contents. Integrity data

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Type	6	4	9	1	0	63	–	Message Type (see section 6)
DFREI	DFREI 54	4	10	13	1	0	15	–	DFRE change indicator for augmented slot index 54
	to DFREI 92	4	162	165	1	0	15	–	to DFRE change indicator for augmented slot index 92
Spare	Spare bits	56	166	221	–	–	–	–	Spare bits
Reserved	Reserved	2	222	223	–	–	–	–	Reserved
IOD	IODM	2	224	225	1	0	3	–	Issue of Data Mask
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

For the DFREI parameters and the IODM fields see section 7.3.1.

7.4 Type 32 message. Clock-Ephemeris Corrections and Covariance Matrix

7.4.1 The Type 32 message contains corrections for a single satellite. For the Type 32 message format (Table 10) the following notation is used:

- δx, δy, δz are x, y, z satellite position corrections in PZ-90 coordinate system for GLONASS satellite or WGS84 for GPS, Galileo, and BDS;
- δB is the satellite clock offset correction in meters;
- $\delta \dot{x}$, $\delta \dot{y}$, $\delta \dot{z}$ are x, y, z satellite position corrections in PZ-90 coordinate system for GLONASS satellite or WGS84 for GPS, Galileo, and BDS;

- $\delta\dot{B}$ is the satellite clock drift error correction (δB variation rate) expressed in m/s;

- t_D is the time of applicability of the parameters δx, δy, δz, δB, $\delta\dot{x}$, $\delta\dot{y}$, $\delta\dot{z}$, $\delta\dot{B}$ expressed in seconds after midnight of the current day.

A Type 32 message is used to broadcast the errors of the slowly changing ephemeris, and clock errors. The corrections and covariance matrix in the Type 32 message are estimated with respect to the clock ephemeris data transmitted by the GNSS.

An SDCM GEO-satellite transmits Type 32 messages only for the satellites with 1 in the respective satellite mask slot provided that the satellites are monitored by SDCM (i.e., $0 \le \text{DFREI} \le 14$). An SDCM GEO-satellite does not transmit Type 32 messages to itself because the data is already presented in Type 39/40 messages are monitored by SDCM (see section 7.5).

Table 10 – Type 32 message contents. Clock-Ephemeris Corrections and Covariance Matrix

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Message Type	6	4	9	1	0	63	–	Message Type (see section 6)
Message header	Satellite slot number	9	10	18	1	0	214	–	Satellite slot number (range 1 to 214)
	IODN	10	19	28	1	0	1023	–	Issue of Data Navigation
Orbit parameters	δx	11	29	39	0.0625	-64	63.9375	m	Coded as two's complement
	δy	11	40	50	0.0625	-64	63.9375	m	
	δz	11	51	61	0.0625	-64	63.9375	m	
	δB	12	62	73	0.03125	-64	63.96875	m	
	$\delta \dot{x}$	8	74	81	2^{-11}	-0.0625	0.06201172	m/s	
	$\delta \dot{y}$	8	82	89	2^{-11}	-0.0625	0.06201172	m/s	
	$\delta \dot{z}$	8	90	97	2^{-11}	-0.0625	0.06201172	m/s	
	$\delta \dot{B}$	9	98	106	2^{-12}	-0.0625	0.06225586	m/s	
	t_D	13	107	119	16	0	86,384	s	The time of corrections applicability (range: 0 to 86,384 s)
Covariance parameters	Scale exponent	3	120	122	1	0	7	–	Covariance matrix scale factor
	$E_{1,1}$	9	123	131	1	0	511	–	–
	$E_{2,2}$	9	132	140	1	0	511	–	–
	$E_{3,3}$	9	141	149	1	0	511	–	–
	$E_{4,4}$	9	150	158	1	0	511	–	–
	$E_{1,2}$	10	159	168	1	-512	511	–	Coded as two's complement
	$E_{1,3}$	10	169	178	1	-512	511	–	
	$E_{1,4}$	10	179	180	1	-512	511	–	
	$E_{2,3}$	10	189	198	1	-512	511	–	
	$E_{2,4}$	10	199	208	1	-512	511	–	
	$E_{3,4}$	10	209	218	1	-512	511	–	

Table 10 (continued)

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Integrity parameters	DFREI	4	219	222	1	0	15	–	Dual-frequency range error indicator
δR_{CORR}	R_{CORR} multiplier	3	223	225	1/8	1/8	1	–	R_{CORR} scale factor
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)
See Table 5 for the satellite slot number (1 to 214).									

The corrections and covariance matrix in Type 32 messages are in the SDCM network time scale. The system-to-system time offsets and measurement differences are estimated by the user by adding the values listed in Appendix E.

To match the Type 32 (or 39/40) message parameters and the integrity parameters (transmitted in Type 34, 35, and 36 messages), a dual-frequency multiconstellation receiver receives Type 32 (or 39/40) messages only within the current validity interval. For precision approach (PA) applications the following equations are true:

$$t - T_{MT32\ reception} \le (I_{VALID})_{MT32},$$
$$t - T_{MT39/40\ reception} \le (I_{VALID})_{MT39/40}, \tag{5}$$

where t is the current time

$T_{MT32\ reception}$ is the time of receiving the last Type 32 message character;

$T_{MT\ 39/\ 40\ reception}$ is the time of receiving the last Type 39/40 message character for the valid ephemeris;

$(I_{VALID})_{MT32}$, $(I_{VALID})_{MT39/40}$ are as defined in the Type 37 message definition (see section 7.6).

Each Type 32 message contains a 10-bit Issue of Data Navigation (IODN) equal to the IOD transmitted by the GNSS (for GLONASS, t_b field contains IOD). If the IODs transmitted by the GNSS differ from the IODN transmitted in Type 32 messages it means that IOD has been changed. In such a situation, the user applies the previously transmitted matching IDs till a new Type 32 message with a valid IODN value is received. Such new Type 32 messages are transmitted within the time frame for the initial positioning procedure.

As the GNSS satellites transmit new time-ephemeris data, SDCM continues broadcasting the correction and covariance matrix for the old time-ephemeris data during the period long enough for every SDCM user to receive new GNSS data.

The time of applicability of the t_D correction is expressed as time after midnight of the current day. When estimating the clock offset note that the t_D value is rounded. In the Type 32 message, the t_D parameter range is minus 43200 to plus 43199 s since the Type 32 message broadcast ends. It accounts for date changes.

The clock offset correction δB and the clock drift correction $\delta\dot{B}$ (δB variation rate) are used to estimate the clock offset $\delta\Delta t_{SV}$ at t as follows

$$\delta\Delta t_{SV} = \frac{\delta B + \delta\dot{B} \times \Delta t_D}{c}, \tag{6}$$

where $\Delta t_D = t - t_D$;

t is the SDCM network time when the signal is transmitted, s;

t_D is the correction applicability time, s;

c is the speed of light in a vacuum (299,792,458 m/s).

Note.– To estimate Δt_D, t and t_D starts at the same epoch. The broadcast parameter t_D is the time of the day. It is to be converted to account for date/week changes.

The clock offset $\delta\Delta t_{SV}$ is used in the equation

$$PR_{i,corrected}(t) = PR_{i,ionofree}(t) + c \cdot (\Delta t_{SV,i}(t) + \delta\Delta t_{SV,i}(t) - T_{GD,i}) + TC_i, \qquad (7)$$

where $PR_{i,ionofree}(t)$ is the ionosphere free dual-frequency pseudorange to the *i*-th satellite (see Appendix C);

$\Delta t_{SV,i}(t)$ is the i-th satellite clock offset transmitted by the augmented GNSS (see Appendix C), s;

$\delta\Delta t_{SV,i}(t)$ is the clock offset of the i-th satellite estimated as (6), s;

$T_{GD,i}$ is an obsolete but still used parameter for GPS satellites only. It is a group delay from the L1 LNAV message for the i-th satellite, s;

TC_i is the tropospheric correction for the i-th satellite, m.

The satellite position correction vector $[\delta x(t) \quad \delta y(t) \quad \delta z(t)]^T$ in WGS84 is estimated as

$$\begin{bmatrix} \delta x(t) \\ \delta y(t) \\ \delta z(t) \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta \dot{x} \\ \delta \dot{y} \\ \delta \dot{z} \end{bmatrix} \times \Delta t_D, \qquad (8)$$

where δx, δy, δz, $\delta\dot{x}$, $\delta\dot{y}$, $\delta\dot{z}$, Δt_D are the orbit parameters transmitted in the Type 32 message (see Table 10).

The correction vector is added to the satellite coordinate vector $\left[x(t) \quad y(t) \quad z(t)\right]$. For GPS, corrections in the Type 32 message see L1 LNAV, and IODN is equal to the transmitted IODC. For Galileo, corrections in the Type 32 message see E5a F/NAV, and IODN is equal to the transmitted IOD_{NAV}. For BDS, corrections in the Type 32 message see B1C, and IODN is equal to the transmitted IODC. For GLONASS, corrections in the Type 32 message see the L1OC message, and IODN is equal to t_b. For the SDCM GEO satellites, corrections in the Type 32 message see Type 39/40 messages, and IODN is equal to IODC.

The covariance matrix **C** is generated as:

$$\mathbf{C} = \mathbf{R}^{\mathbf{T}} \times \mathbf{R}, \tag{9}$$

where **R** is estimated as

$$\mathbf{R} = 2^{scale\ exponent-5} \times \begin{bmatrix} E_{1,1} & E_{1,2} & E_{1,3} & E_{1,4} \\ 0 & E_{2,2} & E_{2,3} & E_{2,4} \\ 0 & 0 & E_{3,3} & E_{3,4} \\ 0 & 0 & 0 & E_{4,4} \end{bmatrix} \tag{10}$$

scale exponent, $E_{1,1}$, $E_{1,2}$, $E_{1,3}$, $E_{1,4}$, $E_{2,2}$, $E_{2,3}$, $E_{2,4}$, $E_{3,3}$, $E_{3,4}$, $E_{4,4}$ are the covariance parameters transmitted in the Type 32 message (see Table 10).

The covariance matrix is intended to correct the transmitted σ_{DFRE} values to match the user location. For this, σ_{DFRE} is multiplied by δ_{DFRE}. The latter is estimated as

$$\delta_{DFRE} = \sqrt{\mathbf{I}^T \cdot \mathbf{C} \cdot \mathbf{I}} + \varepsilon_c, \tag{11}$$

where **I** is a 4D line of sight vector from the user to the satellite in the WGS84 coordinate frame. The first three components are the unit vector from the user to the satellite and the fourth component is a one;

C is the covariance matrix;

$\varepsilon_c = C_{COVARIANCE} \cdot 2^{scale\ exponent-5}$;

$C_{COVARIANCE}$ is the parameter transmitted in the Type 37 message (see section 7.6).

For the DFREI parameter definition see section 7.3.1.

The δR_{CORR} factor is used in combination with the obsolete R_{CORR} of the specific GNSS (see the Type 37 message definition in 7.6 for R_{CORR} details) to estimate the satellite degradation factor (see (16)).

7.5 Type 39/40 messages. SDCM Satellite Ephemeris and Covariance Matrix

7.5.1 These messages contain the ephemeris and covariance matrix of the SDCM satellite.

The satellite position is expressed in Keplerian parameters so various orbit types (IGSO, HEO, MEO, GEO) are supported. As there are many parameters, the navigation data and covariance matrix are transmitted in two messages: Type 39 and 40 messages (see Tables 11 and 12).

Table 11 – Type 39 message contents. SDCM Satellite Ephemeris and Covariance Matrix

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Type	6	4	9	1	0	63	–	Message Type (see section 6)
Message header	Satellite slot delta	6	10	15	1	0	63	–	Satellite slot number minus 119 (range: 1 to 39)
	IODG	2	16	17	1	0	3	–	Type 39/40 message ID
	SBAS provider ID	5	18	22	1	0	31	–	See Table 13
Keplerian parameters (part 1)	C_{uc}	19	23	41	$\pi\times2^{-19}\times$ $\times10^{-4}$	$-\pi/2\times$ $\times10^{-4}$	$\pi/2\times$ $\times10^{-4}\times$ $\times(1-2^{-18})$	rad	Coded as two's complement
	C_{us}	19	42	60	$\pi\times2^{-19}\times$ $\times10^{-4}$	$-\pi/2\times$ $\times10^{-4}$	$\pi/2\times$ $\times10^{-4}\times$ $\times(1-2^{-18})$	rad	
	I_{dot}	22	61	82	$7\pi/6\times$ $\times2^{-21}\times$ $\times10^{-6}$	$-7\pi/6\times$ $\times10^{-6}$	$7\pi/6\times$ $\times10^{-6}\times$ $\times(1-2^{-21})$	rad/s	
	ω	34	83	116	$\pi\times2^{-33}$	$-\pi$	$\pi\times$ $\times(1-2^{-33})$	rad	
	Ω_0	34	117	150	$\pi\times2^{-33}$	$-\pi$	$\pi\times$ $\times(1-2^{-33})$	rad	
	M_0	34	151	184	$\pi\times2^{-33}$	$-\pi$	$\pi\times$ $\times(1-2^{-33})$	rad	
Clock parameters	a_{Gf_0}	25	185	209	0.02	-335,544.32	335,544.3	m	
	a_{Gf_1}	16	210	225	4×10^{-5}	-1.31072	1.31068	m/s	
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

Table 12 – Type 40 message contents. SDCM Satellite Ephemeris and Covariance Matrix

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Type	6	4	9	1	0	63	–	Message Type (see section 6)
Message header	IODG	2	10	11	1	0	3	–	Type 39/40 message ID
Keplerian parameters (part 2)	*II*	33	12	44	$\pi\times\times2^{-33}$	0	$\pi\times(1\text{-}2^{-33})$	rad	Inclination angle at t_e
	e	30	45	74	2^{-30}	0	$1\text{-}2^{-30}$	–	Eccentricity
	a	31	75	105	0.02	6,370,000	49,319,672.94	m	Semi-major axis
SDCM ephemeris time	t_e	13	106	118	16	0	86,384	s	SDCM ephemeris time (range: 0 to 86,384 s)
Covariance parameters	Scale exponent	3	119	121	1	0	7	–	Covariance matrix scale factor
	$E_{1,1}$	9	122	130	1	0	511	–	–
	$E_{2,2}$	9	131	139	1	0	511	–	–
	$E_{3,3}$	9	140	148	1	0	511	–	–
	$E_{4,4}$	9	149	157	1	0	511	–	–
	$E_{1,2}$	10	158	167	1	-512	511	–	Coded as two's complement
	$E_{1,3}$	10	168	177	1	-512	511	–	
	$E_{1,4}$	10	178	187	1	-512	511	–	
	$E_{2,3}$	10	188	197	1	-512	511	–	
	$E_{2,4}$	10	198	207	1	-512	511	–	
	$E_{3,4}$	10	208	217	1	-512	511	–	
Integrity parameters	DFREI	4	218	221	1	0	15	–	See section 7.3
δR_{CORR}	R_{CORR} scale factor	3	222	224	1/8	1/8	1	–	R_{CORR} scale factor
Spare bit	Spare bit	1	225	226	–	0	1	–	–
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

Note.– π is the ratio of the circumference of a circle to its diameter. In this document, π=3.1415926535898.

For the Type 39 message format the following notation is used:

- C_{uc} is the amplitude of the cosine harmonic correction to the argument of latitude;
- C_{us} is the amplitude of the sine harmonic correction to the argument of latitude;
- I_{dot} is the rate of inclination angle;
- ω is the argument of perigee;
- Ω_0 is the longitude of the ascending node of the orbital plane at the beginning of the week;
- M_0 is the mean anomaly.

The Satellite Slot Delta parameter in the Type 39 message denotes the broadcasting SDCM satellite and specifies its position (1 to 39) in the SBAS mask (see Table 6). 1 corresponds to satellite slot 120, while 39 corresponds to satellite slot 158. Any values beyond the 1-39 range are invalid.

Note.– Since Type 39/40 messages contain the ephemeris for the broadcasting SDCM satellite, the relative slot number can be used to confirm the slot number of the tracked SDCM satellite.

Each Type 39/40 message contains the IODG 2-bit field used to compose 39/40 Type message pairs. When the corrections in a Type 32 message are for another SDCM satellite, IODN in the message would be equal to the satellite IODG (see section 7.11 for the relationship between the messages). In SDCM the IODG modulo 4 is increased by 1 each time the message content is modified.

t_e (SDCM ephemeris time) is the ephemeris epoch transmitted as the time after midnight of the current day. When estimating the SDCM satellite geocentric coordinates and the clock offset the user notes that the parameter value is rounded. In the Type 40 message the t_e parameter range is minus 43,200 to plus 43,199 s since the Type 40 message broadcast ends. It accounts for date changes.

The clock offset correction a_{Gf0} and the clock drift correction a_{Gf1} are used to estimate the broadcasting SDCM satellite clock offset Δt_{SBAS} at t as follows

$$\Delta t_{SBAS} = a_{Gf0} + a_{Gf1} \times \Delta t_e , \tag{12}$$

where $\Delta t_e = t - t_e$;

t is the SDCM network time when the L5 signal is transmitted, s;

t_e is the SDCM ephemeris time, s;

Note.– To estimate Δt_e, t and t_e starts at the same epoch. The broadcast parameter t_e is the time of the day. It is to be converted to account for date/week changes.

Table 13 specifies the relationship between the SBAS service provider field value transmitted in the Type 39 message and the SBAS service provider. The covariance matrix elements are estimated as (9), (10) and (11).

For the DFREI parameter definition see section 7.3.1.

The δR_{CORR} factor is used in combination with the obsolete R_{CORR} of the specific GNSS (see the Type 37 message definition in section 7.6 for R_{CORR} details) to estimate the satellite degradation factor (see (16)).

Table 13 – SBAS service provider identifiers

Identifier	SBAS service provider
0	WAAS
1	EGNOS
2	MSAS
3	GAGAN
4	SDCM
5	BDSBAS
6	KASS
7	A-SBAS
8	SouthPAN
9...13	Spare
14...15	Reserved
16...31	Spare for additional SBAS L5 provider only

To match the Type 39/40 message parameters and the integrity parameters (transmitted in Type 34, 35, and 36 messages), a dual-frequency multiconstellation user receives Type 39/40 messages only within the current validity interval. For precision approach (PA) applications the following equation is true:

$$t - T_{MT39/40\ reception} \leq (I_{VALID})_{MT39/40}, \tag{13}$$

where t is the current time;

$T_{MT\ 39/40\ reception}$ is the time of receiving the last Type 39/40 message character for the valid ephemeris;

$(I_{VALID})_{MT39/40}$ is as defined in the Type 37 message definition (see section 7.6).

See section 8.3 for the satellite geocentric coordinates estimation from the Type 39 and 40 message parameters.

7.6 Type 37 message. OBAD Parameters and DFREI Scale Table

7.6.1 The Type 37 message (Table 14) contains the Old But Asctive Data (OBAD) parameters and data used by SDCM to determine the σ_{DFRE} values for each DFREI value.

Table 14 – Type 37 message contents Degradation Parameters and DFREI Scale Table

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Message Type	6	4	9	1	0	63	–	Message Type (see section 6)
Common OBAD parameters	$(I_{VALID})_{MT32}$	6	10	15	6	30	408	s	Validity interval for the Type 32 message
	$(I_{VALID})_{MT39/40}$	6	16	21	6	30	408	s	Validity interval for the Type 39/40 message
	C_{ER}	6	22	27	0.5	0	31.5	m	Step degradation parameter for en-route through Non-Precision Approach (NPA) applications
	$C_{COVARIANCE}$	7	28	34	0,1	0	12.7	–	Clock-Ephemeris covariance degradation parameter
GPS OBAD parameters	I_{CORR}	5	35	39	6	30	216	s	C_{CORR} time interval for application
	C_{CORR}	8	40	47	0.01	0	2.55	m	Step degradation parameter for Precision Approach (PA) applications
	R_{CORR}	8	48	55	0.2	0	51	mm/s	1st order degradation parameter
GLONASS OBAD parameters	I_{CORR}	5	56	60	6	30	216	s	C_{CORR} time interval for application
	C_{CORR}	8	61	68	0.01	0	2.55	m	Step degradation parameter for Precision Approach (PA) applications
	R_{CORR}	8	69	76	0.2	0	51	mm/s	1-st order degradation parameter

Table 14 (continued)

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Galileo OBAD parameters	I_{CORR}	5	77	81	6	30	216	s	C_{CORR} time interval for application
	C_{CORR}	8	82	89	0,01	0	2.55	m	Step degradation parameter for Precision Approach (PA) applications
	R_{CORR}	8	90	97	0.2	0	51	mm/s	1-st order degradation parameter
BDS OBAD parameters	I_{CORR}	5	98	102	6	30	216	s	C_{CORR} time interval for application
	C_{CORR}	8	103	110	0.01	0	2.55	m	Step degradation parameter for Precision Approach (PA) applications
	R_{CORR}	8	111	118	0.2	0	51	mm/s	1-st order degradation parameter
SDCM OBAD parameters	I_{CORR}	5	119	123	6	30	216	s	C_{CORR} time interval for application
	C_{CORR}	8	124	131	0.01	0	2.55	m	Step degradation parameter for PA applications
	R_{CORR}	8	132	139	0.2	0	51	mm/s	1-st order degradation parameter
Reserved for future GNSS	I_{CORR}	5	140	144	6	30	216	s	C_{CORR} time interval for application
	C_{CORR}	8	145	152	0.01	0	2.55	m	Step degradation parameter for PA applications
	R_{CORR}	8	153	160	0.2	0	51	mm/s	1-st order degradation parameter

Table 14 (continued)

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
DFREI Table	σ_{DFRE}: DFREI=0	4	161	164	0.0625	0.125	1.0625	m	σ_{DFRE} values for DFREI from 0 to 14
	σ_{DFRE}: DFREI=1	4	165	168	0.125	0.25	2.125	m	
	σ_{DFRE}: DFREI=2	4	169	172	0.125	0.375	2.25	m	
	σ_{DFRE}: DFREI=3	4	173	176	0.125	0.5	2.375	m	
	σ_{DFRE}: DFREI=4	4	177	180	0.125	0.625	2.5	m	
	σ_{DFRE}: DFREI=5	4	181	184	0.25	0.75	4.5	m	
	σ_{DFRE}: DFREI=6	4	185	188	0.25	1	4.75	m	
	σ_{DFRE}: DFREI=7	4	189	192	0.25	1.25	5	m	
	σ_{DFRE}: DFREI=8	4	193	196	0.25	1.5	5.25	m	
	σ_{DFRE}: DFREI=9	4	197	200	0.25	1.75	5.5	m	
	σ_{DFRE}: DFREI=10	4	201	204	0.5	2	9.5	m	
	σ_{DFRE}: DFREI=11	4	205	208	0.5	2.5	10	m	
	σ_{DFRE}: DFREI=12	4	209	212	1	3	18	m	
	σ_{DFRE}: DFREI=13	4	213	216	3	4	49	m	
	σ_{DFRE}: DFREI=14	4	217	220	6	10	100	m	
Reference time ID	Reference time ID	3	221	223	1	0	7	–	–
Spare	Spare	2	224	225	–	–	–	–	–
Common trailer	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

The degradation parameters contained in Type 37 and Type 32 messages (see section 7.4) are used as follows:

$$\sigma^2_{DFC} = (\sigma_{DFRE} \cdot \delta_{DFRE})^2 + \varepsilon^2_{CORR} + \varepsilon^2_{ER}, \tag{14}$$

where σ^2_{DFC} is the model variance of residual error associated with the SDCM corrections for the user;

σ_{DFRE} is expressed through the DFREI parameter transmitted in Type 32, 34, 35, 36 and 40 messages as the equation (17);

δ_{DFRE} is the user location factor is obtained via the clock ephemeris covariance matrix transmitted in the Type 40 message of the SDCM satellite broadcasting integrity and correction data,or the Type 32 message for other augmented (see equations (9), (10), (11) in 7.4);

ε_{CORR} is the correction degradation parameter estimated as

$$\varepsilon_{CORR} = \left\lfloor \frac{t - t_{CORR}}{I_{CORR}} \right\rfloor \cdot C_{CORR} + (t - t_{CORR}) \cdot \frac{(R_{CORR})_{SV}}{1000} \tag{15}$$

t is the current time, s;

t_{CORR} is the time of applicability [1)] of the last received Type 32 or Type 39/40 message for the satellite, s;

$(R_{CORR})_{SV}$ is the satellite degradation factor estimated from R_{CORR} (transmitted in the Type 37 message) and δR_{CORR}, transmitted either in the Type 32 message (for augmented satellites), or in the Type 40 message (for the SDCM satellite broadcasting correcting data and integrity data) $(R_{CORR})_{SV}$ is estimated as follows

$$(R_{CORR})_{SV} = \begin{cases} (R_{CORR})_{MT37} \cdot \delta R_{CORR}, & \text{if } t - t_{CORR} \le I_{CORR}, \\ (R_{CORR})_{MT37}, & \text{if } t - t_{CORR} > I_{CORR}; \end{cases} \tag{16}$$

$\lfloor x \rfloor$ is the greater integer less than x/

1) The time of applicability is the time when the SDCM network time second begins. It coincides with the broadcast time of the first data block bit by the broadcasting SDCM satellite.

ε_{ER} is the degradation parameter for en-route and non-precision approach (NPA) applications. This parameter is used for broadcasting corrections that have timed out in LNAV/VNAV (lateral navigation/vertical navigation), LP (localizer performance) or LPV (localizer performance with vertical guidance, a new precision approach option combining APV-I and APV-2), but have not timed out for the other navigation options (en-route and non-precision approach).

ε_{ER} values are:

- $\varepsilon_{ER} = 0$ when the corrections have timed out for approach and landing navigation services (LNAV/VNAV, LP or LPV);
- $\varepsilon_{ER} = C_{ER}$ when the corrections have timed out for approach and landing navigation services (LNAV/VNAV, LP or LPV) but have not timed out for en-route and non-precision approach (C_{ER} is transmitted in the Type 37 message, see section 7.6).

For each *i th* DFREI value, the corresponding σ_{DFRE} in meters is estimated as

$$(\sigma_{DFRE})_i = (Range_{\min})_i + (Scale_{factor,i} \cdot field_{value,i}), \quad (17)$$

where $(Range_{\min})_i$, $Scale_{factor,i}$ are the values from Table 14, Range and LSB cells, respectively;

$field_{value,i}$ are the values transmitted in the DFREI table for the i-th DFREI value (see Table 14).

The Type 37 message also contains $(I_{VALID})_{MT32}$ and $(I_{VALID})_{MT39/40}$. They are the validity intervals of Type 32 and 39/40 messages, respectively, for precision approach (PA) applications. For en-route and non-precision approach applications, the validity intervals are multiplied by 1.5. For details see Appendix D.

The reference time ID defines a GNSS with a reference time used to synchronize the SDCM network time (Table 15).

Table 15 – Reference time ID

Reference time ID	GNSS
0	GPS (L1 LNAV data)
1	GLONASS
2	Galileo
3	BDS
4-7	Spare

7.7 Type 47 message. SDCM Satellite Almanacs

7.7.1 The Type 47 message (Table 16) contains navigation data (as Keplerian parameters) for non-precision positioning of the two broadcasting SDCM satellites (for any orbit type). When more (three+) satellites are used, Type 47 messages are transmitted for each SDCM satellite pair.

Table 16 – Type 47 message content. SDCM Satellite Almanacs

Section	Name	Length	Location		Scale factor	Range		Unit	Description
			Start	End		min	max		
Common header	Preamble	4	0	3	–	–	–	–	Preamble (see section 6)
	Message Type	6	4	9	1	0	63	–	Message Type (see section 6)
SBAS I header	Satellite slot delta	6	10	15	1	0	63	–	Satellite slot number minus 119 (range: 1 to 39)
	SBAS provider ID	5	16	20	1	0	31	–	See Table 13
	Broadcast indicator	1	21	21	–	–	–	–	–
SBAS I Keplerian parameters	a	16	22	37	650	6,370,000	48,967,750	m	Semi-major axis
	e	8	38	45	2^{-8}	0	0.99609375	–	Eccentricity
	II	13	46	58	$\pi\times$ $\times 2^{-13}$	0	$\pi\times(1-2^{-13})$	rad	Inclination angle at t_a
	ω	14	59	72	$\pi\times$ $\times 2^{-13}$	-π	$\pi\times(1-2^{-13})$	rad	Argument of perigee
	Ω_0	14	73	86	$\pi\times$ $\times 2^{-13}$	-π	$\pi\times(1-2^{-13})$	rad	Longitude of the ascending node of the orbital plane at weekly epoch
	Ω_{dot}	8	87	94	$1\times$ $\times 10^{-9}$	$-1.28\times$ $\times 10^{-7}$	1.28×10^{-7}	rad/s	Rate of right ascension
	M_0	15	95	109	$\pi\times$ $\times 2^{-14}$	-π	$\pi\times(1-2^{-14})$	rad	Mean anomaly at t_a
	t_a	6	110	115	1800	0	113,400	s	Almanac reference time (range: 0 to 86,400 s)

Table 16 (continued)

Section	Name	Length	Location Start	Location End	Scale factor	Range min	Range max	Unit	Description
SBAS II header	Satellite slot delta	6	116	121	1	0	63	–	Satellite slot number minus 119 (range: 1 to 39)
	SBAS service provider	5	122	126	1	0	31	–	See Table 13
	Broadcast indicator	1	127	127	–	–	–	–	–
SBAS II Keplerian parameters	*a*	16	128	143	650	6,370,000	48,967,750	m	Semi-major axis
	e	8	144	151	2^{-8}	0	0.99609375	–	Orbit eccentricity
	II	13	152	164	$\pi\times 2^{-13}$	0	$\pi\times(1-2^{-13})$	rad	Orbit inclination at t_a
	ω	14	165	178	$\pi\times 2^{-13}$	-π	$\pi\times(1-2^{-13})$	rad	Argument of perigee
	Ω_0	14	179	192	$\pi\times 2^{-13}$	-π	$\pi\times(1-2^{-13})$	rad	Longitude of the ascending node of the orbital plane at weekly epoch
	Ω_{dot}	8	193	200	1×10^{-9}	-1.28×10^{-7}	1.28×10^{-7}	rad/s	Rate of right ascension
	M_0	15	201	215	$\pi\times 2^{-14}$	-π	$\pi\times(1-2^{-14})$	rad	Mean anomaly at t_a
	t_a	6	216	221	1,800	0	113,400	s	Almanac reference time (range: 0 to 86400 s)
Week roll-over count	$WNRO_{count}$	4	222	225	1	0	15	–	Week number roll-over count
Common ending	CRC	24	226	249	–	–	–	–	Cyclic Redundancy Check (see section 6)

Note.– π is the ratio of the circumference of a circle to its diameter. In this document, π=3.1415926535898.

The SDCM satellites almanacs are transmitted automatically to notify the user about the satellite availability and position. The messages are repeated to present information about all the SDCM satellites.

The Satellite Slot Delta parameter in the Type 47 message denotes the broadcasting SDCM satellite and specifies its position (1 to 39) in the SBAS mask (see Table 6). 1 corresponds to satellite slot 120, while 39 corresponds to satellite slot 158. For unused almanacs, the Relative Slot Number value is zero. They are to be ignored.

See section 7.5 for the SBAS provider parameter definition.

The Broadcast Indicator parameter in combination with the Satellite Slot Delta parameter can be used to confirm the slot number of the observed SDCM satellite. When Broadcast Indicator is set to 1, it identifies the almanac data of the SDCM broadcasting satellite.

The Broadcast Indicator and SBAS Provider parameters are continuously updated. They time out as specified in Table D.1 or upon receiving a Type 0 message. Other parameters transmitted in Type 47 messages do not have specific validity intervals, but their accuracy degrades over time.

t_a is the reference element of the almanac. It is estimated as the time after midnight of the current day. When estimating the SDCM satellite coordinates, the user considers that t_a is rounded. One assumes that t_a in a Type 47 message is within minus 43,200 to plus 43,199 s elapsed since the Type 47 message broadcasting ended. It is required to manage date changes.

See section 8.2 for the algorithm for estimating SDCM satellite geocentric coordinates from the Type 47 message parameters.

The Week number roll-over count ($WNRO_{count}$) parameter is the number of week number roll-overs already elapsed for the GNSS constellation identified by the Time Reference Identifier in the Type 37 message. $WNRO_{count}$, a value of 15 is used to indicate that the parameter is not valid. Possible reasons:

- SDCM does not provide $WNRO_{count}$;
- week roll-over occurs within the $WNRO_{count}$ validity interval (see Table D.1);
- the SBAS service provider has changed the Reference time ID value transmitted in Type 37 messages. $WNRO_{count}$ is set to 15 before modifying the

Reference time ID value and then maintained till the validity interval of the previous Reference time ID value times out (see Table D.1).

If $WNRO_{count}$ is valid (from 0 to 14, and has not timed out), the receiver can use the parameter to solve the possible ambiguity of the week number broadcast as the GNSS navigation data.

Note.– If $WNRO_{count}$ is associated with GPS, it refers to the 10-bit GPS week number field in L1 LNAV, not to the extended 13-bit GPS week number field in L5 CNAV.

7.8 Type 42 message. SDCM Time Offset

7.8.1 Currently, the Type 42 message is reserved for future use.

7.9 Type 62 message. L5 Internal Test Message

7.9.1 Type 62 messages are for SDCM internal tests. The user ignores such messages.

7.10 Type 63 Message. Null L5 Message

The null message is a filler when no other message is transmitted within a 1-second interval. The user ignores such messages.

7.11 Links between Messages

7.11.1 Messages are linked with their IOD values. See Figure 12 for the message link flowchart.

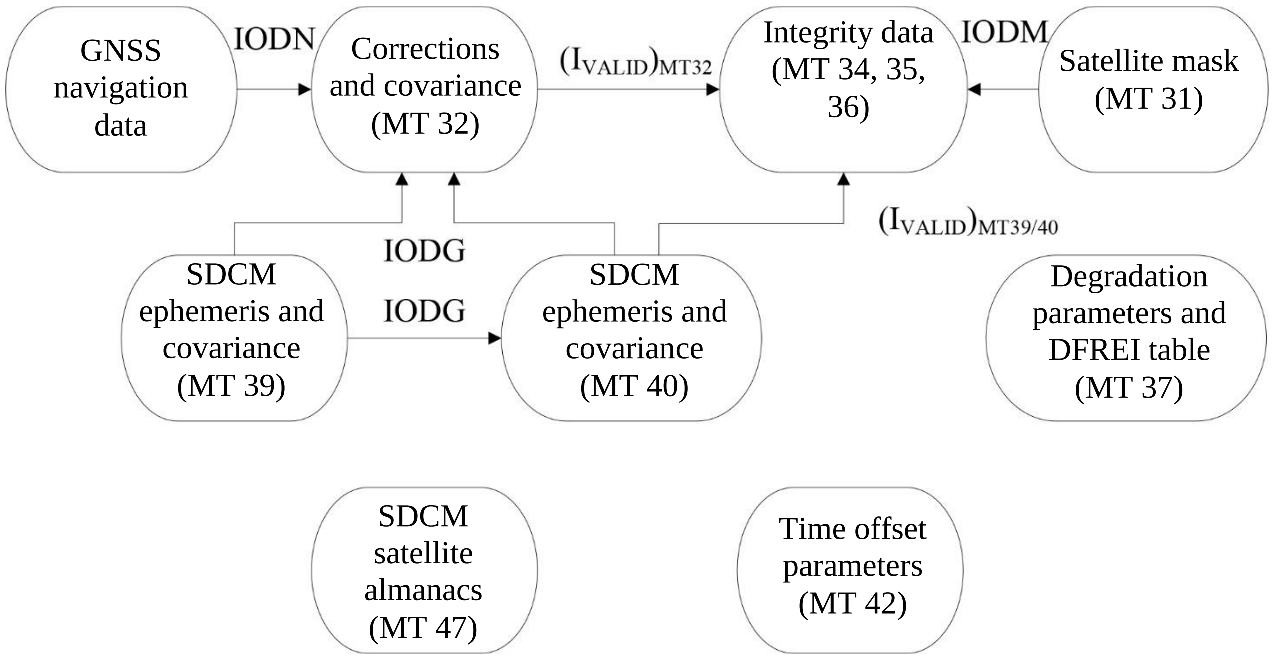

Figure 12 – Links between messages

Note.– IODG links between Type 39/40 and 32 messages are used when a Type 32 message is transmittes for an SDCM satellite (see sections 7.4 and 7.5).

For all flight phases, the SDCM data used by all the satellites is extracted from the same L5 signal (exception: Clock-Ephemeris data from Type 39/40 messages broadcasted by other SDCM satellites can be used if the satellites are used to measure the pseudoranges as required for the SDCM user positioning. In this case, such satellites need a valid Type 32 message from the initial L5 signal).

8 User Algorithm for Determining the Coordinates of the Satellite Broadcasting SDCM Corrections

8.1 Constants Determining the Coordinate System

8.1.1 The constants that define a coordinate system are used to estimate the geocentric coordinates of the satellite antenna phase center. The constants are as follows:

- π is the ratio of the circumference of a circle to its diameter. It takes the value of 3.1415926535898;
- μ is the Earth gravitational parameter. μ takes the value of 398,600.44 km^3/s^2;
- $\dot{\Omega}_e$ is the Earth rotation rate. $\dot{\Omega}_e$ takes the value of $7.2921151467 \cdot 10^{-5}$ rad/s.

8.2 Determination of SDCM Correction Broadcasting Satellite Position Based on Its Almanac (Type 47 Message)

8.2.1 The Type 47 parameters (see section 7.7) are extracted and applied to each SDCM broadcasting satellite:

- t_a is the reference time of the almanac (time after midnight of the current day, s);
- a is the semi-major axis, m;
- e is the eccentricity;
- M_0 is the mean anomaly at t_a, rad;
- ω is the argument of perigee, rad;
- I is the orbit inclination, rad;

- Ω_0 is the longitude of the ascending node of the orbital plane at the beginning of the week, rad;
- Ω_{dot} is the ascending node longitude variation rate, rad/s.

8.2.2 The satellite position at t (SDCM network time) is determined as follows.

8.2.2.1 Estimating the mean motion n_0:

$$n_0 = \sqrt{\frac{\mu}{a^3}} . \tag{18}$$

8.2.2.2 Estimating the time Δt_a since the almanac reference time t_a:

$$\Delta t_a = t - t_a , \tag{19}$$

where t is the SDCM network time when the signal is transmitted, s (i.e., SDCM network time corrected to account for the propagation time (range/speed of light).

Ensure that t and t_a have the same time reference when computing Δt_a. The broadcast parameter t_e is the time of the day. It is to be converted to account for date/week changes.

8.2.2.3 The mean anomaly at M_t t is estimated as follows:

$$M_t = M_0 + n_0 \times \Delta t_a . \tag{20}$$

8.2.2.4 The eccentric anomaly E_t at t is computed iteratively:

$$M_t = E_t - e \times \sin E_t . \tag{21}$$

8.2.2.5 The true anomaly at v_t t is estimated as follows:

$$v_t = 2 \times \mathrm{atan}\left[\sqrt{\frac{1+e}{1-e}}\tan\left(\frac{E_t}{2}\right)\right]. \tag{22}$$

8.2.2.6 The satellite radius vector r_t at t is estimated as follows:

$$r_t = a \times [1 - (e \times \cos E_t)]. \tag{23}$$

8.2.2.7 The satellite argument of latitude Φ_t at t is estimated as follows:

$$\Phi_t = v_t + \omega. \tag{24}$$

8.2.2.8 The satellite coordinates in the orbital plane $y_t^{'}$ at t is estimated as follows:

$$\begin{aligned} x_t^{'} &= r_t \times \cos \Phi_t, \\ y_t^{'} &= r_t \times \sin \Phi_t. \end{aligned} \tag{25}$$

8.2.2.9 The corrected latitude of the ascending node Ω_t at t is estimated as follows:

$$\Omega_t = \Omega_0 + ((\Omega_{dot} - \dot{\Omega}_e) \times \Delta t_a) - (\dot{\Omega}_e \times t_{aTOW}), \tag{26}$$

where t_{aTOW} is the reference element of the almanac t_a expressed as seconds elapsed since the beginning of the week.

8.2.2.10 The satellite geocentric coordinates x_t, y_t, z_t at t are estimated as follows:

$$
\begin{aligned}
x_t &= (x_t^{'} \times \cos\Omega_t) - (y_t^{'} \times \cos I \times \sin\Omega_t), \\
y_t &= (x_t^{'} \times \sin\Omega_t) + (y_t^{'} \times \cos I \times \cos\Omega_t), \\
z_t &= y_t^{'} \times \sin I.
\end{aligned}
\qquad (27)
$$

8.3 Determination of SDCM Broadcasting Satellite Coordinates Based on Its Ephemeris (Type 39 and 40 Messages)

8.3.1 The following parameters are extracted from Type 39 and40 messages (see section 7.5) for the specified SDCM broadcasting satellite:

- t_e is the reference time of the ephemeris (time after midnight of the current day), s;
- a is the semi-major axis, m;
- e is the eccentricity;
- M_0 is the mean anomaly at t_e, rad;
- ω is the argument of perigee, rad;
- I_{dot} is the rate of inclination angle, rad/s;
- I is the orbit inclination, rad;
- Ω_0 is the longitude of the ascending node of the orbital plane at the beginning of the week, rad;
- C_{uc} is the amplitude of the cosine harmonic correction to the argument of latitude, rad;
- C_{us} is the amplitude of the sine harmonic correction to the argument of latitude, rad.

8.3.2 The satellite position at t (SDCM network time) is determined as follows.

8.3.2.1 Estimation of the mean motion n_0:

$$n_0 = \sqrt{\frac{\mu}{a^3}} . \tag{28}$$

8.3.2.2 Estimation of the time Δt_e since the ephemeris reference time t_e:

$$\Delta t_e = t - t_e , \tag{29}$$

where t is the SDCM network time in seconds (i.e., the signal broadcast time corrected by Δt_{SBAS} estimated as (12)).

To estimate Δt_e, t and t_e start at the same epoch. The broadcast parameter t_e is the time of the day. It is to be converted to account for date/week changes.

8.3.2.3 The mean anomaly at M_t t is estimated as follows:

$$M_t = M_0 + n_0 \times \Delta t_e . \tag{30}$$

8.3.2.4 The eccentric anomaly E_t at t is computed iteratively:

$$M_t = E_t - e \times \sin E_t . \tag{31}$$

8.3.2.5 The true anomaly at v_t t is estimated as follows:

$$v_t = 2 \times \operatorname{atan}\left[\sqrt{\frac{1+e}{1-e}} \tan\left(\frac{E_t}{2} \right) \right]. \tag{32}$$

8.3.2.6 The satellite radius vector r_t at *t* is estimated as follows:

$$r_t = a \times [1 - (e \times \cos E_t)]. \tag{33}$$

8.3.2.7 The satellite argument of latitude Φ_t at *t* is estimated as follows:

$$\Phi_t = v_t + \omega. \tag{34}$$

8.3.2.8 The correction to the argument of the satellite latitude δu_t at t is estimated as follows:

$$\delta u_t = [C_{us} \times \sin(2 \times \Phi_t)] + [C_{uc} \times \cos(2 \times \Phi_t)]. \tag{35}$$

8.3.2.9 The corrected argument of the satellite latitude u_t at t is estimated as follows:

$$u_t = \Phi_t + \delta u_t. \tag{36}$$

8.3.2.10 The satellite coordinates in the orbital plane $y_t^{'}$ at t is estimated as follows:

$$\begin{aligned} x_t^{'} &= r_t \times \cos u_t, \\ y_t^{'} &= r_t \times \sin u_t. \end{aligned} \tag{37}$$

8.3.2.11 The corrected latitude of the ascending node Ω_t at t is estimated as follows:

$$\Omega_t = \Omega_0 - (\dot{\Omega}_e \times \Delta t_e)\,. \tag{38}$$

Note: for the $\dot{\Omega}_e$ definition see section 8.1.

8.3.2.12 The corrected inclination i_t at t is estimated as follows:

$$i_t = I + (I_{dot} \times \Delta t_e)\,. \tag{39}$$

8.3.2.13 The satellite geocentric coordinates x_t, y_t, z_t at t are estimated as follows:

$$\begin{aligned} x_t &= (x_t^{'} \times \cos\Omega_t) - (y_t^{'} \times \cos i_t \times \sin\Omega_t), \\ y_t &= (x_t^{'} \times \sin\Omega_t) + (y_t^{'} \times \cos i_t \times \cos\Omega_t), \\ z_t &= y_t^{'} \times \sin i_t. \end{aligned} \tag{40}$$

Note. The Sagnac correction (Earth rotation) is to be considered.

8.3.2.14 To consider the Sagnac correction there is an approximate conversion of the satellite geocentric coordinates $x_{meas\,t}$, $y_{meas\,t}$, $z_{meas\,t}$ at t:

$$\begin{aligned} x_{meas\,t} &= x_t + y_t \times \alpha, \\ y_{meas\,t} &= y_t - x_t \times \alpha, \\ z_{meas\,t} &= z_t, \end{aligned} \tag{41}$$

where $\alpha = \dot{\Omega}_e \times \tau$ is the rotation angle;

τ is the satellite to receiver signal propagation time.

Appendix A

(Obligatory)

Using SDCM Data for Positioning by GLONASS, GPS, Galileo, BDS, and SDCM

A.1 SDCM broadcasts the data as required by its functions. See Table A.1. If the SDCM data are not required to perform a specific function, the data are used to support other functions. Table A.1 lists the maximum data time-out intervals (transmitted as certain type messages).

Table A.1 – Time-outs and functions

Data	Message type	Maximum update interval. s	SDCM pseudorange measurement	Ionosphere free differential correction
Test message	0	6	–	–
Satellite clock-ephemeris corrections	32	$0,5\times(I_{VALID})_{MT32}$	–	K
Covariance matrix	32, 40	120	K	K
PRN mask assignments	31	120	K	K
Integrity data (DFREI, optional for DRFECI)	32, 34, 35, 36, 40	6	K	K
SDCM satellite clock-ephemeris and covariance matrix	39, 40	$0,5\times(I_{VALID})_{MT39/40}$	K	–
OBAD parameters and DFREI scale table, reference time ID	37	120	K	K
SDCM satellite almanac, transmission indicator, and SBAS service provider	47	120	K	K

Note 1.– “R” means that the data is required to enable this function.
Note 2.– The integrity data is the DFRECI parameter if a Type 34 message is received. Otherwise, it is limited to the DFREI parameter.
Note 3.– $(I_{VALID})_{MT32}$ and $(I_{VALID})_{MT39/40}$ are the validity intervals of Type 32 and 39/40 messages integrity data.

Appendix B

(Obligatory)

Recommended Tropospheric Error Estimation Model

B.1 As specified in the SBAS standard, Δt_{tropo} the tropospheric delay error is estimated as

$$\Delta t_{tropo} = -(d_{hyd} + d_{wet}) \cdot m(El)\,, \qquad \text{(B.1)}$$

where d_{hyd}, d_{wet} are estimated as follows:

$$d_{hyd} = \left(1 - \frac{\beta H}{T}\right)^{\frac{g}{R_d \beta}} \cdot z_{hyd}\,, \qquad \text{(B.2)}$$

$$d_{wet} = \left(1 - \frac{\beta H}{T}\right)^{\frac{(\lambda+1)g}{R_d \beta} - 1} \cdot z_{wet}\,; \qquad \text{(B.3)}$$

β is a meteorological parameter: temperature vs. altitude, K/m;

T is a meteorological parameter: temperature, K;

λ is a meteorological parameter: water evaporation gradient;

H is the receiver elevation above sea level, m;

$g = 9.80665$ m/s^2;

$R_d = 287.054$ J·kg^{-1}·K^{-1};

$$z_{hyd} = \frac{10^{-6} k_1 R_d P}{g_m};$$

$$z_{wet} = \frac{10^{-6} k_2 R_d}{g_m(\lambda + 1) - \beta R_d} \cdot \frac{e}{T};$$

k_1 = 77.604 K/mbar;

k_2 = 382000 K^2/mbar;

g_m = 9.784 m/s^2;

P is a meteorological parameter: pressure, mbar;

e is a meteorological parameter: saturated water vapor pressure, mbar;

m(El) is the tropospheric correction function estimated as:

$$m(El) = \frac{1.001}{\sqrt{0.002001 + \sin^2(El)}}, \; El \geq 5; \tag{B.4}$$

El is the elevation, °.

Eq. (B.4) is valid for El not less than 5°.

Each of the five meteorological parameters P, T, e, β, λ depend on the receiver latitude ϕ and the day of the year D starting from January, 1:

$$\xi(\phi, D) = \xi_0(\phi) - \Delta\xi(\phi) \cdot \cos\left(\frac{2\pi \cdot (D - D_{\min})}{365,25}\right), \tag{B.5}$$

where ξ_0, $\Delta\xi$ are the average and seasonal variations of the meteorological parameter

$$D_{min} = \begin{cases} 28, \text{ for northern latitudes,} \\ 211, \text{ for southern latitudes.} \end{cases}$$

The current day of the year D is calculated from the day number N_T in the current four-year period as

$$D = \begin{cases} N_T, \text{ if } N_T < 366, \\ N_T - 365, \text{ if } 366 \le N_T < 731, \\ N_T - 730, \text{ if } 731 \le N_T < 1096, \\ N_T - 1095, \text{ if } N_T \ge 1096. \end{cases} \quad \text{(B.6)}$$

To estimate each of the five meteorological parameters P, T, e, β, λ at the specific receiver latitude, the data listed in Table B.1 are interpolated. The meteorological parameters in the Northern and Southern hemispheres are identical.

Table B.1 – Meteorological parameters used to estimate tropospheric errors

Latitude, °	Average parameter value				
	P_0, mbar	T_0, K	e_0, mbar	β_0, K/m	λ_0
15 or less	1013.25	299.65	26.31	0.00630	2.77
30	1017.25	294.15	21.79	0.00605	3.15
45	1015.75	283.15	11.66	0.00558	2.57
60	1011.75	272.15	6.78	0.00539	1.81
75 or greater	1013.00	263.65	4.11	0.00453	1.55
Latitude, °	Seasonal parameter variation				
	ΔP, mbar	ΔT, K	Δe, mbar	$\Delta\beta$, K/m	$\Delta\lambda$
15 or less	0.00	0.00	0.00	0.0	0.0
30	-3.75	7.00	8.85	0.00025	0.33
45	-2.25	11.00	7.24	0.00032	0.46
60	-1.75	15.00	5.36	0.00081	0.74
75 or greater	-0.50	14.50	3.39	0.00062	0.30

The RMS σ_{tropo} of the tropospheric delay error estimation Δt_{tropo} is calculated as

$$\sigma_{tropo} = 0.12 \cdot m(El)\,. \quad \text{(B.7)}$$

Appendix C

(Obligatory)

Applications of the SDCM Data -

C.1 Introduction

C.1.1 This Appendix defines the parameters used by GLONASS, GPS, Galileo, and BDS SDCM-assisted positioning algorithm. The parameters can be used for positioning and validation (extra protection levels).

C.2 Pseudorange corrections

C.2.1 Pseudorange corrections are independent of the coordinate system. The corrected pseudorange $PR_{i,corrected}$ at t for the i-th satellite is estimated as:

$$PR_{i,corrected} = PR_{i,ionofree} + c \cdot (\Delta t_{SV,i} + \delta\Delta t_{SV,i} - T_{GD,i}) + TC_i \text{, for GPS satellites} \quad (C.1)$$

$$PR_{i,corrected} = PR_{i,ionofree} + c \cdot (\Delta t_{SV,i} + \delta\Delta t_{SV,i}) + TC_i \text{,} \quad (C.2)$$

for GLONASS, Galileo, and BDS satellites

where $PR_{i,ionofree}$ is an ionosphere free combination of initial measurements at L1 and L5 carriers for GPS, Galileo, or BDS, or L1 and L3 carriers for GLONASS estimated as:

$$PR_{i,ionofree} = \begin{cases} \dfrac{\gamma_{15} PR_{i,L1} - PR_{i,L5}}{\gamma_{15} - 1}, \text{ for GPS, Galileo or BDS,} \\ \dfrac{\gamma_{13} PR_{i,L1OC} - PR_{i,L3OC}}{\gamma_{13} - 1}, \text{ for GLONASS;} \end{cases} \quad (C.3)$$

$PR_{i,L1}$, $PR_{i,L5}$, $PR_{i,L1OC}$, $PR_{i,L3OC}$ are the pseudoranges at L1 GPS, L5 GPS, L1 GLONASS, L3 GLONASS, respectively

$\gamma_{15} = \left(f_{L1} / f_{L5} \right)^2 = (1575.42/1176.45)^2 = (154/115)^2$

$\gamma_{13} = \left(f_{L1OC} / f_{L3OC} \right)^2 = (1600.995/1202.025)^2 = (313/235)^2$

f_{L1}, f_{L5}, f_{L1OC}, f_{L3OC} are the rated center frequencies of the received navigation signals

$\Delta t_{SV,i}$ is the i-th satellite clock offset broadcast by the augmented GNSS (GPS, GLONASS, Galileo, or BDS)

$\delta\Delta t_{SV,i}$ is the clock offset of the i-th satellite estimated as (6) (see section 7.4):

TC_i is the tropospheric correction for the i-th satellite.

The satellite clock offset Δt_{SV} estimation algorithm is available in [9] for GPS, [10] for Galileo, and [11] for BDS.

For GLONASS, Δt_{SV} is calculated as

$$\Delta t_{SV} = t_{SV} - t = -\tau^j(t_b) + \gamma^j(t_b)(t_{SV} - t_b) + \beta^j(t_b)(t_{SV} - t_b)^2 + \tau_c(t_b), \qquad \text{(C.4)}$$

where t_{SV} – is the L1OC signal emission epoch expressed in the signal timescale, s;

t is the L1OC signal emission epoch expressed as Moscow Standard Time (MST), s;

t_b, $\tau^j(t_b)$, $\gamma^j(t_b)$, $\beta^j(t_b)$, $\tau_c(t_b)$ are the parameters transmitted in the L1OC signal

See Appendix B for the tropospheric correction TC_i estimation.

Appendix H shows how the corrections are applied to pseudoranges as required to monitor the SBAS L5 service integrity and to enable positioning.

C.3 Satellite Coordinates Correction

C.3.1 GPS uses the WGS84 coordinate system, while GLONASS uses the PZ-90 system. Galileo and BDS use their dedicated coordinate systems similar to WGS84. For system-to-system conversion, the following equation is used

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS-84} = \begin{bmatrix} 1 & 0.0097\cdot 10^{-9} & 0.2036\cdot 10^{-9} \\ -0.0097\cdot 10^{-9} & 1 & 0.0921\cdot 10^{-9} \\ -0.2036\cdot 10^{-9} & -0.0921\cdot 10^{-9} & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ПЗ}-90} + \begin{bmatrix} 0.003 \\ 0.001 \\ 0 \end{bmatrix}. \quad (C.5)$$

WGS84 and PZ-90 systems are continuously improved. For better positioning accuracy is recommended to use the latest available conversion equation, e.g., [12].

The GLONASS, GPS, Galileo or BDS satellite position vector augmented with SDCM data at epoch t expressed in the GPS network time is estimated as

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{corrected} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta \dot{x} \\ \delta \dot{y} \\ \delta \dot{z} \end{bmatrix} (t - t_D), \quad (C.6)$$

where $[x\ y\ z]^T$ is the GLONASS, GPS, Galileo, or BDS satellite position vector;

δx, δy, δz, $\delta \dot{x}$, $\delta \dot{y}$, $\delta \dot{z}$ are the corrections transmitted in the Type 32 message (see section 7.4);

t_D is the time of applicability of the δx, δy, δz, $\delta \dot{x}$, $\delta \dot{y}$, $\delta \dot{z}$ corrections expressed in seconds after midnight of the current day;

$(t – t_D)$ is corrected as a new date begins.

Appendix D
(Obligatory)
Data Validity Intervals

D.1 Integrity data for all the augmented satellites (DFREI or DFRECI in Type 34, 35, 36 messages or DFREI in Type 32, 40 messages) are transmitted for the maximum 6-second interval. All the other messages are transmitted at intervals not exceeding the maximum update interval listed in Table D.1.

The validity intervals listed in Table D.1 limit the applicability interval of the integrity data, correction data, and navigation data transmitted by the SDCM satellite. The validity interval for each type of data begins at the end of receiving the corresponding message.

Besides the messages listed in Table D.1, each alert message (in Type 0, 34, 35, 36, 32, or 40 messages) is repeated three times after the initial notification (overall four times within four seconds) Subsequent messages can be transmitted at the normal update rate.

If no valid SBAS message is received within four seconds (because of the data link problems of L5 signal unavailability), the DFREI parameters transmitted in this L5 signal are to be considered as timed out.

Table D.1 – Update and validity intervals

Data	Message type	Maximum update interval, s	Validity interval for en-route and non-precision approach applications, s	Validity interval for precision approach applications, s
The data from this GEO satellite are not safe	0	6	–	–
Satellite mask	31	120	600	600
Data integrity (DFREI, optional for DRFECI)	32	6	18	12
	34	6	18	12
	35	6	18	12
	36	6	18	12
	40	6	18	12
Clock-ephemeris corrections and covariance matrix	32	$0.5\times(I_{VALID})_{MT32}$	$1.5\times(I_{VALID})_{MT32}$	$(I_{VALID})_{MT32}$
Clock-ephemeris corrections SDCM and covariance matrix	39, 40	$0.5\times(I_{VALID})_{MT39/40}$	$1.5\times(I_{VALID})_{MT39/40}$	$(I_{VALID})_{MT39/40}$
Degradation parameters	37	120	360	240
DFREI table parameters	37	120	360	240
Reference time ID	37	120	360	240
Transmission indicator, and SBAS provider ID	47	120	360	240
Number of week number roll-overs ($WNRO_{count}$)	47	120	360	360

Note 1.– Validity intervals begin at the time of arrival of the last message at the antenna.

Note 2.–Other parameters transmitted in Type 47 messages do not have specific validity intervals except for the above-listed ones.

Note 3.– $(I_{VALID})_{MT32}$ and $(I_{VALID})_{MT39/40}$ are the validity intervals of Type 32 and 39/40 messages integrity data.

Appendix E

(Obligatory)

Basic Weighted Navigation Solution and Positioning Error Estimation with SBAS L5 Integrity Monitoring

E.1 Introduction

E.1.1 The Appendix presents the basic positioning algorithm with SBAS L5 integrity monitoring.

The user calculates the system-to-system timescale offsets by adding (N − 1) unknowns to the equations in [8], where N is the number of augmented satellite groups with the same reference time scale.

Never use the parameters transmitted in a navigation message of an augmented GNSS to synchronize the timescales of satellites from another GNSS with the same reference timescale (see Appendix J). As a result, each augmented GNSS is considered as an individual group.

E.2 Basic Navigation Solution for SBAS L5 Service

E.2.1 From now on, it is assumed that user equipment uses SBAS L5 corrected satellites from two individual groups, G1 and G2.

The following expression defines the basic linearized GNSS positioning model:

$$\mathbf{\Delta y} = \mathbf{G} \times \mathbf{\Delta x} + \boldsymbol{\varepsilon}, \qquad \text{(E.1)}$$

where **Δy** is a P-dimensional vector containing the satellite pseudoranges $PD_{i,\ corrected}$ with the SBAS L5 service (see equation (7) in 7.4) minus the expected ranging values (referred to as vector **y**) based on the location of the SBAS L5 corrected satellites and the estimated location and clock offset of the user calculated as

$$\mathbf{x} = [x, y, z, c \cdot t_{G1}, c \cdot t_{G2-G1}] \qquad \text{(E.2)}$$

or, for the user positioning solution, as

$$\mathbf{x} = [x, y, z, c \cdot t_{G1}, c \cdot t_{G2}] \qquad \text{(E.3)}$$

P is the number of satellites used for determining navigation solutions;

x, y, z are the user coordinates, m;

c is the speed of light in a vacuum (299,792,458 m/s);

t_{G1} is the receiver offset relative to the group reference timescale G1, s;

t_{G2} is the receiver offset relative to the group reference timescale G2, s;

t_{G1-G2} is the difference of the clock offsets between the G1 and G2 group signals as observed by the receiver ($t_{G1-G2} = t_{G2} - t_{G1}$), s;

Δx is a 5-dimensional user clock location and offset vector relative to the linearized user clock location and offset vector **x**.

G is the observation matrix containing P line-of-sight vector rows -from each satellite to **x** added with “0” or “1” to offset the receiver clock or network time relative to the specified reference timescale, s. The i-th row refers to the i-th satellite used to obtain a navigation solution. The satellite is defined with its azimuth Az[i] and elevation El[i]. The positive azimuth is defined clockwise from North. The positive elevation is defined upwards from the N-W horizontal plane;

ε is a P-dimensional vector of errors contained in the satellite expected range vector **y**, m.

The i-th row G_i of the observation matrix **G** is defined as:

$$G_i = \begin{bmatrix} -\cos El[i] \times \sin Az[i] & -\cos El[i] \times \cos Az[i] & -\sin El[i] & 1 & n_{i,2} \end{bmatrix}, \quad \text{(E.4)}$$

where $n_{i,2}$ = 1, if the i-th satellite is a part of the group G2, and $n_{i,2}$ = 0 otherwise.

The 4-th element of **x** is the receiver clock offset relative to the reference timescale of the group G1, while the 5th element of **x** is the group G2 reference timescale offset relative to the group G1 reference timescale.

Another way to calculate the matrix **G** is as follows:

$$G_i = \begin{bmatrix} -\cos El[i] \times \sin Az[i] & -\cos El[i] \times \cos Az[i] & -\sin El[i] & n_{i,1} & n_{i,2} \end{bmatrix}, \quad \text{(E.5)}$$

where $n_{i,1}$ = 1, if the i-th satellite is a part of the group G1, and $n_{i,1}$ = 0 otherwise;

$n_{i,2}$ = 1, if the i-th satellite is a part of the group G2, and $n_{i,2}$ = 0 otherwise.

The 4th element of **x** is the receiver clock offset relative to the reference timescale of the group G1, while the 5th element of **x** is the receiver clock offset relative to the group G2 reference timescale.

The weighted RMS positioning and user clock offset error is estimated as follows

$$\mathbf{\Delta \hat{x}} = \mathbf{S} \cdot \mathbf{\Delta y}, \quad \text{(E.6)}$$

where **S** is a projection matrix defined as

$$\mathbf{S} \equiv (\mathbf{G}^T \cdot \mathbf{W} \cdot \mathbf{G})^{-1} \cdot \mathbf{G}^T \cdot \mathbf{W} \quad \text{(E.7)}$$

W is the weighting matrix. The basic algorithm assumes that the error sources for each satellite do not correlate with error sources for other satellites. The weighting matrix is diagonal and is defined as

$$\mathbf{W} = \begin{bmatrix} w_1 & 0 & \cdots & 0 \\ 0 & w_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & w_P \end{bmatrix} \quad \text{(E.8)}$$

$w_i = 1/\sigma^2[i]$

$\sigma^2[i]$ is the residual error variance of the i-th satellite.

See Appendix F for the $\sigma^2[i]$ residual error variance calculation.

Appendix F

(Obligatory)

Key SDCM Augmented Positioning Accuracy Parameters

F.1 Expressions for SBAS L5 Service Protection Levels. RMS Solution

F.1.1 HAL, VAL, HPL, VPL parameter definition.

The following user positioning accuracy parameters are arbitrarily defined:

- HAL (Horizontal Alert Limit) is the radius of a horizontal circle with its center at the true user location. The integrity requirements are met within the circle: all the plane positioning measurements fall within the circle with the $1\text{-}10^{-7}$ per h [1)] probability;

- VAL (Vertical Alert Limit) is half of the vertical segment at the true user location. The integrity requirements are met within half of the segment: all the vertical positioning measurements fall within {−VAL, +VAL} with the $1\text{-}10^{-7}$ per h[1)] probability.

The following derived parameters called 'protection levels' are used to estimate the SDCM augmented positioning accuracy:

- HPL_{DFSBAS} (Horizontal Protection Level) is the horizontal protection level in double-frequency applications. It is the variance of the true horizontal SDCM augmented positioning error for the 6σ confidence interval (the probability of falling into the range exceeds $1\text{-}10^{-7}$);

- VPL_{DFSBAS} (Vertical Protection Level) is the vertical protection level in double-frequency applications. It is the variance of the true vertical SDCM

[1)] The probability value depends on the integrity requirements. The GLONASS and SDCM failure rate is assumed to be less than 10^{-4} per hour.

augmented positioning error for the 6σ confidence interval (the probability of falling into the range exceeds $1\text{-}10^{-7}$).

The SDCM augmented positioning accuracy meets the integrity requirements (at least $1\text{-}10^{-7}$) provided that the following conditions are true:

$$HAL \geq HPL_{DFSBAS},$$
$$VAL \geq VPL_{DFSBAS}. \tag{F.1}$$

The navigation solution error is estimated by projecting the pseudorange errors onto the user coordinates domain. HPL is the limit of the horizontal positioning error for the given user with the probability defined by the integrity requirements. Similarly, VPL defines the vertical protection limit. If the estimated HPL or VPL exceeds the HAL or VAL alert threshold, the SDCM integrity is insufficient to support the required positioning.

F.1.2 To estimate the protection levels the user may apply the following expressions. The parameters are as defined below:

$$HPL_{DFSBAS} = K_H \cdot d_{major}, \tag{F.2}$$

$$VPL_{DFSBAS} = K_V \cdot d_U, \tag{F.3}$$

$$K_H = \begin{cases} 6.18 & \text{for en route through LNAV,} \\ 6.0 & \text{for LNAV/VNAV, LP, LPV;} \end{cases}$$

where $K_V = 5.33$;

$d_{major} \equiv \sqrt{\dfrac{d_{east}^2 + d_{north}^2}{2} + \sqrt{\left(\dfrac{d_{east}^2 - d_{north}^2}{2}\right)^2 + d_{EN}^2}}$ is the error uncertainty along the semi-major axis of the horizontal error ellipse;

$d_{east}^2 = \sum_{i=1}^{n} s_{east,i}^2 \cdot \sigma[i]^2$ is the variance of model distribution that specifies the upper limit of the true error distribution in the East direction;

$d_{north}^2 = \sum_{i=1}^{n} s_{north,i}^2 \cdot \sigma[i]^2$ is the variance of model distribution that specifies the upper limit of the true error distribution in the North direction;

$d_{EN}^2 = \sum_{i=1}^{n} s_{east,i}^2 \cdot s_{north,i}^2 \cdot \sigma[i]^2$ is the covariance of model distribution in the East and North directions;

$d_U^2 = \sum_{i=1}^{n} s_{up,i}^2 \cdot \sigma[i]^2$ is the variance of model distribution that specifies the upper limit of the true vertical error distribution;

$s_{east,i}$ is the partial derivative of position error in the East direction with respect to the pseudorange error on the i-th satellite;

$s_{north,i}$ is the partial derivative of position error in the north direction with respect to the pseudorange error on the i-th satellite;

$s_{up,i}$ is the partial derivative of position error in the vertical direction with respect to the pseudorange error on the i-th satellite;

$\sigma[i]^2 = \sigma_{DFC}^2[i] + \sigma_{UIRE}^2[i] + \sigma_{tropo}^2[i] + \sigma_{air}^2[i]$ is the residual error variance of the i-th satellite.

$\sigma_{DFC}^2[i]$, $\sigma_{UIRE}^2[i]$, $\sigma_{tropo}^2[i]$, $\sigma_{air}^2[i]$ are the components of $\sigma[i]^2$, defined below.

For RMS positioning using two satellite groups $G1$ and $G2$, the projection matrix **S** is defined as

$$\mathbf{S} \equiv \left(\mathbf{G}^T \cdot \mathbf{W} \cdot \mathbf{G}\right)^{-1} \cdot \mathbf{G}^T \cdot \mathbf{W} = \begin{bmatrix} s_{east,1} & s_{east,2} & \cdots & s_{east,P} \\ s_{north,1} & s_{north,2} & \cdots & s_{north,P} \\ s_{up,1} & s_{up,2} & \cdots & s_{up,P} \\ s_{t_{G1},1} & s_{t_{G1},2} & \cdots & s_{t_{G1},P} \\ s_{t_{G1G2},1} & s_{t_{G1G2},2} & \cdots & s_{t_{G1G2},P} \end{bmatrix} \qquad \text{(F.4)}$$

or, if the user location and clock offset vector **x** is defined as (E.3), then

$$\mathbf{S} \equiv \left(\mathbf{G}^T \cdot \mathbf{W} \cdot \mathbf{G}\right)^{-1} \cdot \mathbf{G}^T \cdot \mathbf{W} = \begin{bmatrix} s_{east,1} & s_{east,2} & \cdots & s_{east,P} \\ s_{north,1} & s_{north,2} & \cdots & s_{north,P} \\ s_{up,1} & s_{up,2} & \cdots & s_{up,P} \\ s_{t_{G1},1} & s_{t_{G1},2} & \cdots & s_{t_{G1},P} \\ s_{t_{G2},1} & s_{t_{G2},2} & \cdots & s_{t_{G2},P} \end{bmatrix}. \qquad \text{(F.5)}$$

The variance and covariance elements are calculated as

$$\begin{bmatrix} d_{easth}^2 & d_{EN} & d_{EU} & d_{ET_{G1}} & d_{ET_{G1G2}} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT_{G1}} & d_{NT_{G1G2}} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT_{G1}} & d_{UT_{G1G2}} \\ d_{ET_{G1}} & d_{NT_{G1}} & d_{UT_{G1}} & d_{T_{G1}}^2 & d_{T_{G1}T_{G1G2}} \\ d_{ET_{G1G2}} & d_{NT_{G1G2}} & d_{UT_{G1G2}} & d_{T_{G1}T_{G1G2}} & d_{T_{G1G2}}^2 \end{bmatrix} = \left(\mathbf{G}^T \cdot \mathbf{W} \cdot \mathbf{G}\right)^{-1} \qquad \text{(F.6)}$$

or, if the user location and clock offset vector **x** is defined as (E.3), then

$$\begin{bmatrix} d_{east}^2 & d_{EN} & d_{EU} & d_{ET_{G1}} & d_{ET_{G2}} \\ d_{EN} & d_{north}^2 & d_{NU} & d_{NT_{G1}} & d_{NT_{G2}} \\ d_{EU} & d_{NU} & d_U^2 & d_{UT_{G1}} & d_{UT_{G2}} \\ d_{ET_{G1}} & d_{NT_{G1}} & d_{UT_{G1}} & d_{T_{G1}}^2 & d_{T_{G1}T_{G2}} \\ d_{ET_{G2}} & d_{NT_{G2}} & d_{UT_{G2}} & d_{T_{G1}T_{G2}} & d_{T_{G2}}^2 \end{bmatrix} = \left(\mathbf{G}^T \cdot \mathbf{W} \cdot \mathbf{G}\right)^{-1}. \qquad \text{(F.7)}$$

F.2 SBAS L5 Residual Error Variance

F.2.1 The value $\sigma^2_{DFC}[i]$ is a model variance of the differential correction residual error estimated as (14) which can be found in 7.6.

F.3 Variance of Ionospheric Correction Residual Errors

F.3.1 $\sigma_{UIRE}[i]$ is the RMS deviation of the normal distribution with zero mean. It defines ionospheric residual errors (including higher orders ionospheric effects, the effects of refractive excess path length and spatial separation of signal paths at different carrier frequencies, the effects of excess total electron concentration in the column) for ionospheric free double-frequency combinations.

F.4 Variance of Satellite Receiver Errors

F.4.1 The value $\sigma^2_{air}[i]$ is an estimated variance of the i-th satellite error.

F.5 Variance of Tropospheric Correction Residual Errors

F.5.1 The value $\sigma_{tropo}[i]$ is the RMS of the normal distribution with zero mean that defines tropospheric residual errors.

F.5.2 For detailed $\sigma^2_{DFC}[i]$, $\sigma^2_{UDRE}[i]$, $\sigma^2_{air}[i]$, $\sigma^2_{tropo}[i]$ parameter definition see [13].

Appendix G

(Obligatory)

Fault Detection with the SBAS L5 Service Integrity Monitoring

G.1 Introduction

G.1.1 This Appendix presents a fault diagnostics algorithm to be used for the SBAS L5 service integrity monitoring. It uses the χ square criterion for SBAS L5 augmented positioning.

G.2 Fault Diagnostics for Integrity Monitoring

G.2.1 The χ square statistics χ^2 for SBAS L5 augmented positioning is defined as:

$$\chi^2 = \mathbf{\Delta y}^T \cdot (\mathbf{W} - \mathbf{W} \cdot \mathbf{G} \cdot \mathbf{S}) \cdot \mathbf{\Delta y}\,, \tag{G.1}$$

where $\mathbf{\Delta y}$ is a P-dimensional vector containing the satellite pseudoranges corrected with the SBAS L5 service minus the expected ranging values based on the location of the SBAS L5 corrected satellites and the estimated location and clock offset of the user

P is the number of satellites used for determining navigation solutions

W is the weighting matrix estimated with Eq. (E.8)

G is the observation matrix estimated with Eq. (E.4) or (E.5)

S is the projection matrix estimated with Eq. (E.7).

The detection threshold T_{χ^2} is defined as

$$F(T_{\chi^2}, P-3-N) = 1 - P_{FA}, \tag{G.2}$$

where F(u, d) is the integral χ square distribution function with d DOFs;

P is the number of satellites used for determining navigation solutions;

N is the number of augmented satellite groups sharing the same reference timescale and used for positioning;

P_{FA} is the false alert probability in a stand-alone fault test.

For aircraft navigation equipment a false alert probability does not exceed 10^{-5} for one flight hour. It corresponds to P_{FA}=3.33x10^{-7}.

If $\chi^2 > T_{\chi^2}$, then the values $HPL_{DFMC\ SBAS}$ and VPL_{DFSBAS} are invalid, and the alert is activated within the time-to-alert (TTA) for the current operation provided that the fault cannot be rectified.

Appendix H

(Obligatory)

Key Integrity Assurance Principles

H.1 The Appendix complements Annex S, standard [8] with the SBAS L5 integrity monitoring algorithm overview.

Figure H.1 shows how the corrections are applied to pseudoranges as required to monitor the SBAS L5 service integrity and to enable positioning.

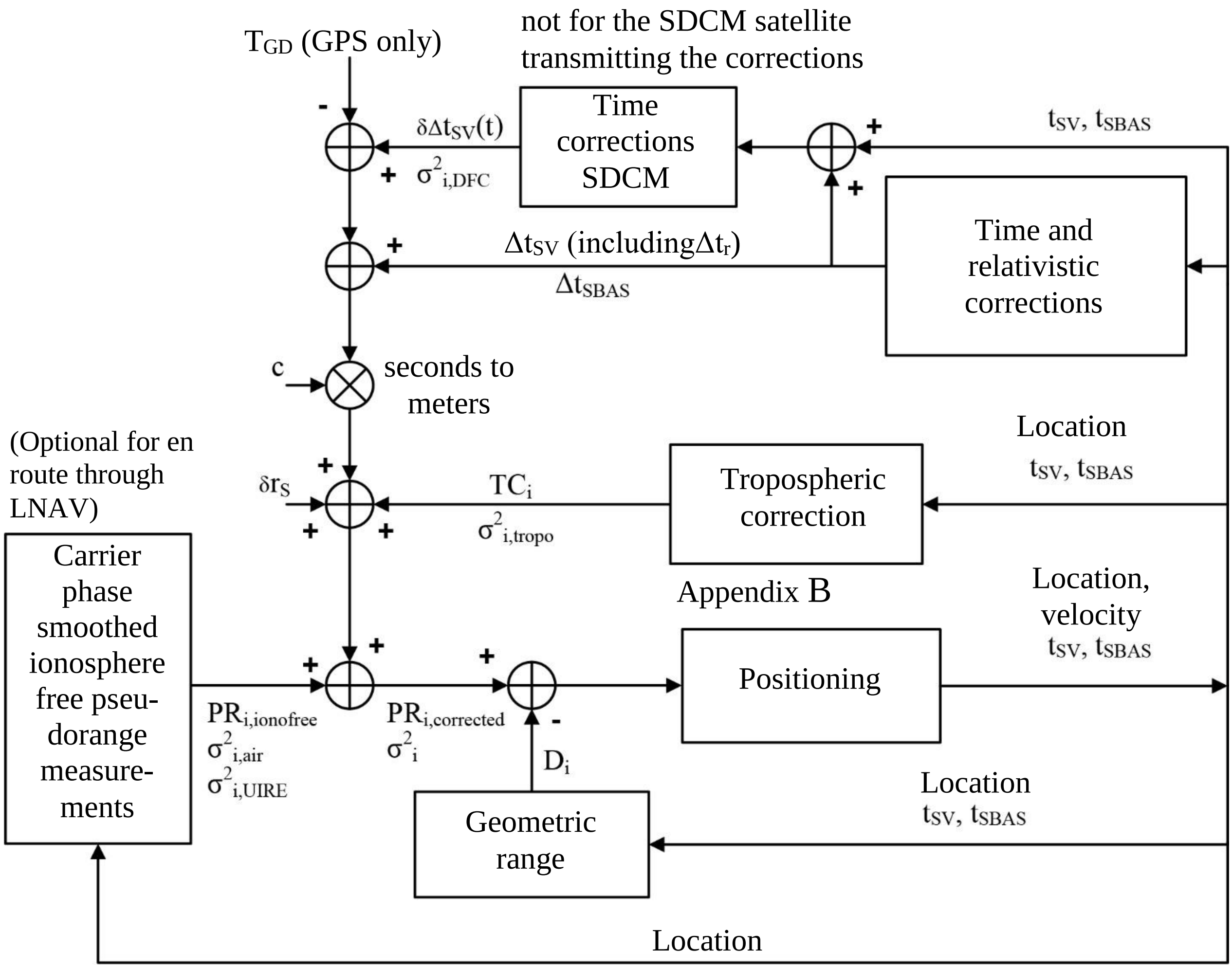

Figure H.1 – Application of SDCM corrections

Figures H.2 and H.3 show the processing of received DFREI and DFRECI, and σ_{DFC} estimation.

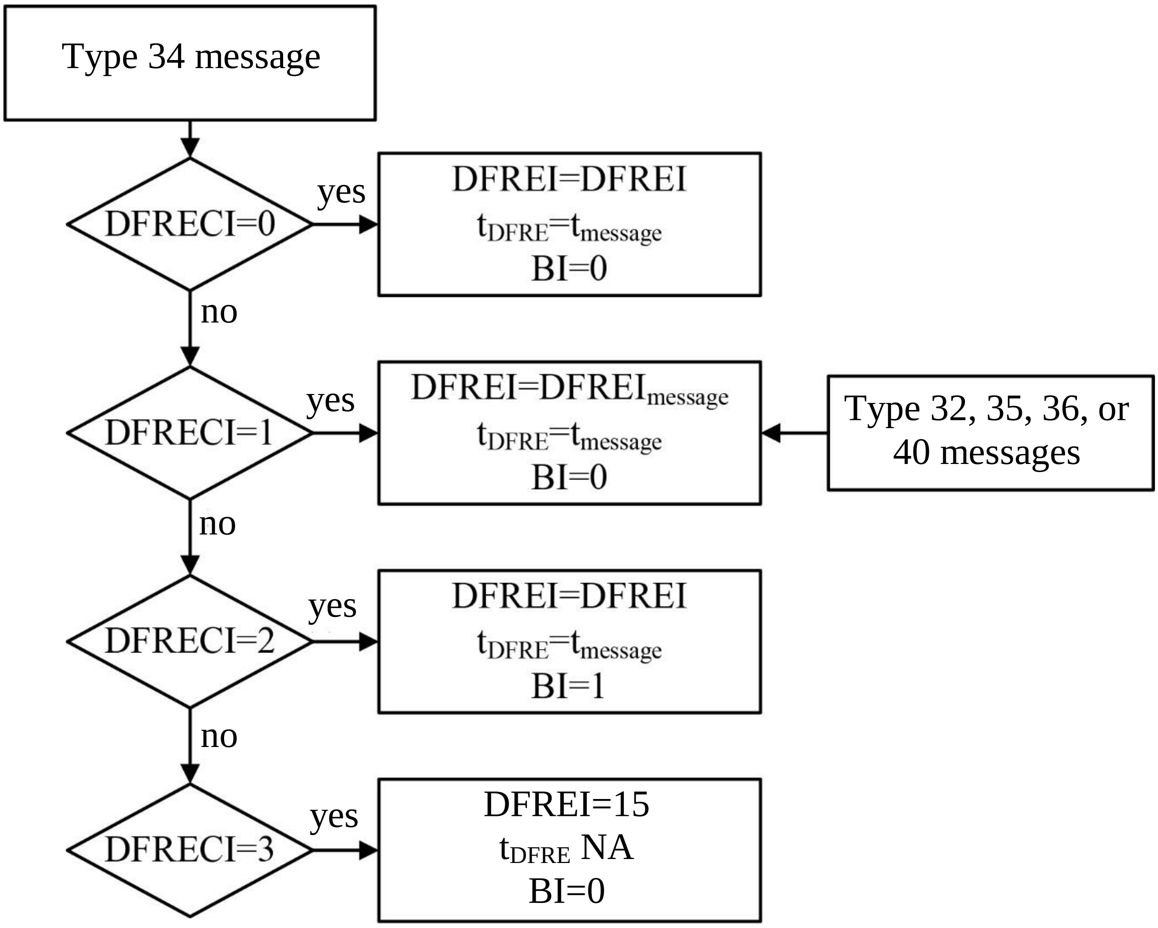

Figure H.2 – DFREI and DFRECI handling

Notes for Figure H.2:

- where t_{SV} (or t_{SBAS}) is the signal emission epoch expressed in the signal timescale;
- The following values are stored for each satellite: DFREI, t_{DFRE}, BI, where BI is the DFREI increment indicator. BI = 1, if DFRECI = 2 (see section 7.3.1), and BI = 0 otherwise;
- if DFREI+BI $\leq$ 14, then σ_{DFRE} is taken from the DFREI table (see Table 14) from the row with the number (DFREI+BI);
- if DFREI+BI $\geq$ 15, the satellite is not used;
- $t_{message}$ is the time of arrival of the last message at the antenna.

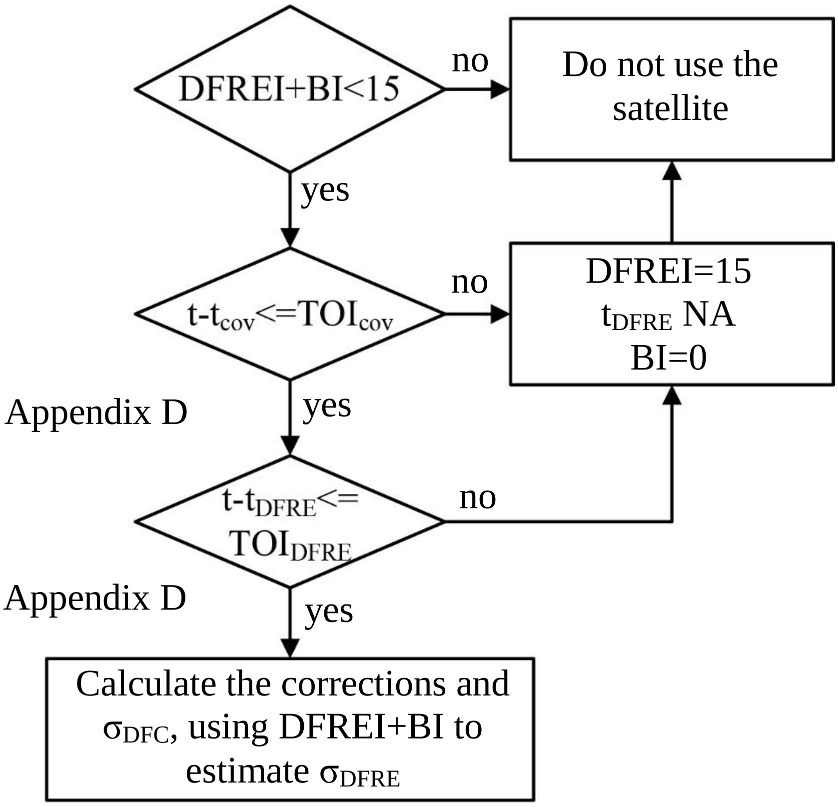

Figure H.3 – σ_{DFC} estimation

Notes for Figure H.3:

- correction data and integrity data epochs are calculated for each interval where the satellite uses the SBAS L5 integrity signals;
- if may be required to store individual DFREI, t_{DFRE} and BI values for horizontal and vertical applications;
- t_{COV} is the time of the covariance matrix received from a Type 32 message (or a Type 40 message for a transmitting SDCM satellite);
- TOI_{COV} is the validity interval of the covariance matrix transmitted in a Type 32 message (or Type 39/40 message for a transmitting SDCM satellite);
- TOI_{DFRE} is the integrity data (DFREI or DFRECI) validity interval for a given application.

Figure H.4 shows how SDCM correction data blocks are used for SBAS L5 integrity monitoring

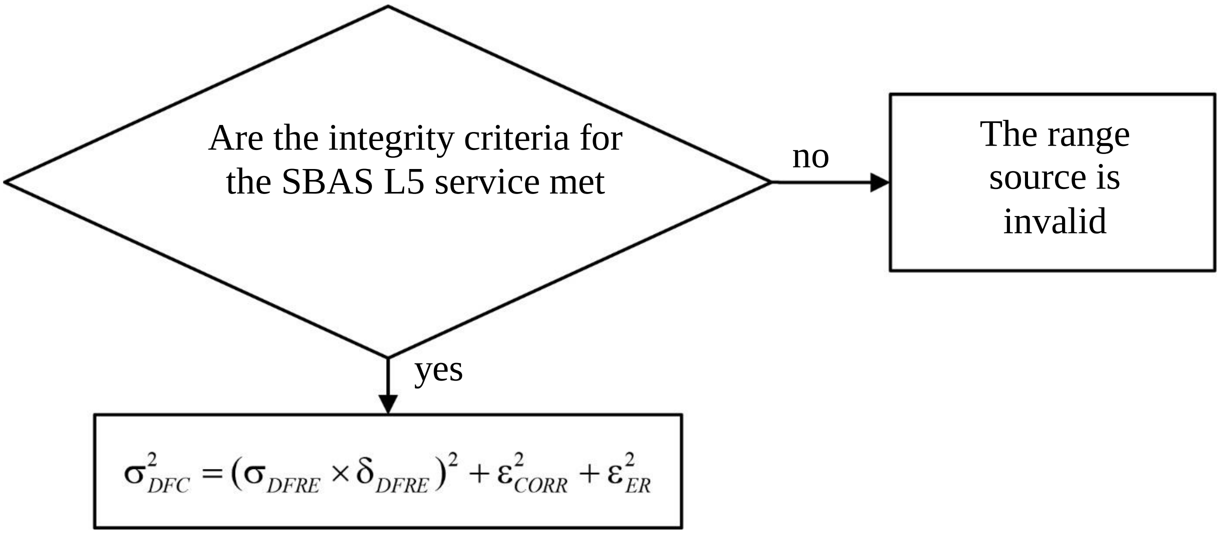

Figure H.4 – SDCM satellite selection and σ_{DFC} estimation

Note.– An SDCM satellite does not transmit Type 32 messages to itself, but to other satellites monitored by SDCM.

Figure H.5 shows the geometric range estimation algorithm.

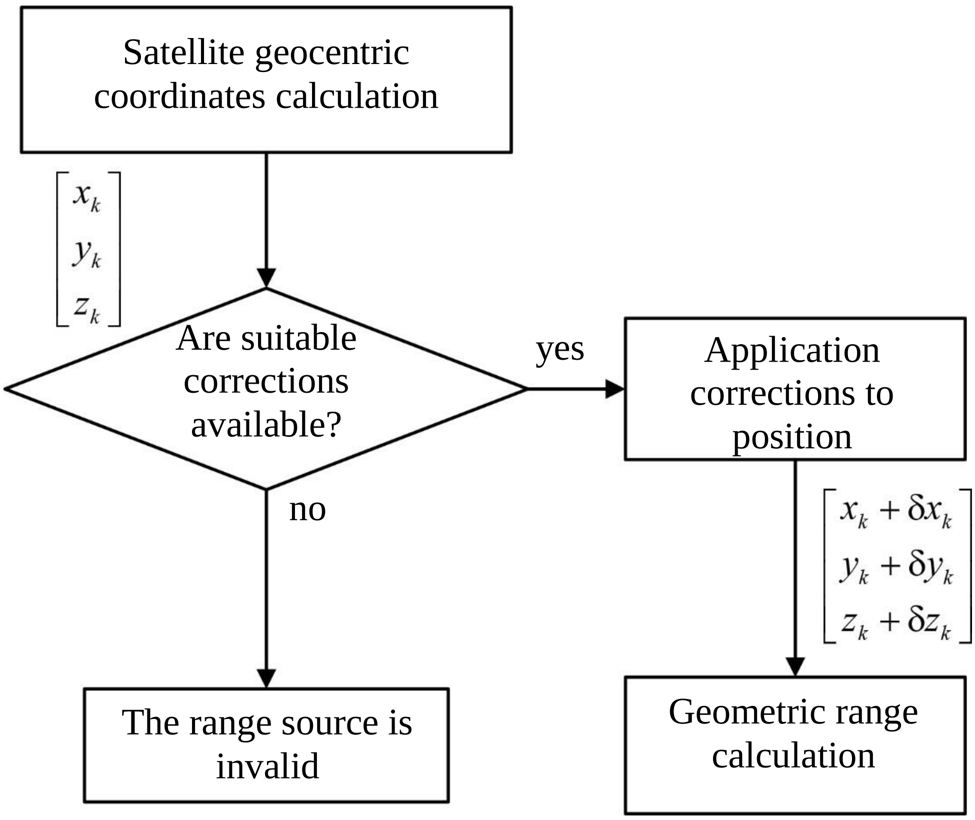

Figure H.5 – Geometric range estimation with SBAS L5 corrections

Note.– SDCM corrections are required for all SDCM satellites except for the satellite transmitting the corrections.

Figure H.6 shows the positioning and protection level estimation with the SBAS L5 service integrity monitoring.

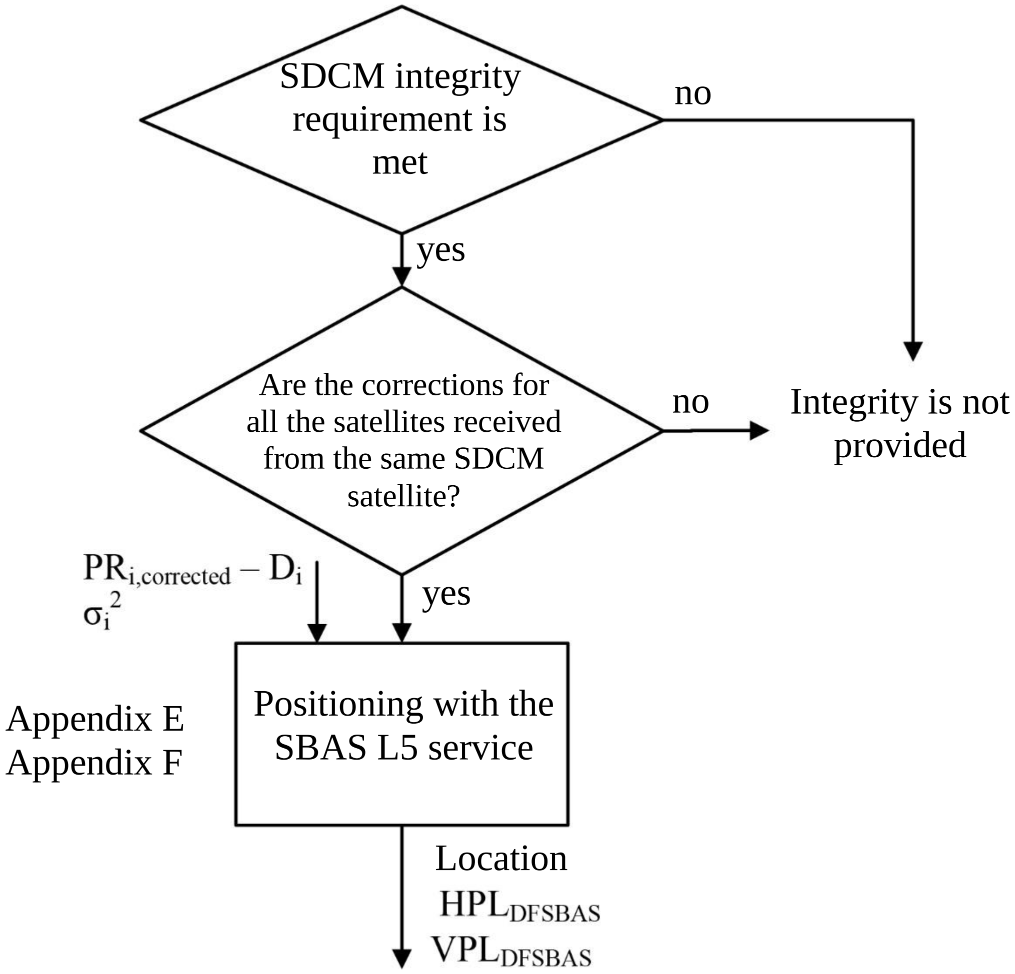

Figure H.6 – Positioning with SBAS L5 corrections

Appendix J

(Obligatory)

Excluded Parameters of Augmented GNSS

J.1 This Appendix lists parameters not to be used by SBAS L5 navigation equipment for each GNSS.

Presently, GPS and Galileo operators have a list of parameters not to be used since they conflict with SBAS L5 parameters. There are no excluded parameters for GLONASS and BDS.

Note.– Any parameter not listed in this Appendix can be used by the user equipment. It does not mean that user equipment uses all the parameters.

Tables J.1 and J.2 list the excluded parameters for GPS and Galileo.

Table J.1 – Excluded GPS parameters

Symbol	Parameter name	L1 LNAV subframe	L5 CNAV message
ISF	Integrity Status Flag	All	10
AODO	Age of Date Offset	2	–
NMCT	Navigation Message Correction Table	4 (page 13)	–
L2	L2 Signal Health	–	10
ISC_{L5I5}	Inter-Signal Correction L5-I5	–	30
ISC_{L2C}	Inter-Signal Correction L2C	–	30
–	Earth Orientation Parameters (EOP)	–	32
–	Differential corrections	–	34, 13, 14
–	GPS/GNSS Time Offset (GGTO) parameters	–	35

Table J.2 – Excluded Galileo parameters

Symbol	Parameter name	E1 I/NAV word	E5a F/NAV page
–	GPS to Galileo System Time Conversion and Parameters	10	4

Appendix K

(Obligatory)

Supplemental Materials

K.1 It is important to distinguish between the coverage area and service areas of SDCM.A coverage area typically corresponds to the SDCM GEOs footprint areas or to the area where the user receives SDCM data via terrestrial communication channels.

SDCM service area within the SDCM coverage area is defined by boundaries of one or several areas, probably not intersecting, throughout which a service provider (namely, an organization operating SDCM) provides user equipment with an access to SDCM functions and ensures the required accuracy and reliability of navigation.

Figure K.1 service areas of five SBAS:

- the Wide Area Augmentation System (WAAS);
- the European Geostationary Navigation Overlay Service (EGNOS);
- the Michibiki Satellite Based Augmentation Service (MSAS);
- the GPS-Aided Geo-Augmented Navigation (GAGAN);
- the System of Differential Correction and Monitoring (SDCM).

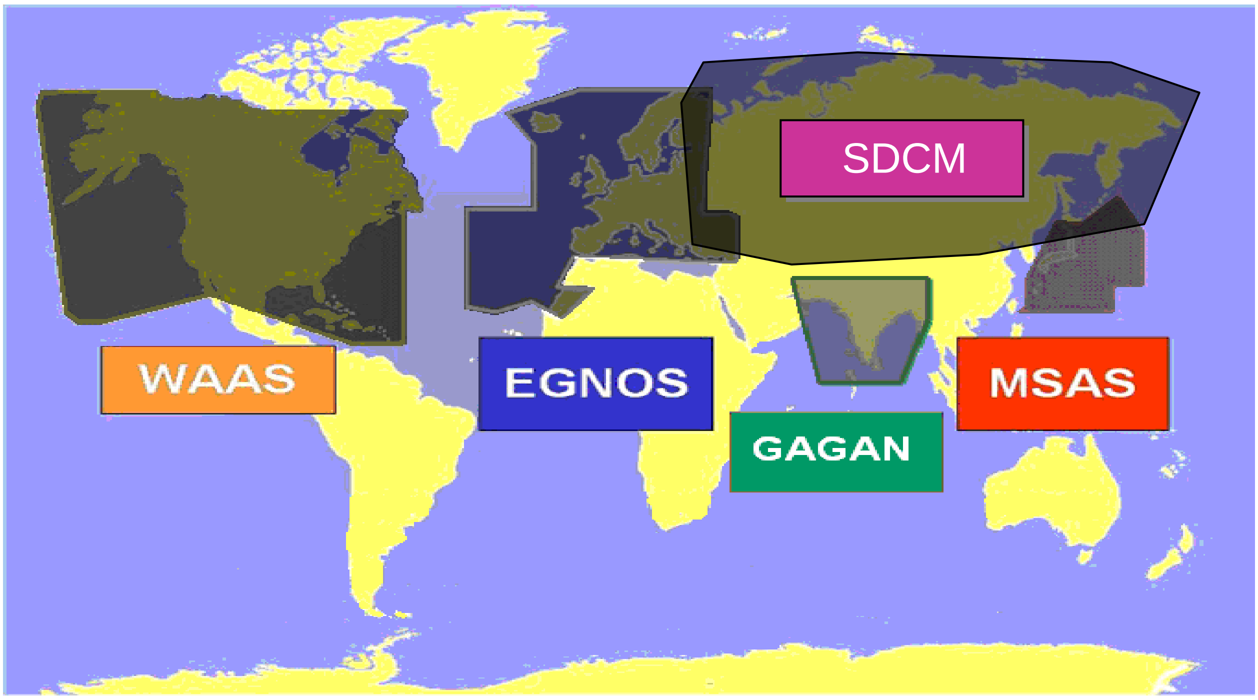

Figure K.1 – SBAS service areas

Currently the MSAS service is provided by the QZSS satellites.

List of acronyms and abbreviations

APV	–	Approach Procedure with Vertical guidance
BDS	–	BeiDou Navigation Satellite System
BI	–	Bump Indicator (DFREI increment)
BPSK	–	Binary Phase-Shift Keying
CNAV	–	Civil Navigation Message
CRC	–	Cyclic Redundancy Check
DFMC	–	Dual Frequency, Multi-Constellation
DFRE	–	Dual-Frequency Range Error
DFRECI	–	Dual-Frequency Range Error Change Indicator
DFREI	–	Dual-Frequency Range Error Indicator
EGNOS	–	European Geostationary Navigation Overlay Service
F/NAV	–	Galileo Open Service Message
GAGAN	–	GPS-Aided Geo-Augmented Navigation
GEO	–	Geostationary Orbit
GGTO	–	GPS/GNSS Time Offset
GLONASS	–	Global Navigation Satellite System of Russian Federation
GNSS	–	Global Navigation Satellite System
GPS	–	Global Positioning System
HAL	–	Horizontal Alert Limit
HEO	–	High Earth Orbit
HPL	–	Horizontal Protection Level
ICAO	–	International Civil Aviation Organization
ICD	–	Interface Control Document
IGSO	–	Inclined Geosynchronous Orbit
IOD	–	Issue of Data
IODC	–	Issue of Data, Clock
IODE	–	Issue of Data, Ephemeris
IODG	–	Issue of Data GEO (an identifier linking Type 39 and 40 messages)
IODM	–	Issue of Data, Mask
LNAV	–	Lateral Navigation
LP	–	Localizer Performance without vertical guidance
LPV	–	Localizer Performance with Vertical guidance APV-I and APV-II)
LSB	–	Least Significant Bit
MEO	–	Medium Earth Orbit
MSAS	–	Michibiki Satellite Based Augmentation Service
MSB	–	Most Significant Bit
MT	–	Message Type
NPA	–	Non-Precision Approach
OBAD	–	Old But Actual Data
PA	–	Precision Approach

PRC	–	Pseudorandom Code
PRN	–	Rseudo Random Noise
RTCA	–	Radio Technical Commission for Aeronautics
RTCM	–	Radio Technical Commission for Maritime Services Special Committee
SARPs	–	Standards and Recommended Practices
SBAS	–	Satellite-Based Augmentation System
SDCM	–	System of Differential Correction and Monitoring
SNT	–	SBAS Network Time
TTA	–	Time To Alert
UTC	–	Universal Time Coordinated
VAL	–	Vertical Alert Limit
VNAV	–	Vertical Navigation
VPL	–	Vertical Protection Level
WAAS	–	Wide Area Augmentation System

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