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 Radio Signals and Data Block Format

Edition 2.0

MOSCOW
2020

APPROVED

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“_____”_________________2020

Interface Control Document
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Table of Contents

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.

1.2 SDCM Components

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.

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 and GPS satellites;
- continuous correction of orbits and clocks of GLONASS and GPS satellites;

- generation of differential corrections – correction data and integrity data;
- transmission of differential corrections to the user via Space Segment and ground facilities.

In the future, it is planned to develop the SDCM space segment by implementation of the satellites Luch-5VM, Luch-5M and others developed under The Unified State Space Program.

1.3 SDCM Interface Definition

1.3.1 Figure 1 shows the common interface from the space-based segment to the end-user navigation equipment. The signals are open service L1 SDCM, GLONASS L1OF and GPS L1 C/A.

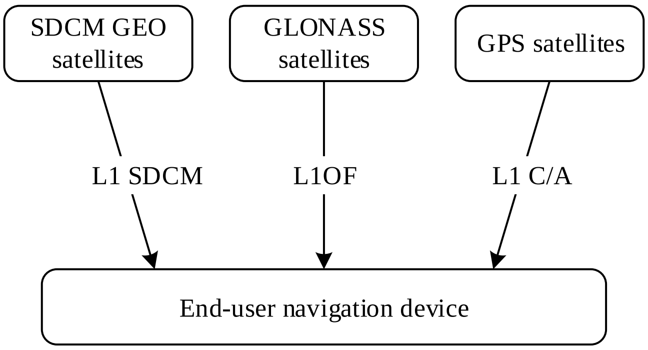

Figure 1 – SDCM interface from space-based segment to the end-user navigation equipment

Interface of L1OF signal is regulated by GLONASS ICD “Frequency Division Multiple Access Open Service Navigation Signals in L1, L2 frequency bands”, (http://russianspacesystems.ru).

SDCM L1 information signal transmitted by GEO-satellites 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 [1-5]. It defines the format of the L1 signal transmitted by the SDCM satellites. The most used standards in the development of this ICD are International Standards and Recommended Practices (SARPs) [1] and MOPS SBAS RTCA/DO-229E [5].

2.2 ICD Approval and Revision 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-5A	Luch-5B	Luch-5V
PRN code number (see. 5.3.2)	141	125	140
Orbital position	E167°	W16°	E95°
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

4 SDCM to User Interaction Overview

4.1 Requirements for SDCM Time to alert (TTA) are shown in Appendix D (for state functions of GNSS satellites, standard differential corrections and accurate differential corrections, respectively). Figure 2 shows components of total TTA for both ground and space segments.

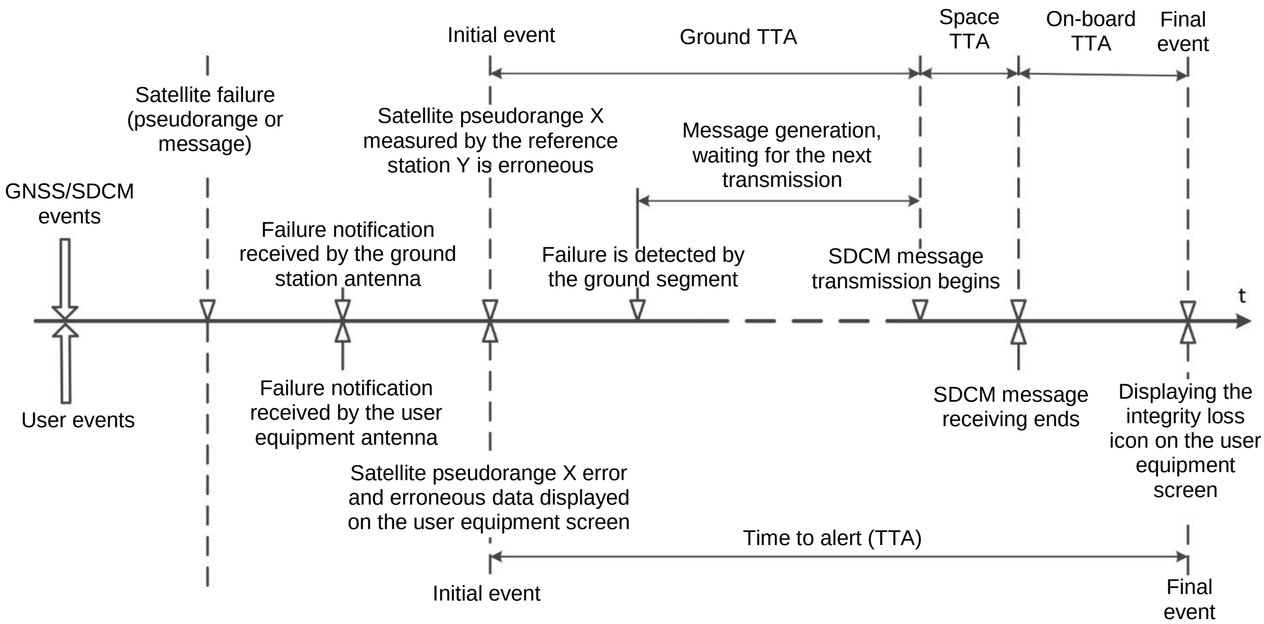

Figure 2 – SDCM Time to Alert

As shown in Figure 2, “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 information 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 E (based on [5]) 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.

SDCM uses a special mechanism to prevent any ambiguity when applying corrections. This mechanism is explained in B.2.

GPS and GLONASS systems use coordinate systems WGS84 and PZ-90 respectively.

SDCM generates corrections for GPS satellites expressed in WGS84 latest revision and for GLONASS satellites the latest PZ-90 revision is used.

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

5 SDCM Signals Specification

5.1 L1 SDCM Signal Structure

5.1.1 The L1 SDCM radio signal is transmitted by three SDCM GEO-satellites, the antenna is deflected to the north by 7° from the equator.

5.2 L1 SDCM Frequency Properties

5.2.1 Carrier frequency of L1 signal

A pseudo random noise radio signal is used at a carrier frequency of 1,575.42 MHz. Code-division multiplexing of the three SDCM GEO-satellite channels is used.

5.2.2 Carrier frequency stability

Short-time L1 carrier frequency deviations at the output of the satellite transmitting antenna do not exceed $5 \cdot 10^{-11}$ (averaged over 1 to 10 s periods).

5.2.3 Carrier phase noise

The spectral density of the L1 unmodulated carrier phase noise is such that the RMS carrier phase tracking error in a locked loop with a 10 Hz one-sided noise bandwidth is 0.1 rad.

5.2.4 Spurious emissions

The spurious components of the L1 out-of-band emission at any frequency are at least 40 dB below the unmodulated carrier power.

5.2.5 Modulation

Transmitted message 250 bps with convolutional encoding at a rate of 500 sps will be added modulo 2 to a 1,023-bit pseudo-random noise code. It will then be binary phase-shift keying (BPSK) modulated onto the carrier at a rate of 1,023 Mbps.

Symbols of SDCM message (transmission rate of 500 sps are synchronized with time interval of 1 millisecond of C/A code.

5.2.6 L1 Signal Bandwidth

The L1 SDCM signal bandwidth (at 3 dB) will occupy a frequency band with a width of 2.046 MHz.

5.2.7 Doppler shift

The Doppler shift of the L1 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 ±40 m/s relative to the user; the corresponding Doppler shift would not exceed ±210 Hz.

5.2.8 Polarization

The L1 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.

5.2.9 Received Signal Power

The SDCM L1 signal power, when received by an isotropic right circular polarization terrestrial antenna, which radiation pattern is shown in Table 2, is at least minus 164 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 -152 dBW.

Table 2 – Antenna radiation pattern

Elevation angle, °	Gain, dB
0	-7
5	-5.5
10	-4
From 15 to 90	-2

Table 3 represents the SDCM L1 signal power as received by a terrestrial isotropic antenna (gain = 1) with the right circular polarization and the radiation pattern shown in Table 2 vs. the elevation for the rated signal power. The data are valid for terrestrial users arranged longitudinally under the SDCM GEO-satellite.

Table 3 – L1 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	-162.1
	10	-160.3
	20	-158.4
	30	-158.1
	40	-157.9
	50	-157.8
	60	-157.8
	70	-157.9
	80	-158.1
	90	-158.5
Terrestrial user in the Southern latitudes	80	-159.1
	70	-159.8
	60	-160.7
	50	-161.5
	40	-162.4
	30	-163.2
	20	-164.0
	10	-166.2
	5	-168.1

Figure 3 shows the estimated coverage areas of SDCM GEO-satellites. The SDCM GEO-satellite coverage area is identified by the signal power (at least -164 dBW and elevation (at least 5°) for the worst-case scenario.

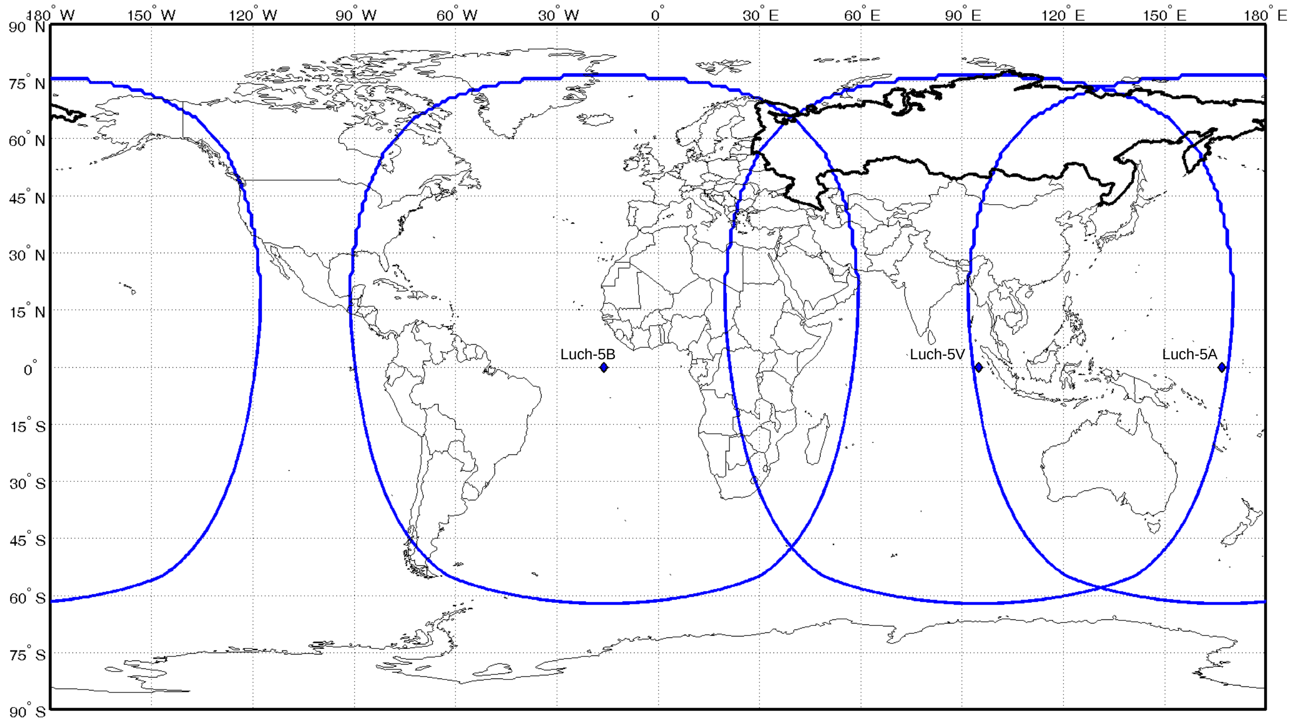

Figure 3 – SDCM GEO-satellites coverage areas

5.2.10 Correlation loss

The correlation loss of the L1 signal due to imperfect modulation and filtration by the GEO-satellite equipment does not exceed 1 dB.

5.3 SDCM L1 C/A Codes

5.3.1 C/A codes are Gold codes and are formed by adding modulo 2 two 1,023-bit pseudorandom sequences G1 and G2 formed by two 10-bit registers that have different feedbacks: for G1 from bits 3 and 10; for G2 from bits 2, 3, 6, 8, 9, 10 (see Figures 4 and 5).

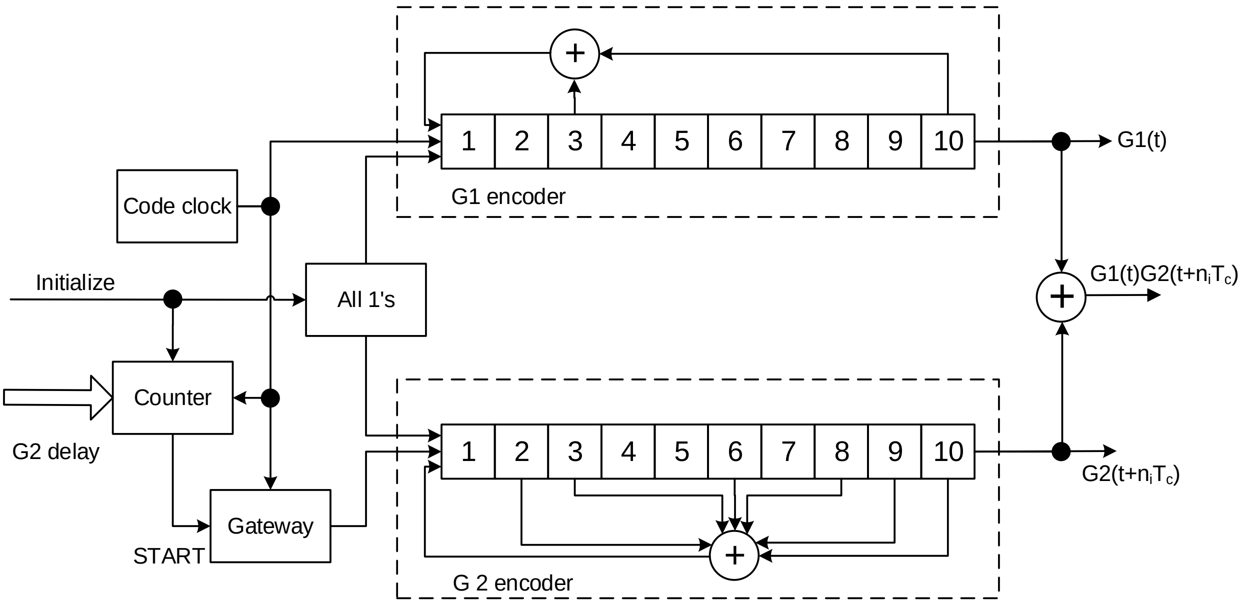

Figure 4 – Programmable G2 delay

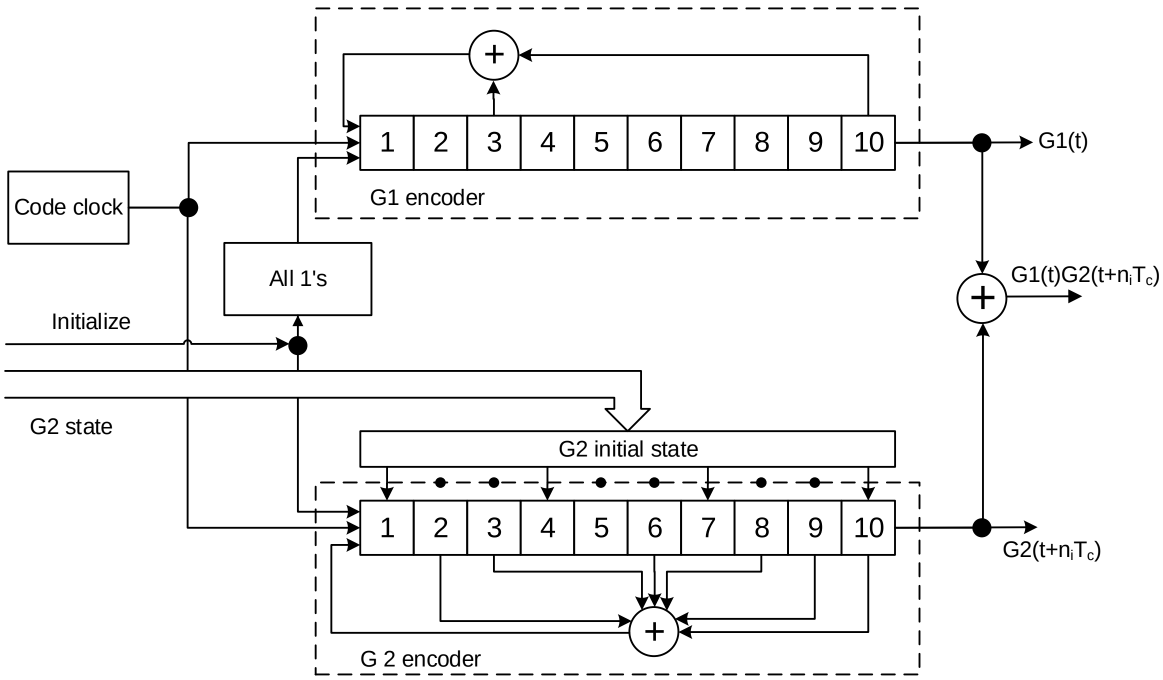

Figure 5 – Programmable G2 initial state

C/A codes are identified in three ways:

- PRN number (see 5.3.2);
- G2 delay in chips (see Figure 4);

- Initial G2 register state (see Figure 5).

5.3.2 C/A code (PRN code number) is a number used in SBAS standard for unique identification for each satellite and its belonging to a certain system (for more information, see 7.2).

SDCM uses 125, 140 and 141 C/A codes. G2 delay values for these C/A codes are shown in Table 4. Initial G2 state and first 10 chips of SDCM are written as follows: the most significant bit is 0 or 1 for the first chip, the next three bits in octal notation represent the remaining 9 chips. The first 10 SDCM chips of are inversed to the initial G2 state and are also represented in octal notation.

Table 4 – SDCM C/A codes

PRN	G2 delay (chips)	Initial G2 state	First 10 SDCM chips
125	235	1076	0701
140	456	1653	0124
141	499	1411	0366

5.4 Convolutional Encoding of Transmitted Data

5.4.1 In L1 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 6). In the first half of each bit, the output switch of the convolutional encoder occupies position 1.

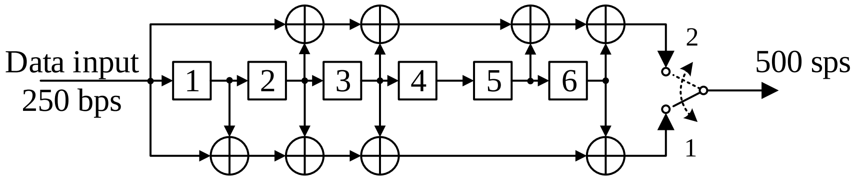

Figure 6 – Convolutional encoder

6 SDCM Data Format

6.1 Data Format General Information

6.1.1 The following definitions are used to describe data structure of navigation 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 customer ignores the spare field contents.

The SDCM data is transmitted as a sequence of 1 s-long strings of 250 bits each (Figure 7). A string contains the following fields: Preamble (8 bits), Message Type (6 bits), Data Field (212 bits), Cyclic Redundancy Check (CRC) (24 bits).

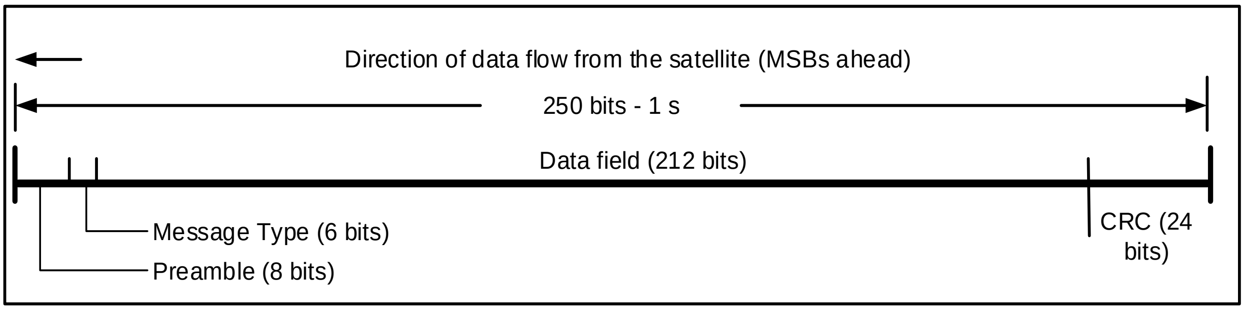

Figure 7 – Data format

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 8-bit Preamble field. For three successive data blocks, the three Preamble fields would contain 01010011, 10011010, 11000110 according to SBAS standard.

Message Type identifier consists of 6 bits and defines 64 message types (0-63), as Table 5 shows. Message Type identifier is transmitted MSBs ahead.

Data field consists of 212 bits and contains SDCM message. These messages are transmitted with different rate depending on the data broadcast interval or on message priority. Table 6 represents data broadcast and time-out intervals (the time interval for which data is applicable). For the message types, see section 7. The content of the string field is determined by the type of transmitted message and is described in section 7.

The CRC field contains the verification bits of the cyclic code. The CRC field is filled according to the cyclic coding scheme given in 6.3.

Table 5 – Message types

Type	Content
0	Test Message (see 7.1)
1	PRN Mask Assignments (see 7.2)
2–5	Fast Corrections (see 7.6)
6	Integrity Data (see 7.7)
7	Fast Correction Degradation Factor (see. 7.10)
8	Spare
9	SDCM Satellite Navigation Message (see 7.3)
10	Degradation Factors (see 7.10)
11	Spare
12	SDCM Network Time /UTC Offset Parameters (see 7.11)
13–16	Spare
17	SDCM Satellite Almanac (see 7.4)
18	Ionospheric Grid Point Masks (see 7.8)
19–23	Spare
24	Mixed Fast/Long-Term Corrections (see 7.5)
25	Long-Term Satellite Error Corrections (see 7.5)
26	Ionospheric Delay Corrections (see 7.9)
27	Service Message (see 7.12)
28	Clock-Ephemeris Covariance Matrix (see 7.13)
29–61	Spare
62	Internal Test Message (see 7.14)
63	Null Message (see 7.14)

Table 6 – Data broadcast intervals and time-out intervals

Data	Message type	Maximum broadcast interval, s	En-route, terminal, NPA time-out, s	Precision approach, APV time-out, s
SDCM in test mode	0	6	–	–
PRN mask	1	120	600	600
Fast corrections	2-5, 24	60	18 *	12 *
Long-term corrections	24, 25	120	360	240
SDCM satellite navigation message	9	120	360	240
Degradation factors	7, 10	120	360	240
Ionospheric grid mask	18	300	1200	1200
Ionospheric delay corrections	26	300	600	600
SDCM network time/UTC offset parameters	12	300	86,400	86,400
SDCM satellites almanac	17	300	–	–

* For fast corrections time-out intervals are given taking into account the additional data transmitted in Type 7 message.

6.2 Relationship Between Message Types

6.2.1 To associate data in different message types, a number of Data (IOD – Issue of Data) parameters are used, as described in B.2. IOD identifiers (including GPS IODC, IODE and similar GLONASS data) correspond individually to each satellite. The transmitted SDCM data also corresponds to the current PRN mask, ionospheric grid and service message data.

6.3 Cyclic Redundancy Check (CRC) (250, 226)

6.3.1 CRC (250, 226) is used for filling the CRC field in Data Field. The location of the CRC field in a string is given in Table 7. The string contains 250 bits, where 24 bits are allocated for check bits of CRC code, 8 bits for Preamble, and 212 bits for data. String transmission starts from Preamble field.

Table 7 – CRC (250, 226) in a 1-second string structure of SDCM signal

Preamble	Type	Data	CRC
8 bit	6 bit	212 bit	24 bit
CRC Data bits			Checking bits

CRC generator polynomial (250, 226) is as follows:

$$g(X) = 1 + X + X^{3} + X^{4} + X^{5} + X^{6} + X^{7} + X^{10} + X^{11} + X^{14} + X^{17} + X^{18} + X^{23} + X^{24}.$$

CRC is filled by cycling CRC encoding scheme which is shown in Figure 8. The 226-bit string is delivered to the input of encoder (starting from the first bit of Preamble and ending with the last of 212 bits of Data). The 250-bit code block is generated output of encoder by adding 24 check bits.

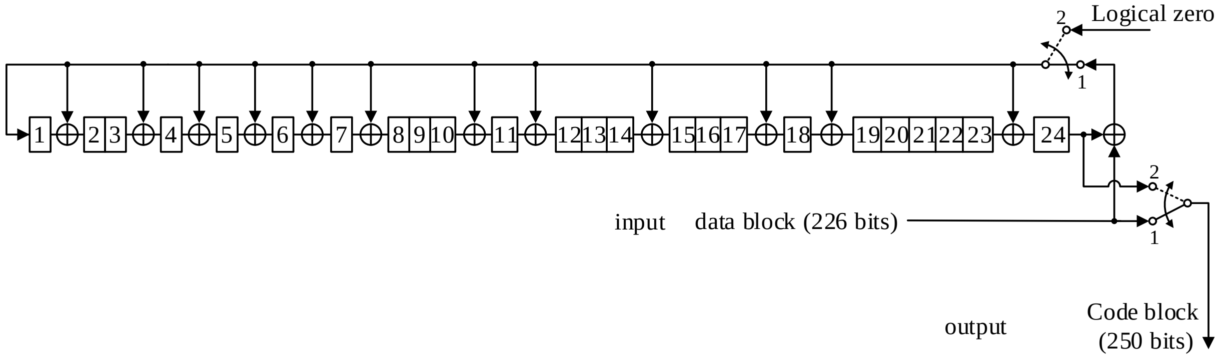

Figure 8 – CRC (250, 226) encoding scheme

The following steps describe the encoding procedure using the device shown in Figure 8:

- initial state of the 24-bit shift register is zeros;
- during first 226 shifts both keys are set to position 1, string is directly transmitted to the output of the encoder, the register feedback is closed, and the register state is being updated;
- after transmitting the last 226th data bit, both keys are set to position 2, the register feedback is opened, and during next 24 shifts the register state is being replaced by zeros, check bits are being transmitted to the output of the encoder.

Error detection in a string is performed by analyzing the syndrome, which is calculated for each string of data by using the scheme shown in Figure 9.

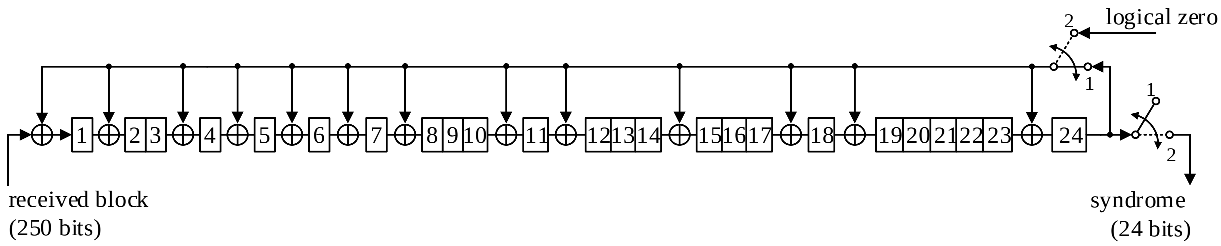

Figure 9 – CRC (250, 226) syndrome calculation scheme

The following steps describe the procedure of error detection in a received block (a string, starting from the 1-st bit of preamble and ending with the 24-th bit of CRC field) using the device shown in Figure 9:

- initial state of the 24-bit shift register is some bits (ones and zeros);
- during first 24 shifts both keys are set to position 2, the received block (first 24 bits) is being downloaded to the register;
- after downloading the 24-th bit of the received block, keys are set to position 1, the received block (the remaining 226 bits) keeps being downloaded to the register. Syndrome is the name of the state of the register at the instant when the last 250-th bit of the received block is downloaded to trigger 1;

- after downloading the 250-th bit of the received block to the register, both keys are set to position 2 for the next 16 shifts in order to enable extraction of the syndrome from the register (and simultaneous downloading of first 24 bits of the next string to the register). Zeros in all 16 bits of the syndrome indicate absence of errors. Otherwise it is decided that the received block (string) contains errors.

7 SDCM Data Content

7.1 Type 0 message. Test Message

7.1.1 This type of message is transmitted in the following cases:

- when SDCM testing;
- when testing new SDCM GEO-satellite;
- when unreliable messages of any SDCM GEO-satellite are identified.

Type 0 message is transmitted not less than one time per minute and informs user about identification of data usage reasonability due to feasible accuracy and integrity performance degradation. When Type 0 message is transmitted it is prohibited to use SDCM data in Safety of Life (SoL) operations.

When testing is performed some message types could not be transmitted. Type 0 message could be used for additional transmission of fast corrections per placing Type 2 message string into Type 0 message string.

7.2 Type 1 message. PRN Mask Assignments

7.2.1 Type 1 message contains the list of satellites for which data is transmitted. The compliance of C/A codes (see 5.3.2) with satellites is shown in the Table 8.

The structure and content of Type 1 message are given in Figure 10 and Table 9, respectively.

Table 8 – PRN code number assignments

PRN code number	Assignment
1 – 37	GPS
38 – 61	GLONASS Slot Number plus 37
62 – 119	Spare
120 – 138 (158) *, including 125, 140, 141 for SDCM	SBAS including SDCM
139 (159) – 210	Future GNSS, GSO satellites, SBAS, pseudolites

* Currently authorized international organizations are in the process of resolving the issue of enhancing the number of SBAS codes from 19 to 39. After the decision has been approved SBAS PRN Slots will reserve the numbers 120 – 158.

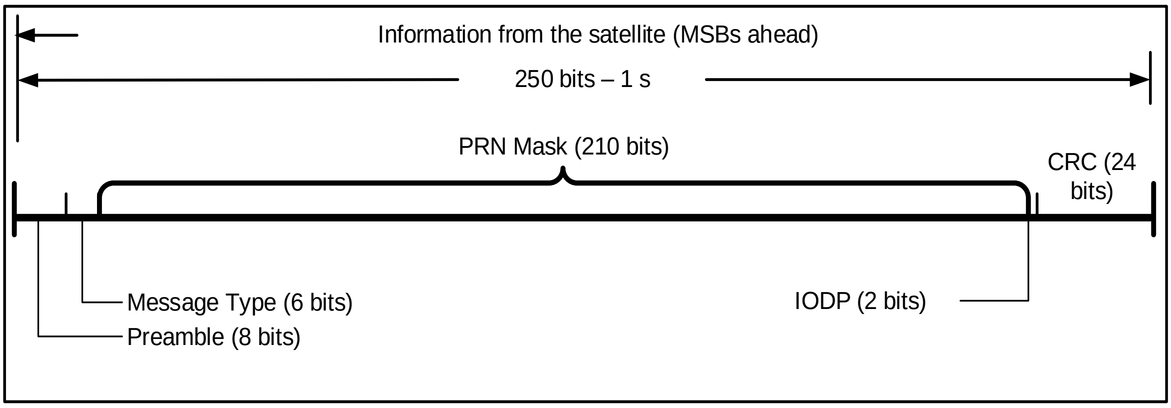

Figure 10 – Type 1 message structure. PRN mask assignments

Table 9 – Type 1 message content. PRN mask assignments

Data content	Bits used	Least significant bit (LSB) value	Range of values	Unit
PRN Mask	210	–	–	unitless
IODP	2	1	0–3	unitless

Preamble, Message Type, and CRC descriptions are given in section 6.

The PRN Mask contains a list of satellites for which data is transmitted. It consists of 210-ordered slots filling in with zeros and ones in the following way. The ones are filled in all positions which numbers are equal to C/A codes numbers (see Table 8) of the satellites for which SDCM transmits data. All the rest positions are filling in with zeros.

The first transmitted bit of PRN Mask corresponds to the C/A code 1. For example, if the bit with number 5 equals “1” the data for satellite with C/A code 5 is transmitted. If this bit equals “0” the data for this satellite is not transmitted. (However SDCM could transmit this data from the other GEO-satellite).

Due to the restrictions on the data broadcast interval in SBAS channel in each string it is possible to transmit the data for 51 satellites (out of 210 satellites shown in Table 8). Therefore, it could be written not more than 51 “1s” in the PRN Mask.

Figure 11 shows the principle of forming a list of C/A codes and determining of a string sequence with PRN Mask. Non-counted C/A codes are indicated by the word “empty”.

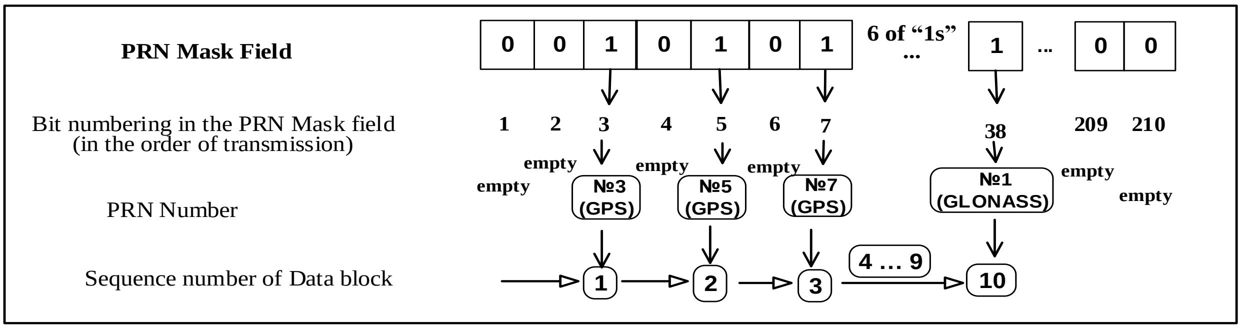

Figure 11 – Principle of forming a list of C/A codes of used satellites

PRN Mask Number is a satellite sequence number in the list of satellites (sequence number of single bit in the PRN Mask). This number is transmitted in Types 25 and 28 messages to indicate the satellite for which the transmitted data in these messages is related to. The Figure 11 shows that if PRN Mask Number equals 3, the C/A code equals 7 and the data is related to GPS satellite with number 7.

IODP is an identifier of the current satellite list. It indicates the current PRN Mask field.

These parameters are transmitted in the following messages:

- “PRN Mask” (satellite list) is transmitted in Type 1 message;
- “PRN Mask Number” (sequence number of the satellite in satellite list) is transmitted in Type 25 and 28 messages;
- C/A code is transmitted in the Type 17 message;
- IODP (identifier of the current satellite list) is transmitted in the Type 1, 2, 3, 4, 5, 7, 24, 25 and 28 messages.

7.3 Type 9 Message. SDCM Satellite Navigation Message

7.3.1 Type 9 message contains ephemeris data as well as time-frequency data of SDCM satellite. This message is transmitted by SDCM to ensure compatibility with previously released navigation equipment for WAAS system. It is intended only for searching for a satellite signal and not intended for ranging.

The structure and content of Type 9 message are given in Figure 12 and Table 10, respectively.

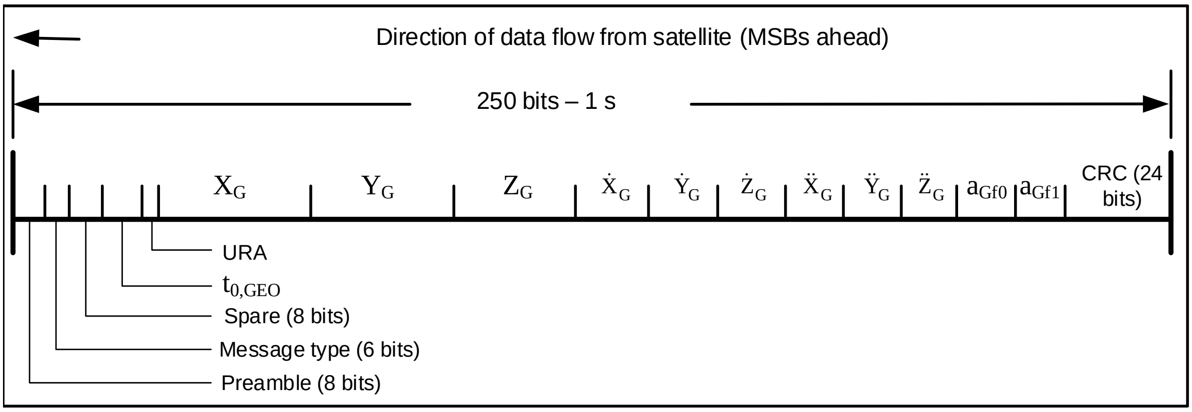

Figure 12 – Type 9 message structure. SDCM satellite navigation message

Table 10 – Type 9 message content. SDCM satellite navigation message

Data content	Bits used	LSB value	Range of values	Unit
Spare	8	–	–	–
$t_{0,GEO}$	13	16	0–86,384	s
URA	4	1	15	unitless
X_G	30	0.08	±42,949,673	m
Y_G	30	0.08	±42,949,673	m
Z_G	25	0.4	±6,710,886.4	m
$\dot{X}_G$	17	0.000625	±40.96	m/s
$\dot{Y}_G$	17	0.000625	±40.96	m/s
$\dot{Z}_G$	18	0.004	±524.288	m/s
$\ddot{X}_G$	10	0.0000125	±0.0064	m/s^2
$\ddot{Y}_G$	10	0.0000125	±0.0064	m/s^2
$\ddot{Z}_G$	10	0.0000625	±0.032	m/s^2
a_{Gf0}	12	2^{-31}	$\pm 0.9537 \times 10^{-6}$	s
a_{Gf1}	8	2^{-40}	$\pm 1.1642 \times 10^{-10}$	s/s

Preamble, Message Type, and CRC descriptions are given in section 6.

$t_{0,GEO}$ is a data reference time of GEO-satellite range function which is expressed as the time from midnight of the current day.

X_G, Y_G, Z_G are the coordinates of GEO-satellite at $t_{0,GEO}$.

$\dot{X}_G$, $\dot{Y}_G$, $\dot{Z}_G$ are the velocity of GEO-satellite at $t_{0,GEO}$.

$\ddot{X}_G$, $\ddot{Y}_G$, $\ddot{Z}_G$ are the acceleration of GEO-satellite at $t_{0,GEO}$.

a_{Gf0} is a shift between onboard time scale of GEO-satellite and SBAS (SDCM) network time (SNT) defined at $t_{0,GEO}$.

a_{Gf1} is a drift speed of a shift between onboard time scale of GEO-satellite and SNT.

URA is user range measurement accuracy, parameter of root-mean-square error of user range measurement without atmosphere impact. In accordance with SBAS standard, if URA equals 15 it means that satellite measurement signal cannot be used. SDCM does not provide pseudorange measurements to SDCM GEO-satellite so that for compatibility with previously released equipment the URA value is equal to 15.

7.4 Type 17 Message. SDCM Satellite Almanac

7.4.1 Type 17 message contains the almanac of 3 SDCM GEO-satellites. For nonexistent SDCM GEO-satellites positions in PRN Mask equal null and data in relevant Type 17 message is ignored. Almanac contains information about satellite health and status. Also it contains service provider identifier which provides data uplinking to the GEO-satellite board.

The structure of Type 17 message is shown in Figures 13 and 14. Type 17 message allows transmitting data for three SDCM satellites simultaneously. Satellite identification is performed with use of IODP field.

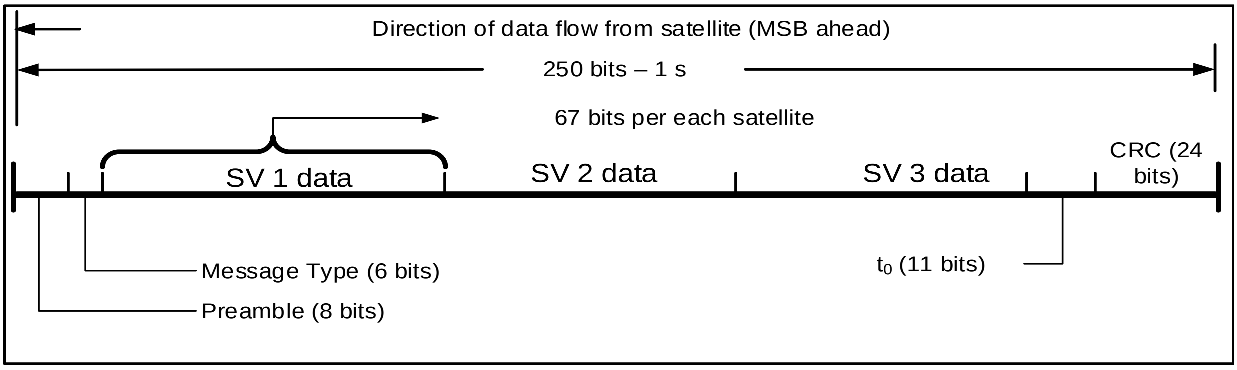

Figure 13 – Type 17 message structure. SDCM satellite almanac

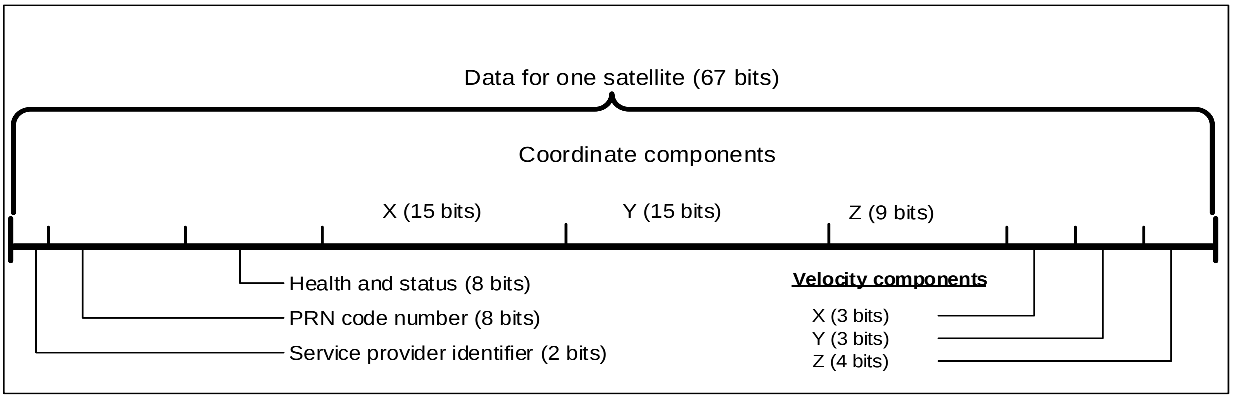

Figure 14 – Type 17 structure message. Structure of data for one SDCM satellite

The content of Type 17 message is shown in Table 11.

Table 11 – Type 17 message content. SDCM satellite almanac

Data content	Bits used	LSB value	Range of values	Unit
For each of three satellites				
Service provider identifier	2	1	0–3	unitless
PRN code number	8	1	1–210	unitless
Health and status	8	–	–	–
X_G	15	2,600	±42,595,800	m
Y_G	15	2,600	±42,595,800	m
Z_G	9	26,000	±6,630,000	m
$\dot{X}_G$	3	10	±40	m/s
$\dot{Y}_G$	3	10	±40	m/s
$\dot{Z}_G$	4	60	±480	m/s
t_0	11	64	0–86,336	s

Preamble, Message Type, and CRC descriptions are given in section 6.

Service provider identifier always equals 00_2 in Type 17 message.

IODP is defined in 5.3.

Health and status parameter contains data of SDCM GEO-satellite and fills in according to Table 12. Service provider identifiers are shown in Table 13.

Table 12 – Health and status parameter content in Type 17 message

Number of bit	Transmitted data
0 (LSB)	Ranging On (0), Off (1) *
1	Precision corrections On (0), Off (1)
2	Integrity data On (0), Off (1)
3	Spare
4 – 7	Service provider identifier

* GEO ranging is not applied in SDCM, therefore the bit 0 (LSB) is always equal to "1".

Table 13 – Service provider ID

Identifier	Service provider
0	WAAS
1	EGNOS
2	MSAS
3	GAGAN
4	SDCM
5–13	Spare
14–15	Reserved

X_G, Y_G, Z_G, $\dot{X}_G$, $\dot{Y}_G$, $\dot{Z}_G$ are the coordinates and satellite velocity components at t_0 (time from midnight of the current day). These fields are transmitted in Type 17 message for providing the compatibility with previously released navigation equipment.

7.5 Type 24 and 25 Messages. Long-Term and Mixed Satellite Corrections

7.5.1 Type 24 and 25 messages transmit data to compensate the slowly changing satellite ephemeris errors and its clocks. These messages are not transmitted for GEO-satellites as far as Type 9 message allows one to compensate slowly changing ephemeris errors and onboard clocks of GEO-satellite.

Type 24 message contains the fast corrections (see 7.6).

Long-term corrections are differential corrections for orbit and clocks of navigation satellite with broadcast interval which is not exceed 120 s.

Mixed corrections contain long-term corrections as well as fast corrections (see 7.6).

Type 25 message structure has two variants shown in Figures 15 and 16. In the Figures the structure for only the first part of data field is shown. The second part of data field has a similar structure. At the beginning of each of two parts of Data the 1-bit Velocity code field is transmitted.

This field takes value 1 if $\delta\dot{x}$, $\delta\dot{y}$, $\delta\dot{z}$, δa_{f1} (corrections change velocity) are transmitted and takes value 0 if indicated fields are not transmitted.

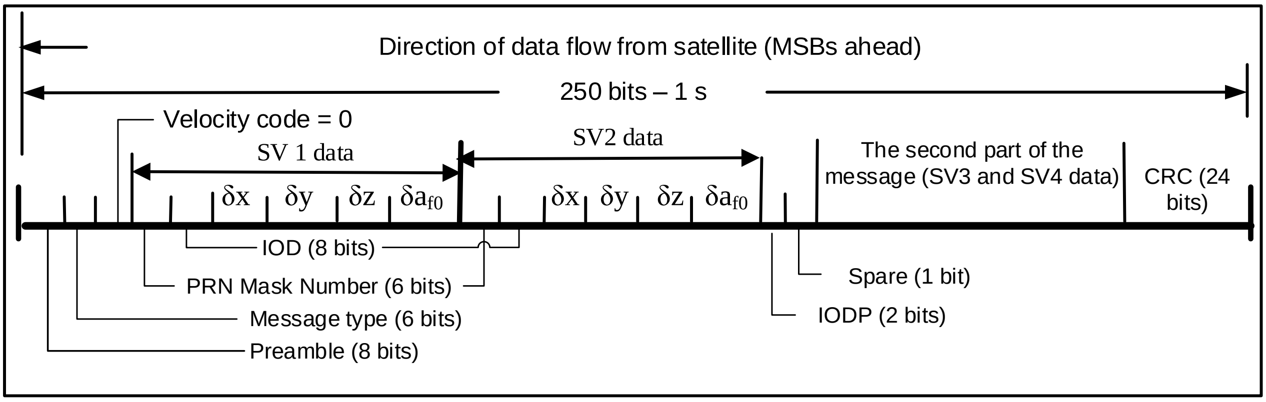

Figure 15 – Type 25 message structure for velocity code = 0. Long-term corrections for satellites

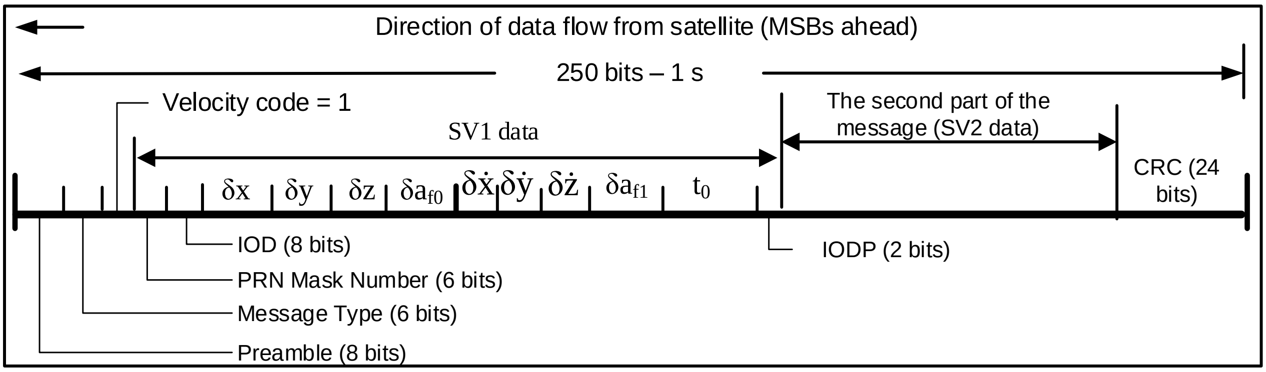

Figure 16 – Type 25 message structure for velocity code = 1 (with transmission of corrections change velocities). Long-term corrections for satellites

Type 25 message parameters are shown in Tables 14 and 15.

Table 14 – Half-message Type 25 content for velocity code = 0. Long-term corrections for satellites

Data content	Bits used	LSB value	Range of values	Unit
Velocity code	1	1	0	unitless
For two satellites	–	–	–	–
PRN Mask Number	6	1	0–51	unitless
IOD	8	1	0–255	unitless
δx	9	0.125	±32	m
δy	9	0.125	±32	m
δz	9	0.125	±32	m
δa_{f0}	10	2^{-31}	$\pm 2^{-22}$	s
IODP	2	1	0–3	unitless
Spare	1	–	–	–
Note 1.– IODP is described in sections 7.2 and B.2. Note 2.– PRN Mask Number is given in 7.2.				

Table 15 – Half-message Type 25 content for velocity code = 1. Long-term corrections for satellites

Data content	Bits used	LSB value	Range of values	Unit
Velocity code	1	1	1	–
PRN Mask Number	6	1	0–51	–
IOD	8	1	0–255	–
δx	11	0.125	±128	m
δy	11	0.125	±128	m
δz	11	0.125	±128	m
δa_{f0}	11	2^{-31}	$\pm 2^{-21}$	s
$\delta \dot{x}$	8	2^{-11}	±0.0625	m/s
$\delta \dot{y}$	8	2^{-11}	±0.0625	m/s
$\delta \dot{z}$	8	2^{-11}	±0.0625	m/s
δa_{f1}	8	2^{-39}	$\pm 2^{-32}$	s/s
t_0	13	16	0–86,384	s
IODP	2	1	0–3	–
Note 1.– IODP is described in 7.2 and B.2. Note 2.– PRN Mask Number is given 7.2.				

Preamble, Message Type, and CRC descriptions are given in section 6.

IOD identifier of Data is described in 7.5.2.

δx, δy, δz are the corrections to satellite ephemeris (which is defined by PRN Mask Number) on x, y, z axis.

δa_{f0} – correction for satellite clock.

$\delta \dot{x}$, $\delta \dot{y}$, $\delta \dot{z}$ – velocity of δx, δy, δz corrections change.

δa_{f1} – velocity of δa_{f0} correction change.

t_0 – time of long-term corrections applicability; time from the beginning of the current day with set-up δx, δy, δz, δa_{f0}, $\delta\dot{x}$, $\delta\dot{y}$, $\delta\dot{z}$, δa_{f1} parameters. Application of these parameters is given in Appendix H.

Message Type 24 structure and content which contain mixed corrections for satellites are shown in Figure 17 and in Table 16, respectively.

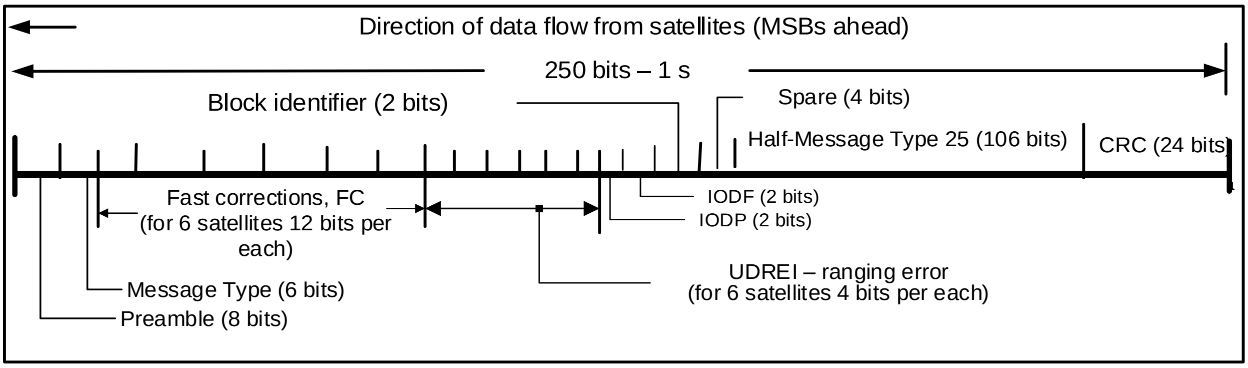

Figure 17 – Type 24 message structure. Mixed corrections for satellites

Block identifier takes the values 0, 1, 2, 3. Notice that Type 24 message contains fast corrections related to Type 2, 3, 4, 5 messages, respectively.

Table 16 – Type 24 message content. Mixed corrections for satellites

Data content	Bits used	LSB value	Range of values	Unit
For six satellites				
FC	12	0.125	± 256.000	m
For six satellites				
UDREI	4	See Table 20		
IODP	2	1	0–3	–
IODF	2	1	0–3	–
Block identifier	2	1	0–3	–
Spare	4	–	–	–
Half of Type 25 message	106	–	–	–
Note 1.– FC is defined in 7.6. Note 2.– UDREI is defined in 7.7. Note 3.– IODP is defined in 7.2 and B.2. Note 4.– IODF is defined in 7.6 and B.2.				

The basic provisions of SBAS standard concerning fast and long-term corrections transmission are:

- long-term corrections of GLONASS and GPS satellites ephemeris are transmitted in the following way: for GLONASS satellites corrections are transmitted in PZ-90 system, for GPS satellites corrections are transmitted in WGS84 system;
- the following application rules are establishing for long-term corrections.

7.5.2 IOD is an identifier which links the long-term corrections for the satellite with ephemeris transmitted by this satellite. The principle of its application is different for GLONASS and GPS.

For GLONASS IOD set the time interval during which GLONASS data is used with SDCM data:

- five LSBs of IOD contain V parameter (validity interval) that is the time interval during which information about GLONASS ephemeris is used;

- three MSBs of IOD contain L parameter (latency time) that is time interval from the epoch of the latest GLONASS ephemeris update to the anticipated time of reception of the long-term corrections by the user.

Description of V and L parameters is shown in Table 17.

Table 17 – IOD content for GLONASS

Data content	Bits used	LSB value, s	Range of values, s
Validity interval (V)	5	30	30 – 960
Latency time (L)	3	30	0 – 120

For GLONASS satellites the receiver applies long-term corrections only if the time of reception t_r of the latest GLONASS ephemeris is inside the following IOD validity interval:

$$t_{LT} - L - V \le t_r \le t_{LT} - L, \qquad (1)$$

where t_{LT} is the time of reception of long-term corrections.

For GPS satellites the long-term corrections are applied only if IOD in received SDCM corrections matches both with IODE in received GPS ephemeris and eight LSBs of IODC.

7.6 Type 2-5 Messages. Fast Corrections

7.6.1 Fast corrections contain data about corrections of navigation satellites measured ranges.

Fast correction allows compensating the fast-changing errors in pseudorange measurements due to inaccuracy of satellites onboard clock shift estimation (prediction).

Fast corrections apart Type 2-5 messages contain information about satellite range measurement accuracy in UDREI format described in 7.7. It allows user to determine the navigation accuracy.

For fast correction transmission of 51 satellites the four types of messages are used:

- Type 2 message transmits fast corrections of satellites with IODP numbers from 1 to 13 (13 SVs);
- Type 3 message – for IODP numbers from 14 to 26 (13 SVs);
- Type 4 message – for IODP numbers from 27 to 39 (13 SVs);
- Type 5 message – for IODP numbers from 40 to 51 (12 SVs).

Type 2-5 messages have the same structure which is shown in Figure 18. Type 2-5 messages content are shown in Table 18.

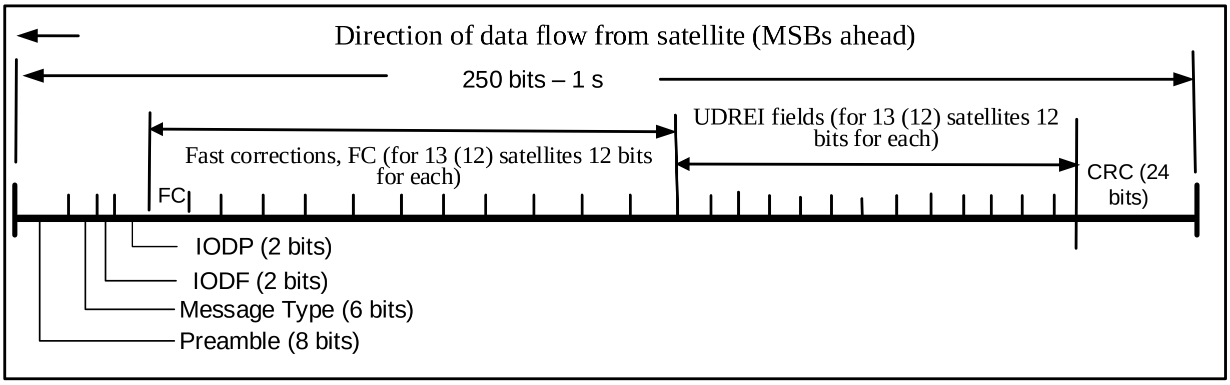

Figure 18 – Type 2-5 messages structure. Fast corrections

Table 18 – Types 2-5 message content. Fast corrections

Data content	Bits used	LSB value	Range of values	Unit
IODF	2	1	0–3	unitless
IODP	2	1	0–3	unitless
For 13 (12) satellites				
FC	12	0.125	±256.000	m
For 13 (12) satellites				
UDREI	4	See Table 20		
Note 1.– IODP is described in 7.2 and B.2. Note 2.– UDREI is described in 7.7.				

Preamble, Message Type, and CRC descriptions are given in section 6.

FC is a Fast Correction. It is a correction for fast changing satellite clock errors. This correction is added to measured pseudorange for this satellite.

Fast correction is applied as follows:

$$PR_{corrected}(t) = PR_{measured}(t) + FC + RRC(t_{0f}) \times (t - t_{0f}), \qquad (2)$$

where measured range to satellite is a $PR_{measured}$;

t – is the current time;

$$RRC(t_{0f}) = \frac{FC - FC_{previous}}{t_{0f} - t_{0f\_previous}};$$

FC – is the current (last) fast correction from Type 2-5 messages;

$FC_{previous}$ – is a previous fast correction;

t_{0f} – is a reference time for FC;

$t_{0f\_previous}$ – is a reference time for $FC_{previous}$.

IODF is a fast correction type identifier. In Type 2, 3, 4 and 5 messages this identifier named accordingly $IODF_2$, $IODF_3$, $IODF_4$ and $IODF_5$. 2-bit code for each identifier receives 0_{10}, 1_{10}, 2_{10} and 3_{10} values. When alarm signal is absent the sequential codes change in $IODF_2$, $IODF_3$, $IODF_4$ and $IODF_5$ identifiers (each code sequentially possess the value: 0_{10}, 1_{10} and 2_{10}) ensures the connection of Type 2-5 messages data with Type 6 message data (the synchronize method is described in Appendix B). However, if degradation of differential correction accuracy for one or several satellites (Data for them is transmitted in Type 2-5, 24 messages) is occurred Type 6 message in which relevant IODF value equals 3 is transmitted. The case of $IODF_j = 3_{10}$ indicates that for one or several satellites from Type j message differential range error σ^2_{UDRE} (see 7.7) has sharply increased. Compliance of $IODF_2$, $IODF_3$, $IODF_4$ and $IODF_5$ and satellite numbers is shown in section 7.7.

7.7 Type 6 Message. Integrity Data

7.7.1 Type 6 message contains information about accuracy of user differential range error (UDREI), and information which allows determining the integrity of all data. If new satellite becomes available, the Type 6 message shows it.

The structure and content of Type 6 message are given in Figure 19 and Table 19, respectively.

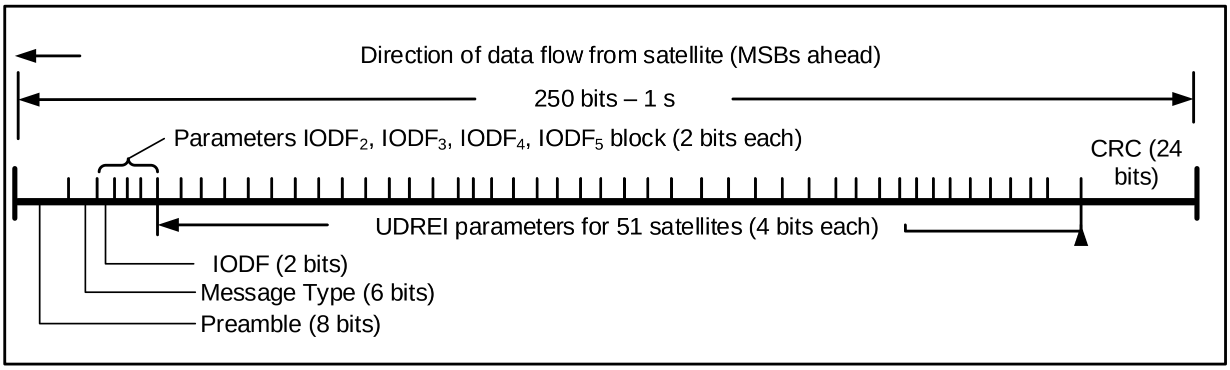

Figure 19 – Type 6 message structure. Integrity data

Table 19 – Type 6 message content. Integrity data

Data content	Bits used	LSB value	Range of values	Unit
$IODF_2$	2	1	0–3	unitless
$IODF_3$	2	1	0–3	unitless
$IODF_4$	2	1	0–3	unitless
$IODF_5$	2	1	0–3	unitless
For 51 satellite				
UDREI	4	See Table 20		

Preamble, Message Type, and CRC descriptions are given in section 6.

IODF is defined in section 7.6 and B.2. Apart standard synchronize functions during changing of data in channel (see Appendix B) IODF could also be used for rapid user alarm about satellite data integrity damaging entering the relevant group. IODF value is equal to 3 is used for this purpose. The following equivalence is acceptable:

- $IODF_2$ = 3 – data integrity damaging for satellites 1-13;
- $IODF_3$ = 3 – data integrity damaging for satellites14-26;
- $IODF_4$ = 3 – data integrity damaging for satellites 27-39;
- $IODF_5$ = 3 – data integrity damaging for satellites 40-51.

After receiving and analyzing UDREI in full value from the Type 6 message it is possible to determine in which satellite data integrity is damaged.

UDREI is accuracy of fast and long-term corrections for each satellite which is defined by PRN Mask (see 7.2). The value of each UDREI is defined according to Table 20 shows the RMS residual error σ_{UDRE} for the satellite with C/A code number equal to the order number of UDREI.

Table 20 – Evaluation of UDREI

UDREI	σ^2_{UDRE}
0	0.0520 m^2
1	0.0924 m^2
2	0.1444 m^2
3	0.2830 m^2
4	0.4678 m^2
5	0.8315 m^2
6	1.2992 m^2
7	1.8709 m^2
8	2.5465 m^2
9	3.3260 m^2
10	5.1968 m^2
11	20.7870 m^2
12	230.9661 m^2
13	2,078.695 m^2
14	“Not Monitored”
15	“Do Not Use”

Variance σ^2_{UDRE} of satellite residual error array (satellite clock and ephemeris) is defined by errors of ranging after application of fast and long-term corrections by user (without correction of ionospheric error). The residual error is used by the user when the estimated integrity parameters are evaluated, particularly during the calculations of specified alert limits HAL and VAL (see Appendix A).

Timeliness of delivery UDREI integrity parameters ensures the users reliability of navigation positioning. These parameters are transmitted along with fast corrections in Message Types 2-5 and 24.

7.8 Type 18 Message. Ionospheric Grid Point Masks

7.8.1 Type 18 message along with Type 26 message (see 7.9) allows evaluating ionospheric delay of L1 signal and its accuracy.

The structure and content of Type 18 message are given in Figure 20 and Table 21, respectively.

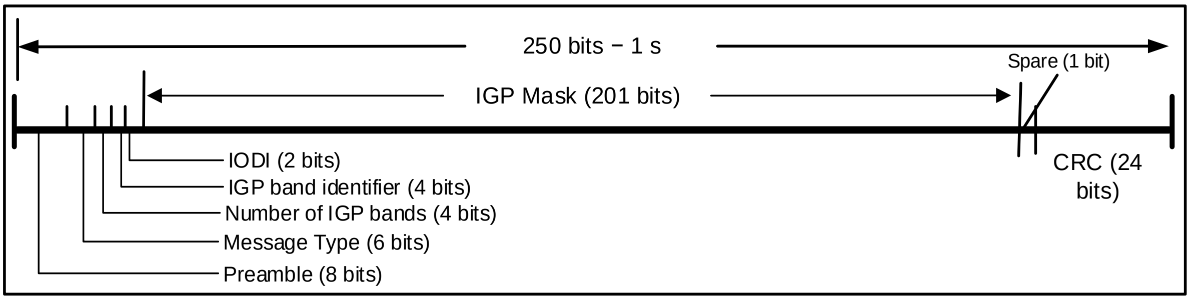

Figure 20 – Type 18 message structure. Ionospheric grid point masks

Table 21 – Type 18 message content. Ionospheric grid point masks

Data content	Bits used	LSB value	Range of values	Unit
Number of IGP bands	4	1	0–11	unitless
IGP band identifier	4	1	0–10	unitless
IODI	2	1	0–3	unitless
IGP Mask	201	–	–	unitless
Spare	1	–	–	–

Preamble, Message Type, and CRC descriptions are given in section 6.

Ionospheric grid is a set of points at the Earth’s surface for which vertical delays are estimated.

Ionospheric corrections to user’s pseudoranges (corrections which compensate for ionospheric delay) are transmitted in accordance with the SBAS standard as (see 7.9):

- ionospheric vertical delay;
- GIVEI, which is a value uniquely associated with ionospheric vertical error estimate variance.

These values are evaluated in ionospheric grid points (IGP) and estimate ionospheric vertical delay of L1 signal (1,575.42 MHz) when a signal passes through this IGP. The user interpolates the ionospheric vertical delay into a slant ionospheric delay for a given satellite line of sight using the values and technique described in Appendix H.

The ionospheric grid is evaluated as follows. The Earth’s surface is divided into 11 bands of IGP locations, where:

- 9 vertical bands, from 0 to 8, which cover the equator and middle latitudes;
- 2 horizontal bands, from 9 to 10, which cover high south and north latitudes.

IGP locations are given in Table 22. The predefined 1,808 IGP locations for all 11 bands are illustrated in Figure 21.

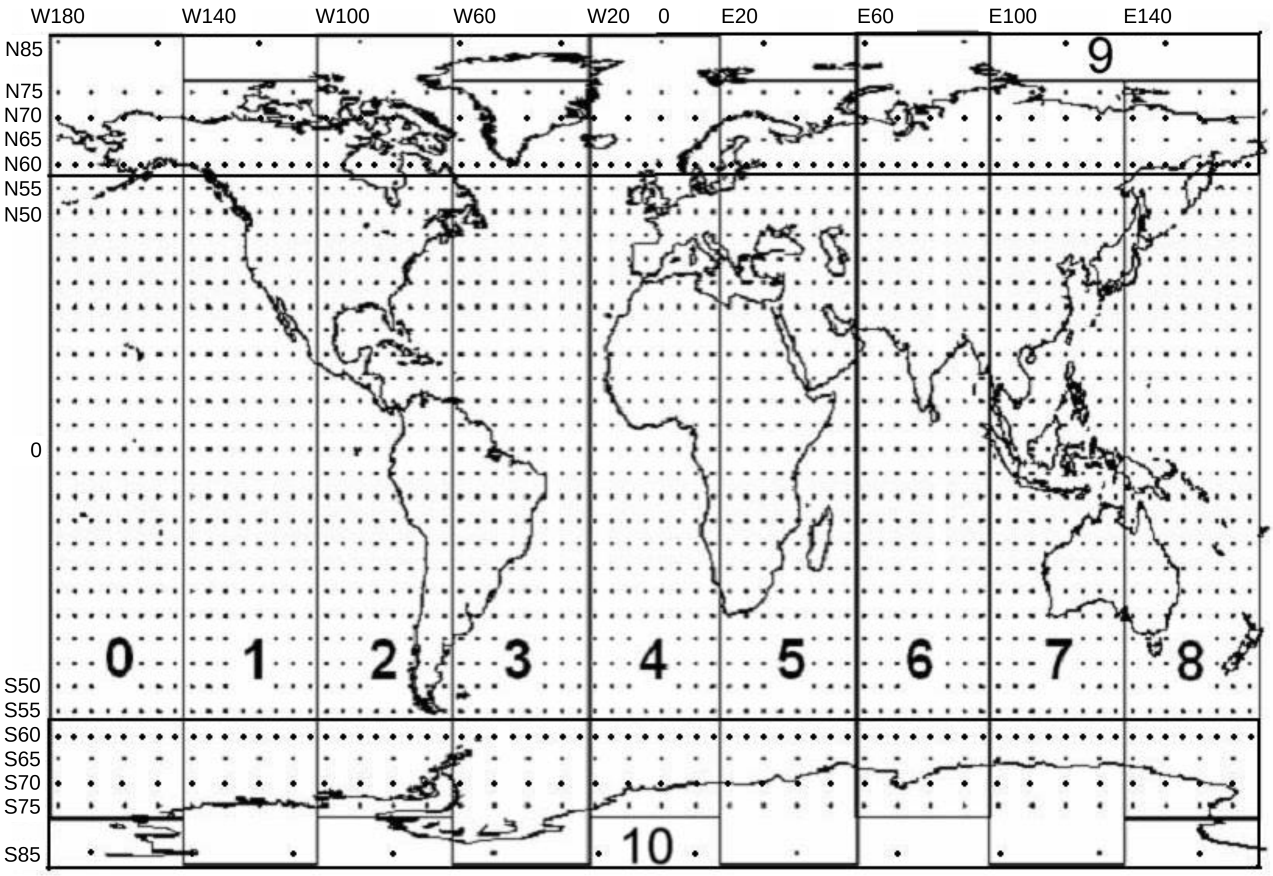

Figure 21 – IGP locations

Table 22 – IGP locations and band numbers, N – North, S – South, W – West, E – East

IGP location		IGP band mask
Longitude	All bands point latitudes:	
Band 0		
180W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	1–28
175W	55S, 50S, 45S, ..., 45N, 50N, 55N	29–51
170W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	52–78
165W	55S, 50S, 45S, ..., 45N, 50N, 55N	79–101
160W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102–128
155W	55S, 50S, 45S, ..., 45N, 50N, 55N	129–151
150W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152–178
145W	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201

Table 22 (continued)

IGP location		IGP band mask
Longitude	All bands point latitudes:	
Band 1		
140W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–28
135W	55S, 50S, 45S, ..., 45N, 50N, 55N	29–51
130W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	52–78
125W	55S, 50S, 45S, ..., 45N, 50N, 55N	79–101
120W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102–128
115W	55S, 50S, 45S, ..., 45N, 50N, 55N	129–151
110W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152–178
105W	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201
Band 2		
100W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
95W	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
90W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	51–78
85W	55S, 50S, 45S, ..., 45N, 50N, 55N	79–101
80W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102–128
75W	55S, 50S, 45S, ..., 45N, 50N, 55N	129–151
70W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152–178
65W	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201
Band 3		
60W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
55W	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
50W	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51–78
45W	55S, 50S, 45S, ..., 45N, 50N, 55N	79–101
40W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	102–128
35W	55S, 50S, 45S, ..., 45N, 50N, 55N	129–151
30W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152–178
25W	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201

Table 22 (continued)

IGP location		IGP band mask
Longitude	All bands point latitudes:	
Band 4		
20W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
15W	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
10W	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51–77
5W	55S, 50S, 45S, ..., 45N, 50N, 55N	78–100
0	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	101–128
5E	55S, 50S, 45S, ..., 45N, 50N, 55N	129–151
10E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152–178
15E	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201
Band 5		
20E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
25E	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
30E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51–77
35E	55S, 50S, 45S, ..., 45N, 50N, 55N	78–100
40E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101–128
45E	55S, 50S, 45S, ..., 45N, 50N, 55N	129–151
50E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	152–178
55E	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201
Band 6		
60E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
65E	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
70E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51–77
75E	55S, 50S, 45S, ..., 45N, 50N, 55N	78–100
80E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101–127
85E	55S, 50S, 45S, ..., 45N, 50N, 55N	128–150
90E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N, 85N	151–178
95E	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201

Table 22 (continued)

IGP location		IGP band mask
Longitude	All bands point latitudes:	
Band 7		
100E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
105E	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
110E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51–77
115E	55S, 50S, 45S, ..., 45N, 50N, 55N	78–100
120E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101–127
125E	55S, 50S, 45S, ..., 45N, 50N, 55N	128–150
130E	85S, 75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	151–178
135E	55S, 50S, 45S, ..., 45N, 50N, 55N	179–201
Band 8		
140E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	1–27
145E	55S, 50S, 45S, ..., 45N, 50N, 55N	28–50
150E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	51–77
155E	55S, 50S, 45S, ..., 45N, 50N, 55N	78–100
160E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	101–127
165E	55S, 50S, 45S, ..., 45N, 50N, 55N	128–150
170E	75S, 65S, 55S, 50S, 45S, ..., 45N, 50N, 55N, 65N, 75N	151–177
175E	55S, 50S, 45S, ..., 45N, 50N, 55N	178–200
Band 9		
60N	180W, 175W, 170W, …, 165E, 170E, 175E	1–72
65N	180W, 170W, 160W, …, 150E, 160E, 170E	73–108
70N	180W, 170W, 160W, …, 150E, 160E, 170E	109–144
75N	180W, 170W, 160W, …, 150E, 160E, 170E	145–180
85N	180W, 150W, 120W, … , 90E, 120E, 150E	181–192
Band 10		
60S	180W, 175W, 170W, …, 165E, 170E, 175E	1–72
65S	180W, 170W, 160W, …, 150E, 160E, 170E	73–108
70S	180W, 170W, 160W, …, 150E, 160E, 170E	109–144

Table 22 (continued)

IGP location		IGP band mask
Longitude	All bands point latitudes:	
75S	180W, 170W, 160W, …, 150E, 160E, 170E	145–180
85S	170W, 140W, 110W, …, 100E, 130E, 160E	181–192

IGP Mask is a set of IGPs for which the data is transmitted. The IGPs are numbered from 1 to 201, and bits are set to "0" or to "1" as follows. A bit set to one ("1") indicates that ionospheric correction data is being provided for the associated IGP (see Table 22) in Type 26 message. In all others the bit is set to zero ("0").

Number of IGP bands indicates the number of bands for which ionospheric delay data is transmitted.

IGP band identifier indicates a band from 0 to 10 to which ionospheric delays in Type 26 message are applied. Division of IGPs by bands is given in Table 22.

IODI is an issue of data about the ionosphere which indicates the current IGP Mask (see B.2).

7.9 Type 26 Message. Ionospheric Delay Corrections

7.9.1 Type 26 message along with Type 18 message (see 7.8) estimate ionospheric delays of L1 signal and their accuracy.

The structure and content of Type 26 message are given in Figure 22 and Table 23, respectively.

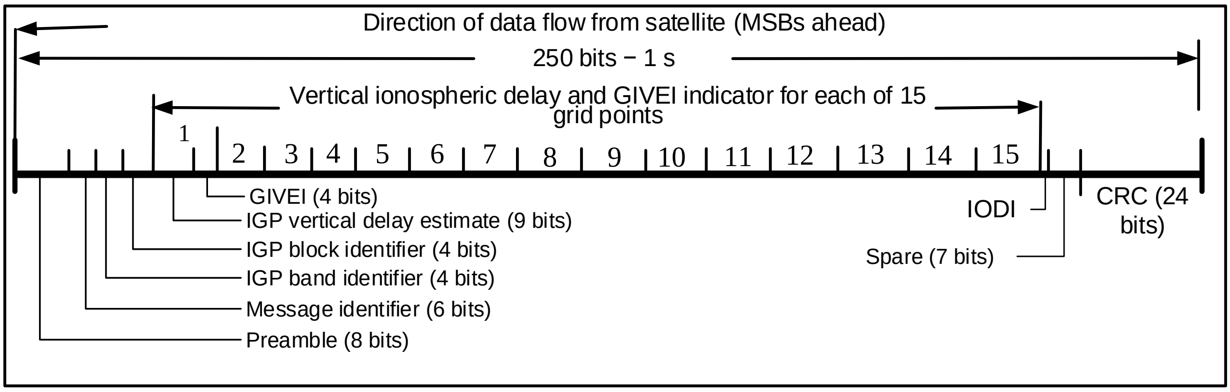

Figure 22 – Type 26 message structure. Ionospheric delay corrections

Table 23 – Type 26 message content. Ionospheric delay corrections

Data content	Bits used	LSB value	Range of values	Unit
IGP band identifier	4	1	0–10	unitless
IGP block identifier	4	1	0–13	unitless
For each of 15 IGPs				
Vertical ionospheric delay	9	0.125	0 – 63.875	m
GIVEI	4	See table 24		
IODI	2	1	0–3	unitless
Spare	7	–	–	–
Note.– IODI is described in 7.8 and B.2.				

Preamble, Message Type, and CRC descriptions are given in section 6.

Type 26 message indicates to which ionospheric grid points transmitted delays are applied by transmitting:

- an IGP band number which is identified in the same way as for Type 18 message (see 7.8);
- identifier of the block which identifies a group of 15 IGPs within the band for which ionospheric delays are transmitted. The IGP blocks are defined by dividing the sequence of 201 IGPs within a given band into groups of 15 IGPs;

- transmission of delays for IGPs within a block in which the corresponding "1" in the IGP Mask field follows (see 7.8). This procedure is similar to the data identification procedure described in section 7.2.

The user receives ionospheric corrections for each IGP in Type 26 message as two parameters:

- vertical ionospheric delay in L1 band caused by ionospheric impact in meters;

- Grid Ionospheric Vertical Error Indicator (GIVEI), which estimates error variance σ^2_{GIVE} of a pseudorange due to vertical delay. 4-bit GIVEI is uniquely associated with a variance value as given in Table 24.

Table 24 – Evaluation of GIVEI

GIVEI	σ^2_{GIVE}, m^2
0	0.0084
1	0.0333
2	0.0749
3	0.1331
4	0.2079
5	0.2994
6	0.4075
7	0.5322
8	0.6735
9	0.8315
10	1.1974
11	1.8709
12	3.3260
13	20.787
14	187.0826
15	"Not Monitored"

7.10 Type 7 and 10 Messages. Degradation Factors

7.10.1 Type 7 message contains information about time-out interval of fast corrections and changing rate of fast and long-time corrections.

Type 10 message contains a number of auxiliary parameters used to evaluate the positioning accuracy.

Degradation factors are used to define the validity of transmitted SDCM data. Degradation factors are transmitted through two messages:

- degradation factors of fast corrections are broadcast in Type 7 message;
- degradation factors of long-time corrections and ionospheric delays are broadcast in Type 10 message.

The structure and content of Type 7 message are given in Figure 23 and Table 25, respectively.

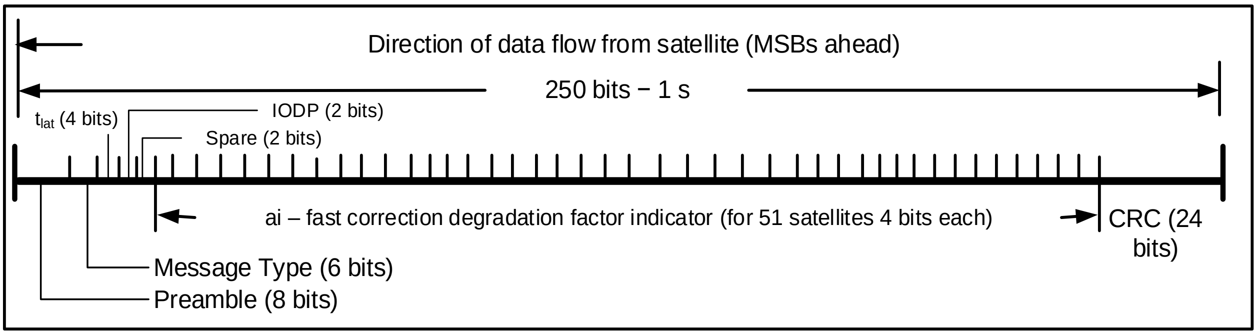

Figure 23 – Type 7 message structure. Fast correction degradation factors

Table 25 – Type 7 message content. Fast correction degradation factors

Data content	Bits used	LSB value	Range of values	Unit
t_{lat}	4	1	0–15	s
IODP	2	1	0–3	unitless
Spare	2	–	–	–
For 51 satellites				
a_i	4	See Table 26		
Note.– IODP is described in 7.2 and B.2.				

Preamble, Message Type, and CRC descriptions are given in section 6.

t_{lat} is the system latency, which is the time interval between the origin of the correction degradation (the time for which the correction is estimated) and the time the data is uplinked into SDCM channel (the retransmission delay is assumed to be equal to 0);

a_i is fast correction degradation factor indicator. The indicators are transmitted for the satellites given in PRN Mask. The a_i values are defined by correction changing rate (degradation factor) as given in Table 26.

Table 26 – Fast Correction Degradation Indicator and Factor Compliance

Fast correction degradation factor indicator (a_i)	Fast correction degradation factor, m/s^2
0	0.00000
1	0.00005
2	0.00009
3	0.00012
4	0.00015
5	0.00020
6	0.00030
7	0.00045
8	0.00060
9	0.00090
10	0.00150
11	0.00210
12	0.00270
13	0.00330
14	0.00460
15	0.00580
Note.– Fast correction time-out interval is given in Table D.3.	

The structure and content of Type 10 message containing degradation parameters of long-term corrections and ionospheric delays are given in Figure 24 and Table 27, respectively.

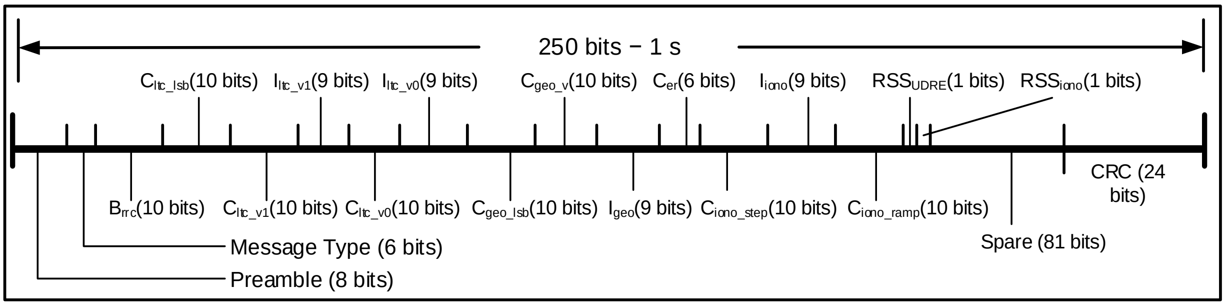

Figure 24 – Type 10 message structure. Long-term correction degradation factors

Table 27 – Type 10 message content. Long-term correction degradation factors

Data content	Bits used	LSB value	Range of values	Unit
B_{rrc}	10	0.002	0–2.046	m
C_{ltc_lsb}	10	0.002	0–2.046	m
C_{ltc_v1}	10	0.00005	0–0.05115	m/s
I_{ltc_v1}	9	1	0–511	s
C_{ltc_v0}	10	0.002	0–2.046	m
I_{ltc_v0}	9	1	0–511	s
C_{geo_lsb}	10	0.0005	0–0.5115	m
C_{geo_v}	10	0.00005	0–0.05115	m/s
I_{geo}	9	1	0–511	s
C_{er}	6	0.5	0–31.5	m
C_{iono_step}	10	0.001	0–1.023	m
I_{iono}	9	1	0–511	s
$C_{iono\ ramp}$	10	0.000005	0–0.005115	m/s
RSS_{UDRE}	1	1	0, 1	–
RSS_{iono}	1	1	0, 1	–
$C_{covariance}$	7	0.1	0–12.7	–
Spare	81	–	–	–

Preamble, Message Type, and CRC descriptions are given in section 6.

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

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

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

I_{ltc_v1} is the minimal update interval for long-term corrections if velocity code = 1.

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

I_{ltc_v0} is the minimum update interval for long-term corrections if velocity code = 0.

C_{geo_lsb} is not applicable for SDCM.

C_{geo_v} is not applicable for SDCM.

I_{geo} is not applicable for SDCM.

C_{er} is the bound on the residual error associated with using data beyond the time-out.

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

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

C_{iono_ramp} is the rate of change of the ionospheric corrections.

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

- RSS_{UDRE} = 0 – correction residuals are linearly summed;
- RSS_{UDRE} = 1 – correction residuals are root-sum-squared.

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

- RSS_{iono} = 0 – correction residuals are linearly added;
- RSS_{iono} = 1 – correction residuals are root-sum-squared.

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

Note 1.– The parameters a_i and t_{lat} are broadcast in Type 7 message.

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

7.11 Type 12 Message. SDCM Network Time/UTC Offset Parameters

7.11.1 Type 12 message contains information about SDCM network time/UTC offset. The message also transmits GLONASS/GPS time offsets.

The SDCM network time is reference time maintained by SDCM for the purpose of measurement data processing, forming, and uplinking.

The structure and content of Type 12 message are given in Figure 25 and Table 28, respectively.

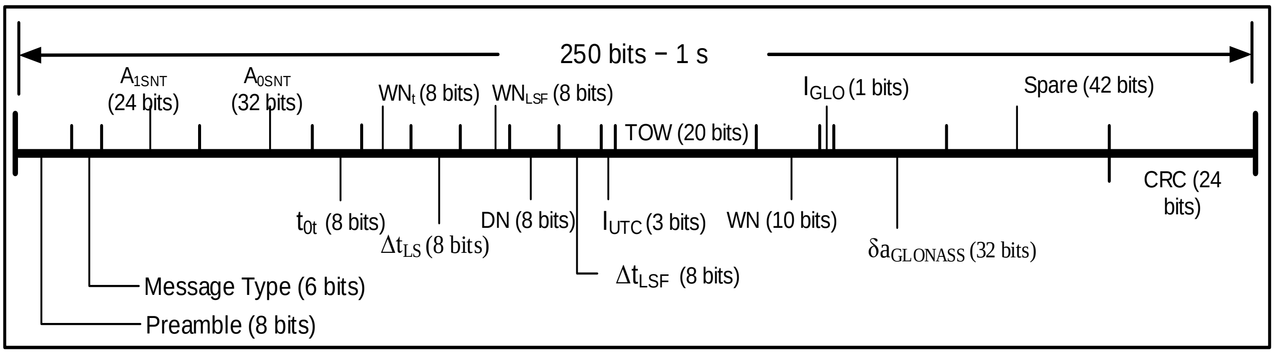

Figure 25 – Type 12 message structure. SDCM network time/UTC offset parameters

Table 28 – Type 12 message content. SDCM network time/UTC offset parameters

Data content	Bits used	LSB value	Range of values	Unit
A_{1SNT}	24	2^{-50}	$\pm 7.45 \times 10^{-9}$	s/s
A_{0SNT}	32	2^{-30}	±1	s
t_{0t}	8	4,096	0–602,112	s
WN_t	8	1	0–255	week
Δt_{LS}	8	1	±128	s
WN_{LSF}	8	1	0–255	week
DN	8	1	1–7	day
Δt_{LSF}	8	1	±128	s
I_{UTC}	3	1	BIPM, NIST, USNO	unitless
TOW	20	1	0–604,799	s
WN	10	1	0–1,023	week
I_{GLO}	1	1	0, 1	unitless
$\delta a_{GLONASS}$	32	2^{-31}	±1	s
Spare	42	–	–	–

Preamble, Message Type, and CRC descriptions are given in section 6.

A_{1SNT}, A_{0SNT}, t_{0t}, WN_t, Δt_{LS}, WN_{LSF}, DN and Δt_{LSF} are UTC parameters.

I_{UTC} is an indicator of the UTC standard that represents the reference UTC source in accordance with Table 29.

Table 29 – UTC standard identifier

I_{UTC}	UTC Standard
0	UTC as operated by the Communications Research Laboratory (CRL), Tokyo, Japan
1	UTC as operated by the U.S. National Institute of Standards and Technology
2	UTC as operated by the U.S. Naval Observatory
3	UTC as operated by the International Bureau of Weights and Measures
4	UTC as operated by the European Laboratory
5	UTC as operated by the Russian Federation – UTC(SU)
6	Not reserved
7	UTC not provided

TOW is GPS time-of-week, number of seconds elapsed from the transition from a previous GPS-week to the current.

WN is GPS week number.

I_{GLO} is the GLONASS indicator which indicates whether the GLONASS time parameters are being transmitted:

- If I_{GLO} equals 0, the GLONASS time parameters are not provided.
- If I_{GLO} equals 1, the GLONASS time parameters are provided.

$\delta a_{GLONASS}$ is the correction to the τ_{GPS} parameter transmitted in the GLONASS navigation message (τ_{GPS} represents GPS/GLONASS time offset).

7.12 Type 27 Message. Service Message

Type 27 message contains information about UDRE value for the specified region. It allows the user to estimate the quality of navigation service, namely, the degree of certainty of a position vector. This message contains information about the integral quality of the whole SDCM system.

The structure and content of Type 27 message are given in Figure 26 and Table 30, respectively.

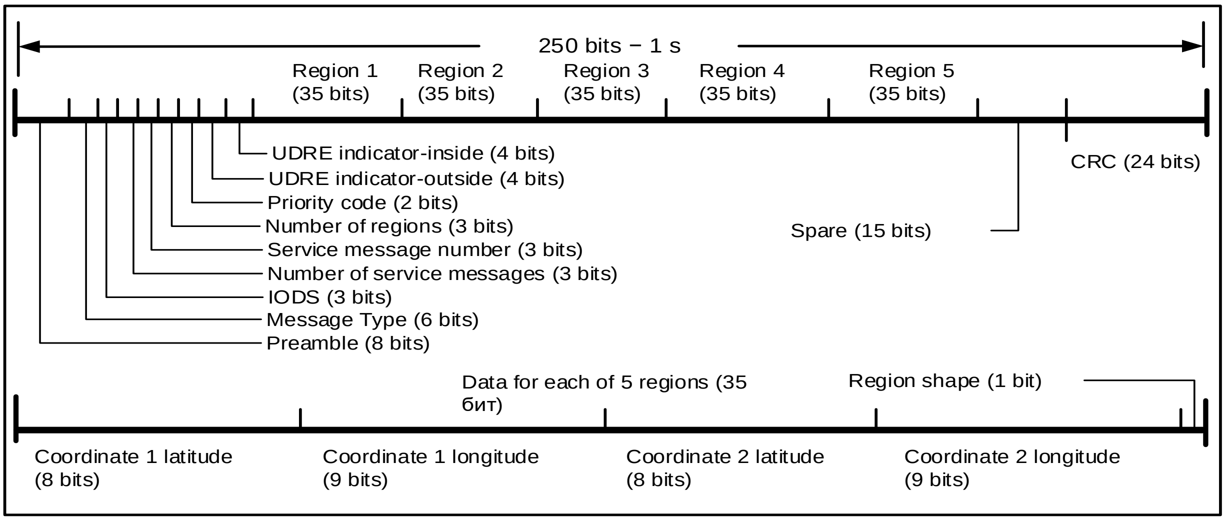

Figure 26 – Type 27 message structure. Service message

Table 30 – Type 27 message content. Service message

Data content	Bits used	LSB value	Range of values	Unit
IODS	3	1	0–7	unitless
Number of service messages	3	1	0–7	unitless
Service message number	3	1	0–7	unitless
Number of regions	3	1	0–5	unitless
Priority code	2	1	0–3	unitless
δUDRE indicator-inside	4	1	0–15	unitless
δUDRE indicator-outside	4	1	0–15	unitless
For 5 regions				
Coordinate 1 (latitude)	8	1	±90	°

Coordinate 1 (longitude)	9	1	±180	°
Coordinate 2 (latitude)	8	1	±90	°
Coordinate 1 (longitude)	9	1	±180	°
Region Shape	1	1	0, 1	unitless
Spare	15	–	–	–

Preamble, Message Type, and CRC descriptions are given in section 6.

IODP identifies service information and serves to identify service information in different Type 27 messages (see B.2).

Number of service messages determines the number of Type 27 messages being transmitted. If one message has already been transmitted, the number of service messages equals 0.

Service message number is a sequential number identifying the message within a currently transmitted set of Type 27 messages. Value is coded with 0.

Number of regions is a number of service regions for which coordinates are transmitted in the message.

Priority code is an indication of message precedence if two messages define overlapping regions. The message with a higher value of priority code takes precedence. If priority codes are equal, the message with the lower δUDRE takes precedence.

δ_{UDRE} indicator-inside is an indication of regional UDRE degradation factor (δUDRE) defined in accordance with Table 31. This indication is only applicable at locations inside any region defined in the Type 27 message.

δ_{UDRE} indicator-outside is an indication of regional UDRE degradation factor (δUDRE) defined in accordance with Table 31. This indication is only applicable at locations outside any region defined in the Type 27 message.

Coordinate 1 latitude and Coordinate 1 longitude are the latitude and longitude of corner point 1of a region (number of regions may vary from 1 to 5).

Coordinate 2 latitude and Coordinate 2 longitude are the latitude and longitude of corner point 2 of a region.

Region shape is a bit which define the region shape:

- Region shape equals 0 is a triangular region.
- Region shape equals 1 is a quadrangular region.

Table 31 – δ_{UDRE} indicator evaluation

δ_{UDRE} indicator	δ_{UDRE}
0	1
1	1.1
2	1.25
3	1.5
4	2
5	3
6	4
7	5
8	6
9	8
10	10
11	20
12	30
13	40
14	50
15	100

Regions boundary is set as follows:

- Coordinate 3 has Coordinate 1 latitude and Coordinate 2 longitude;

- if region is a quadrangle, Coordinate 4 has Coordinate 2 latitude and Coordinate 1 longitude;
- region boundary is formed by joining coordinates in the sequence 1-2-3-1 (triangle) or 1-2-3-4-1 (quadrangle). Boundary segments have constant latitude, constant longitude, or constant slope in degrees of latitude per degree of longitude. The change in latitude or longitude along any boundary segment between two coordinates is less than ±180 degrees.

7.13 Type 28 Message. Clock-Ephemeris Covariance Matrix

7.13.1 Type 28 message contains clock-ephemeris error covariance matrix. Type 28 message increases availability inside the SDCM service area and integrity outside.

These elements are used to compute the user differential range estimate (UDRE) degradation factor (δ_{UDRE}) as a function of user position.

To compress the transmitted data, SBAS clock-ephemeris error covariance matrix is transmitted as a set of its decomposition matrices: scale exponent SF ($SF_{i,j;}$), i, j = 1…4 and triangular matrix (E_{4x4}) of the Cholesky factorization: $C = (E_{SF})^T E_{SF}$.

The Cholesky factorization is an upper triangular matrix (4x4), which in combination with SF_{4x4} scale factor matrix, minimizes the amount of transmitted data.

The structure and content of Type 28 message are given in Figure 27 and Table 32, respectively.

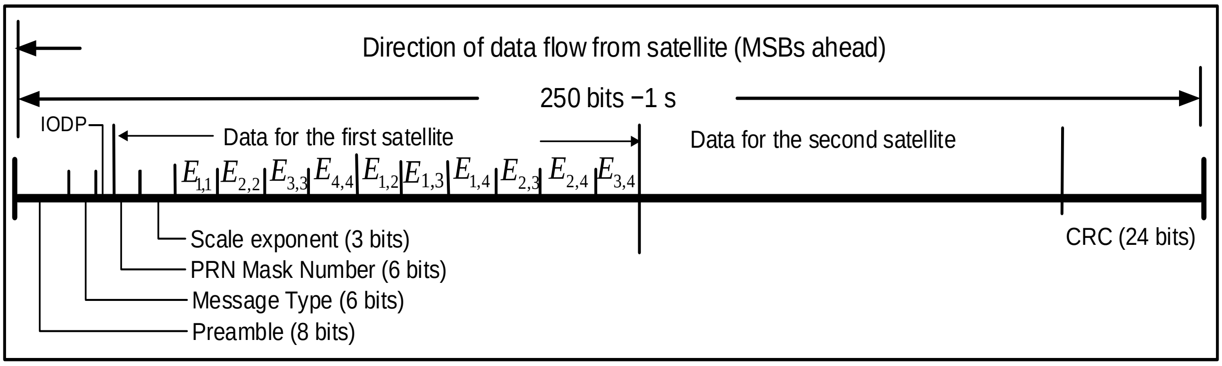

Figure 27 – Type 28 message structure. Clock-ephemeris covariance matrix

Table 32 – Type 28 message content. Clock-ephemeris covariance matrix

Data content	Bits used	LSB value	Range of values	Unit
IODP	2	1	0–3	unitless
For 2 satellites				
PRN Mask Number	6	1	0–51	unitless
Scale exponent	3	1	0–7	unitless
$E_{1,1}$	9	1	0–511	unitless
$E_{2,2}$	9	1	0–511	unitless
$E_{3,3}$	9	1	0–511	unitless
$E_{4,4}$	9	1	0–511	unitless
$E_{1,2}$	10	1	±512	unitless
$E_{1,3}$	10	1	±512	unitless
$E_{1,4}$	10	1	±512	unitless
$E_{2,3}$	10	1	±512	unitless
$E_{2,4}$	10	1	±512	unitless
$E_{3,4}$	10	1	±512	unitless
Note 1.– IODP is described in 7.2 and B.2. Note 2.– «PRN Mask Number» is described in 7.2.				

7.14 Type 62 and Type 63 Messages. Internal Test and Null Messages

7.14.1 Type 62 message is an internal message used to test some SDCM components. The user does not process it. Type 63 message has an empty content and it is transmitted when there are no any other messages. It is also ignored by a user.

Appendix A

(obligatory)

Estimated and Measured Variables Affecting the SDCM-Based Positioning Accuracy

A.1 The following variables are pre-configured to estimate the positioning accuracy:

- HAL (Horizontal Alert Limit) – a radius of a circle in the horizontal plane. Its center is at the true user position, that describes the region that is required to contain the indicated horizontal position with the required probability for a particular navigation mode (e.g. 10^{-7} per flight hour for en-route [1]);
- VAL (Vertical Alert Limit) – a half the length of a segment on the vertical axis. Its center being at the true position, that describes the region {−VAL, +VAL} that is required to contain the indicated vertical position with a probability of $1\text{-}10^{-7}$ in compliance with the integrity requirement [1].

The following variables, called protection levels, are evaluated to estimate user equipment positioning accuracy with SDCM data:

- HPL_{SDCM} – Horizontal Protection $Level_{SDCM}$. It is equal to the variance of the distribution model of the true horizontal positioning error, taking into account the use of SDCM data, with a confidence interval of "6σ" (the probability of falling into the interval is more than $1\text{-}10^{-7}$);
- VPL_{SDCM} –Vertical Protection $Level_{SDCM}$. It is equal to the variance of the distribution model of the true horizontal positioning error, taking into account the use of SDCM data, with a confidence interval of "6σ" (the probability of falling into the interval is more than $1\text{-}10^{-7}$).

[1)] This probability is defined by integrity requirements. The probability of a GPS, GLONASS and SDCM satellite integrity failure is assumed to be less than 10^{-4} per hour.

The user positioning accuracy applying SDCM data meets integrity requirements ($1\text{-}10^{-7}$ or higher) when:

$$\begin{aligned} HAL &\geq HPL_{SDCM}, \\ VAL &\geq VPL_{SDCM}. \end{aligned} \tag{A.1}$$

Appendix B
(obligatory)
Integrity Foundations

B.1 GLONASS, GPS, and SDCM Integrity

B.1.1 The user positioning performance entirely depends on GLONASS and GPS integrity monitoring. GNSS integrity is based on a large set of various factors which can be classified as follows:

- ground equipment accuracy factor which affects the uplink correction data;
- GLONASS and GPS onboard satellite equipment accuracy;
- residual errors due to atmospheric effects along signal path.

GNSS users don’t distinguish the first two types of factors as they appear as a summary ranging signal error. For the satellite status and basic corrections functions, an error uncertainty for the ephemeris and clock corrections is determined by the SDCM ground segment. This uncertainty is modeled by the variance of a zero-mean, normal distribution that describes the user differential range error (UDRE) for each ranging source after application of fast and long-term corrections and excluding atmospheric effects and receiver errors. UDRE bounds GNSS integrity as the upper limit of a pseudorange error.

B.1.2 A single-frequency user receiver also requires the UIRE value for precise GNSS integrity evaluation. The UIRE is a residual error of the ionospheric affect estimation based on an ionospheric delay map data in the SDCM-signal. This map is a data set of grid ionospheric vertical delays and grid ionospheric vertical errors (GIVEI) related to a dispersion of these delays estimation. Basing on the GIVEI value and its own position, the user evaluates UIRE. The UIRE value is similar to the GIVE but for a user position, for example, between grid nodes of the ionospheric delay~~s~~ map (see H.4.7).

B.1.3 There is a finite probability that an SDCM receiver would not receive a SDCM message. In order to continue navigation in that case, the SDCM broadcasts degradation values in the signal-in-space. These values are used in a number of mathematical models that evaluates the additional residual error from both long-term and quick corrections caused by using old but valid SDCM data. These models are used to update the UDRE and UIRE variables if appropriate.

B.1.4 Receiver uses the UDRE and UIRE values to estimate positioning error. The error is evaluated by projecting the pseudorange error models to the position domain. Horizontal Protection Level (HPL) bounds the user horizontal positioning error with the probability in compliance with the integrity requirements. Similarly, VPL provides a bound on the vertical position. If estimated HPL or VPL exceeds HAL or VAL alert limit, SDCM integrity becomes risky.

B.1.5 Residual Orbit and Clocks Errors (σ_{UDRE}).

The residual clock error is well characterized by a zero-mean, normal distribution. The residual ephemeris error depends upon the user location. For the precise differential function, the residual error for all users within a defined service area is reflected in the σ_{UDRE}.

B.1.6 Vertical Ionospheric Error (σ_{GIVE}).

The residual ionospheric error is characterized by a zero-mean, normal distribution. The errors are caused by a measurement noise, ionospheric map data accuracy and spatial decorrelation of the ionosphere.

B.1.7 User Equipment Errors

There are two error sources: a multipath effect and receiver hardware accuracy, here a standard multipath model may be used. In particular, the following expression is assumed to be true for user equipment: $\sigma^2_{air} = \sigma^2_{receiver} + \sigma^2_{multipath}$, where $\sigma_{receiver}$ is estimated in meters using equation:

$$\sigma_{receiver} = \begin{cases} 0.36 \text{ for GPS satelltes,} \\ 0.72 \text{ for GLONASS satellites.} \end{cases} \tag{B.1}$$

and $\sigma_{multypath}$ is estimated in meters using equation:

$$\sigma_{multypath} = 0.13 + 0.53e^{(-El/10)}\ , \tag{B.2}$$

where *El* is an elevation angle, °.

B.1.8 Tropospheric Model Error

A receiver uses the model to eliminate tropospheric effects. The user applies a specified model for the residual tropospheric error (σ_{tropo}) using the equation (E.7), presented in Appendix E.

B.2 SDCM Data Integrity

B.2.1 Synchronization of Data Transmitted by SDCM GEO-Satellites

B.2.1.1 SDCM data is considered correctly received by navigation user equipment when a complete set of data is selected for each operational satellite from a received data flow and selected messages that belong to the same data validity interval are properly applied.

When receiving SDCM messages the user takes into account that the data is transmitted and received with a certain delay. Moreover, the sequence of data transmission is not constant and may vary in SDCM channel. SDCM channel serves mainly broadcast data within data update intervals defined by the SBAS standard. The user is provided with all necessary information to identify and bind the received data, i.e. to synchronize the received data with the number of navigation satellite for which it is generated, and with the time to which these data belong.

Data identification and synchronization methods defined by the standard also consider restrictions from data transmission channel. The format of data described herein identifies and synchronizes data under the following channel restrictions:

- the lowest possible capacity for data transmission in compliance with the SBAS standard. The SBAS standard permits the transmission of data flow with the rate of 250 bps for no more than 51 satellites.;
- SDCM assumes that the SBAS standard could be expanded and applied in the user equipment in force. To service a future expanded orbital satellite constellation it is required to multiplex a data flow due to limited channel capacity. For this purpose, non-relevant data, for antipodal satellites, is removed from transmitted messages. The SBAS standard assumes that SDCM satellite transmits the data for the navigation satellites at user's line of sight. This version of the standard assumes the same data decoding and application procedures and ensures the backward compatibility with legacy user equipment. The SBAS standard is amended because it is necessary to change to the dynamic model of the mask. This mask identifies exactly those satellites for which data is transmitted via the given SDCM satellite (for no more than 51 satellites);
- asynchronous channel data update. Data is transmitted and received asynchronously in a channel. That is why the data in the channel may contain both new (updated) data and data from previous update cycle. Recall that for a user the data is considered to be valid and compatible only when it is received and transmitted at the same update cycle.

The review of the SBAS standard and the total number of satellites in GPS, GLONASS, Galileo, WAAS, EGNOS and SDCM justifies the necessity to take these restrictions into consideration. The number of satellites will make up 100 given the declared redundancy. In compliance with the SBAS standard, this number significantly exceeds the SDCM channel capacity as the channel can transmit data only for 51 satellites. However, the total number of satellites at user’s line of sight will not exceed 43. This document assumes a backward capability as its provisions are fully applicable to existing user equipment widely used for the GPS and WAAS systems in compliance with the previous version of the SBAS standard.

SDCM applies the following procedures for data synchronization given the described capacity restrictions. The procedures are presented in a descending priority which the user observes for data decoding:

- each message starts with a preamble (see 6.1);
- decoding data format and rules are given in a message type identifier (see 6.1);
- validity data is controlled by CRC (see 6.3);
- synchronization data for various satellites is performed either by:

  1) providing a PRN code number (see 5.3) of the related satellite in a message directly;

  2) by matching the related satellite with data in a PRN Mask if the PRN is missing (see 7.2). The following rule is applied: data blocks in a decoded message follow exactly the same sequence as numbers of PRN Mask bits. Each PRN Mask bit number equals to PRN code number. Zero-bit value means that the corresponding satellite is not identified in data and is ignored. For example, 210-bit PRN Mask equal to 1001 1000 1100 0010 0000…0000 indicates availability of data for the satellites with PRN code numbers 1, 4, 5, 9, 10 and 15 and sets a message transmission sequence relatively to in PRN code number ascending order of increase;

- Data time synchronization is performed by selecting received data with the same Issue of Data value (see B.2.2). Compatible data has the same data Identifiers/Issue of Data value. Data Identifier/ Issue of Data is at least 2 bits long. It identifies the old/new data for at least two consecutive data updates.

B.2.2 Checking Messages for Data Compatibility

B.2.2.1 As there are no requirements for synchronous data reception and transmission in the SBAS standard, data may be updated in the SBAS channel while the user receives messages. In this case received messages relate to different time and become incompatible. For correct use all data must be preliminary checked by the user for compatibility. Compatible data has the same code value in the field Issue of Data. The following Issue of Data are used in the SDCM system: (IOD – Issue of Data):

- $IODC_k$ (GPS IOD Clock) – is GPS satellite time, where k is a satellite number;
- $IODE_k$ (GPS IOD Ephemeris) – is GPS satellites ephemeris, where k is a satellite number;
- $IODG_k$ (GLONASS Data) – identifies clocks and ephemeris of the GLONASS satellites, where k is a satellite number;
- IODP (IOD PRN Mask) – identifies the current list of satellites and the current PRN Mask;
- $IODF_j$ (IOD Fast $Corrections_j$) – identifies fast corrections, where j is a Type 2 to 5 message;
- IODI (IOD Ionospheric Grid Point Mask) – identifies ionospheric conditions and the current IGP Mask;
- IODS (IOD Service Message) – identifies Type 27 Service Message.

Figure B.1 shows block diagram for checking SDCM messages compatibility at the user’s end.

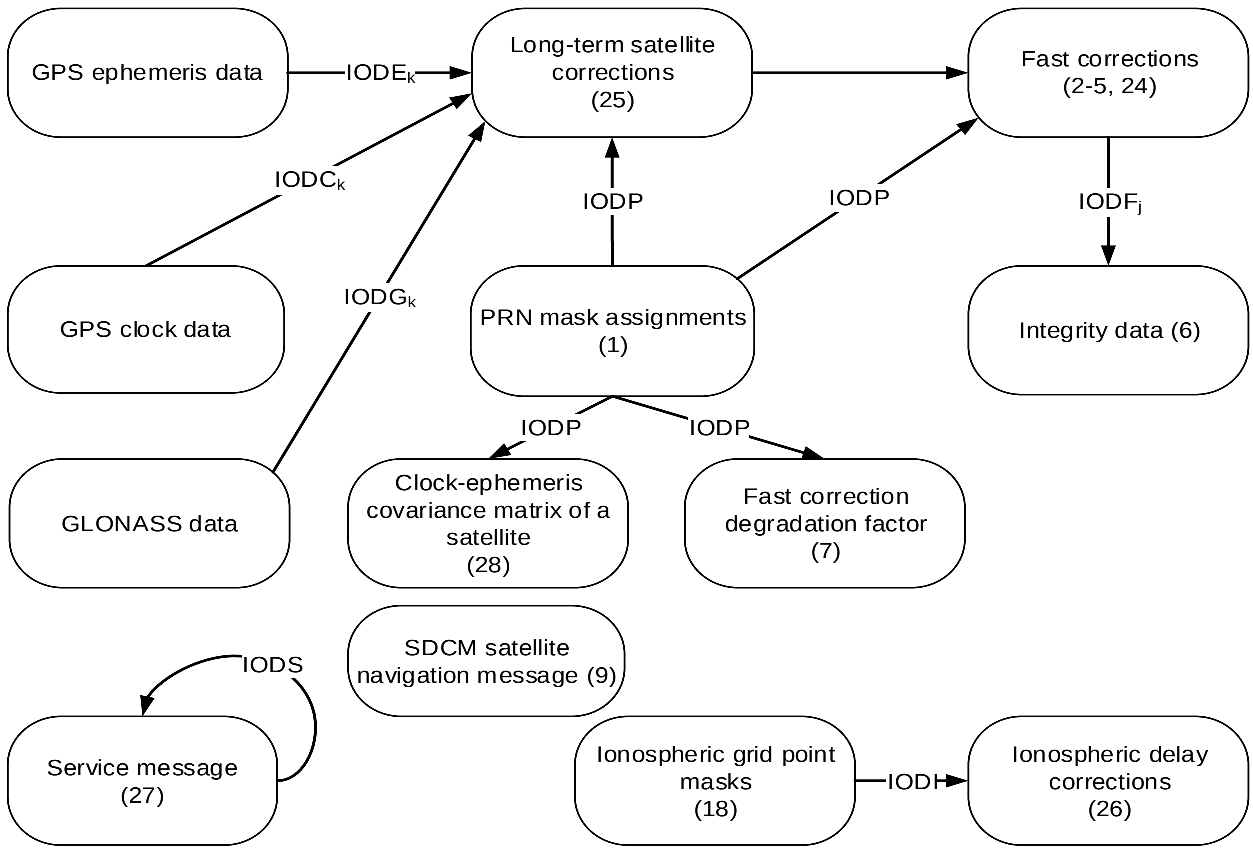

Figure B.1 – Message Block Diagram

Before applying data, the user must check message types indicated in the Figure B.1 for compatibility applying the IODs presented.

Appendix C

(obligatory)

Tables of SDCM Messages Content

C.1 Each SDCM message is coded in accordance with an established message format defined in Tables C.1−C.19. The most significant bit is a sign bit in the fields which values can be either positive or negative. Sign zero represents plus, sign one represents minus.

Table C.1 – Type 0 message. Test Message

Data content	Bits used	LSB value	Range of values	Unit
Spare	212	–	–	–

Table C.2 – Type 1 message. PRN Mask Assignments

Data content	Bits used	LSB value	Range of values	Unit
PRN Mask	210	–	–	unitless
IODP	2	1	0–3	unitless
Note.– All fields are described in 7.2.				

Table C.3 – Type 2-5 messages. Fast Corrections

Data content	Bits used	LSB value	Range of values	Unit
IODF	2	1	0–3	unitless
IODP	2	1	0–3	unitless
For 13 (12) satellites	–	–	–	–
FC	12	0.125	±256.000	m
For 13 (12) satellites	–	–	–	–
UDREI	4	See Table 20		
Note 1.– IODF and FC are described in 7.6. Note 2.– IODP is described in 7.2 and B.2. Note 3.– UDREI is described in 7.7.				

Table C.4 – Type 6 message. Integrity Data

Data content	Bits used	LSB value	Range of values	Unit
$IODF_2$	2	1	0–3	unitless
$IODF_3$	2	1	0–3	unitless
$IODF_4$	2	1	0–3	unitless
$IODF_5$	2	1	0–3	unitless
For 51 satellites	–	–	–	–
UDREI	4	See Table 20		
Note 1.– $IODF_2$, $IODF_3$, $IODF_4$, $IODF_5$ are described in 7.6. Note 2.– UDREI is described in 7.7.				

Table C.5 – Type 7 message. Fast Correction Degradation Factor

Data content	Bits used	LSB value	Range of values	Unit
t_{lat}	4	1	0–15	s
IODP	2	1	0–3	unitless
Spare	2	–	–	–
For 51 satellites	–	–	–	–
a_i	4	See Table C.6		
Note 1.– IODP is described in 7.2 and B.2. Note 2.– t_{lat} and a_i are described in 7.10.				

Table C.6 – Fast Correction Degradation Indicator and Factor Compliance

Fast correction degradation factor indicator (a_i)	Fast correction degradation factor, m/s^2
0	0.00000
1	0.00005
2	0.00009
3	0.00012
4	0.00015
5	0.00020
6	0.00030
7	0.00045
8	0.00060
9	0.00090
10	0.00150
11	0.00210
12	0.00270
13	0.00330
14	0.00460
15	0.00580

Table C.7 – Type 9 message. SDCM Satellite Navigation Message

Data content	Bits used	LSB value	Range of values	Unit
Spare	8	–	–	–
$t_{0,GEO}$	13	16	0–86,384	s
URA	4	See Table C.8		
X_G	30	0.08	±42,949,673	m
Y_G	30	0.08	±42,949,673	m
Z_G	25	0.4	±6,710,886.4	m
$\dot{X}_G$	17	0.000625	±40.96	m/s
$\dot{Y}_G$	17	0.000625	±40.96	m/s
$\dot{Z}_G$	18	0.004	±524.288	m/s
$\ddot{X}_G$	10	0.0000125	±0.0064	m/s^2
$\ddot{Y}_G$	10	0.0000125	±0.0064	m/s^2
$\ddot{Z}_G$	10	0.0000625	±0.032	m/s^2
a_{Gf0}	12	2^{-31}	$\pm 0.9537 \times 10^{-6}$	s
a_{Gf1}	8	2^{-40}	$\pm 1.1642 \times 10^{-10}$	s/s
Note.– All fields are described in 7.3.				

Table C.8 – User range accuracy

URA	Accuracy (RMS), m
0	2
1	2.8
2	4
3	5.7
4	8
5	11.3
6	16
7	32
8	64
9	128
10	256
11	512
12	1,024
13	2,048
14	4,096
15	“Do Not Use”

Table C.9 – Type 10 message. Degradation Factors

Data content	Bits used	LSB value	Range of values	Unit
B_{rrc}	10	0.002	0–2.046	m
C_{ltc_lsb}	10	0.002	0–2.046	m
C_{ltc_v1}	10	0.00005	0–0.05115	m/s
I_{ltc_v1}	9	1	0–511	s
C_{ltc_v0}	10	0.002	0–2.046	m
I_{ltc_v0}	9	1	0–511	s
C_{geo_lsb}	10	0.0005	0–0.5115	m
C_{geo_v}	10	0.00005	0–0.05115	m/s
I_{geo}	9	1	0–511	s
C_{er}	6	0.5	0–31.5	m
C_{iono_step}	10	0.001	0–1.023	m
I_{iono}	9	1	0–511	s
$C_{iono\ ramp}$	10	0.000005	0–0.005115	m/s
RSS_{UDRE}	1	1	0, 1	unitless
RSS_{iono}	1	1	0, 1	unitless
$C_{covariance}$	7	0.1	0–12.7	unitless
Spare	81	–	–	–
Note.– All fields are described in 7.10.				

Table C.10 – Type 12 message. SDCM Network Time /UTC Offset Parameters

Data content	Bits used	LSB value	Range of values	Unit
A_{1SNT}	24	2^{-50}	$\pm 7.45 \times 10^{-9}$	s/s
A_{0SNT}	32	2^{-30}	±1	s
t_{0t}	8	4,096	0–602,112	s
WN_t	8	1	0–255	week
Δt_{LS}	8	1	±128	s
WN_{LSF}	8	1	0–255	week
DN	8	1	1–7	day
Δt_{LSF}	8	1	±128	s
I_{UTC}	3	1	BIPM, NIST, USNO	unitless
TOW	20	1	0–604,799	s
WN	10	1	0–1,023	week
I_{GLO}	1	1	0, 1	unitless
$\delta a_{GLONASS}$	32	2^{-31}	±1	s
Spare	42	–	–	–
Note.– All fields are described in 7.11.				

Table C.11 – Type 17 message. SDCM Satellite Almanac

Data content	Bits used	LSB value	Range of values	Unit
For each of three satellites	–	–	–	–
Spare	2	–	–	–
PRN code number	8	1	0–210	unitless
Health and status	8	–	–	unitless
Spare	49	–	–	–
Spare	11	–	–	–
Note.– All fields are described in 7.4.				

Table C.12 – Type 18 message. Ionospheric Grid Point Masks

Data content	Bits used	LSB value	Range of values	Unit
Number of IGP bands	4	1	0–11	unitless
IGP band identifier	4	1	0–10	unitless
IODI	2	1	0–3	unitless
IGP Mask	201	–	–	unitless
Spare	1	–	–	–
Note.– All fields are described in 7.8.				

Table C.13 – Type 24 message. Mixed Fast/Long-Term Corrections

Data content	Bits used	LSB value	Range of values	Unit
For 6 satellites	–	–	–	–
FC	12	0.125	±256.000	m
For 6 satellites	–	–	–	–
UDREI	4	See Table 20		
IODP	2	1	0–3	unitless
IODF	2	1	0–3	unitless
Block identifier	2	1	0–3	unitless
Spare	4	–	–	–
Half of Type 25 message	106	–	–	–
Note 1.– FC is described in 7.6. Note 2.– UDREI is described in 7.7. Note 3.– IODP is described in 7.2 and B.2. Note 4.– IODF is described in 7.6 and B.2.				

Table C.14 – Type 25 message for velocity code = 0. Fast corrections

Data content	Bits used	LSB value	Range of values	Unit
Velocity code	1	1	0	unitless
For two satellites	–	–	–	–
PRN Mask Number	6	1	0–51	unitless
IOD	8	1	0–255	unitless
δx	9	0.125	±32	m
δy	9	0.125	±32	m
δz	9	0.125	±32	m
δa_{f0}	10	2^{-31}	$\pm 2^{-22}$	s
IODP	2	1	0–3	unitless
Spare	1	–	–	–

Note 1.– IODP is described in 7.2 and B.2.
Note 2.– PRN Mask Number is described in 7.2.
Note 3.– All others are described in 7.5.

Table C.15 – Type 25 message for velocity code = 1. Long-term corrections

Data content	Bits used	LSB value	Range of values	Unit
Velocity code	1	1	1	unitless
PRN Mask Number	6	1	0–51	unitless
IOD	8	1	0–255	unitless
δx	11	0.125	±128	m
δy	11	0.125	±128	m
δz	11	0.125	±128	m
δa_{f0}	11	2^{-31}	$\pm 2^{-21}$	s
$\delta \dot{x}$	8	2^{-11}	±0.0625	m/s
$\delta \dot{y}$	8	2^{-11}	±0.0625	m/s
$\delta \dot{z}$	8	2^{-11}	±0.0625	m/s
δa_{f1}	8	2^{-39}	$\pm 2^{-32}$	s/s
t_0	13	16	0–86,384	s
IODP	2	1	0–3	unitless
Note 1.– PRN Mask and IODP are described in 7.2 and B.2. Note 2.– PRN Mask Number is described in 7.2. Note 3.– All others are described in 7.5.				

Table C.16 – Type 26 message. Ionospheric Delay Corrections

Data content	Bits used	LSB value	Range of values	Unit
IGP band identifier	4	1	0–10	–
IGP block identifier	4	1	0–13	–
For each of 15 IGPs	–	–	–	–
Vertical ionospheric delay	9	0.125	0–63.875	m
GIVEI	4	See Table 24		
IODI	2	1	0–3	unitless
Spare	7	–	–	–
Note 1.– IODI is described in 7.8 and B.2. Note 2.– All others are described in 7.9.				

Table C.17 – Type 27 message. Service message

Data content	Bits used	LSB value	Range of values	Unit
IODS	3	1	0–7	unitless
Number of service messages	3	1	0–7	unitless
Service message number	3	1	0–7	unitless
Number of regions	3	1	0–5	unitless
Priority code	2	1	0–3	unitless
δUDRE indicator-inside	4	1	0–15	unitless
δUDRE indicator-outside	4	1	0–15	unitless
For 5 regions	–	–	–	–
Coordinate 1 (latitude)	8	1	±90	°
Coordinate 1 (longitude)	9	1	±180	°
Coordinate 2 (latitude)	8	1	±90	°
Coordinate 1 (longitude)	9	1	±180	°
Region Shape	1	1	0, 1	unitless
Spare	15	–	–	–
Note.– All parameters are described in 7.12.				

Table C.18 – Type 63 message. Null message

Data content	Bits used	LSB value	Range of values	Unit
Spare	212	–	–	–

Table C.19 – Type 28 message. Clock-Ephemeris Covariance Matrix

Data content	Bits used	LSB value	Range of values	Unit
IODP	2	1	0–3	unitless
For 2 satellites				
PRN Mask Number	6	1	0–51	unitless
Scale exponent	3	1	0–7	unitless
$E_{1,1}$	9	1	0–511	unitless
$E_{2,2}$	9	1	0–511	unitless
$E_{3,3}$	9	1	0–511	unitless
$E_{4,4}$	9	1	0–511	unitless
$E_{1,2}$	10	1	±512	unitless
$E_{1,3}$	10	1	±512	unitless
$E_{1,4}$	10	1	±512	unitless
$E_{2,3}$	10	1	±512	unitless
$E_{2,4}$	10	1	±512	unitless
$E_{3,4}$	10	1	±512	unitless
Note 1.– IODP is described in 7.2 and B.2. Note 2.– PRN Mask Number is described in 7.2. Note 3.– All others are described in 7.13.				

Appendix D

(obligatory)

Recommendations on SDCM Data Use in the GLONASS/GPS/SDCM Systems

D.1 General Provisions

D.1.1 Required Data and Broadcast Intervals

SDCM transmits data required for the functions performed by the system, as shown in Table D.1. If SDCM data transmitted by the system is not required for a specific function, the data is used for other functions. Maximum data broadcast intervals are defined in Table D.1.

Table D.1 – Data broadcast intervals and supported functions

Data type	Maximum broadcast interval, s	SDCM ranging	GNSS satellite status	Basic differential correction	Precise differential correction	Associated message types
Clock-ephemeris covariance matrix	120	–	–	–	–	28
SDCM in test mode	6	–	–	–	–	0
PRN Mask	120	–	R	R	R	1
UDREI	6	–	R*	R	R	2–6, 24
Fast corrections	60	–	R*	R	R	2–5, 24
Long-term corrections	120	–	R*	R	R	24, 25
SDCM GEO ranging function data	120	R	–	–	–	9
Fast correction degradation	120	–	R*	R	R	7
Degradation factors	120	–	–	–	R	10

Table D.1 (continued)

Data type	Maximum broadcast interval, s	SDCM ranging	GNSS satellite status	Basic differential correction	Precise differential correction	Associated message types
Ionospheric grid mask	300	–	–	–	R	18
Ionospheric delay corrections	300	–	–	–	R	26
Offset parameters of SDCM and UTC network time	300	–	R	R	R	12
SDCM almanac data	300	–	R	R	R	17
Service message	300	–	–	–	–	27
Note 1.– “R” indicates that the data must be broadcast to support the function. Note 2.– “R*” indicates special coding as described in D.2.4. Note 3.– Type 12 messages are only required if data are provided for GLONASS satellites.						

D.1.2 Test Message

SDCM transmits a test message Type 0 when it is necessary to inform users that SDCM data is invalid.

D.1.3 Almanac

SDCM transmits the almanacs of the SDCM satellites (see 7.4) where satellites coordinates are defined with the error of less than 150 km. Unused almanacs in the Type 17 Message will have PRN code number 0.

“Health” and “status” indicate the status of a satellite and a service provider (see Table 12).

D.2 GNSS Satellites Status

D.2.1 The satellite status data provided by SDCM complies with the requirements described in this section.

D.2.2 Performance of Satellite Status Functions

Given any valid combination of valid data, the probability of a horizontal error exceeding the HPL_{SDCM} (as defined in Appendix H) for longer than 8 consecutive seconds is less than 10^{-7} in any hour, assuming a user with zero latency.

Note.– Valid data is defined to be the data that is not timed out according to Table D.1.

D.2.3 «PRN Mask» and IODP

SDCM transmits a PRN mask and IODP (Type 1 message).

The PRN mask values indicate whether or not data is being provided for each GNSS satellite. The IODP changes when there is a change in the PRN mask. IODP in Type 1 Message is changed before IODP change in any other message. The IODP in Type 2 to 5, 7, 24, 25 and 28 messages are equal to the IODP transmitted in the PRN Mask message (Type 1 message) used to designate the satellites providing data in the message.

When the PRN Mask value is changed, SDCM repeats the Type 1 message several times before referencing it in other messages to ensure that users receive the new PRN Mask value.

D.2.4 The Integrity Data

If SDCM does not provide the required differential correction accuracy and the pseudorange error exceeds 150 meters, then SDCM sets "Do Not Use" indicator (URDEI = 15).

If SDCM does not provide the required differential correction accuracy and the pseudorange error is not determined, then SDCM sets “Not Monitored” indicator (URDEI = 14).

If SDCM does not provide the required differential correction accuracy and “Do Not Use” or “Not Monitored” indicators are not set for the current satellite, then SDCM broadcast a UDREI=13 value.

If data integrity is violated, the IODFj parameter in Type 2 to 5, 6 or 24 messages is defined equal to 3 (see 7.7).

D.3 Differential Correction

D.3.1 SDCM provides the required accuracy of differential correction in compliance with the requirements contained in this section.

D.3.2 Standard Differential Correction Performance

Given any valid combination of SDCM data, the probability of an out-of-tolerance condition for longer than the relevant time-to-alert is less than 2×10^{-7} during any approach (less than 6 s), assuming a user with zero latency. An out-of-tolerance condition it is defined as a horizontal error exceeding the HPL_{SDCM} or a vertical error exceeding the VPL_{SDCM} (as defined in Appendix H). When an out-of-tolerance condition is detected, the resulting alert message (broadcast in a Type 6 message) is repeated three times. Thus, the SDCM alert message is repeated for a total of four times in 4 seconds.

Note 1.– Valid data is defined to be data that has not timed out according to Table D.1. This requirement includes the GLONASS, GPS and SDCM failures.

Note 2.– Serial messages are updated with a standard period.

D.3.3 Precise Differential Correction Performance

With any reliable combination of valid information and assuming that the consumer has zero delay, the probability of exceeding the permissible threshold values for a period of time longer than the corresponding time interval before the alarm is triggered during any approach operation is less than 2×10^{-7}. The time interval before the alarm is triggered is 5.2 seconds in the case of SDCM, which provides accurate approaches (e.g., APV-II operations), and 8 seconds in the case of SDCM, which provides APV-I operations. Exceeding the permissible threshold is defined as exceeding of the HPL_{SDCM} value or the VPL_{SDCM} value (as defined in Appendix H). If an excess is detected, the final alarm message is repeated three times (transmitted in Type 2-5 and 6, 24, 26 or 27 messages) after the initial notification of the alarm threshold, a total of four times within 4 seconds.

D.3.4 Long-Term Corrections

Except for SDCM GEO satellites, SDCM determines and broadcasts long-term corrections for each visible GNSS satellite [1)] indicated in the PRN mask. For each GLONASS satellite, SDCM transforms satellite coordinates into WGS84 as defined in H.2.4 prior to determining the long-term corrections. For each GPS satellite, the broadcast IOD matches both the GPS IODE and 8 LSBs of IODC associated with the clock and ephemeris data used to evaluate the corrections (see 7.5). While GPS satellite transmits new ephemeris, SDCM continues to use the old ephemeris to determine the fast and long-term error corrections for at least 2 minutes and not more than 4 minutes. For each GLONASS satellite, SDCM evaluates and broadcasts an IOD that consists of a latency and a validity interval as defined in 7.5.2.

[1)] The criteria for satellite visibility include the locations of reference stations and the achieved angle mask at those locations (5°).

D.3.5 Fast Corrections

SDCM determines fast corrections for each visible GNSS satellite indicated in the PRN mask. Unless the IODF = 3, each time any fast correction data in Type 2, 3, 4 or 5 message changes, the IODF equals the sequence "0, 1, 2, 0, ...".

Note.– If there is an alarm condition, the IODF may equal 3 (see 7.6).

D.3.6 Timing Data

If data is provided in UTC, it is determined as given in Table 28 (Type 12 message).

If data is provided for GLONASS, SDCM broadcasts the GLONASS and UTC network time offset message (Type 12 message) including GLONASS time offset as defined in 7.11.

D.3.7 The Integrity Data

For each satellite for which corrections are provided, SDCM broadcasts integrity data (UDREI and, optionally, Type 27 or 28 message data to calculate δ_{UDRE}) to meet the integrity requirements in Appendix B. If the fast corrections or long-term corrections exceed their value range, SDCM indicates this satellite as "Do Not Use" (UDREI = 15). If σ^2_{UDRE} cannot be determined, SDCM indicates the satellite as "Not Monitored" (UDREI = 14).

If Type 6 message is used to broadcast σ^2_{UDRE}, then the $IODF_j$ matches the $IODF_j$ for the fast corrections received in Type j message to which the σ^2_{UDRE} is applicable; or the $IODF_j$ equals 3 if the σ^2_{UDRE} is applicable to all valid fast corrections received in Type j message which have not timed out.

D.3.8 Ionospheric Grid Point (IGP) Mask

SDCM broadcasts an IGP mask and IODI (up to 11 Type 18 messages, corresponding to the 11 IGP bands). The IGP mask values indicate whether or not data is being provided for each IGP. If IGP Band 9 is used, then the IGP mask values for IGPs north of 55°N in Bands 0 through 8 are set to “0”. If IGP Band 10 is used, then the IGP mask values for IGPs south of 55°S in Bands 0 through 8 are set to “0”. The IODI is changed when there is a change of IGP mask values in the k^{th} band. The new IGP mask is transmitted in a Type 18 message before it is referenced in a related Type 26 message. The IODI in Type 26 message equals the IODI transmitted in the IGP mask message (Type 18 message) used to designate the IGPs for which data is provided in that message.

D.3.9 Ionospheric Corrections

SDCM broadcasts ionospheric corrections for the IGPs designated in the IGP mask.

D.3.10 Ionospheric Integrity Data

For each IGP with corrections provided, SDCM broadcasts GIVEI data to meet the integrity requirements in Appendix B. If the ionospheric correction or σ^2_{UDRE} exceed their value range, SDCM indicates that the data in not valid for the IGP. If σ^2_{UDRE} cannot be determined, SDCM indicates that the IGP is “Not Monitored” (GIVEI = 15).

D.3.11 Degradation Factors

SDCM broadcasts degradation parameters (Type 7 and 10 messages) to meet the integrity requirements in Appendix B.

D.4 Optional Functions

D.4.1 Service Indication

If service indication data is broadcast, it is as defined in Table 30 (Type 27 message) and Type 28 messages are not transmitted. The IODS in all Type 27 messages increment when there is a change in any Type 27 message data.

D.4.2 Clock-Ephemeris Covariance Matrix

If clock-ephemeris covariance matrix data is broadcast, it is transmitted for all monitored satellites as defined in Table 32 (Type 28 message) and Type 27 messages are not transmitted.

D.5 Monitoring

D.5.1 Data Monitoring

D.5.1.1 SDCM monitors the satellite signals to detect conditions that will result in improper operation of differential processing for user receivers with the tracking performance.

D.5.1.2 SDCM monitors all active GNSS data that can be used by any user within the service area.

D.5.1.3 SDCM raises an alarm within 6 seconds if any active data and/or GNSS signals-in-space results in an out-of-tolerance condition.

Note.– The monitoring applies to all failure conditions, including failures in the GLONASS and GPS constellations or SDCM satellites.

D.5.2 Robustness to core satellite constellation(s) failures. When any core constellation(s) satellite malfunction occurs, SDCM continues to operate normally using the available healthy satellite signals that can be tracked.

D.6 Recommended Specifications for Receivers

D.6.1 Preliminary Notes

D.6.1.1 The requirements of this section are optional for the equipment that integrates additional navigation sensors, such as equipment that integrates with inertial navigation sensors.

D.6.1.2 SDCM-capable GNSS receiver

Except as specifically noted, the SDCM-capable GNSS receiver processes the signals of SDCM, GPS and GLONASS jointly. Pseudorange measurements for each satellite smoothed using carrier measurements and a smoothing filter which deviates less than 0.1 meter within 200 seconds after initialization, relative to the steady-state response of the filter in the presence of when there is a difference between the code phase and integrated carrier phase of up to 0.01 m/s.

D.6.2 Conditions for use of data

D.6.2.1 Reception of a Type 0 message from SDCM satellite results in exclusion of that satellite for at least one minute in critical applications. For GPS satellites, the receiver applies long-term corrections only if the IOD matches both the IODE and 8 LSBs of the IODC. For GLONASS satellites, the receiver applies long-term corrections only if the time of reception (t_{r}) of the GLONASS ephemeris and time of long-terms corrections reception by the user (t_{LT}) is inside the following validity interval

$$t_{LT} - L - V \le t_r \le t_{LT} - L\,. \qquad \text{(D.1)}$$

Description of parameters L and V is given in Table 17.

Note.– This requirement does not imply that the receiver has to stop tracking the SDCM satellite.

D.6.2.2 The receiver uses integrity or correction data only if the IODP associated with that data matches the IODP associated with the PRN mask.

D.6.2.3 The receiver uses SDCM-provided ionospheric data (IGP vertical delay estimate and GIVEI) only if the IODI associated with that data in a Type 26 message matches the IODI associated with the relevant IGP band mask transmitted in a Type 18 message.

D.6.2.4 The receiver uses the most recently received integrity data for which the IODF equals 3 or matches the IODF associated with the fast correction data being applied (if corrections are provided).

D.6.2.5 The receiver applies any local degradation to the σ^2_{UDRE} as defined by a Type 27 service message. If a Type 27 message with a new IODS indicates a higher σ^2_{UDRE} for the user location, the higher δ_{UDRE} is applied immediately. A lower δ_{UDRE} in a new Type 27 message is not applied until the complete set of messages with the new IODS has been received.

D.6.2.6 The receiver applies satellite-specific degradation data to the σ^2_{UDRE} as defined by a Type 28 clock ephemeris covariance matrix message. The δ_{UDRE} derived from a Type 28 message with an IODP matching that of the PRN mask is applied immediately.

D.6.2.7 For GPS satellites, the receiver applies long-term corrections only if the IOD matches both the IODE and 8 least significant bits of the IODC.

D.6.2.8 The receiver does not use a timed-out broadcast data parameter after it has timed out as defined in Table D.2.

Table D.2 – Data time-out intervals

Data	Associated message types	Time-out intervals, s
Clock-ephemeris covariance matrix	28	360
SDCN in test mode	0	–
PRN Mask	1	600
UDREI	2–6, 24	18
Fast corrections	2–5, 24	See Table D.3
Long-term corrections	24, 25	360
Fast correction degradation	7	360
Degradation factors	10	360
Ionospheric grid mask	18	1,200
Ionospheric corrections, GIVEI	26	600
Timing data	12	86,400
SDCM/UTC network time offset parameters	12	600
SDCM almanac data	17	–
Service message	27	86,400
Note.– The time-out intervals are defined from the end of the reception of a message.		

D.6.2.9 The receiver does not use a fast correction if Δt as defined in (H.10) for the associated RRC exceeds the time-out interval for the fast corrections I_{fc} as defined in Table D.3, or if the age of the RRC exceeds $8\Delta t$.

D.6.2.10 The calculation of the RRC is reinitialized if a "Do Not Use" (UDREI = 15) or "Not Monitored" (UDREI = 14) flag is set for that satellite. RRC is not applied during reinitialization. Even if $IODF_j$ are the same, RRC is calculated.

D.6.2.11 The receiver only uses satellites with elevation angles at or above 5 degrees.

D.6.2.12 The receiver uses a particular satellite if the UDREI received is less than 12.

Note.–The receiver no longer supports LNAV/VNAV, LP and LPV precision approach if the UDREI received is greater than or equal to 12, though the satellites are considered healthy.

Table D.3 – Fast correction time-out interval evaluation

Fast correction degradation factor indicator (a_i)	NPA time-out interval for fast correction I_{fc}, s	PA/APV time-out interval for fast correction I_{fc}, s
0	180	120
1	180	120
2	153	102
3	135	90
4	135	90
5	117	78
6	99	66
7	81	54
8	63	42
9	45	30
10	45	30
11	27	18
12	27	18
13	27	18
14	18	12
15	18	12

D.6.2.13 SDCM satellites health and status

D.6.2.13.1 GEO satellite positioning. The receiver decodes Type 17 message and position of the SDCM GEO satellite.

D.6.2.13.2 SDCM satellite identification. The receiver discriminates between SDCM satellites.

D.6.2.13.3 If SDCM-provided integrity is used, the receiver is not required to exclude GPS satellites based on the GPS-provided ephemeris health flag or to exclude GLONASS satellites based on GLONASS-provided ephemeris health flag.

Note 1.– In the case of a satellite designated marginal or unhealthy by the GPS or GLONASS constellations health flag, SDCM may be able to broadcast ephemeris and clock corrections that will allow enable the user to continue using the satellite.

Note 2.– If a satellite with SDCM flag "Not Monitored" (UDREI = 14) is used for positioning, the integrity data is not provided by SDCM.

D.6.2.14 The receiver differential functions

D.6.2.14.1 Core satellite constellation(s) ranging accuracy. The root-mean-square (1σ) of the total airborne contribution to the error in a corrected pseudorange for a GPS satellite at the minimum received signal power level under the worst interference environment is less than or equal to 0.4 meters, excluding multipath effects, tropospheric and ionospheric residual errors. The RMS (1σ) of the total airborne contribution to the error in a corrected pseudorange for a GLONASS satellite at the minimum received signal power level under the worst interference environment is less than or equal to 0.8 meters, excluding multipath effects, tropospheric and ionospheric residual errors.

D.6.2.14.2 The receiver computes estimate and apply long-term corrections, fast corrections, range rate corrections and the broadcast ionospheric corrections. For the GLONASS satellites, the ionospheric corrections received from SDCM are multiplied by the square of the ratio of GLONASS to GPS frequencies $(f_{GLONASS}/f_{GPS})^2$.

D.6.2.14.3 The receiver uses a weighted-least-squares position solution.

D.6.2.14.4 The receiver applies a tropospheric model such that residual pseudorange errors have a mean value (μ) less than 0.15 meters and a 1σ deviation less than 0.07 meters. Tropospheric model development guidance is provided in Appendix E.

D.6.2.14.5 The receiver computes and apply horizontal and vertical protection levels defined in H.4. In this computation, σ_{tropo} is:

$$\sigma_{\mathrm{tropo}} = \frac{1.001}{\sqrt{0.002001 + \sin^2(\theta_{\mathrm{i}})}} \cdot 0.12, \tag{D.2}$$

where θ_i is the elevation angle of the i-th satellite.

In addition, σ_{air} satisfies the condition that a normal distribution with zero mean and a standard deviation equal to σ_{air}, bounds the error distribution for residual receiver pseudorange errors as follows:

$$\int_{\mathrm{y}}^{\infty} f_n(x)\mathrm{d}x \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0, \tag{D.3}$$

$$\int_{-\infty}^{-y} f_n(x)\mathrm{d}x \le Q\left(\frac{y}{\sigma}\right) \text{ for all } \frac{y}{\sigma} \ge 0, \tag{D.4}$$

where $f_n(x)$ – is probability density function of the residual pseudorange error;

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

Note.– The standard mitigation of a receiver multipath may be used to bound the multipath errors.

D.6.2.15 Continuous wave (CW) interference

D.6.2.15.1 GPS L1 receivers

GPS L1 receivers need to meet the performance objectives with CW interfering signals present with a power level at the antenna port equal to the interference thresholds specified in Table D.4 and shown in Figure D.1, and with a desired signal level of –164.5 dBW at the antenna port.

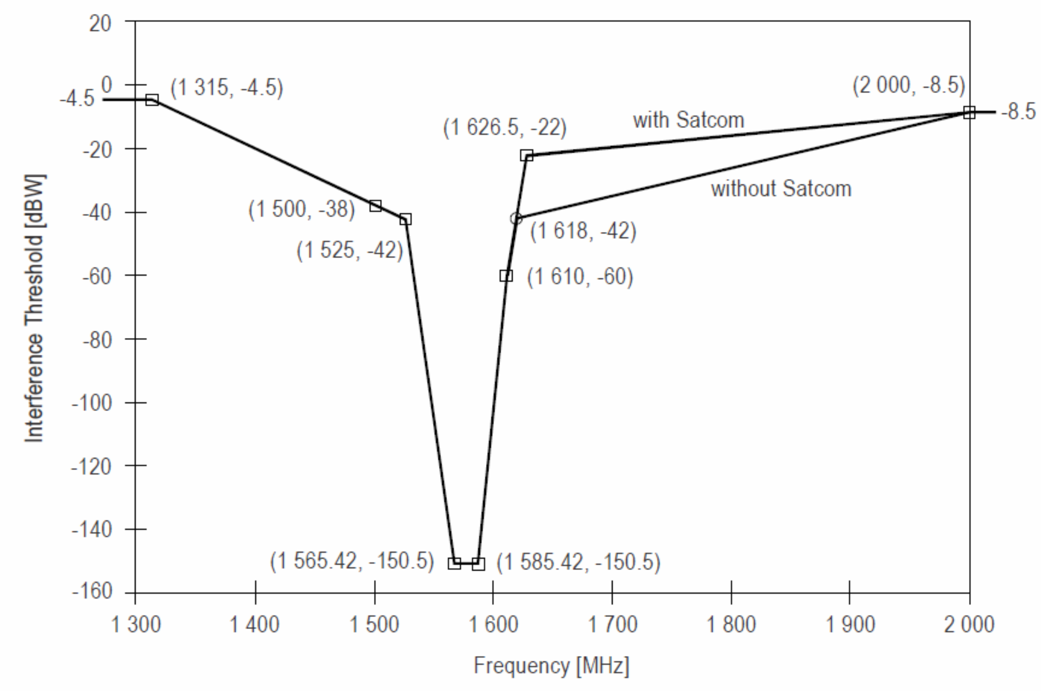

Figure D.1 – CW interference thresholds for GPS L1 receivers

D.6.2.15.2 GLONASS L1 receivers

GLONASS receivers need to meet the performance objectives with CW interfering signals present with a power level at the antenna port equal to the interference thresholds specified in Table D.5 and shown in Figure D.2 and with a desired signal level is –165.5 dBW at the antenna port.

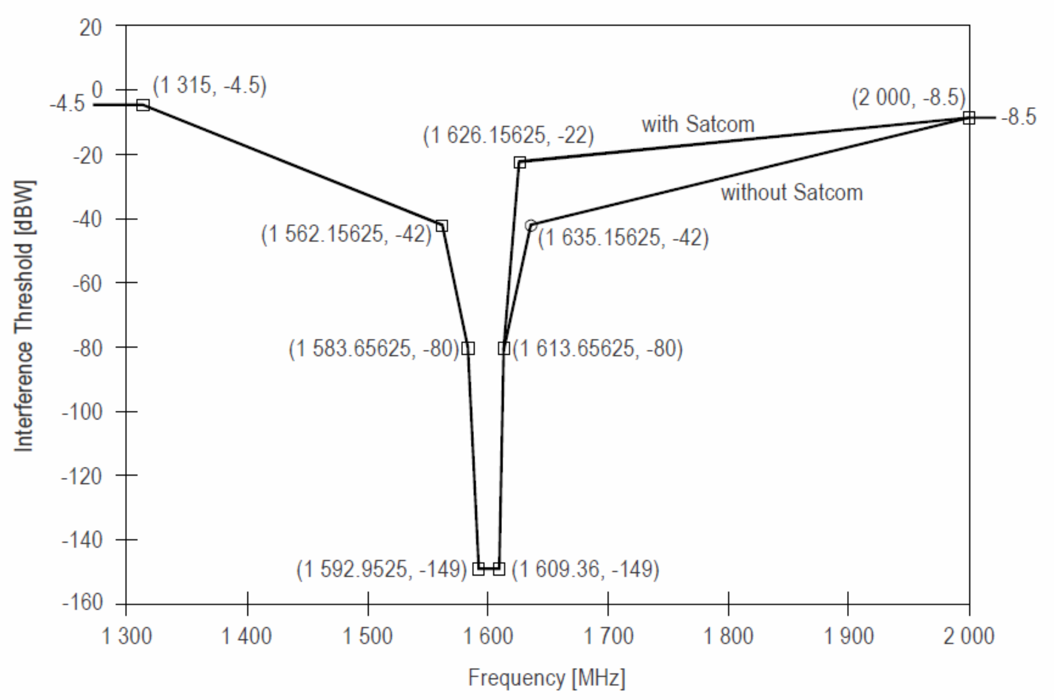

Figure D.2 – CW interference thresholds for GLONASS L1 receivers

Table D.4 – CW interference thresholds for GPS L1 receivers

Frequency range f_i of the interference signal, MHz	Interference thresholds for receivers, dBW
$f_i \leq 1{,}315$	–4.5
$1{,}315 < f_i \leq 1{,}525$	Linearly decreasing from –4.5 to –42
$1{,}525 < f_i \leq 1{,}565.42$	Linearly decreasing from –42 to –150.5
$1{,}565.42 < f_i \leq 1{,}585.42$	–150.5
$1{,}585.42 < f_i \leq 1{,}610$	Linearly increasing from –150.5 to –60
$1{,}610 < f_i \leq 1{,}618$	Linearly increasing from –60 to –42
$1{,}618 < f_i \leq 2{,}000$	Linearly increasing from –42 to –8.5
$1{,}610 < f_i \leq 1{,}626.5$	Linearly increasing from –60 to –22
$1{,}626.5 < f_i \leq 2{,}000$	Linearly increasing from –22 to –8.5
$f_i > 2{,}000$	–8.5

Table D.5 – CW interference thresholds for GLONASS L1 receivers

Frequency range f_i of the interference signal, MHz	Interference thresholds for receivers, dBW
$f_i \le 1315$	–4.5
$1{,}315 < f_i \le 1{,}562.15625$	Linearly decreasing from –4.5 to –42
$1{,}562.15625 < f_i \le 1{,}583.6525$	Linearly decreasing from –42 to –80
$1{,}583.65625 < f_i \le 1{,}592.9525$	Linearly decreasing from –80 to –149
$1{,}592.9525 < f_i \le 1{,}609.36$	–149
$1{,}609.36 < f_i \le 1{,}613.65625$	Linearly increasing from –149 to –80
$1{,}613.65625 < f_i \le 1{,}635.15625$	Linearly increasing from –80 to –42
$1{,}613.65625 < f_i \le 1{,}626.15625$	Linearly increasing from –80 to –22
$1{,}635.15625 < f_I \le 2{,}000$	Linearly increasing from –42 to –8.5
$1{,}626.15625 < f_i \le 2{,}000$	Linearly increasing from –22 to –8.5
$f_i > 2{,}000$	–8.5

D.6.2.16 Band-limited noise-like interference

D.6.2.16.1 GPS L1 receivers

After steady-state navigation has been established, GPS L1 receivers need to meet the performance objectives with noise-like interfering signals present in the frequency range of $1{,}575.42 \pm Bw_i/2$ and with power levels at the antenna port equal to the interference thresholds specified in Table D.6 and shown in Figure D.3 and with the desired signal level of –164.5 dBW at the antenna port. Bw_i – is an equivalent bandwidth of a noise-like interfering signal.

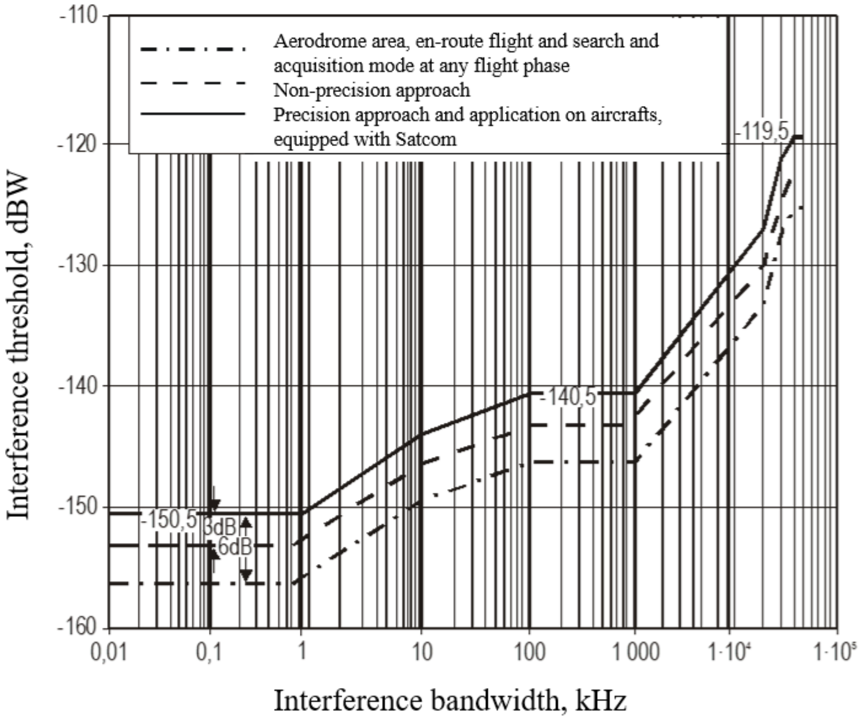

Figure D.3 – Interference thresholds versus bandwidth for GPS L1 receivers

Table D.6 – Interference threshold for band-limited noise-like interference to GPS L1 receivers

Interference bandwidth	Interference threshold for receivers, dBW
0 Hz < $Bw_i \leq$ 700 Hz	–150.5
700 Hz < $Bw_i \leq$ 10 kHz	–150.5 + 6 $\log_{10}$(BW/700)
10 kHz < $Bw_i \leq$ 100 kHz	–143.5 + 3 $\log_{10}$(BW/10000)
100 kHz < $Bw_i \leq$ 1 MHz	–140.5
1 MHz < $Bw_i \leq$ 20 MHz	Linearly increasing from –140.5 to –127.5*
20 MHz < $Bw_i \leq$ 30 MHz	Linearly increasing from –127.5 to –121.1*
30 MHz < $Bw_i \leq$ 40 MHz	Linearly increasing from –121.1 to –119.5*
40 MHz < Bw_i	–119.5 *

* Interference threshold value is below – 140.5 dBW/MHz at (1,575.42 ± 10) MHz.

D.6.2.16.2 GLONASS L1 receiver

After steady-state navigation has been established, GLONASS L1 receivers need to meet the performance objectives while receiving noise-like interfering signals in the frequency band ($f_k \pm Bw_i/2$), with power levels at the antenna port equal to the interference thresholds specified in Table D.7 and with a desired signal level of –165.5 dBW at the antenna port, where f_k is the center frequency of a GLONASS channel with $f_k = (1{,}602 + k \times 0.6525)$ MHz and $k = -7$ to $+6$ and Bw_i is an equivalent bandwidth of a noise-like interfering signal.

Pulsed interference. After steady-state navigation has been established, the receiver need to meet the performance objectives while receiving pulsed interference signals with characteristics according to Table D.8 where the interference threshold is defined at the antenna port.

Table D.7 – Interference threshold for band-limited noise-like interference to GLONASS L1 receivers

Interference bandwidth	Interference threshold, dBW
0 Hz < $Bw_i \leq$ 1 kHz	–149
1 kHz < $Bw_i \leq$ 10 kHz	Linearly increasing from –149 to –143
10 kHz < $Bw_i \leq$ 0.5 MHz	–143
0.5 MHz < $Bw_i \leq$ 10 MHz	Linearly increasing from –143 to –130
10 MHz < Bw_i	–130

Table D.8 – Interference thresholds for pulsed interference

System	GPS and SDCM	GLONASS
Bandwidth	1,575.42 ± 10 MHz	1,592.9525–1,609.36 MHz
Interference threshold (pulse peak power)	–10 dBW	–10 dBW
Pulse duration	≤ 125 microseconds, ≤ 1 ms *	≤ 1 ms
Pulse duty cycle	≤ 10 %	≤ 10 %

* Refers to GPS receiver without SDCM.

D.7 GNSS Satellite Antenna for Reception of the GLONASS, GPS and SDCM Signals

D.7.1 Antenna Directional Pattern

D.7.1.1 The GNSS antenna needs to meet the performance requirements for the reception of GNSS satellite signals from 0 to 360 degrees in azimuth and from 0 to 90 degrees in elevation relative to the user horizontal plane.

D.7.2 Antenna Gain

D.7.2.1 The minimum antenna gain is less than that shown in Table D.9 for the specified elevation angle above the horizon. The maximum antenna gain does not exceed +7 dB for elevation angles above 5 degrees.

Table D.9 – Minimum Antenna Gain — GPS, GLONASS and SDCM

Elevation Angle, °	Minimum Antenna Gain, dB
0	–7.5
5	–4.5
10	–3
15–90	–2

D.7.3 Polarization

D.7.3.1 The GNSS antenna polarization is right-hand circular (clockwise with respect to the direction of propagation).

Appendix E

(obligatory)

Recommended Model for Computing the Tropospheric Delay

E.1 Tropospheric correction, according to SBAS standard, for navigation signal propagation delay can be computed using formula

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

where d_{hyd}, d_{wet} – determined as follows:

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

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

β – temperature lapse rate, K/m;

T – temperature, K;

λ – water vapor “lapse rate”, dimensionless;

H – user receiver altitude, 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 – pressure, mbar;

e – water vapor pressure, mbar;

m(El) – mapping function, defined as follows:

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

where El – actual satellite elevation angle, °.

Formula (E.4) is valid for satellite elevation angles El of not less than 2°.

Each of five meteorological parameters P, T, e, β, λ depends on receiver’s latitude ϕ and day-of-year D starting from January, 1:

$$\xi(\varphi, D) = \xi_0(\varphi) - \Delta\xi(\varphi) \cdot \cos\left(\frac{2\pi \cdot (D - D_{\min})}{365.25}\right), \tag{E.5}$$

where ξ_0, $\Delta\xi$ – average and seasonal variation values for the particular meteorological parameter P, T, e, β or λ at the receiver’s latitude;

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

The day-of-year D can be determined from the current day number N_T within the current 4-year interval using formula

$$D = \begin{cases} N_T \text{ for } N_T \leq 366, \\ N_T - 366 \text{ for } 367 \leq N_T \leq 731, \\ N_T - 731 \text{ for } 732 \leq N_T \leq 1{,}096, \\ N_T - 1{,}096 \text{ for } N_T \geq 1{,}097. \end{cases} \tag{E.6}$$

For determination the value of each of five meteorological parameters P, T, e, β, λ for a given user receiver latitude one uses linear interpolation of data given in Table E.1. Values of meteorological parameters for northern and southern hemispheres are the same.

Table E.1 – Meteorological parameters for tropospheric delay

Latitude, °	Average parameter value				
	P_0, mbar	T_0, K	e_0, mbar	β_0, K/m	λ_0
15 or less	1,013.25	299.65	26.31	0.00630	2.77
30	1,017.25	294.15	21.79	0.00605	3.15
45	1,015.75	283.15	11.66	0.00558	2.57
60	1,011.75	272.15	6.78	0.00539	1.81
75 or greater	1,013.00	263.65	4.11	0.00453	1.55
Latitude, °	Sesonal 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

Root-mean-square error σ_{tropo}, in meters, of calculation tropospheric correction is determined as follows:

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

Appendix F
(obligatory)
SDCM Message Transmission Order

F.1 Table F.1 gives SDCM message transmission order where messages are sequentially broadcast in 6-second frames. The total duration of this sequence is 264 s.

Table F.1 – SDCM Message Broadcast Order

Data Transmission Epoch, s	Data contents (types of broadcast messages)					
1-6	1	2	3	4	5	25
7-12	18	2	3	4	5	25
13-18	7	2	3	4	5	25
19-24	18	2	3	4	5	25
25-30	10	2	3	4	5	25
31-36	18	2	3	4	5	25
37-42	9	2	3	4	5	25
43-48	18	2	3	4	5	25
49-54	17	2	3	4	5	25
55-60	18	2	3	4	5	25
61-66	1	2	3	4	5	25
67-72	18	2	3	4	5	25
73-78	27	2	3	4	5	25
79-84	26	2	3	4	5	25
85-90	7	2	3	4	5	25
91-96	26	2	3	4	5	25
97-102	10	2	3	4	5	25
103-108	26	2	3	4	5	25
109-114	9	2	3	4	5	25

Table F.1 (continued)

Data Transmission Epoch, s	Data contents (types of broadcast messages)					
115-120	26	2	3	4	5	25
121-126	1	2	3	4	5	25
127-132	26	2	3	4	5	25
133-138	26	2	3	4	5	25
139-144	26	2	3	4	5	25
145-150	7	2	3	4	5	25
151-156	26	2	3	4	5	25
157-162	10	2	3	4	5	25
163-168	26	2	3	4	5	25
169-174	12	2	3	4	5	25
175-180	26	2	3	4	5	25
181-186	1	2	3	4	5	25
187-192	26	2	3	4	5	25
193-198	27	2	3	4	5	25
199-204	26	2	3	4	5	25
205-210	7	2	3	4	5	25
211-216	26	2	3	4	5	25
217-222	10	2	3	4	5	25
223-228	26	2	3	4	5	25
229-234	9	2	3	4	5	25
235-240	26	2	3	4	5	25
241-246	1	2	3	4	5	25
247-252	26	2	3	4	5	25
253-258	10	2	3	4	5	25
259-264	26	2	3	4	5	25

Type 0 message contains fast corrections of Type 2 message to Data field during the system validation/test.

Table F.2 gives SBAS requirements to maximum time between data transmissions

Table F.2 – Maximum time between data transmissions

Data	Types of Message	Broadcast Interval, s
PRN Mask	1	120
UDREI	2-6, 24	6
Fast corrections	2-5, 24	12
Long-term corrections	25, 24	120
Ionospheric grid	18	300
Ionospheric delays	26	300
UTC time	12	300
Degradation of fast corrections	7	120
Navigation message	9	120
SDCM satellite status	17	300
Degradation factors	10	120
Service region	27 (28)	300

Appendix G

(obligatory)

SDCM Message Transmission Order upon PRN Mask

G.1 Figure G.1 displays the transmission order of the SDCM messages upon PRN Mask transition. This transition occurs when data used by satellites changes.

The transition undergoes three steps.

Phase 1. Before PRN Mask is changed, four sequential Type 1 messages with a new PRN Mask are transmitted.

Phase 2. Setting up a new PRN Mask application. At this phase lasting 22 seconds, the user continues to use an old PRN Mask while thirteen Type 25 messages with long-term corrections for a new PRN Mask are being transmitted.

Phase 3. New PRN Mask application. The Phase 3 repeats Type 1 message then followed by fast corrections relating to a new PRN Mask.

Figure G.1 describes transmission of data upon PRN Mask change.

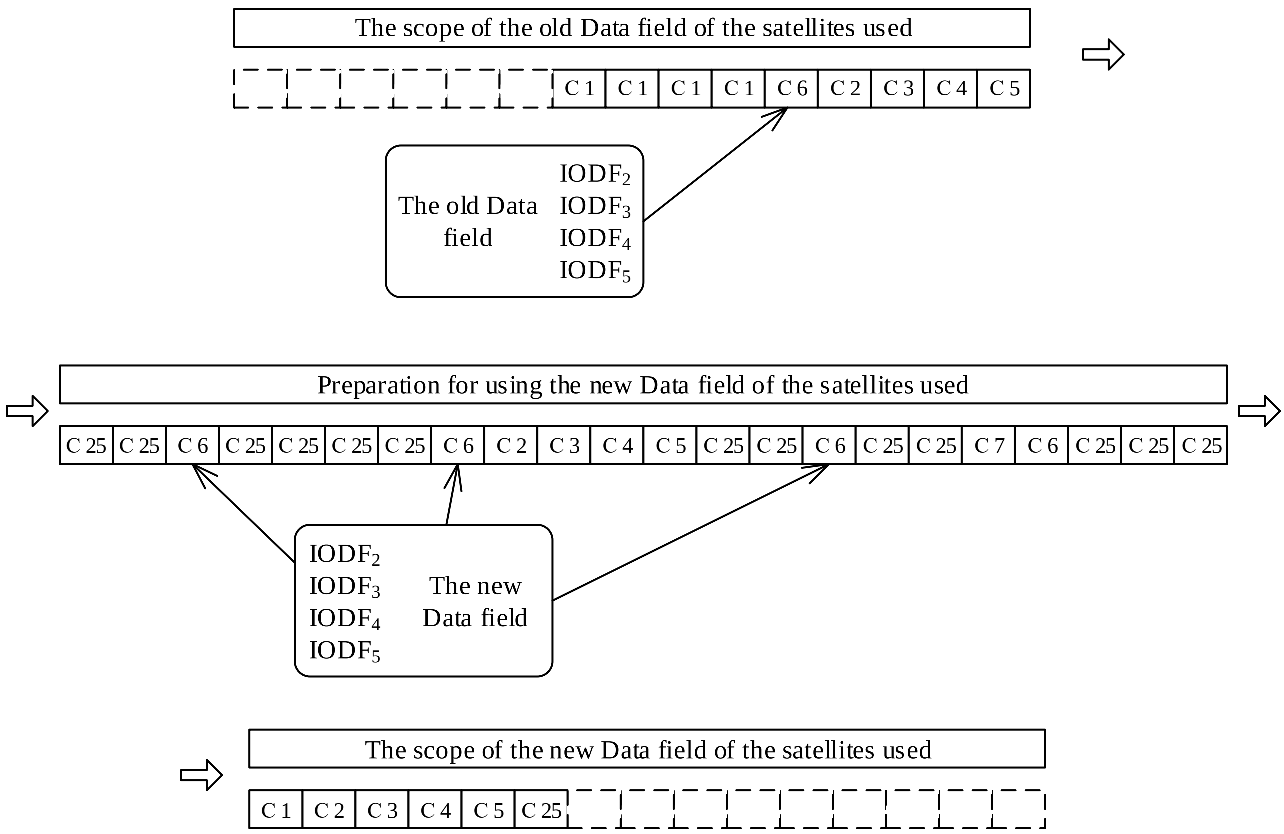

Figure G.1 – Transmission of Data upon PRN Mask Change

Appendix H

(obligatory)

Definitions of Protocols for SDCM Data Application

H.1 Introduction

H.1.1 This Appendix provides definitions of parameters used by GLONASS and GPS navigation algorithms given the SDCM data. These parameters are used to determine the positioning and its integrity (protection levels).

H.2 Long-Term Corrections

H.2.1 GPS clock correction. The clock correction for a GPS satellite is applied in accordance with the following equation:

$$\mathrm{t} = \mathrm{t}_{\mathrm{SV}} - [(\Delta \mathrm{t}_{\mathrm{SV}})_{\mathrm{L1}} + \delta\Delta \mathrm{t}_{\mathrm{SV}}], \tag{H.1}$$

where t – is the current GPS network time;

t_{SV} – is the GPS satellite time at the message broadcast epoch;

$(\Delta \mathrm{t}_{\mathrm{SV}})_{\mathrm{L1}}$ – is the satellite PRN code phase offset;

$\delta\Delta \mathrm{t}_{\mathrm{SV}}$ – is the code phase offset correction.

H.2.2 The code phase offset correction $\delta\Delta \mathrm{t}_{\mathrm{SV}}$ for a GPS satellite at any time of day t_k for GPS network time and at the current day is as follows:

$$\delta\Delta t_{\mathrm{SV}} = \delta a_{\mathrm{f0}} + \delta a_{\mathrm{f1}}(t_k - t_0), \tag{H.2}$$

where δa_{f0}, δa_{f1}, t_0 are transmitted in Type 25 message.

Value $\delta\Delta t_{SV}$ is added to Δt_{SV}, as defined in GPS ICD. T_{GD} is applied as given in [6]:

$$(\Delta t_{SV})_{L1} = \Delta t_{SV} - T_{GD}. \quad \text{(H.3)}$$

H.2.3 GLONASS Clock Correction

The clock correction for a GLONASS satellite is applied in accordance with the following equation:

$$t = t_{SV} + \tau_n(t_b) - \gamma_n(t_b)(t_{SV} - t_b) - \delta\Delta t_{SV}, \quad \text{(H.4)}$$

where t – is the current GLONASS network time;

t_{SV} – is the GLONASS satellite time at the message broadcast epoch;

t_b, $\tau_n(t_b)$, $\gamma_n(t_b)$ – are GLONASS time parameters;

$\delta\Delta t_{SV}$ – is the code phase offset correction.

The code phase offset correction $\delta\Delta t_{SV}$ for a GLONASS satellite is defined as follows:

$$\delta\Delta t_{SV} = \delta a_{f0} + \delta a_{f1}\,(t - t_0), \quad \text{(H.5)}$$

where $(t - t_0)$ is corrected for end-of-day crossover. If the velocity code equals 0, then $\delta a_{f1} = 0$.

The code phase offset correction $\delta\Delta t_{SV}$ for a GLONASS satellite at GPS network time is determined given GPS and GLONASS time offset:

$$\delta\Delta t_{SV} = \delta a_{f0} + \delta a_{f1}\,(t - t_0) + \tau_{GPS} + \delta a_{GLONASS}, \quad \text{(H.6)}$$

where t – is the current GPS network time;

τ_{GPS} – is a fractional part of a second in GPS time scale offset relatively to GLONASS time scale transmitted as a part of GLONASS satellites ephemeris information;

$\delta a_{GLONASS}$ – is a correction τ_{GPS}, transmitted by SDCM in Type12 message.

H.2.4 Satellite Position Correction

GPS uses the WGS84 system, GLONASS uses the PZ-90 system. The following equation is used to convert coordinates from one system into another:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS-84} = \begin{bmatrix} 1 & 0.0097\cdot 10^{-9} & 0.2036\cdot 10^{-9} \\ -0.0097\cdot 10^{-9} & 1 & 0.0921\cdot 10^{-9} \\ -0.2036\cdot 10^{-9} & -0.0921\cdot 10^{-9} & 1 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PZ-90} + + \begin{bmatrix} 0.003 \\ 0.001 \\ 0 \end{bmatrix}. \qquad \text{(H.7)}$$

As WGS84 and PZ-90 undergo regular improvements, it is recommended to accomplish conversion computations in the most current realizations recent edition of PZ-90 and WGS84, for example [7], to improve the accuracy of navigation solutions.

SDCM-corrected vector for a GLONASS and GPS satellite at time t is:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{corrected} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta\dot{x} \\ \delta\dot{y} \\ \delta\dot{z} \end{bmatrix} (t - t_0), \qquad \text{(H.8)}$$

where $(t - t_0)$ – is corrected for end-of-day crossover; and;

$[x\ y\ z]^T$ – is GPS or GLONASS satellite position vector.

If the velocity code equals 0, then $\left[\delta\dot{x}\ \delta\dot{y}\ \delta\dot{z}\right]^T = \left[0\ \ 0\ \ 0\right]^T$.

It is recommended to apply a simplified algorithm for conversion of coordinates and components of a satellite center-of-mass velocity vector at a given time of Moscow time scale [8].

H.2.5 Pseudorange Corrections

The pseudorange corrections don’t depend on applied coordinates system.

The corrected pseudorange $PR_{corrected}$ at time t for a satellite is

$$PR_{corrected} = PR + FC + RRC(t - t_{0f}) + IC + TC, \tag{H.9}$$

where PR – is the measured pseudorange after application of the satellite clock correction;

FC – is the fast correction;

RRC – is the range rate correction;

IC – is the ionospheric correction;

TC – is the tropospheric correction (negative value representing the troposphere delay);

t_{0f} – is the time of applicability of the most recent fast corrections, which is the start of the epoch of the SDCM second that is coincident with the transmission at the SDCM satellite of the first symbol of the message block.

H.2.6 Range Rate Corrections (RRC).

The range rate correction for a satellite for which fast corrections are transmitted is calculated by the formula:

$$RRC = \frac{FC - FC_{previous}}{\Delta t}, \tag{H.10}$$

where FC – is the most recent fast correction;

$FC_{previous}$ – is a previous fast correction;

$\Delta t = (t_{0f} - t_{0f\_previous})$;

t_{0f} – is the time of applicability of FC;

$t_{0f\_previous}$ – is the time of applicability of $FC_{previous}$.

H.3 Transmitted Ionospheric Corrections

H.3.1 Location of Ionospheric Pierce Points (IPP)

H.3.1.1 The location of an IPP is defined to be the intersection of the line segment from the receiver to the satellite and an ellipsoid with constant height of 350 km above the WGS84 ellipsoid. The following equations evaluate latitude and longitude of the pierce point. Firstly, latitude ϕ_{pp} is estimated in radians by the formula

$$\phi_{pp} = \sin^{-1}\left(\sin\phi_u \cos\psi_{pp} + \cos\phi_u \sin\psi_{pp} \cos A\right), \tag{H.11}$$

where ψ_{pp} – is the Earth’s central angle between user position and Earth surface projection of ionospheric intersection point (Figure H.1):

$$\psi_{pp} = \frac{\pi}{2} - E - \sin^{-1}\left(\frac{R_e}{R_e + h_I}\cos E\right); \tag{H.12}$$

A – is an azimuth angle between the satellite and the user (ϕ_u, λ_u). The azimuth is measured clockwise from the North;

E – is an elevation angle between the satellite and the user (ϕ_u, λ_u), measured relative to local tangential plane;

R_e – is the Earth ellipsoid radius (assumed 6378.1363 km);

h_I – is a height of maximum electronic concentration (assumed 350 km).

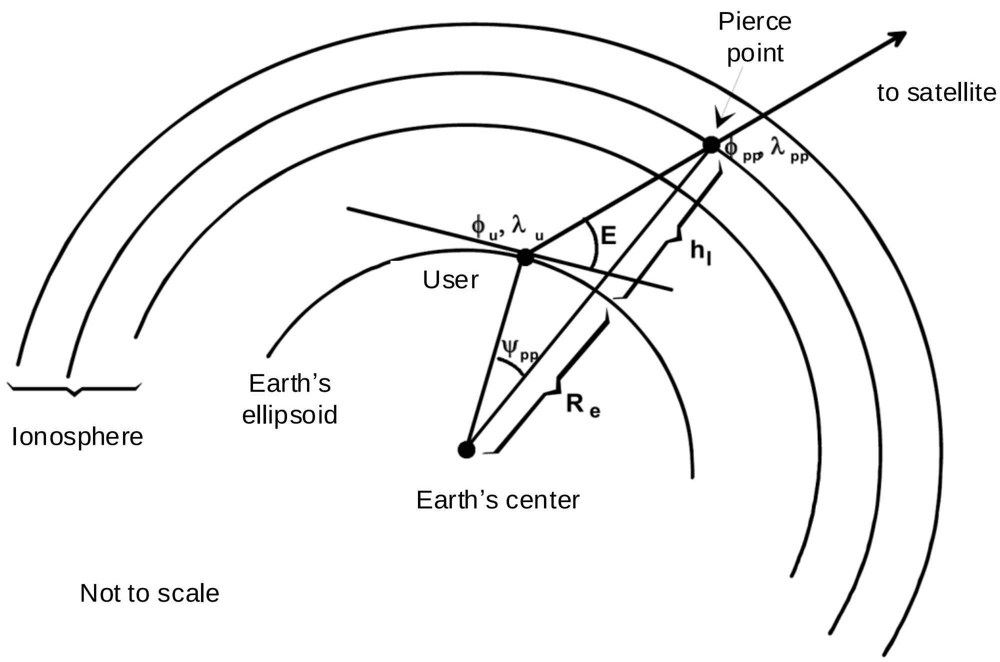

Figure H.1 – IPP geometry

IPP longitude λ_{pp}, is estimated as follows (in radians). If $\phi_u > 70°$ and $\mathrm{tg}\,\psi_{pp}\cos A > \mathrm{tg}(\pi/2 - \phi_u)$ or if $\phi_u < -70°$ and $\mathrm{tg}\,\psi_{pp}\cos(A+\pi) > \mathrm{tg}(\pi/2+\phi_u)$, then

$$\lambda_{pp} = \lambda_u + \pi - \sin^{-1}\left(\frac{\sin\psi_{pp}\sin A}{\cos\phi_{pp}}\right), \tag{H.13}$$

otherwise

$$\lambda_{pp} = \lambda_u + \sin^{-1}\left(\frac{\sin\psi_{pp}\sin A}{\cos\phi_{pp}}\right). \tag{H.14}$$

H.3.2 Selection of Ionospheric Grid Points

H.3.2.1 After determining the location of the user ionospheric pierce point, the user must select the IGPs to be used to interpolate the ionospheric correction and model variance.

The selection process will take place as described below:

- for an IPP between N60° and S60°:

1) if four IGPs that define a 5-degree-by-5-degree cell around the IPP are set to one in the IGP mask, they are selected; else

2) if any three IGPs that define a 5-degree-by-5-degree triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else,

3) if any four IGPs that define a 10-degree-by-10-degree cell around the IPP are set to one in the IGP mask, they are selected; else,

4) if any three IGPs that define a 10-degree-by-10-degree triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else;

5) an ionospheric correction is not available;

- for an IPP between N60° and N75° or between S60° and S75°:

1) if four IGPs that define a 5-degree latitude-by-10-degree longitude cell around the IPP are set to one in the IGP mask, they are selected; else,

2) if any three IGPs that define a 5-degree latitude-by-10-degree longitude triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else,

3) if any four IGPs that define a 10-degree-by-10-degree cell around the IPP are set to one in the IGP mask, they are selected; else,

4) if any three IGPs that define a 10-degree-by-10-degree triangle that circumscribes the IPP are set to one in the IGP mask, they are selected; else;

5) an ionospheric correction is not available;

- for an IPP between N75° and N85° or between S75° and S85°:

1) if the two nearest IGPs at 75° and the two nearest IGPs at 85° (separated by 30° longitude if Band 9 or 10 is used, separated by 90° otherwise) are set to one in the IGP mask, a 10-degree-by-10-degree cell is created by linearly interpolating between the IGPs 85° to obtain wirtual IGPs at longitudes equal to the longitudes of the IGPs at 75°; else,

Note.– The σ^2_{GIVE} s are linearly interpolated along the 85 degree line to form virtual σ^2_{GIVE} s to go with the virtual IGPs;

2) an ionospheric correction is not available;

- for an IPP north of N85°:

1) if the four IGPs at N85° latitude and longitudes of W180°, W90°, 0° and E90° are set to one in the IGP mask, they are selected; else,

2) an ionospheric correction is not available;

- for an IPP south of S85°:

1) if the four IGPs at S85° latitude and longitudes of W140°, W50°, E40° and E130° are set to one in the IGP mask, they are selected; else,

2) an ionospheric correction is not available.

This selection is based only on the information provided in the mask, without regard to whether the selected IGPs are monitored, “Not Monitored”, or “Do Not Use” (field “Vertical delay” = 111111111_2). If any of the selected IGPs is identified as “Do Not Use”, an ionospheric correction is not available. If four IGPs are selected, and one of the four is identified as “Not Monitored” (field GIVEI = 15), then three-point interpolation is used if the IPP is within the triangular region covered by the three corrections that are provided. This algorithm is explained by the Figure H.2, in which the IPP is designated as “x”.

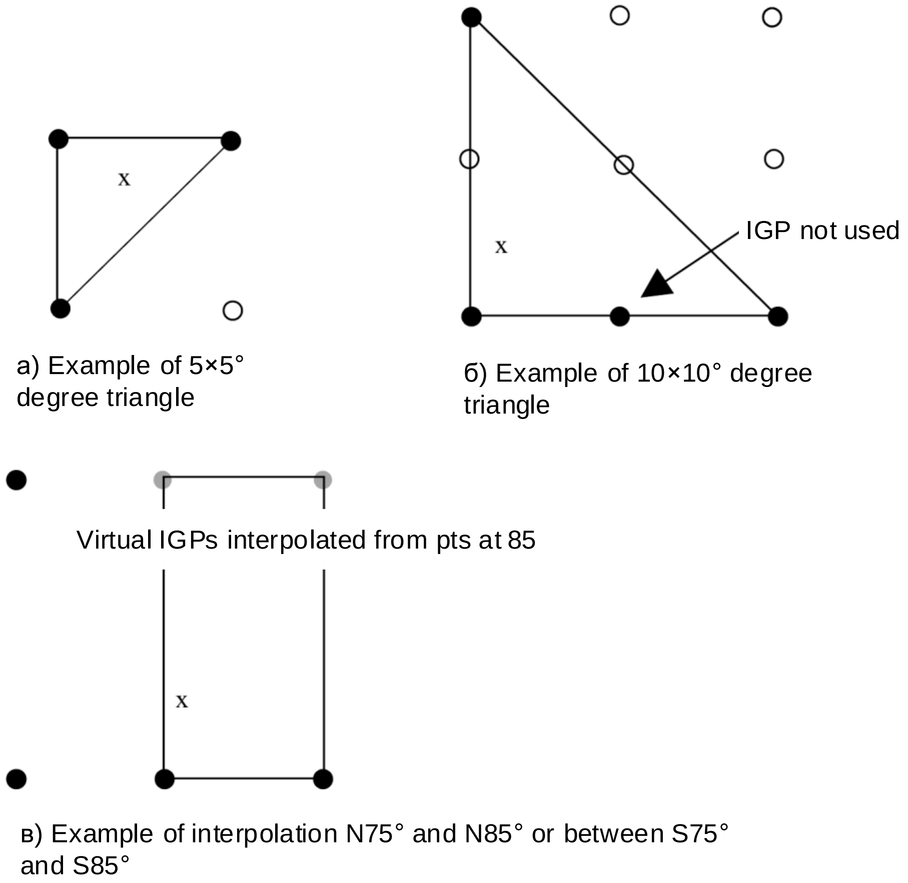

Figure H.2 – IGP interpolation

H.3.3 Interpolated Vertical Ionospheric Delay Estimation

H.3.3.1 Although the data broadcast to the user is in the form of vertical IGP delays, these points do not generally correspond with his computed IPP locations. Thus, it is necessary for the user to interpolate from the broadcast IGP delays to that at his computed IPP locations. Given three or four nodes of a cell of the IGP grid described above that surround the user's IPP to a satellite, the user interpolates from those nodes to his pierce point (examples are presented in Figure H.2) using the following algorithm.

The IGPs selected as described in H.3.2 must be used in this interpolation, with one exception. If four IGPs were selected, and one of the four is identified as "Not Monitored" (field GIVEI = 15), then the three-point interpolation is used if the user's pierce point is within the triangular region covered by the three corrections that are provided. If one of the four is identified as "Do Not Use" (field "Vertical delay" = 1111111112), the entire square must not be used.

For four-point interpolation, the mathematical formulation for interpolated vertical IPP delay τ_{vpp} at latitude ϕ_{pp} and longitude λ_{pp} equals:

$$\tau_{vpp} = \sum_{k=1}^{4} W_k \tau_{vk}, \qquad \text{(H.15)}$$

where τ_{vk} – are the broadcast grid point vertical delay values at the k corner of the IGP grid, as shown in Figure H.3;

$W_1 = x_{pp} \cdot y_{pp}$;

$W_2 = (1 - x_{pp}) y_{pp}$;

$W_3 = (1 - x_{pp})(1 - y_{pp})$;

$W_4 = x_{pp}(1 - y_{pp})$.

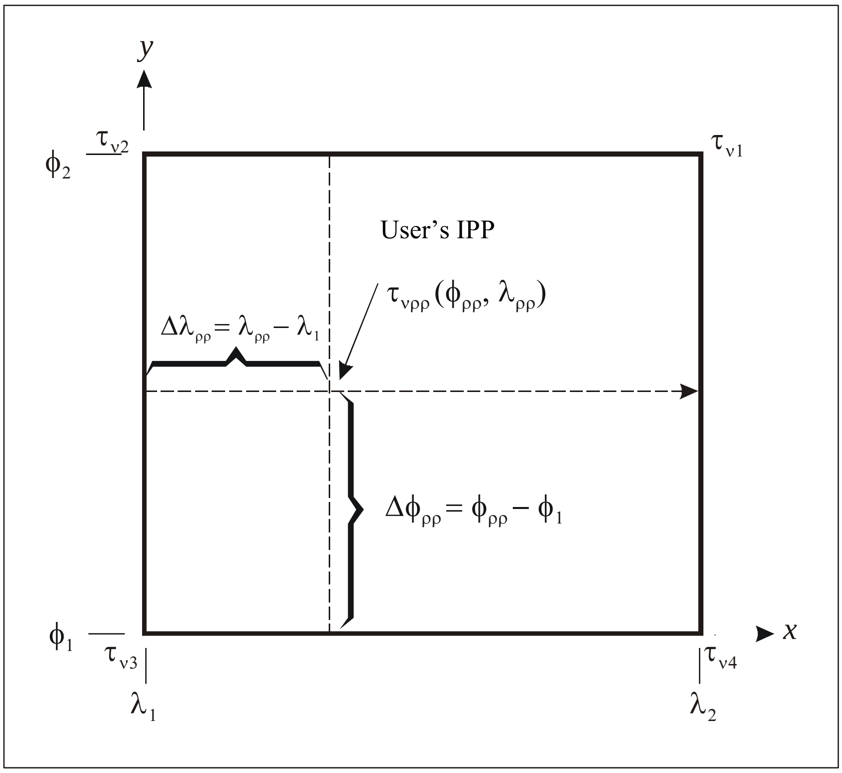

Figure H.3 – Four-point interpolation algorithm definitions

For IPPs between N85° and S85°:

$$x_{pp} = \frac{\lambda_{pp} - \lambda_1}{\lambda_2 - \lambda_1},\ y_{pp} = \frac{\phi_{pp} - \phi_1}{\phi_2 - \phi_1}, \quad \text{(H.16)}$$

where λ_1 – longitude of IGPs west of IPP;

λ_2 – longitude of IGPs east of IPP;

ϕ_1 – latitude of IGPs south of IPP;

ϕ_2 – latitude of IGPs north of IPP.

Note.– If λ_1 and λ_2 cross 180° of longitude, the calculation of x_{pp} must account for the discontinuity in longitude.

For IPPs north of N85° or south of S85°:

$$y_{pp} = \frac{\left|\phi_{pp}\right| - 85°}{10°}, \; x_{pp} = \frac{\lambda_{pp} - \lambda_3}{90°} \cdot (1 - 2y_{pp}) + y_{pp}, \tag{H.17}$$

where λ_1 – longitude of the second IGP to the east of the IPP;

λ_2 – longitude of the second IGP to the west of the IPP;

λ_3 – longitude of the closest IGP to the west of the IPP;

λ_4 – longitude of the closest IGP to the east of the IPP.

For the three-point interpolation between S75° and N75°, a similar algorithm is used:

$$\tau_{vpp} = \sum_{k=1}^{3} W_k \tau_{vk}, \tag{H.18}$$

where $W_1 = y_{pp}$;

$W_2 = 1 - x_{pp} - y_{pp}$;

$W_3 = x_{pp}$.

x_{pp} and y_{pp} are calculated in the same way as for 4-point interpolation, except that λ_1 and ϕ_1 are always the longitude and the latitude of the 2-nd IPP and λ_2 and ϕ_2 – are the other latitude and longitude. The 2-nd point is always the vertex opposite the hypotenuse of the triangle defined by these three points; the 1-st point has the same longitude as the 2-nd point and the 3-rd point has the same latitude as the 2-nd point (an example is shown in Figure H.4).

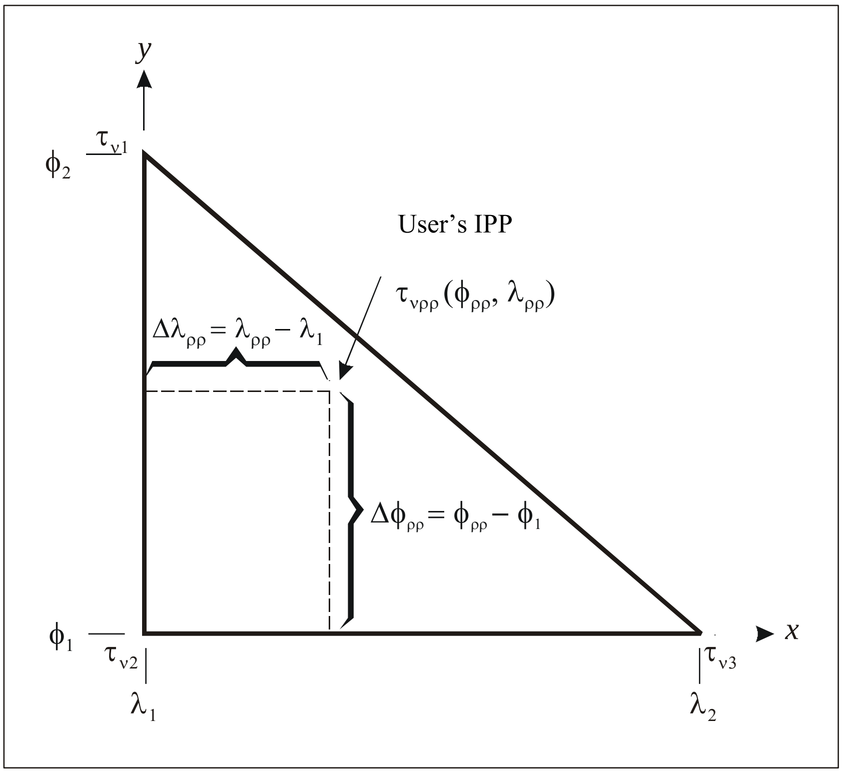

Figure H.4 – Three-point interpolation algorithm definitions between S75° and N75°

H.3.4 Ionospheric Corrections

The ionospheric correction IC for each satellite is defined as:

$$IC = -F_{pp} \cdot \tau_{vpp}, \tag{H.19}$$

where F_{pp} – is an obliquity factor estimated by the formula

$$F_{pp} = \left[1 - \left(\frac{R_e \cos\theta}{R_e + h_I}\right)^2\right]^{-\frac{1}{2}}; \tag{H.20}$$

τ_{vpp} – is interpolated vertical ionospheric delay estimate;

R_e = 6 378.1363 km;

θ – is elevation angle of satellite;

h_I = 350 km.

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

H.4 Protection Levels

H.4.1 The equipment uses the following equations for computing the Horizontal Protection Level (HPL) and the Vertical Protection Level (VPL), which are used to decide on reliable positioning:

$$\begin{aligned} HPL_{SDCM} &= \begin{cases} K_{H,NPA} \times d_{major} \text{ for non-precision approach,} \\ K_{H,PA} \times d_{major} \text{ for precision approach,} \end{cases} \\ VPL_{SDCM} &= K_{V,PA} \times d_V, \end{aligned} \tag{H.21}$$

where $d_v^2 = \sum_{i=1}^{N} s_{v,i}^2 \sigma_i^2$ – is the variance of model distribution that overbounds the true error distribution in the vertical axis;

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

$d_x^2 = \sum_{i=1}^{N} s_{x,i}^2 \sigma_i^2$ – is the variance of model distribution that overbounds the true error distribution in x axis;

$d_y^2 = \sum_{i=1}^{N} s_{y,i}^2 \sigma_i^2$ – is the variance of model distribution that overbounds the true error distribution in the y axis;

$d_{xy} = \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma_i^2$ – is the covariance model of distribution in the x and y axis;

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

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

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

$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2$.

The variances $\sigma^2_{i,flt}$ and $\sigma^2_{i,UIRE}$ are defined in H.4.3 and H.4.7. The parameters $\sigma^2_{i,air}$ and $\sigma^2_{i,tropo}$ are determined by onboard components.

The x and y axes are defined to be in the local horizontal plane, and the v axis represents local vertical.

For a general least-squares method position solution, the projection matrix S is:

$$S \equiv \begin{bmatrix} s_{x,1} & s_{x,2} & \cdots & s_{x,N} \\ s_{y,1} & s_{y,2} & \cdots & s_{y,N} \\ s_{v,1} & s_{v,2} & \cdots & s_{v,N} \\ s_{t,1} & s_{t,2} & \cdots & s_{t,N} \end{bmatrix} = \left(G^T \times W \times G\right)^{-1} \times G^T \times W, \qquad \text{(H.22)}$$

where the i-th row of G is determined by the formula

$$G_i = \left[-\cos El_i \cos Az_i \quad -\cos El_i \sin Az_i \quad -\sin El_i \quad 1\right]; \qquad \text{(H.23)}$$

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

El_i – is the elevation angle of the i-th ranging source (in degrees);

Az_i – is the azimuth of the i-th ranging source taken counter-clockwise from the x axis in degrees;

w_i – is the weight coefficient associated with satellite i, $w_i = \sigma_i^2$.

Note 1.– To improve readability, the subscript i was omitted from the protection matrix's equation.

Note 2.– For an unweighted least-squares solution, the weighting matrix is an identity matrix ($w_i = 1$).

H.4.2 Definition of K values.

The value of K_H for computing HPL is:

$$\begin{aligned} &K_{H,NPA} = 6.18 \text{ for non-precision approach,} \\ &K_{H,PA} = 6.0 \text{ for precision approach.} \end{aligned} \tag{H.24}$$

The value of $K_{V,PA}$ for computing VPL is:

$$K_{V,PA} = 5.33. \tag{H.25}$$

H.4.3 Definition of Fast and Long-Term Correction Error Model $\sigma_{i,flt}$

If fast corrections and long-term correction, SDCM ranging parameters are applied, and degradation parameters are applied:

$$\sigma_{i,flt}^2 = \begin{cases} \left[\left(\sigma_{i,UDRE}\right)\left(\delta UDRE\right) + \varepsilon_{fc} + \varepsilon_{rrc} + \varepsilon_{ltc} + \varepsilon_{er}\right]^2, \text{if } RSS_{UDRE} = 0, \\ \left[\left(\sigma_{i,UDRE}\right)\left(\delta UDRE\right)\right]^2 + \varepsilon_{fc}^2 + \varepsilon_{rrc}^2 + \varepsilon_{ltc}^2 + \varepsilon_{er}^2, \text{if } RSS_{UDRE} = 1, \end{cases} \tag{H.26}$$

where RSS_{UDRE} – is broadcast in Type 10 message;

δ_{UDRE} is one of the following three values, if:

- using message Type 27, δ_{UDRE} is a region-specific term;
- using message Type 28, δ_{UDRE} is a satellite-specific term;
- using neither message, δ_{UDRE} equals to 1.
- If fast corrections and long-term corrections and SDCM ranging parameters are not applied, degradation parameters are not applied and $\sigma_{i,flt}$ in meters is evaluated by the formula

$$\sigma^2_{i,flt} = \left[\left(\sigma_{i,UDRE}\right)\left(\delta UDRE\right) + 8\right]^2. \tag{H.27}$$

When long term, fast and SDCM range rate corrections are not applied to a satellite and when Type 28 message is not received with ephemerid covariance, but Type 28 message is received for another satellite, $\sigma_{i,flt}$ in meters is evaluated by the formula

$$\sigma^2_{i,flt} = \left(60\right)^2. \tag{H.28}$$

H.4.4 Fast Correction Degradation

The degradation parameter ε_{fc} for fast correction data is:

$$\varepsilon_{fc} = a\frac{(t - t_u + t_{lat})^2}{2}, \tag{H.29}$$

where a – is fast correction degradation factor derived from Type 7 message (see 7.10);

t – is the current time;

t_u – is UDREI reference time. If IODF is not equal to 3, t_u is the start time of the SNT 1-second epoch that is coincident with the start of the transmission of the message block that contains the most recent $UDREI_i$ data (Type 2 to 5, or Type 24 messages) that matches the $IODF_j$ of the fast correction being used. If $IODF_j$ is equal to 3, the start time of the epoch of the SNT 1-second epoch that is coincident with the start of transmission of the message that contains the fast correction for the i-th satellite;

t_{lat} – is the system delay (as defined in 7.10).

Note.– For UDREs broadcast in Type 2 to 5, and Type 24 messages, t_u equals the time of applicability of the fast corrections since they are in the same message. For UDREs broadcast in Type 6 message and if the IODF equls 3, t_u also equals the time of applicability of the fast corrections (t_{0f}). For UDREs broadcast in Type 6 message and IODF is not equal to 3, t_u is defined to be the broadcast time of the first bit of Type 6 message at the SDCM satellite.

H.4.5 Range Rate Correction Degradation

If the RRC equals 0, then the degradation parameter for range rate data ε_{rrc} equals 0.

If the RRC is not equal to 0 and IODF is not equal to 3, the degradation parameter ε_{rrc} for fast correction data is:

$$\varepsilon_{rrc} = \begin{cases} 0, & \text{if } (IODF_{current} - IODF_{previous}) \text{ MOD } 3 = 1, \\ \left(\dfrac{aI_{fc}}{4} + \dfrac{B_{rrc}}{\Delta t} \right)(t - t_{0f}), & \text{if } (IODF_{current} - IODF_{previous}) \text{ MOD } 3 \neq 1, \end{cases} \qquad \text{(H.30)}$$

where t – is the current time;

$IODF_{current}$ – is IODF associated with most recent fast correction;

$IODF_{previous}$ – is IODF associated with previous fast correction;

$\Delta t = t_{0f} - t_{0f\_previous}$;

I_{fc} – is the user time-out interval for fast corrections.

If RRC is not equal to 0 and IODF equals 3, the parameter ε_{rrc} is defined as follows:

$$\varepsilon_{rrc} = \begin{cases} 0, & \text{if } \left|\Delta t - \frac{I_{fc}}{2}\right| = 0, \\ \left(\frac{a\left|\Delta t - \frac{I_{fc}}{2}\right|}{2} + \frac{B_{rrc}}{\Delta t} \right)(t - t_{0f}), & \text{if } \left|\Delta t - \frac{I_{fc}}{2}\right| \neq 0. \end{cases} \quad \text{(H.31)}$$

H.4.6 Long-Term Correction Degradation of the GLONASS and GPS Systems.

For velocity code equal 1, the degradation parameter ε_{ltc} for long-term corrections of each satellite is

$$\varepsilon_{ltc} = \begin{cases} 0, \text{if } t_0 < t < t_0 + I_{ltc\_v1}, \\ C_{ltc\_lsb} + C_{ltc\_v1} \max(0, t_0 - t, t - t_0 - I_{ltc\_v1}), \text{ otherwise,} \end{cases} \quad \text{(H.32)}$$

where t – is the current time;

t_0 – is time of applicability of long-term corrections (see 7.5);

I_{ltc_v1}, C_{ltc_lsb}, C_{ltc_vl} – are the parameters transmitted in Type 10 message (see 7.10).

For velocity code equal 0, the degradation parameter ε_{ltc} for long-term corrections of each satellite is

$$\varepsilon_{ltc} = C_{ltc\_v0}\left\lfloor \frac{t - t_{ltc}}{I_{ltc\_v0}} \right\rfloor, \tag{H.33}$$

where t – is the current time;

t_{ltc} – is the time of transmission of the first bit of Type 25 message (long-term corrections) at the SDCM;

$\lfloor x \rfloor$ – is the greatest integer less than x.

Degradation parameter ε_{er} of residual error is defined as follows:

$$\varepsilon_{er} = \begin{cases} 0, \text{ if neither fast nor long-term corrections have timed out} \\ C_{er}, \quad \text{ if fast or long-term corrections have timed out} \end{cases} \tag{H.34}$$

where C_{er} – is the residual error band linked with the application of timed-out data (see 7.10).

UDRE degradation factor calculated with message Type 28 data. The δ_{UDRE} is:

$$\delta UDRE = \sqrt{I^T \cdot C \cdot I} + \varepsilon_c, \tag{H.35}$$

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

$\begin{bmatrix} i_x \\ i_y \\ i_z \end{bmatrix}$ – is the unit vector from the user to the satellite in the WGS84 ECEF coordinate frame;

$C = R^T \cdot R$;

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

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

$R = E \cdot SF$;

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

H.4.7 Determination of Ionospheric Correction Error Model σ_{UIRE}.

Broadcast ionospheric corrections. If SDCM-based ionospheric corrections are applied, σ^2_{UIRE} is as follows

$$\sigma^2_{UIRE} = F^2_{pp} \cdot \sigma^2_{UIVE}, \tag{H.36}$$

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

The same weights (W_n) for IPPs as well as the same IGPs which were selected for the ionospheric correction are used. If degradation parameters are used, for each grid point the following is true:

$$\sigma^2_{i,ionogrid} = \begin{cases} (\sigma_{GIVE} + \varepsilon_{iono})^2, \text{if } RSS_{iono} = 0, \\ \sigma^2_{GIVE} + \varepsilon^2_{iono}, \text{if } RSS_{iono} = 1, \end{cases} \tag{H.37}$$

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

RSS_{iono}, C_{iono_step}, C_{iono_ramp} – are transmitted in Type 10 message (see 7.10);

t – is the current time;

t_{iono} – is the time of transmission of the first bit of the ionospheric correction message at the SDCM;

$\lfloor x \rfloor$ – is the greatest integer less than x.

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

H.4.8 Ionospheric Corrections Dispersion.

If SDCM-based ionospheric corrections are not applied, then σ^2_{UIRE} is:

$$\sigma^2_{UIRE} = MAX\left\{\left(\frac{c \cdot T_{iono}}{5}\right)^2, \left(F_{pp} \cdot \tau_{vert}\right)^2\right\}, \qquad \text{(H.38)}$$

there c – speed of light in the vacuum, equal 299 792 458 m/s;

T_{iono} – is the ionospheric delay estimated by the chosen model;

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

ϕ_m – is the geomagnetic latitude of IPP projection (average ionospheric altitude is assumed as 350 km) in degrees [6].

Appendix J

(obligatory)

Additional Reference Materials and Information

J.1 Coverage Area and Service Areas of SDCM

J.1.1 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 J.1 shows 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).

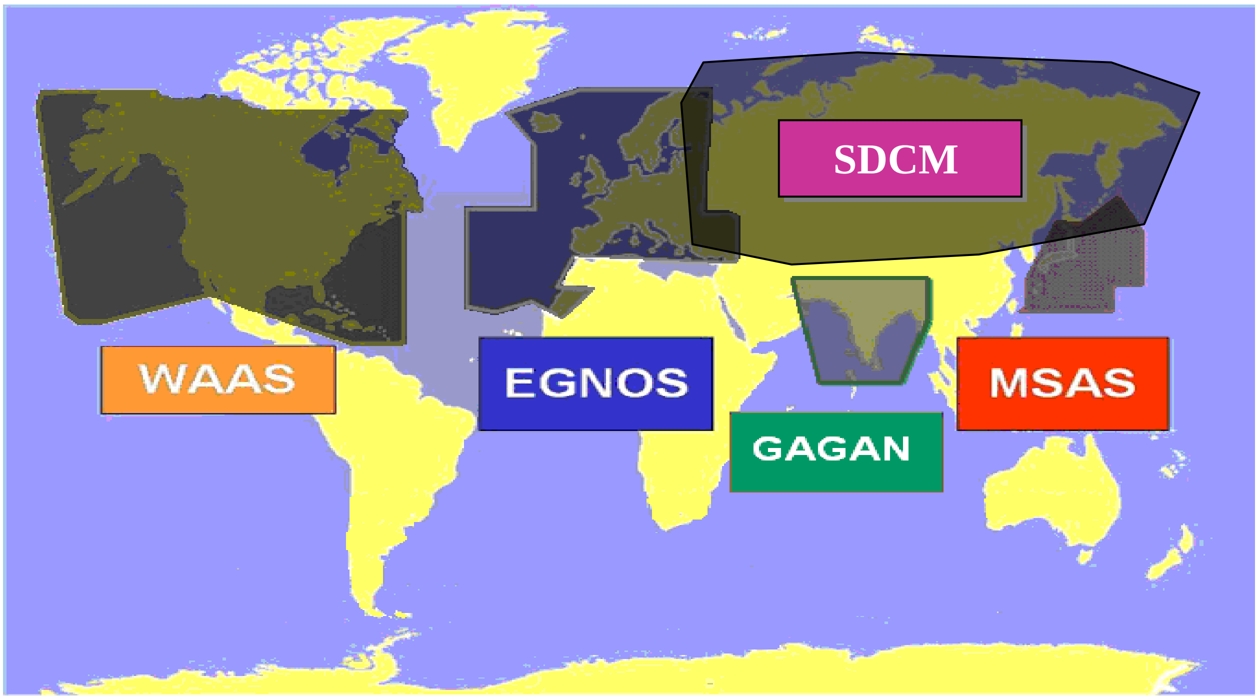

Figure J.1 – SBAS service areas

Currently all these systems, WAAS, EGNOS, MSAS, GAGAN, broadcast corrections only to the GPS satellites.

J.2 SBAS PRN codes list

J.2.1 Currently the SBAS systems use an enlarged PRN code list where the number of available codes is expanded from 19 to 39 (Table J.1).

Table J.1 – SBAS PRN codes list

PRN code number	G2 delay, chips	First 10 SBAS chips
120	145	0671
121	175	0536
122	52	1510
123	21	1545
124	237	0160

Table J.1 (continued)

PRN code number	G2 delay, chips	First 10 SBAS chips
125	235	0701
126	886	0013
127	657	1060
128	634	0245
129	762	0527
130	355	1436
131	1 012	1226
132	176	1257
133	603	0046
134	130	1071
135	359	0561
136	595	1037
137	68	0770
138	386	1327
139	797	1472
140	456	0124
141	499	0366
142	883	0133
143	307	0465
144	127	0717
145	211	0217
146	121	1742
147	118	1422
148	163	1442
149	628	0523
150	853	0736
151	484	1635
152	289	0136
153	811	0273

Table J.1 (continued)

PRN code number	G2 delay, chips	First 10 SBAS chips
154	202	1026
155	1021	0003
156	463	1670
157	568	0624
158	904	0235

J.3 Positioning Accuracy Improvement Techniques

J.3.1 User Equipment Calibration

J.3.1.1 The user positioning accuracy while using SDCM corrections is significantly affected by GLONASS code inter-frequency biases (IFBs) as they can't be estimated in combination with clock drifts as it is done for GPS. Since calibrated user equipment or calibration techniques significantly improve positioning accuracy, the user is recommended to apply calibration to improve its SDCM services. Calibration techniques for GPS/GLONASS equipment are provided, for example, in [9-11].

J.3.2 Smoothing of Pseudorange Measurements by Pseudocode measurements

J.3.2.1 It is recommended to smooth pseudoranges to each satellite by carrier phase measurements and application of a smoothing filter [10]. The SDCM broadcast correction is applicable to carrier smoothed pseudorange measurements that have not had the satellite broadcast troposphere and ionosphere corrections applied to them.

The carrier smoothing is defined by the following filter:

$$P_{CSC,n} = \alpha P + (1-\alpha)\left(P_{CSC,n-1} + \frac{\lambda}{2\pi}(\varphi_n - \varphi_{n-1})\right), \tag{J.1}$$

where $P_{CSC,n}$ – is the smoothed pseudorange;

$P_{CSC,n-1}$ – is the previous smoothed pseudorange;

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

λ – is the L1 wavelength;

φ_n – is the carrier phase;

φ_{n-1} – is the previous carrier phase;

α – is the filter weighting function equal to the sample interval divided by the smoothing time constant equal to 100 seconds.

List of Acronyms and Abbreviations

APV	–	Approach Procedure with Vertical guidance
BDS	–	BeiDou System
BPSK	–	Binary Phase Shift Keying
CRC	–	Cyclic Redundancy Check
CW	–	Continuous Wave
ECEF	–	Earth-Centered Earth-Fixed
EGNOS	–	European Geostationary Navigation Overlay Service
FC	–	Fast Corrections
GAGAN	–	GPS-Aided Geo-Augmented Navigation
GEO	–	Geostationary Orbit
GIVE	–	Grid Ionospheric Vertical Error
GIVEI	–	Grid Ionospheric Vertical Error Indicator
GLONASS	–	Global Navigation Satellite System of Russian Federation
GNSS	–	Global Navigation Satellite System
GPS	–	Global Positioning System
HAL	–	Horizontal Alert Limit
HPL	–	Horizontal Protection Level
ICAO	–	International Civil Aviation Organization
ICD	–	Interface Control Document
IGP	–	Ionospheric Grid Point
IOD	–	Issue of Data
IODC	–	GPS Issue of Data, Clock
IODE	–	GPS Issue of Data, Ephemeris
IODF	–	Issue of Data, Fast Corrections
IODG	–	Issue of Data, GLONASS
IODI	–	Issue of Data, Ionospheric Grid Point Mask
IODP	–	Issue of Data, PRN Mask
IODS	–	Issue of Data, Service Message
IPP	–	Ionospheric Pierce Point
LSB	–	Least Significant Bit
MOPS	–	Minimum Operation Performance Standards
MSAS	–	Michibiki Satellite Based Augmentation Service
MSB	–	Most Significant Bit
NPA	–	Non-Precision Approach
PA	–	Precision Approach
PRN	–	Rseudo Random Noise
RMS	–	Root Mean Square
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
SoL	–	Safety Of Life service
TTA	–	Time To Alert
UDRE	–	User Differential Range Error
UDREI	–	User Differential Range Error Indicator
UIRE	–	User Ionospheric Range Error
URA	–	User Range Accuracy
UTC	–	Universal Time Coordinated
VAL	–	Vertical Alert Limit
VPL	–	Vertical Protection Level
WAAS	–	Wide Area Augmentation System

References

1 International Standards and Recommended Practices / Annex 10 to the Convention on International Civil Aviation. Aeronautical Telecommunications. Volume I – International Civil Aviation Organization, Seventh Edition, Amendment 1-91, 2018.

2 Wide Area Augmentation System (SBAS), Federal Aviation Administration Specification, FAA-E-2892B – U.S. Department of transportation, September 1999.

3 Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS) - Document NO. RTCA/DO-208, Washington, 1991.

4 Software Considerations in Airborne Systems and Equipment Certification - Document NO. RTCA/DO-178B, Washington, 1992.

5 Minimum Operational Performance Standards for Global Positioning System / Wide Area Augmentation System Airborne Equipment - Document NO. RTCA/DO-229E, Washington, 2016.

6 Global positioning systems directorate. Systems engineering & integration. Interface specification. IS-GPS-200. Navstar GPS Space Segment/Navigation User Interfaces, September, 2013.

7 https://structure.mil.ru/files/pz-90.pdf.

8 Global Navigation Satellite System GLONASS, Interface Control Document. General description of CDMA signal system. Edition 1.0. Moscow, 2016.

9 V.Ye. Vovasov, D.N. Chunin. Elimination of Weighted Differences Bias in Pseudoranges Obtained by a Dual-Frequency SRNS Receiver GPS + GLONASS // Joint Stock Company “Russian Space Systems”. 2017, Vol. 4, No 4, pp. 15–23.

10 A.N. Zhukov, S.M. Zotov, I.N. Tupitsyn, D.Yu. Chenin. Improvement of GLONASS Users Positioning Accuracy Using Calibration Corrections to Pseudorange Measurements Estimated on the Basis of High-Precision Ephemerides and Time Corrections. Radionavigation technologies. Ed. by A.I. Perov. Moscow, Radiotekhnika, 2016, 146 p.

11 Yu.V. Isaev, A.N. Podkorytov. Calibration of GLONASS Pseudorange Measurements from Combined GPS/GLONASS Receiver for SDCM User // Joint Stock Company “Russian Space Systems”. 2019, Vol. 6, No 3, pp. 3–14.