GLOBAL NAVIGATION SATTELITE SYSTEM

GLONASS

INTERFACE
CONTROL
DOCUMENT

Navigation radiosignal
In bands L1, L2

(Version 5.1)

MOSCOW
2008

EXAMPLES OF ALGORITHMS FOR CALCULATION OF COORDINATES, VELOCITY AND TRANSFORMATION OF GLONASS-M CURRENT DATA INFORMATION INTO COMMON FORM
A. 3.1.1. Accurate algorithm for re-calculation of ephemeris to current time
 A.3.1.2.Simplified algorithm for re-calculation of ephemeris to current time
A.3.1.3. Algorithm of transformation of current data information into common form
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ABBREVIATIONS

BIH	Bureau International de l'Heure
CCIR	Consultative Committee for International Radio
CS	Central Synchronizer
FDMA	Frequency division multiple access
GMT	Greenwich Mean Time
ICD	Interface Control Document
KNITs	Coordination Scientific Information Center
KX	Hamming Code
LSB	Least Significan Bit
MT	Moscow Time
MSB	Most Significan Bit
msd	mean-solar day
NPO PM	Scientific and Production Association of Applied Mechanics
PR	Pseudo random
RF	Radio frequency
RMS (σ)	Root mean square
ROM	Read only memory
RNII KP	Research Institute of Space Device Engineering
SC	Spacecraft
UTC	Coordinated Universal Time

Russian Institute of Space Device Engineering

1. INTRODUCTION

1.1 GLONASS purpose

The purpose of the Global Navigation Satellite System GLONASS is to provide air, marine, and any other type of users with positioning, velocity measuring and timing data .

1.2 GLONASS components

GLONASS includes three components:
Constellation of satellites (space segment);
Ground-based control facilities (control)
User equipment (user segment).

Completely deployed GLONASS constellation is composed of 24 satellites in three orbital planes whose ascending nodes are 120 apart. 8 satellites are equally spaced in each plane with argument of latitude displacement 45. The orbital planes have 15 - argument of latitude displacement relative to each other. The satellites operate in circular 19100-km orbits at an inclination 64.8, and each satellite completes the orbit in approximately 11 hours 15 minutes. The spacing of the satellites allows providing continuous and global coverage of the terrestrial surface and the near-earth space.
The control segment includes the System Control Center and the network of the Command and Tracking Stations that are located throughout the territory of Russia. The control segment provides monitoring of GLONASS constellation status, correction to the orbital parameters and navigation data and control commands uploading.
User equipment consists of receivers and processors receiving and processing the GLONASS navigation signals, and allows user to calculate the coordinates, velocity and time.

1.3 Navigation determination concept

User equipment performs one-way measurements of pseudoranges and pseudorange rate of at least four (three) GLONASS satellites as well as receives and processes navigation messages contained within navigation signals of the satellites. The navigation message describes position of the satellites both in space and in time. Combined processing of the measurements and the navigation messages of the four (three) GLONASS satellites allows user to determine three (two) position coordinates, three (two) velocity vector constituents, and to refer user time scale to the National Reference of Coordinated Universal Time UTC(SU).

The data ensuring of sessions scheduling for navigational determinations, selection of working "constellation" of SVs and detection of radiosignals transmitted by them, are transmitted as a part of the navigation message.

2. GENERAL

The section 2 contains the definition of the Interface Control Document (ICD), procedure of approval and revision of ICD, and the list of organizations approving this document and authorized to insert additions and amendments to agreed version of ICD.

2.1 ICD definition

The GLONASS Interface Control Document specifies parameters of interface between GLONASS space segment and user equipment in L1 and L2 Bands.

2.2 ICD approval and revision

The «Russian Institute of Space Device Engineering» (RIS DE) is a developer of the GLONASS satellite onboard equipment, being considered as a developer of control interface, is responsible for development, coordination, revision and maintenance of ICD.

To inter into effect, ICD should be signed by the following organizations:
The «Russian Institute of Space Device Engineering» (RIS DE) – head organization for the GLONASS system, developer of payload and onboard service radio and telemetry systems, ground control segment, user equipment of various application.

Open joint-stock company «Informational satellite systems» n.a. the academician M. F. Reshetnev (Open Society "ISS") Roscosmos –developer of the GLONASS space segment, including the space-rocket system, ground control segment, navigation satellites and satellites control software.

The 4th Central scientific research institute of the Russian Federation Defense Ministry – a head research establishment of the Russian Ministry of Defense on the GLONASS system.

ICD is adopted by authorized representatives of the Space troops and Roscosmos.
In the course of the GLONASS system deployment and development its separate parameters can vary. Revisions of the prior approved edition of ICD can be offered

by any of the responsible parties and, are subject to approval and adoption by all parties responsible. The developer of control interface is responsible for obtaining approval of any revisions from all responsible parties and issuing a new revised version of the document if necessary.

The present ICD version recognizes a number of comments and proposals on the prior version of the document made by users and comprises some characteristics of interface between space segment and user equipment.

The «Russian Institute of Space Device Engineering» is an official distributor of ICD.

3. REQUIREMENTS

This section specifies general characteristics of GLONASS navigation signal, requirements to its quality, and provides brief description of its structure.

3.1 Interface definition

The interface between GLONASS space segment and users equipment consists of L-band radio links (fig. 3.1).

Each SC of the "Glonass" and "Glonass-M" families transmits navigational radiosignals on fundamental frequencies in two frequency sub-bands (L1 ~ 1,6 GHz, L2 ~ 1,25 GHz). SVs located in opposite orbital planes (antipodal SC), can transmit navigation radiosignals on the same frequencies.

SVs "Glonass" in sub-band L1 broadcast navigational signals of 2 types: a signal of a standard accuracy (ST), available to any users and a signal of pinpoint accuracy (PP), available only to special users and in sub-band L2 only one signal of PP.

SC "Glonass M" in sub-bands L1 and L2 broadcast navigational signals of 2 types: ST and PP.

The PP signal is modulated by a special code and intended for usage in interests of the Ministry of Defense.

Usage of a PP signal should be agreed with the Russian Federation Defense Ministry.

The present document reviews structure and characteristics of ST navigation signal in sub-bands L1 and L2, broadcast by "Glonass" and "Glonass M" SC.

3.2 Navigation signal structure

Navigation signal broadcast in carriers of L1 and L2 is a multi-component phase-shift key modulated signal. The phase shift keying of the carrier is performed at π radians with the maximum error ±0,2 radians.

The carrier of L1 sub-band and phases of bearing oscillations of sub-bands L1 and L2 is modulated by the Modulo-2 addition of the following binary signals: pseudo random (PR) ranging code, digital data of navigation message and auxiliary meander sequence.

All above-mentioned components are generated using a single onboard time/frequency oscillator (standard).

3.2.1 Ranging code

PR ranging code is a sequence of the maximum length of a shift register (M-sequence) with a period 1 millisecond and bit rate of 511 kilobits per second.

3.2.2 Digital data of navigation message

The navigation message includes immediate and non-immediate data.

The immediate data relate to the satellite, which transmits given navigation signal. The non-immediate data (GLONASS almanac) relate to all satellites within the GLONASS constellation.

The digital data are transmitted at 50 bits per second.

The content and the characteristics of the navigation message are given in Section 4.

3.3 Interface description

3.3.1 Navigation RF signal characteristics

3.3.1.1 Frequency plan

The nominal values of L1 and L2 carrier frequencies are defined by the following expressions:

$$f_{K1} = f_{01} + K\Delta f_1,$$
$$f_{K2} = f_{02} + K\Delta f_2, \text{ where}$$

K-is a frequency number of the signals transmitted by GLONASS satellites in the L1 and L2 sub-bands correspondingly;

$f_{01} = 1602$ M; $\Delta f_1 = 562,5$ kHz, for sub-band L1;
$f_{02} = 1246$ M; $\Delta f_2 = 437,5$ kHz, for sub-band L2.

The nominal values of carrier frequencies f_{K1} and f_{K2} for channel numbers K are given in Table 3.1.

Frequency number K for any particular GLONASS satellite is provided in almanac (non-immediate data of navigation message, see paragraph 4.5).

Subsystem of space vehicles
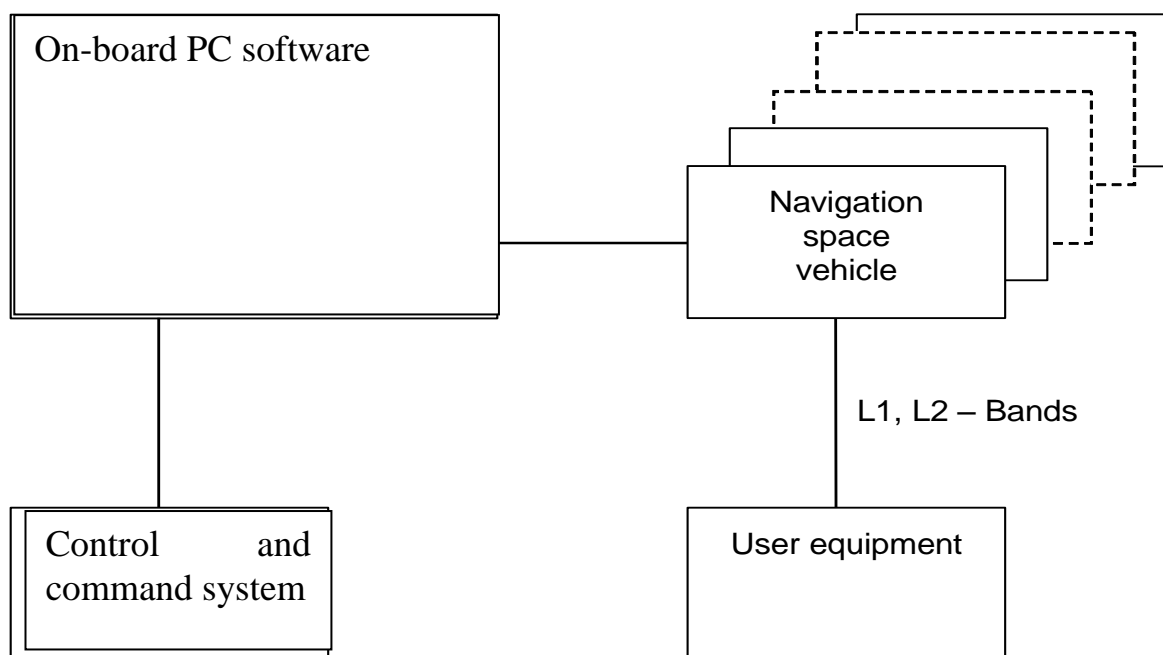
Fig. 3.1. SV Interface and User equipment

For each satellite, carrier frequencies of L1 and L2 sub-bands are coherently derived from a common onboard time/frequency standard. The nominal value of frequency, as observed on the ground, is equal to 5.0 MHz. To compensate relativistic effects, the nominal value of the frequency, as observed at satellite, is biased from 5.0 MHz by relative value $f/f = -4.36 \cdot 10_{-10}$ or $f = -2.18 \cdot 10_{-3}$ Hz that is equal to 4.99999999782 MHz (the value is given for nominal orbital height 19100 km). Ratio of carrier frequencies of L1 and L2 sub-bands is equal to $f_{K2}/f_{K1} = 7/9$

The actual values of carrier frequencies of the satellites are within $2 \times 10_{-11}$ relative to its nominal value f_k.

Table 3.1 GLONASS carrier frequencies in L1 and L2 sub-bands

No. of channel	Nominal value of frequency in L1 sub-band, MHz	No. of channel	Nominal value of frequency in L2 sub-band, MHz
06	1605,375	06	1248,625
05	1604,8125	05	1248,1875
04	1604,25	04	1247,75
03	1603,6875	03	1247,3125
02	1603,125	02	1246,875
01	1602,5625	01	1246,4375
00	1602,0	00	1246,0
-01	1601,4375	-01	1245,5625
-02	1600,8750	-02	1245,1250
-03	1600,3125	-03	1244,6875
-04	1599,7500	-04	1244,2500
-05	1599,1875	-05	1243,8125
-06	1598,6250	-06	1243,3750
-07	1598,0625	-07	1242,9375

According to recommendations of the International Telecommunications Union (ITU) the frequency numbers of ST signals may change from K=0…+24 to K=(-7…+6) in the GLONASS system.

All GLONASS SVs launched after 2005 will use numbers of frequencies K = (-7...+6).

3.3.1.2 Correlation loss

Correlation losses are stipulated by non sublime modulator and limitation of a radio signal spectrum in the transmitter of NS. For a navigational signal of a standard accuracy correlation losses are negligibility small.

3.3.1.3 Carrier phase noise

The phase noise spectral density of the non-modulated carrier is such that a phase locked loop of 10 Hz one-sided noise bandwidth provides the accuracy of carrier phase tracking not worse than 0.01 radian (mean-square value).

3.3.1.4 Spurious emissions

Power of transmitted unwanted RF signal beyond of the following GLONASS allocated bandwidths
(1598.0625 1605.375) MHz 0.511 MHz,
(1242.9375 1248.625) MHz 0.511 MHz
(see paragraph 3.3.1.1) shall not be more than -40 dB relative to power of non-modulated carrier.

"Glonass-M"SV is equipped with filters improving unwanted emissions in frequency bandwidth
        (1610,6 … 1613,8) MHz;
        (1660,0 … 1670,0) MHz,
to the level stipulated by the recommendations RA.769 of ITU-R.

3.3.1.5 Intrasystem interference

Intrasystem interference caused by the inter-correlation properties of PR ranging code and FDMA technique utilized in GLONASS. When receiving navigation signal on frequency channel K = n, an interference created by navigation signal with frequency K = n-1 or K = n+1 is mitigated not less than -48 dB relatively to signal power with K=n provided that the satellites transmitting these signals are simultaneously visible to a user.

3.3.1.6 Received power level

The power level of the received RF signal from GLONASS satellite at the output of a 3dBi linearly polarized antenna is not less than -161 dBW for L1 sub-band provided that the satellite is observed at an angle of 5 or more.
The power level of the received RF signal from GLONASS-M satellite at the output of a 3dBi linearly polarized antenna is not less than -161 dBW for L1 and L2 sub-bands provided that the satellite is observed at an elevation angle of 5 or more. Further information on received power level is given in Appendix 1.

3.3.1.7 Equipment group delay

Equipment group delay is defined as a delay between transmitted RF signal (measured at phase center of transmitting antenna) and a signal at the output of onboard time/frequency standard.

The delay consists of determined and undetermined components.

The determined component is no concern to a user since it has no effect on the GLONASS time computations. The undetermined component does not exceed 8 nanoseconds for GLONASS satellite and 2 nanoseconds for GLONASS-M satellite.

3.3.1.8 Signal coherence

All components of transmitted RF signal are coherently derived from carrier frequency of only one onboard time/frequency standard.

3.3.1.9 Polarization

Navigation RF signal transmitted in L1 and L2 sub-bands by each GLONASS satellite is right-hand circularly polarized. The elliptic coefficient of the field for the angular range is 19 deg. relatively to antenna pattern.

Not worse 0,7 in L1 sub-band;

Not worse 0,7 in L2 sub-band.

3.3.2 Modulation

The modulating sequence used for modulation of carrier frequencies sub-bands (when generating standard accuracy signals) in L1 for GLONASS satellites and L1, L2 for GLONASS-M satellites is generated by the Modulo-2 addition of the following three binary signals:

PR ranging code transmitted at 511 kbps;

navigation message transmitted at 50 bps,

and a meander sequence transmitted at 100 bps.

Given sequences are used for modulation of carriers in L1 and L2 sub-bands when generating standard accuracy signals.

3.3.2.1 Ranging code generation

PR ranging code is a sequence of maximum length of shift register with a period 1 millisecond and bit rate 511 kbps.

PR ranging code is sampled at the output of 7_{th} stage of the 9-stage shift register. The code of initial shift register represents "1" in all register stages. The initialization vector to generate this sequence is (111111111). The first character of the PR ranging code is the first character in the group 111111100, and it is repeated every 1 millisecond. The generating polynomial, which corresponds to the 9-stage shift register (see Fig. 3.2), is

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

Simplified block-diagram of the PR ranging code and clock pulse generation is given in Fig. 3.3.

3.3.2.2 Navigation message generation

The navigation message is generated as a pattern of continuously repeating strings with duration 2 seconds. During the first 1.7 seconds within this two-second interval navigation data are transmitted. During the last 0.3 second within this two second interval the time mark is transmitted.

Binary train of the navigation message is Modulo-2 addition of the following binary components:

a sequence of bits of the navigation message digital data in relative code and with duration of one bit 20 milliseconds;

a meander sequence with duration of one bit 10 millisecond.

The binary code of the time mark is a shortened pseudo random sequence of 30 bits, and duration of one bit is equal to 10 milliseconds. This sequence is described by the following generating polynomial:

$g(x) = 1 + x_3 + x_5,$

or may be shown as 111110001101110101000010010110.
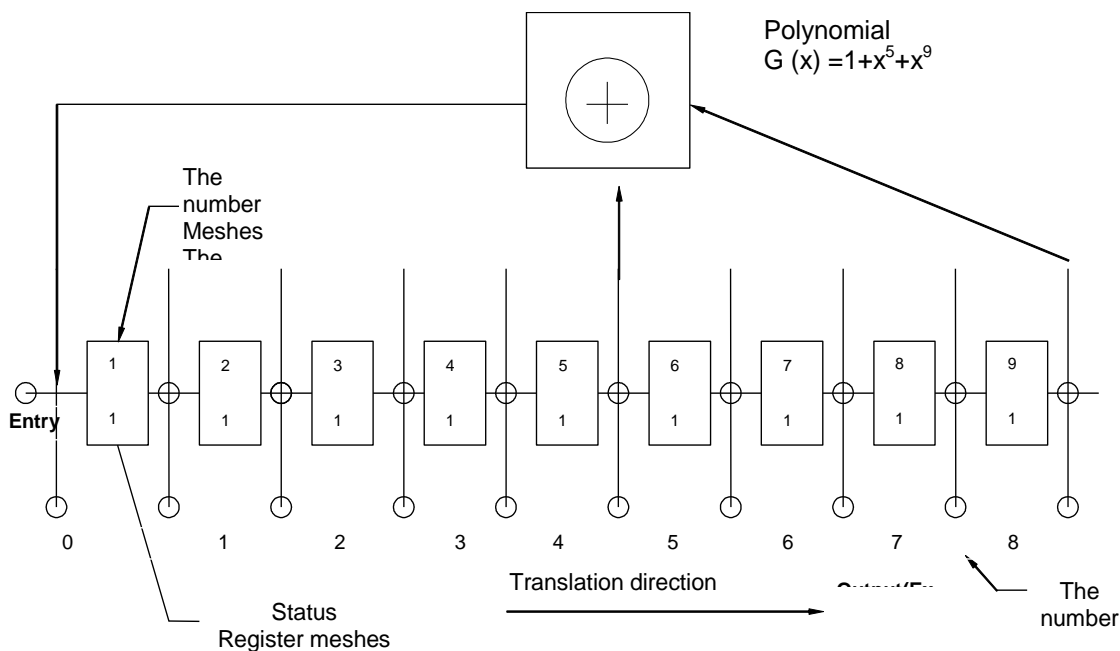
Fig. 3.2. Structure of the shift register shaping a ranging code

The first bit of the digital data in each string is always 0 . It is idle character which supplements shortened pseudo random sequence of the previous string time mark to the complete (non- shortened) one.

Simplified block-diagram of the data sequence generation is given in Fig. 3.4

The boundaries of the two-second strings, data bits, meander bits, time mark bits and ranging code bits are synchronized with each other within transmitted navigation signal. The boundaries of the meander bits and the data bits coincide with leading edge of the ranging code initial bit. The trailing edge of the latest bit of time mark corresponds to the moment that differs from the beginning of the current day by integer and even number of seconds referring to the satellite onboard time scale.

Time relationship between synchronizing pulses of the modulating binary train of the navigation message and PR ranging code is given in Fig. 3.5. A process of the navigation message generation is explained in Fig. 3.6. A content and a format of the navigation message are given in Section 4 of the document.

Standard frequency 5,0 МГц

Sync signals
f = 5,0 МГц
(T=200
nanosecond)

$f_T=0{,}511$ МГц

The squaring circuit
Sync signals
(f = 5,0 МГц)

Oscillator PSPD shift register

+

:10   :10   +   :50   + | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Reset to "0"

Installation all "1"

PSPD to
To the modulator

: 50 000

The flip-flop
Synchronisations

Sync signals T=10 a msec

To the processor

Strobes Tc =1 with

From frequency standard NKA

The flip-flop
Synchronisations

Sync signals T=1 with

To the processor

Figure 3.3 Simplified diagram of PR ranging code and clock pulse generation

Symbol Sequence
ПСПМВ

Symbol Sequence
ПСПД
(Tc ≈ 2 мкс)

relative code
Transformation

(0,3 с)

Symbol Delay

To the
modulator

coder

+

+

+

(1,7 с)

Sequence
Information symbols
$a_1 ... a_K$
(Tc = 20 мс)

Symbol Sequence
Information Verifying
$b_1 ... b_n$
(Tc = 20 мс)

$C_1 ... Cn$
(Tc = 20 мс)

Meander:
$d_1 ... d_m$
(Tc = 10 мс)
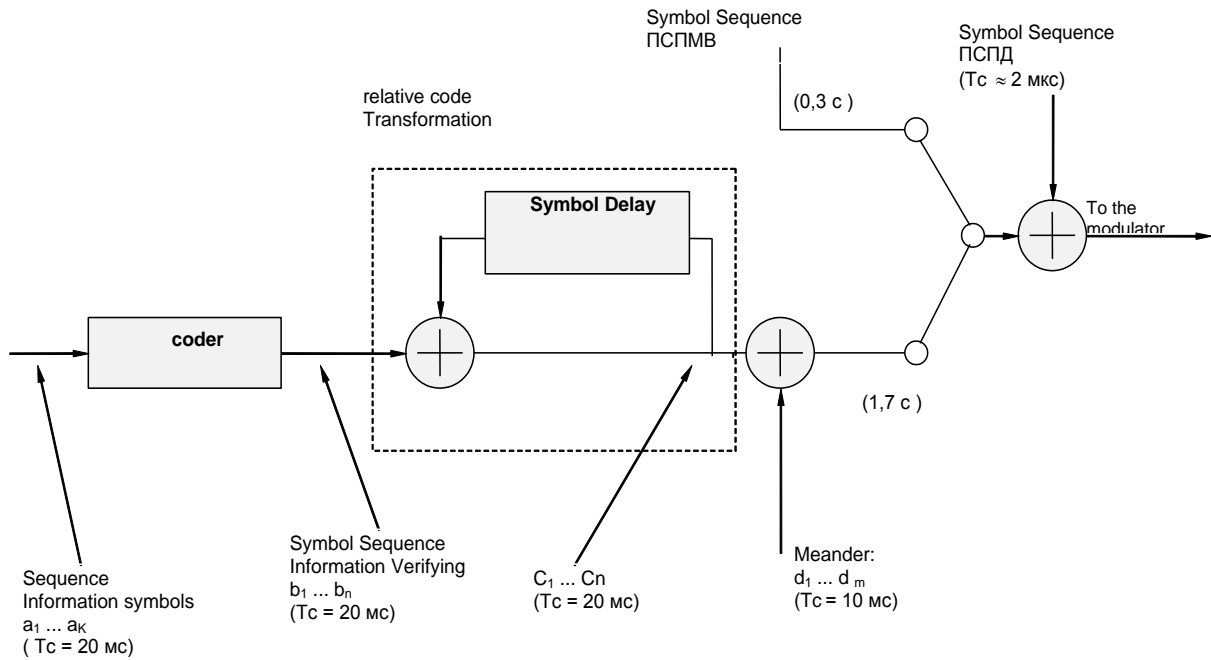
Figure 3.4 Simplified block-diagram of data sequence generation
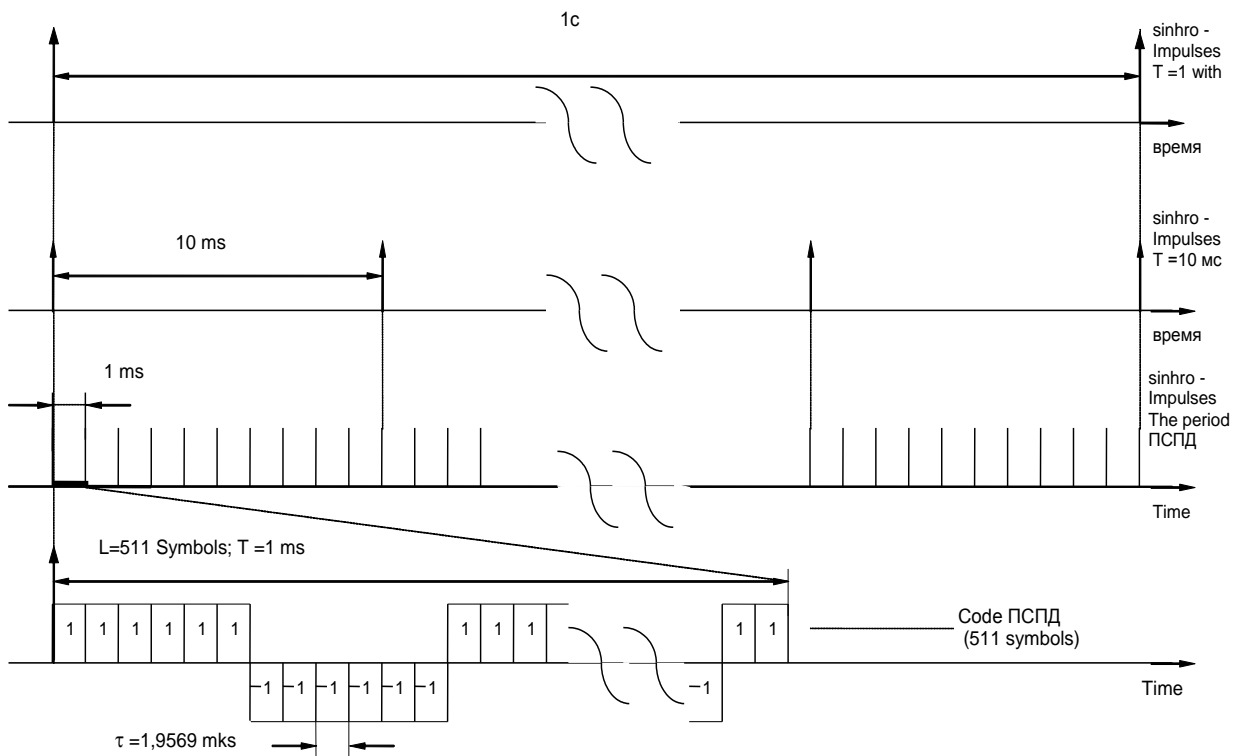
Figure 3.5 Time relationship between clock pulses and PR ranging code
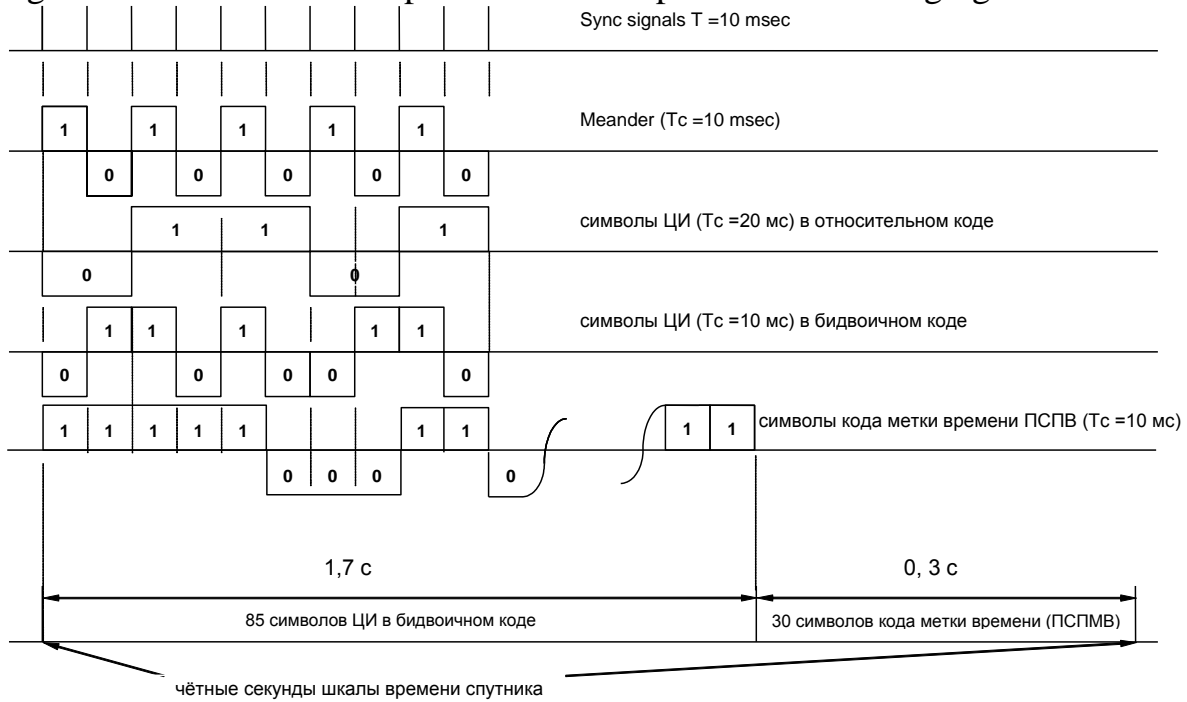
Figure 3.6 Data sequence generation in onboard processor

3.3.3 GLONASS time

The GLONASS satellites are equipped with clocks (time/frequency standards) which daily instability is not worse than $5*10^{-13}$ for GLONASS satellites and $1*10^{-13}$ for the GLONASS-M satellites. An accuracy of mutual synchronization of the satellite time scales is not worse than 20 nanoseconds (RMS) for the GLONASS and to 8 nanoseconds (RMS) for the GLONASS-M satellites.

GLONASS time is generated on a base of GLONASS Central Synchronizer (CS) time. Daily instability of the Central Synchronizer hydrogen clocks in not worse than 2×10^{-15}

The time scales of the GLONASS satellites are periodically compared with the CS time scale. Corrections to each onboard time scale relative to GLONASS time and UTC (SU) (see Section 4), re computed and uploaded to the satellites twice a day by control segment. The error of a scale system between UTC (SU) and the GLONASS time scale should not exceed 1 mks.

The error of comparison of on-board time scale with CS time scale is less than 10 ns at the time of measuring.

The GLONASS time scale is periodically corrected to integer number of seconds simultaneously with UTC corrections that are performed according to the Bureau International de l Heure (BIH) notification (leap second correction). Typically, these corrections (1s) are performed once a year (or 1.5 years) at midnight 00 hours 00 minutes 00 seconds UTC from December 31 to January 1 1-st quarter (or from March 31 to April 1 2-nd quarter or from June 30 to July 1 3-rd quarter or from September 30 to October 1- 4-th quarter) by all UTC users.

The GLONASS users are notified in advance (at least three months before) on these planned corrections through relevant bulletins, notifications etc. The GLONASS satellites have not any data concerning the UTC leap second correction within their navigation messages.

Navigation message of GLONASS-M satellites stipulates provision of advance notice for users on forthcoming UTC leap second correction, its value and sign (see Section 4.5, word KP within almanac).

Along with UTC corrections as stipulated by BIH/BIMP recommendations the GLONASS time corrections are performed through appropriate change of enumeration of second impulses sequence of all the GLONASS on-board clocks.

Time marker of the GLONASS frame string (broadcast every 2 seconds) change its place (on continuous time scale) to ensure synchronization with 2-second epoch of UTC corrected scale. This change takes place at midnight sharp UTC. General

recommendations concerning operation of GLONASS receiver upon the UTC leap second correction are given in Appendix 2.

Due to the leap second correction there is no integer-second difference between GLONASS time and UTC (SU). However, there is constant three-hour difference between these time scales due to GLONASS control segment specific features:

$T_{ГЛ} = T_{UTC (SU)}$ + 03 hour 00 mines

To re-compute satellite ephemeris at a moment of measurements in UTC(SU) the following equation shall be used:

$$T_{UTC(SU)} + 03 \text{ hour } 00 \text{ mines} = t + \tau_c + \tau_n(t_b) - \gamma_n(t_b)(t - t_b),$$

time of transmission of navigation signal in onboard time scale (parameters $_c$, $_n$, $_n$, and t_b are given in Sections 4.4 and 4.5).

GLONASS-M satellite transmit coefficients B1 and B2 to shift to Universal Time UT1 and t_{GPS} corrections to shift to GPS time.

t_{GPS} correction accuracy shall be better than 30 ns (RMS).

3.3.4 Coordinate system

The GLONASS broadcast ephemeris describes a position of transmitting antenna phase center of given satellite in the PZ-90.11 Earth-Centered Earth-Fixed reference frame defined as follows:

The ORIGIN is located at the center of the Earth's body;

The Z-axis is directed to the Conventional Terrestrial Pole as recommended by the International Earth Rotation Service (IERS);

The X-axis is directed to the point of intersection of the Earth's equatorial plane and the zero meridian established by BIH;

The Y-axis completes the coordinate system to the right-handed one.

Geodetic coordinates of a point in the PZ-90.11 coordinate system refers to the ellipsoid which semi-major axis and flattening are given in Table 3.2

Geodetic latitude B of a point M is defined as angle between the normal to the ellipsoid surface and equatorial plane.

Geodetic longitude L of a M point is determined as a corner between a plane of a prime meridian and a meridian plane, M. Transiting through a point a direction of the score of longitudes - from a prime meridian to the east from 0 to 360 grades.

Geodetic height H of a point M is defined as a distance from the ellipsoid surface to the point M along the normal.

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Fundamental geodetic constants and other significant parameters of the common terrestrial ellipsoid PZ-90.11 are given in Table 3.2.

Table 3.2 Geodesic constants and parameters of the Earth's ellipsoid PZ-90.11

Earth rotation angular rate	$7{,}292115 \times 10^{-5}$ rad/s
Geocentric constant of the Earth's gravitational field with atmosphere	$398\ 600{,}4418 \times 10^{9}$ m^3/s^2
Gravitational constant of atmosphere(fM_a)	0.35×10^{9} m^3/s^2
Speed of light	$299\ 792\ 458$ m/s
Semi-major axis	$6\ 378\ 136$ m
Flattening	$1/298{,}257\ 84$
Equatorial acceleration of gravity	$978\ 032{,}84$ мГал
Correction to acceleration of gravity at sea-level due to Atmosphere	$-0{,}87$ мГал
Second zonal harmonic of the geopotential (J_2^{0})	$1082625{,}75 \times 10^{-9}$
Fourth zonal harmonic of the geopotential (J_4^{0})	$(-2370{,}89 \times 10^{-9})$
Sixth zonal harmonic of the geopotential(J_6^{0})	$6{,}08 \times 10^{-9}$
Eighth zonal harmonic of the geopotential (J_8^{0})	$1{,}40 \times 10^{-11}$
Normal potential at surface of common terrestrial ellipsoid (U_0)	$62\ 636\ 861{,}4$ m^2/s^2

Note. Several sources for ballistic calculations use fixed harmonic coefficients of normal gravitational field of Earth (PZ-90.11):

$$\overline{C}_{20}^{0} = -484165{,}0 \times 10^{-9}; \qquad \overline{C}_{40}^{0} = 790{,}3 \times 10^{-9}$$

There is a relation between these parameters and ICD parameters:

$$J_2^{0} = -(5)^{1/2}\,\overline{C}_{20}^{0} ; \qquad\qquad (J_4^{0}) = -3\,\overline{C}_{40}^{0}$$

$$J_6^{0} = -(11)^{1/2}\,\overline{C}_{60}^{0}; \qquad\qquad J_8^{0} = -(7)^{1/2}\,\overline{C}_{80}^{0}$$

One should take into account the following relation while changing from normal to abnormal gravitational field:

$$\Delta\overline{C}_{20} = \overline{C}_{20} - \overline{C}_{20}^{0} \qquad\qquad \Delta\overline{C}_{40} = \overline{C}_{40} - \overline{C}_{40}^{0}$$

4. NAVIGATION MESSAGE

Content and a format of the GLONASS and GLONASS-M satellites navigation message are given in this Section.

4.1 Navigation message purpose

The navigation message transmitted by the GLONASS and GLONASS-M satellites within navigation signal is purposed to provide users with requisite data for positioning, timing and planning observations.

4.2 Navigation message content

The navigation message includes immediate data and non-immediate data.
The immediate data relate to the GLONASS satellite which broadcasts given RF navigation signal and include:
enumeration of the satellite time marks;
difference between onboard time scale of the satellite and GLONASS time;
relative difference between carrier frequency of the satellite and its nominal value;
ephemeris parameters and the other parameters (see section 4.4).
The non-immediate data contain almanac of the system including:
data on status of all satellites within space segment (status almanac);
coarse corrections to onboard time scale of each satellite relative to GLONASS time (phase almanac);
orbital parameters of all satellites within space segment (orbit almanac);
correction to GLONASS time relative to UTC(SU) and the other parameters (see section 4.5).

4.3 Navigation message structure

The navigation message is transmitted as a pattern of digital data that are coded by Hamming code and transformed into relative code. Structurally the data pattern is generated as continuously repeating super frames. A superframe consists of the frames, and a frame consists of the strings.
The boundaries of strings, frames and Superframe of navigation messages from different GLONASS satellites are synchronized within 2 milliseconds.

4.3.1 Superframe structure

The superframe has a duration of 2.5 minutes and consists of 5 frames. Each frame has a duration of 30 seconds and consists of 15 strings. Each string has a duration of 2 seconds. Within each frame a total content of non-immediate data (almanac for 24 GLONASS system satellites) are transmitted. Superframe structure with indication of frame numbers in the superframe and string numbers in the frames is given in Fig. 4.1.

| Number of frame in superframe | Number of string in frame | 2 c | | | |
		1, 7			0, 3
I	1	0	Immediate	KX	MB
	2	0	data for	KX	MB
	3	0	transmitting	KX	MB
	4	0	satellite	KX	MB
	. .		Non-immediate (almanac) for		
	15	0	five satellites	KX	MB
II	1	0	Immediate	KX	MB
	2	0	data for	KX	MB
	3	0	transmitting	KX	MB
	4	0	satellite	KX	MB
	. .		Non-immediate (almanac) for		
	15	0	five satellites	KX	MB
III	1	0	Immediate	KX	MB
	2	0	data for	KX	MB
	3	0	transmitting	KX	MB
	4	0	satellite	KX	MB
	. .		Non-immediate (almanac) for	.	
	15	0	five satellites	KX	MB
IV	1	0	Immediate	KX	MB
	2	0	data for	KX	MB
	3	0	transmitting	KX	MB
	4	0	satellite	KX	MB
	. .		Non-immediate (almanac) for	.	
	15	0	five satellites	KX	MB
V	1	0	Immediate	KX	MB
	2	0	data for	KX	MB
	3	0	transmitting	KX	MB
	4	0	satellite	KX	MB
	. .		Non-immediate (almanac) for four satellites		
	14	0	reserve	KX	MB
	15	0	reserve	KX	MB

30 c

30c x 5=2,5 мин

85   84...................9   8.........1

Number of byte in a string

Data symbols in relative bi-binary code

Hamming code in relative bi-binary code

Figure 4.1 Superframe structure

4.3.2 Frame structure

Navigation frame is a part of a superframe. Each frame has a duration of 30 seconds and consists of 15 strings. Each string has a duration of 2 seconds. Within each frame the total content of immediate data for given satellite and a part of no immediate data are transmitted. Frame structure within superframe is given in Fig. 4.2. The frames from 1 to 4 are identical. Shaded area in Fig. 4.2 indicates reserved bits are to be utilized in future modernizations and augmentations of the navigation message structure.

The data contained in strings from 1 to 4 of each frame relate to the satellite that transmits given navigation message (immediate data). The immediate data are the same within one superframe. The strings 6 to 15 of each frame contain non-immediate data (almanac) for 24 satellites. The frames 1 4 contain almanac for 20 satellites (5 satellites per frame). The 5_{th} frame contains remainder of almanac for 4 satellites. Non-immediate data (almanac) for one satellite occupy two strings. Data contained in 5_{th} string of each frame are the same within one superframe and relate to non-immediate data. Arrangement of almanac within superframe is given in Table 4.1.

Table 4.1 Arrangement of GLONASS almanac within superframe

Frame number within superframe	Satellite numbers, for which almanac is transmitted within given superframe
1	1 – 5
2	6 – 10
3	11 – 15
4	16 – 20
5	21 - 24

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(P2 ^{1}) 1	m ^{4}	^{2} P1 ^{2}	t_k ^{12}	$x_n^{'}(t_b)$ ^{24}	$x_n^{''}(t_b)$ ^{5}	$x_n(t_b)$ ^{27}	KX ^{8}	MB
2	m ^{4}	B_n ^{3} t_b ^{7} ^{5}		$y_n^{'}(t_b)$ ^{24}	$y_n^{''}(t_b)$ ^{5}	$y_n(t_b)$ ^{27}	KX ^{8}	MB
(P3 ^{1}) 3	m ^{4}	$\gamma_n(t_b)$ ^{11} ^{1} ^{2}p l_n^1 ^{1}		$z_n^{'}(t_b)$ ^{24}	$z_n^{''}(t_b)$ ^{5}	$z_n(t_b)$ ^{27}	KX ^{8}	MB
4	m ^{4}	$\tau_n(t_b)$ ^{22}	$\Delta\tau_n$ ^{5} E_n ^{5}	P4 ^{14} ^{1} F_T ^{4} ^{3} N_T ^{11} n ^{5} M ^{2}			KX ^{8}	MB
5	m ^{4}	N^A ^{11}	τ_c ^{32} ^{1} N_4 ^{5}	τ_{GPS} ^{22} l_n			KX ^{8}	MB
(C$_n$) 6	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10}	λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
7	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21}	ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
8	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10}	λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
9	m	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21}	ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
10	m	M_n^A ^{2} n^A ^{5} τ_n^A ^{10}	λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
11	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21}	ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
12	m	M_n^A ^{2} n^A ^{5} τ_n^A ^{10}	λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
13	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21}	ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
14	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10}	λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
15	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21}	ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB

Figure 4.2a Frame structure, 1_{st} 4_{th} frames

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(P2 ^{1}) 1	m ^{4}	^{2} P1 ^{2} t_k ^{12}	$x_n^{'}(t_b)$ ^{24}	$x_n^{''}(t_b)$ ^{5}	$x_n(t_b)$ ^{27}	KX ^{8}	MB
2	m ^{4}	B_n ^{3} t_b ^{7} ^{5}	$y_n^{'}(t_b)$ ^{24}	$y_n^{''}(t_b)$ ^{5}	$y_n(t_b)$ ^{27}	KX ^{8}	MB
(P3 ^{1}) 3	m ^{4}	$\gamma_n(t_b)$ ^{11} ^{1} p ^{2} l_n ^{1}	$z_n^{'}(t_b)$ ^{24}	$z_n^{''}(t_b)$ ^{5}	$z_n(t_b)$ ^{27}	KX ^{8}	MB
4	m ^{4}	$\tau_n(t_b)$ ^{22} $\Delta\tau_n$ ^{5} E_n ^{5}	P4 ^{14} ^{1} F_T ^{4} ^{3}	N_T ^{11} n ^{5} M ^{2}		KX ^{8}	MB
5	m ^{4}	N^A ^{11} τ_c ^{32} ^{1} N_4 ^{5}	τ_{GPS} ^{22} l_n			KX ^{8}	MB
(C$_n$) 6	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10} λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
7	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21} ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
8	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10} λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
9	m	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21} ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
10	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10} λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
11	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21} ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
12	m ^{4}	M_n^A ^{2} n^A ^{5} τ_n^A ^{10} λ_n^A ^{21}	Δi_n^A ^{18}	ε_n^A ^{15}		KX ^{8}	MB
13	m ^{4}	ω_n^A ^{16} $t_{\lambda^n}^A$ ^{21} ΔT_n^A ^{22}	$\Delta T_n^{'A}$ ^{7} H_n^A ^{5} l_n			KX ^{8}	MB
14	m ^{4}	B_1 ^{11} B_2 ^{10} KP ^{2}				KX ^{8}	MB
15	m ^{4}				l_n	KX ^{8}	MB

Figure. 4.2b Frame structure, 5_{th} frame

4.3.3 String structure

String is a structural element of the frame. String structure is given in Fig. 4.3. Each string contains data bits and time mark. String has duration 2 seconds, and during the last 0.3 seconds within this two-second interval (in the end of each string) the time mark is transmitted. The time mark (shortened pseudo random sequence) consists of 30 chips. Duration of the chip is 10 milliseconds (see paragraph 3.3.2.2). During the first 1.7 seconds within this two-second interval (in the beginning of each string) 85 bits of data are transmitted (the Modulo-2 addition of 50 Hz navigation data and 100 Hz auxiliary meander sequence (bi-binary code)).

The numbers of bits in the string are increased from right to the left. Along with data bits (bit positions 84-9) the check bits of Hamming code (KX) (bit positions 1 8) are transmitted.

The Hamming code has a code length of 4. The data of one string are separated from the data of adjacent strings by time mark (MB). The words of the data are registered by most significant bit (MSB) ahead. The last bit in each string (bit position 85) is idle chip ("0"). It serves for realization of sequential relative code when transmitting the navigation data via radio link.
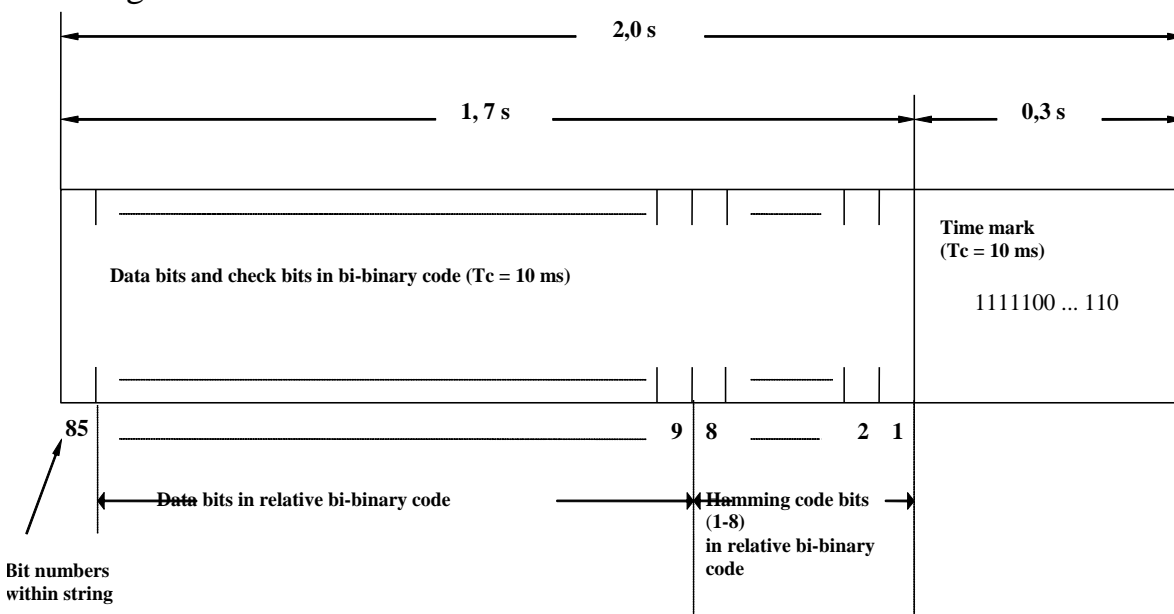

Figure 4.3 String structure

4.4 Immediate information and ephemeris parameters

Number of bits, minor bit value, value range and units of measuring ephemeris parameters are given in Table 4.5. In the words which numerical values may be positive or negative, the MSB is the sign bit. The chip "0" corresponds to the sign "+", and the chip "1" corresponds to the sign "-".

Ephemeris parameters are periodically computed and uploaded to the satellites by control segment. Mean square errors of transmitted coordinates and velocities of the satellites are given in Table 4.2.

Table 4.2 Accuracy of transmitted coordinates and velocity of the GLONASS satellite

Error component	Mean square error			
	predicted coordinates (m)		velocity (cm/s)	
SV	GLONASS	GLONASS-M	GLONASS	Glonass-M
Along track component	20	7	0,05	0,03
Cross track component	10	7	0,1	0,03
Radial component	5	1,5	0,3	0,2

The designations, units of measurement and value range of immediate navigation message words are given below in table 4.5.

The foregoing gives letter designation of immediate information words and explains their meaning.

Word m is the string number within the frame;

Word t_K is the time referenced to the beginning of the frame within the current day. It is calculated according to the satellite time scale. The integer number of hours elapsed since the beginning of current day is registered in the five MSBs. The integer number of minutes elapsed since the beginning of the current hour is registered in the next six bits. The number of thirty-second intervals elapsed since the beginning of the current day is registered in the one LSB. The beginning of the day according to the satellite time scale coincides with the beginning of the recurrent superframe;

The beginning of the day according to the satellite time scale coincides with the beginning of the recurrent superframe;

Word B_n is the health flag. The user navigation equipment analyzes the only one MSB of this word, where 1 indicates the fact of malfunction of given satellite. The user navigation equipment does not consider both second and third bits of this word.

Word t_b is an index of a time interval within current day according to the scale of GLONASS system time. Duration of the time interval and therefore maximum value of the word t_b depend on value of a flag P1 (see below).

Word **P** is a technological parameter of control segment, indication the satellite operation mode in respect of time parameters $_{(1)}$:

00 $_C$ parameter relayed from control segment, $_{GPS}$ parameter relayed from control segment;

01 - $_C$ parameter relayed from control segment, $_{GPS}$ parameter calculated on-board the GLONASS-M satellite;

10 - $_C$ parameter calculated on-board the GLONASS-M satellite, $_{GPS}$ parameter relayed from control segment;

11 - $_C$ parameter calculated on-board the GLONASS-M satellite, $_{GPS}$ parameter calculated on-board the GLONASS-M satellite.

Word **P1** is flag of the immediate data updating. It indicates a time interval between two adjacent values of t_b parameter (in minutes) in both current and previous frames as indicated in Table 4.3;

Table 4.3 Word P1

Word P1	Time interval between adjacent values of t_b, minutes
00	0
01	30
10	45
11	60

Word **P2** is flag of oddness ("1") or evenness ("0") of the value of t_b (for intervals 30 or 60 minutes);

Word **P3** is flag indicating a number of satellites for which almanac is transmitted within given frame: 1 corresponds to five satellites and 0 corresponds to four satellites;

Word **P4** is flag to show that ephemeris parameters are present. "1" indicates that updated ephemeris or frequency/time parameters have been uploaded by the control

segment $_{(1)}$, (0) indicates that no updated ephemeris or frequency/time parameters have been uploaded by the control segment

Note: Updated ephemeris or frequency/time information are transmitted only at the end of the current interval t_b where new parameters have been uploaded.

Word N_T is current date, calendar number of day within four-year interval starting from the 1-st of January in a leap year $_{(1)}$. An example of N_T transformation into the common form of current data information (dd/mm/yy) is presented in Attachment A 3.1.3.

Word n is an index of the satellite transmitting given navigation signal. It corresponds to a slot number within GLONASS constellation $_{(1)}$;

Word F_T is a parameter that provides the predicted satellite user range accuracy in the form of parameters set (ephemeris and frequency-time parameters) transmitted in a navigation message at time t_b as indicated in Table 4.4 $_{(1)}$;

Word $\Delta\tau_n$ is difference between navigation RF signal transmitted in L2 sub-band and RF signal transmitted in L1 sub-band by n_{th} satellite.
$\Delta\tau_n = t_{f2} - t_{f1}$, where t_{f1}, t_{f2}
equipment delays in L1 and L2 sub-bands correspondingly, expressed in units of time;

Word M is type of a satellite transmitting navigation signal. "00" refers to GLONASS satellite, "01" refers to a GLONASS-M satellite $_{(1)}$;

Table 4.4 Word F_T

Value of word F_T	Accuracy of measurements , m
0	1
1	2
2	2,5
3	4
4	5
5	7
6	10
7	12
8	14
9	16
10	32
11	64
12	128

13	256
14	512
15	Not used

Word $\gamma_n (t_b)$ is relative deviation of predicted carrier frequency value of n-satellite from nominal value at the instant t_b:

$$\gamma_n(t_b) = \frac{f_n(t_b) - f_{Hn}}{f_{Hn}},$$

$f_n(t_b)$ is predicted carrier frequency value of n-satellite taking account of gravitational and relativistic effects at the instant t_b

f_{Nn} is nominal value of carrier frequency of n_{th} satellite;

Word $\tau_n (t_b)$ is correction to the n_{th} satellite time t_n relative to GLONASS time t_c, which is equal to phase shift of PR ranging code of navigation signal transmitted by n_{th} satellite relative to the system reference signal at instant t_b, and expressed in units of time:

$$\tau_n (t_b) = t_c (t_b) - t_n (t_b);$$

Word l_n is health flag for n_{th} satellite; $l_n = 0$ indicates the n-th satellite is healthy, $l_n = 1$ indicates malfunction of this n_{th} satellite.

Table 4.5 Characteristics (bits, units and range of value) of words of immediate information

Word*	No. of bits	Scale factor (LSB)	Effective range	Units
m	4	1	0...15	dimensionless
	5	1	0...23	hours
tk	6	1	0...59	minutes
	1	30	0;30	seconds
tb	7	15	15...1425	minutes
M(1)	2	1	0-3	dimensionless
$\gamma_n(t_b)$(2)	11	2^{-40}	$\pm 2^{-30}$	dimensionless

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τ n(tb)(2)	22	2-30	$\pm$2-9	seconds
x n(tb), y n(tb), z n(tb)(2)	27	2-11	$\pm$2,7*104	kilometers
x n(tb), y n(tb), z n(tb)(2)	24	2-20	$\pm$4,3	km/s
x n(tb), y n(tb), z n(tb)(2)	5	2-30	$\pm$6,2*10-9	km/s$_2$
Bn	3	1	0…7	dimensionless
P(1)	2	1	00,01,10,11	dimensionless
NT (1)	11	1	0…1461	days
FT(1)	4	(Table 4.4)		
n(1)	5	1	0…31	dimensionless
$\Delta\tau$n (2)	5	2-30	$\pm$13,97*10-9	seconds
En	5	1	0...31	days
P1	2	(Table 4.3)		
P2	1	1	0;1	dimensionless
P3	1	1	0;1	dimensionless
P4(1)	1	1	0;1	dimensionless
ln(1)	1	1	0;1	dimensionless

Note (1): - Parameters of words are transmitted in a navigation message of a "Glonass M" satellite.
Note (2): - In the words with positive and negative parameters high-order bit is character. Thus "0 character matches to"+ sign, and "1 character to the sign" −".

Arrangement of words of immediate information in a navigation message frame is presented in table 4.6.
Table 4.6 shows immediate information words layout in a frame.

Table 4.6 Immediate information words layout in a frame

Word	No. of bits	String number within frame	Bit number within string
m	4	1...15	81 - 84
t_k	12	1	65 - 76
t_b	7	2	70 - 76
M	2	4	9 - 10
$\gamma_n(t_b)$	11	3	69 - 79
$\tau_n(t_b)$	22	4	59 - 80
$x_n(t_b)$	27	1	9 - 35
$y_n(t_b)$	27	2	9 - 35
$z_n(t_b)$	27	3	9 - 35
$\dot{x}_n(t_b)$	24	1	41 - 64
$\dot{y}_n(t_b)$	24	2	41 - 64
$\dot{z}_n(t_b)$	24	3	41 - 64
$\ddot{x}_n(t_b)$	5	1	36 – 40
$\ddot{y}_n(t_b)$	5	2	36 – 40
$\ddot{z}_n(t_b)$	5	3	36 - 40
P	2	3	66 - 67
N_T	11	4	16 – 26
n	5	4	11 – 15
F_T	4	4	30 – 33
E_n	5	4	49 – 53
B_n	3	2	78 – 80
P1	2	1	77 – 78
P2	1	2	77
P3	1	3	80
P4	1	4	34
$\Delta\tau_n$	5	4	54 - 58
l_n	1	3,5,7,9,11,13,15	65(3st string), 9(5,7,9,11,13,15 string)

Words $x_n (t_b)$, $y_n (t_b)$, $z_n (t_b)$ - Co-ordinates of n th SV in co-ordinate system PZ-90.11 at an instant t_b;

Words $\dot{x}_n (t_b)$, $\dot{y}_n (t_b)$, $\dot{z}_n (t_b)$ - Components of vector velocity of n th SV in co-ordinate system PZ-90.11 at an instant t_b;

Words $\ddot{x}_n (t_b)$, $\ddot{y}_n (t_b)$, $\ddot{z}_n (t_b)$ –Components of acceleration of n th SV in PZ 90.11 induced by the Moon and the SC at an instant t_b,;

Word E_n - Characterizes "age" of immediate information, that is the time between immediate data uploading and time t_b of n th SC. Word E_n is generated on board a SC.

4.5 Non-immediate information and almanac

Non-immediate information (almanac) includes:
data on GLONASS time;
data on onboard time scales of all GLONASS satellites;
data on orbital elements and health status of all GLONASS satellites.
Characteristics of words of non-immediate information (almanac) are given in Table 4.9.
The designations and explanations of the almanac words are given below:

Word τ_c is GLONASS time scale correction to UTC(SU) time. The correction τ_c is given at the instant of beginning of the day N^A ;

$\tau_c = T_{UTC(SU)} + 03\ h\ 00\ min - T_{GL}$
Word N_4 is four-year interval number starting from 1996 [1];

Word τ_{GPS} is correction to GPS time relative to GLONASS time.
$T_{GPS} - T_{GL} = \Delta T + \tau_{GPS}$, where
ΔT is integer part, and τ_{GPS} is fractional part of the difference between the system time scales expressed in seconds.
Note. The integer part ΔT is determined from GPS navigation message in user receiver [1];

Word N^A is calendar day number within the four-year period beginning since the leap year. The correction τ_c and other almanac data (almanac of orbits and almanac of phases) relate to this day number;

Word $\mathbf{n^A}$ is conventional number of satellite within GLONASS space segment, which corresponds to number of slot occupied by this satellite;

Word $\mathbf{H_n^A}$ is carrier frequency number of navigation RF signal transmitted by n^A - satellite;

Word $\mathbf{\lambda_n^A}$ is longitude of the first (within the N^A -day) ascending node of n^A -satellite orbit in PZ-90.11 coordinate system;

Word $\mathbf{t_{\lambda n}^A}$ is time of the first ascending node passage of n^A -satellite within N^A -day;

Word $\mathbf{\Delta i_n^A}$ is correction to the mean value of inclination of n^A -satellite at instant of $t_{\lambda n}^A$ (mean value of inclination is equal to 63°);

Word $\mathbf{\Delta T_n^A}$ is correction to the mean value of Draconian period of the n^A -satellite at instant of $t_{\lambda n}^A$ (mean value of Draconian period T is equal to 43200 s);

Word $\mathbf{\Delta \dot{T}_n^A}$ is rate of change of Draconian period of n^A -satellite;

Word $\mathbf{\varepsilon_n^A}$ is eccentricity of n^A -satellite at instant of $t_{\lambda n}^A$;

Word $\mathbf{\omega_n^A}$ is argument of perigee of n^A -satellite at instant of $t_{\lambda n}^A$;

Word $\mathbf{M_n^A}$ is a type of satellite n^A [1]; coding "00" indicates a GLONASS satellite, coding "01" indicates a GLONASS-M satellite;

;

Words B1 and **B2** are coefficients of linear polynom to determine ΔUT1 which is the difference between UT1 (time of initial direction given polar motion) and UTC (SU) coordinated time of the Russian state standard.

ΔUT1 = UTC(SU) - UT1

Word **B1** is coefficient to determine ΔUT1 at the beginning of the day (N^A), expressed in second [1]
Word B2 is the velocity of ΔUT1 change expressed in second for a mean sun day [1].

$$\Delta UT1 = B1 + B2*(NT - N^A),$$

Word **KP** is notification on forthcoming leap second correction of UTC (± 1 s), as shown in Table 4.7 [1].

Table 4.7 Word KP

KP	Information on UTC leap second correction
00	No UTC correction at the end of current quarter
01	UTC correction by plus (+1 s) at the end of current quarter.
11	UTC correction by minus (-1 s) at the end of current quarter.

The word **KP** appears in the navigation message at least eight weeks before the correction. However, a decision on forthcoming leap second correction can be made earlier than eight weeks before. So in case the decision has been taken the one of above three values of the word KP is transmitted in the beginning of current quarter. Otherwise KP = 10 is transmitted.

Word τ_n^A is coarse value of n^A- satellite time correction to GLONASS time at instant $t_{\lambda n}^A$, which is equal to phase shift of PR ranging code of transmitted navigation signal relative to the nominal position expressed in units of time;

Word C_n^A is generalized "unhealthy flag" of n^A-satellite at instant of almanac upload (almanac of orbits and phases). When $C_n = 0$, this indicates non-operability of n-satellite.
When $C_n = 1$, this indicates operability of n-satellite.

An accuracy of almanac parameters allows user to determine coordinates and radial velocity with the mean square errors depending of "age" of the almanac as indicated in Table 4.8.

Table 4.8 Relationship between "age" of almanac and accuracy of positioning

"Age" of almanac	Mean square error of measurement	
	range (km)	*Radial velocity (m/s)*
1 day	0.83	0.33
10 days	2.0	0.7
20 days	3.3	4.2

Table 4.9 Characteristics of words of non-immediate information (almanac)

Word*	No. of bits	Scale factor(LSB)	Effective range	Units
τ_c [1] [2] [3] [4]	28	2^{-27}	± 1	s
	32	2^{-31}	± 1	s
τ_{GPS} [1] [2]	22	2^{-30}	$\pm 1.9*10^{-3}$	day
N_4 [1]	5	1	1…31	4-year interval
N^A	11	1	1...1461	days
n^A	5	1	1...24	dimensionless
H_n^A [3]	5	1	0...31	dimensionless
λ_n^A [2]	21	2^{-20}	± 1	semi-circle
$t_{\lambda n}^A$	21	2^{-5}	0...44100	s
Δi_n^A [2]	18	2^{-20}	± 0.067	semi-circle
ΔT_n^A [2]	22	2^{-9}	$\pm 3.6*10^3$	s/orbital period
[2] $\Delta \dot{T}_n^A$	7	2^{-14}	$\pm 2^{-8}$	s/orbital period^2
ε_n^A	15	2^{-20}	0...0.03	dimensionless
ω_n^A [2]	16	2^{-15}	± 1	semi-circle
M_n^A [1]	2	1	0 - 3	dimensionless
B1 [1] [2]	11	2^{-10}	± 0.9	s
B2 [1] [2]	10	2^{-16}	$(-4,5…3,5)*10^{-3}$	s/msd
KP	2	1	0,1	dimensionless

(1)				
τ_n^A	10	2^{-18}	$\pm 1,9*10^{-3}$	s
C_n^A	1	1	0...1	dimensionless

Note (1): - These words are inserted into navigation message of GLONASS-M satellite.

Note (2): - In the words that numerical values may be positive or negative, the MSB is the sign bit. The chip "0" corresponds to the sign "+", and the chip "1" corresponds to the sign "-".

Note (3): - Negative values of frequency channel numbers are designated within navigation message as indicated in Table 4.10

Note (4): - Scale factor (LSB) of the word τ_C is increased to 2^{-31}s (that is to 0.46 ns) by allocation of additional bits for τ_C in navigation message of GLONASS-M satellite (up to 32 bits). The word τ_C will be located in 5th, 20th, 35th, and 65th strings within superframe, and it will occupy 38th to 69th bits.

Table 4.10 Negative numbers of GLONASS carriers within navigation message

Frequency channel number	Value of word H_n^A
-01	31
-02	30
-03	29
-04	28
-05	27
-06	26
-07	25

Arrangement of almanac words within frame is given in Table 4.11.

Table 4.11 Arrangement of non-immediate information within frame

Word*	No. of bits	(1) String number within frame	Bit number within string
τ_c	32	5	38 – 69 (see Note 4 for Table 4.9)
$N_4^{(1)}$	5	5	32 – 36
τ_{GPS}	22	5	10 - 31

N^A	11	5	70 - 80
n^A	5	6, 8, 10, 12, 14	73 - 77
H_n^A	5	7, 9, 11, 13, 15	10 - 14
λ_n^A	21	6, 8, 10, 12, 14	42 - 62
$t_{\lambda n}^A$	21	7, 9, 11, 13, 15	44 - 64
Δi_n^A	18	6, 8, 10, 12, 14	24 - 41
ΔT_n^A	22	7, 9, 11, 13, 15	22 - 43
$\Delta \dot{T}_n^A$	7	7, 9, 11, 13, 15	15 - 21
ε_n^A	15	6, 8, 10, 12, 14	9 – 23
ω_n^A	16	7, 9, 11, 13, 15	65 – 80
M_n^A	2	6,8,10,12,14	78-79
B1	11	74	70-80
B2	10	74	60-69
KP	2	74	58-59
τ_n^A	10	6, 8, 10, 12, 14	63 – 72
C_n^A	1	6, 8, 10, 12, 14	80

4.6 Reserved bits

There are reserved bits within superframe for insertion an additional information. Arrangement of reserved bits within superframe, with an indication of the string number (unique indexing of strings within superframe is used) and the bit number are given in Table 4.12.

Table 4.12 Arrangement of reserved bits within super frame

String numbers within superframe	Position of bits within string	Number of bits
1, 16, 31, 46, 61	79, 80	2
2, 17, 32, 47, 62	65 – 69	5
3, 18, 33, 48, 63	68	1
4, 19, 34, 49, 64	27,28,29, 35 – 48	17
5, 20, 35, 50, 65	37	1
74	9 – 57	49
75	10 – 80	71

Note: - Arrangement of reserved bits in superframe is given basing on Notes 1 and 4 to Tables 4.5 and 4.9.

4.7 Data verification algorithm

This algorithm allows correcting an error in one bit within the string and detecting an two or more even errors in bits within the string. Each string includes 85 data bits where 77 most significant bits are data chips (b_{85}, b_{84},..., b_{10}, b_9), and 8 least significant bits are check bits (β_8, β_7,..., β_2, β_1).

To correct one bit error within the string the following checksums are generated: (C_1, C_2,...,C_7), and to detect two-bit error (or more-even-number-of-bits error) a checksum C_Σ.is generated. The rules for generation of the checksums (C_1,...,C_7 and C_Σ) when verifying the data within the string are given in Table 4.13.

The following rules are specified for correcting single errors and detecting multiple errors:

a) a string is considered correct if all checksums (C_1,...,C_7, and C_Σ) are equal to zero, or if only one of the checksums (C_1,...,C_7) is equal to1 but $C_\Sigma = 1$;

b) if two or more of the checksums (C_1,...,C_7) are equal to 1 and $C_\Sigma = 1$, then character b_{icor} is corrected to the opposite character in the following bit position:

$$i_{cor} = C_7\,C_6\,C_5\,C_4\,C_3\,C_2\,C_1 + 8 - K,\ \text{provided that } i_{cor} \le 85,\ \text{where}$$

$C_7\,C_6\,C_5\,C_4\,C_3\,C_2\,C_1$ − binary number generated from the checksums (C_1,...,C_7) where all binary numbers are written by LSB to the right);

K is ordinal number of most significant checksum not equal to zero;

If a formula for i_{cor} gives $i_{KOP} > 85$ then it indicates that there is odd number of multiple errors. In this case data are not corrected but erased;

c) if at least one of the checksums (C_1,...,C_7) is equal to 1 and $C_\Sigma = 0$, or if all checksums (C_1,...,C_7) are equal to zero but $C_\Sigma = 1$, then it indicates that there are multiple errors and data are to be erased.

Table 4.13 Algorithm for verification of data within string (an example)

β_1, β_2,…,β_8 – check bits of Hamming code (1-8); b_{77},b_{76},…,b_2, b_1 – data bits (9-85); C_1, C_2,…,C_7, C_Σ - checksums; $C_1 = \beta_1 \oplus [\ \sum_i b_i]\bmod 2$

i = 9, 10, 12, 13, 15, 17, 19, 20, 22, 24, 26, 28, 30, 32, 34, 35, 37, 39, 41, 43, 45, 47, 49, 51, 53, 55, 57, 59, 61, 63, 65, 66, 68, 70, 72, 74, 76, 78, 80, 82, 84.

$C2 = \beta2 \oplus [\sum_j b_j] \bmod 2$

j = 9, 11, 12, 14, 15, 18, 19, 21, 22, 25, 26, 29, 30, 33, 34, 36, 37, 40, 41, 44, 45, 48, 49, 52, 53, 56, 57, 60, 61, 64, 65, 67, 68, 71, 72, 75, 76, 79, 80, 83, 84.

$C3 = \beta3 \oplus [\sum_k b_k] \bmod 2$

k = 10-12, 16-19, 23-26, 31-34, 38-41, 46-49, 54-57, 62-65, 69-72, 77-80, 85.

$C4 = \beta4 \oplus [\sum_l b_l] \bmod 2$

l = 13-19, 27-34, 42-49, 58-65, 73-80.

$C5 = \beta5 \oplus [\sum_m b_m] \bmod 2$

m = 20-34, 50-65, 81-85.

$C6 = \beta6 \oplus [\sum_{n=35}^{65} b_n] \bmod 2 \qquad\qquad C7 = \beta7 \oplus [\sum_{p=66}^{85} b_p] \bmod 2$

$C\Sigma = [\sum_{q=1}^{8} \beta_q] \bmod 2 \oplus [\sum_{q=9}^{85} b_q] \bmod 2$

5 GLONASS SPACE SEGMENT

This section describes GLONASS SV constellation and its orbital parameters

5.1 Constellation structure

Completely deployed GLONASS constellation consists of 24 satellites.
Satellites are placed in three orbital planes. There are 8 satellites in each plane.
Longitudes of ascending nodes of orbit planes are discriminated on 120° The orbital

planes have ordinal numbers 1, 2 and 3 counting towards Earth rotation. The 1ˢᵗ orbital plane has slot numbers 1…8, the 2ⁿᵈ orbital plane – slots 9…16, and the 3ʳᵈ orbital plane – slots 17…24. Slot numbers within orbital plane are increased backward satellite rotation around the Earth.

5.2 Orbital parameters

Nominal values of absolute longitudes of ascending nodes for ideal orbital planes fixed at 00 hours 00 minutes 00 seconds MT (UTC + 03 hours 00 minutes 00 seconds) on January 1ˢᵗ, 1983 are equal to:

251° 15' 00"+ 120° (i - 1),
where "i" is orbital plane number (i = 1, 2, 3).

Nominal spacing between adjacent satellites within single orbital plane, according to argument of latitude, is equal to 45°.
Mean rate of orbital plane precession is equal to (- $0.59251*10^{-3}$) radian/day.
Ideal values of argument of latitude for satellites located in slots j = N + 8 and j = N + 16 differ from arguments of latitude for satellites located in slots j = N and j = N + 8 by 15° correspondingly, where N = 1,...,8 also make on $0^h00^m00^s$ on January, 1st, 1983 and are equal to:

145° 26' 37" + 15° (27 - 3j + 25j*),

where: "**j**" is slot number (j = 1, 2,..., 24);

$$j^* = E\left\{ \frac{j-1}{8} \right\} \text{ - integer part of } \frac{j-1}{8}.$$

An interval of repetition for satellite tracks and visibility zones as observed on the ground is equal to 17 orbital periods (7 days 23 hours 27 minutes 28 seconds).
Nominal orbit parameters of the GLONASS system satellites are as follows:
Draconian period - 11 hours 15 minutes 44 seconds;
Orbit altitude - 19100 km;
Inclination - 64.8° ;
Eccentricity - 0.
Maximum deviation of a satellite position relative to ideal slot position does not exceed ± 5° on the period of lifetime.

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5.3 Integrity monitoring

The integrity monitoring of GLONASS space segment performance includes checking quality of both characteristics of RF navigation signal and data within navigation message. The monitoring is implemented by two ways.

At first on the GLONASS satellites, there is continuous autonomous operability monitoring of principal onboard systems at each satellite. In case a malfunction is detected that affects quality of navigation signal or navigation data, the "unhealthy" flag appears within immediate information of navigation message. The "unhealthy" flag is transmitted with a period 30 seconds.

Maximum delay from an instant of the malfunction detection to an instant of the "unhealthy" flag generation does not exceed 1 minute for the Glonass-M satellites.

Note: - It is planned to decrease this delay down to 10 seconds by inserting a word l_n to navigation message of GLONASS-M satellite and to increase a update rate of Bn.

At second, a quality of GLONASS space segment performance is monitored using special tracking stations within the ground-based control segment. Another one "unhealthy" flag as a result of this monitoring are generated on the ground and then re-transmitted within non-immediate data of navigation message of all satellites with a period 2.5 minutes. Maximum delay, from an instant of the malfunction detection to an instant of the "unhealthy" flag generation, does not exceed 16 hours.

Thus the following two types of "unhealthy" flag are transmitted within navigation message of GLONASS system satellites:

Tag B_n (l_n):- where "0" indicates the satellite is operational and suitable for navigation;

Tag C_n (n = 1,...,24) is "unhealthy" flag that are transmitted within non-immediate data and indicates overall constellation status at the moment of almanac uploading. $C_n = 0$ indicates malfunction of n-satellite. $C_n = 1$ indicates that n-satellite is operational.

GLONASS system users should analyze both B_n (l_n) and C_n flags to take decision on to use or not to use given satellite, as indicated in Table 5.1.

Table 5.1 Health flags Bn (ln), Cn and operability of satellite

Value of flags	Operability of satellite

Bn (ln)	C_n	
0	0	-
0	1	+
1	0	-
1	1	-

APPENDIX 1

Received power level in L1 and L2 sub-bands

A guaranteed minimum signal power level Received by a user from "Glonass" and "Glonass-M" (in L1 and L2 sub-bands) is specified in paragraph 3.3.1.6.

Received power level as a function of angle of elevation of satellite for user located on the ground is shown in following Figs. The following assumptions were made when drawing the Fig.A1:

a) signal power level is measured at output of + 3dBi linearly polarized receiving antenna.;

b) angle of elevation of a satellite is at least 5°;

c) an atmosphere attenuation is 2dB;

d) a satellite angular attitude error is 1° (towards reducing signal power level).

Accuracy of satellite orientation is not worse than ± 1°, but after complete installation of the satellite into its orbital slot.

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Angle of elevation (deg)
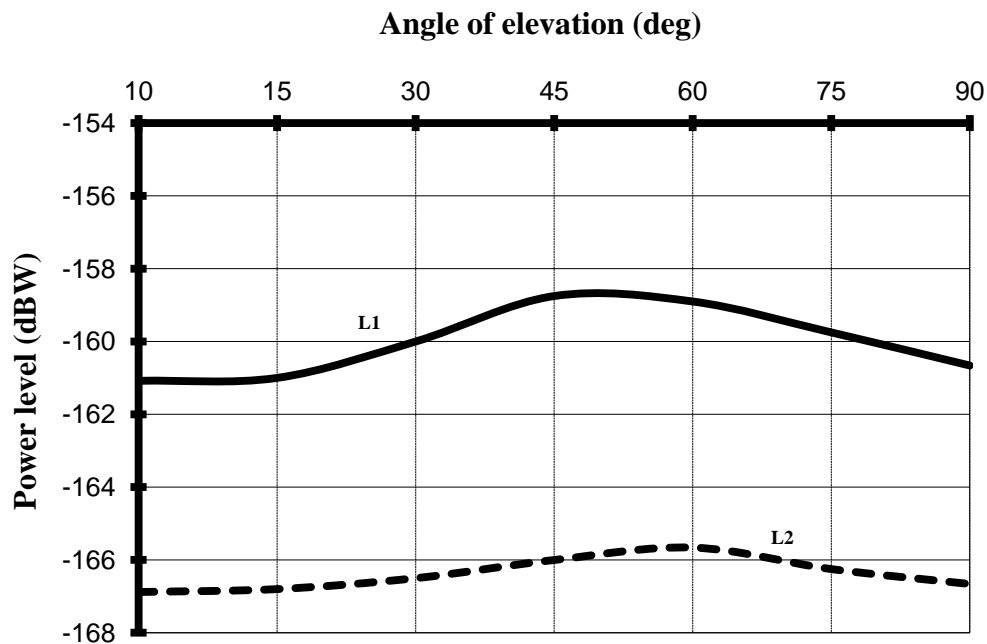
Figure A.1 Relationship between minimum received power level and elevation angle

Higher power level of received signal can be caused by the following reasons:
deviation (within admissible range) from nominal orbit altitude;
different values of gain of satellite transmitting antenna in different azimuths and frequency band;
accuracy of angular orientation of the satellite;
variations in output signal power due to technological reasons,
temperature, voltage and gain variations,
and variations in atmospheric attenuation.

It is expected that maximum received power level will not be more than −155.2 dBW provided that user's antenna has above-mentioned characteristics, atmospheric loss is 0.5 dB, and accuracy of angular orientation of a satellite is 1° (towards increasing signal power level).

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APPENDIX 2

RECOMMENDATIONS FOR USERS ON OPERATION OF ECEIVER DURING UTC LEAP SECOND CORRECTION

Essential moment of operation of user's receiver upon UTC leap second correction is requirement of simultaneous utilization of UTC_{old} (UTC prior to the correction) and corrected UTC until receiving new ephemeris parameters from all observed GLONASS system satellites.

Upon UTC leap second correction, the receiver should be capable:
to generate smooth and valid series of pseudorange measurements;
to re-synchronize the data string time mark without loss of signal tracking.

After the UTC leap second correction, the receiver shall utilize the UTC time as follows:
utilize old (prior to the correction) UTC time together with the old ephemeris (transmitted before 00 hours 00 minutes 00 seconds UTC);
utilize the updated UTC time together with the new ephemeris (transmitted after 00 hours 00 minutes 00 seconds UTC).

.
Time and UTC value corrections data are either manually put into the receiver memory or extracted from a proper navigation message.
One second prior to UTC correction the algorithm to check and use further corrected GLONASS time is triggered in the receiver. Such an algorithm is applied until:
 onboard time scales of all observed satellites and navigation receivers are corrected;
new ephemeris parameters, i.e. ephemeris relative to instant $t_b =$ of 00 hours of 15 minutes of 00 seconds of UTC, of all observed satellites are received.

To generate correct values of range measurements the receiver should monitor the moments when satellites signals are transmitted and received.

In case transmission and reception are registered in different time systems (not corrected or corrected UTC time) pseudo-range value should be corrected to the value of corrected UTC time, multiplied by velocity of light.

Pseudo-range value should be referred to the moment of UTC $_{old}$ time scale

To calculate current Glonass ephemeris parameters valid until new ephemeris parameters are received one should use ephemeris data transmitted by the satellite before correction. All measurements are in UTC$_{old}$.

As soon as new ephemeris parameters come from a satellite its location shall be calculated on their basis in corrected UTC time.

Navigation solutions and all data calculated by the receiver and provided through interfaces as soon as its clocks are corrected, should be referred to corrected UTC time which is implemented by the GLONASS time generated in the navigation receiver.

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APPENDIX 3

EXAMPLES OF ALGORITHMS FOR CALCULATION OF COORDINATES, VELOCITY AND TRANSFORMATION OF GLONASS-M CURRENT DATA INFORMATION INTO COMMON FORM

The examples of algorithms for calculation of coordinates and velocity of the satellites using ephemeris parameters and almanac are given below.

A.3.1 Example of algorithms for re-calculation of ephemeris to current time

A.3.1.1. Accurate algorithm for re-calculation of ephemeris to current time

Re-calculation of ephemeris from instant t_e to instant t_i within the interval of measurement ($|\tau_i| = |t_i - t_e| < 15$ minutes) is performed using technique of numerical integration of differential equations that describe motion of the satellites. Right-hand parts of these equations take into account the accelerations determined by gravitational constant μ and second zonal coefficient J_2^0, (that characterizes polar flattening of Earth), and accelerations due to lunar-solar gravitational perturbation.

The equations are integrated in direct absolute geocentric coordinate system $OX_aY_aZ_a$, connected with current equator and vernal equinox, using 4th order Runge-Kutta technique as indicated below:

$$\frac{dx_o}{dt} = Vx_o \quad,$$

$$\frac{dy_o}{dt} = Vy_o \quad,$$

$$\frac{dz_o}{dt} = Vz_o \quad,$$

$$\frac{dVx_o}{dt} = -\hat{\mu}\,\hat{x}_o - \frac{3}{2}J_2^0\,\hat{\mu}\,\hat{x}_o\rho^2(1-5\hat{z}_o^2) + j_{X_oC} + j_{X_o\Pi} \quad,$$

$$\frac{dVy_o}{dt} = -\hat{\mu}\,\hat{y}_o - \frac{3}{2}J_2^0\,\hat{\mu}\,\hat{y}_o\rho^2(1-5\hat{z}_o^2) + j_{y_oC} + j_{y_o\Pi} \quad,$$

$$\frac{dVz_o}{dt} = -\hat{\mu}\,\hat{z}_o - \frac{3}{2}J_2^0\,\hat{\mu}\,\hat{z}_o\rho^2(3-5\hat{z}_o^2) + j_{Z_oC} + j_{Z_o\Pi} \quad. \tag{1}$$

where

$$\mu = \frac{\mu}{r^2} \quad , \quad \overline{x}_o = \frac{x_o}{r} \quad , \quad \overline{y}_o = \frac{y_o}{ro} \quad , \quad \overline{z}_o = \frac{z_o}{ro} \quad , \quad \rho = \frac{a_e}{ro} \quad ,$$

$$ro = \sqrt{x_o{}^2 + y_o{}^2 + z_o{}^2},$$

$j_{x_o C}$, $j_{y_o C}$, $j_{z_o C}$ - Accelerations due to solar gravitational perturbation;

$j_{x_o Л}$, $j_{y_o Л}$, $j_{z_o Л}$ - Accelerations due to lunar gravitational perturbations;

a_e - Equatorial radius of Earth, 6378.136 km;

μ - Gravitational constant, (398600.44 km^3/s^2);

J_2^0 - Second zonal harmonic of the geopotential,
(1082625,75·10^{-9});

Accelerations due to both lunar and solar perturbations are computed using the following formulae:

$$j_{x_o K} = \hat{\mu}_K \left[\frac{(\xi_K - \hat{x}_K)}{\Delta_K^3} - \xi_K \right] \quad ,$$

$$j_{y_o K} = \hat{\mu}_K \left[\frac{(\eta_K - \hat{y}_K)}{\Delta_K^3} - \eta_K \right] \quad ,$$

$$j_{z_o K} = \hat{\mu}_K \left[\frac{(\Im_K - \hat{z}_K)}{\Delta_K^3} - \Im_K \right] \quad ,$$

(2)

where:

$$\hat{x}_K = \frac{x_o}{r_K} \quad , \quad \hat{y}_K = \frac{y_o}{r_K}, \quad \hat{z}_K = \frac{z_o}{r_K}, \quad \hat{\mu}_K = \frac{\mu_K}{r_K^2},$$

$$\Delta_K^2 = (\xi_K - \hat{x}_K)^2 + (\eta_K - \hat{y}_K)^2 + (\Im_K - \hat{z}_K)^2,$$

κ – Index for a perturbing body; k = m indicates "lunar", and k = s indicates "solar";
The parameters ξ_K , η_K , $\Im_K$, r_K from equations (2) are computed (at instant t$_e$) once per interval (± 15 minutes) using the following formulae [Duboshin G.N., Celestial

Mechanics, M. "Nauka", 1975; Abalakin V.K., Principles of ephemeris astronomy, M., "Nauka", 1979]:

$$\xi_m = (sin\,\vartheta_m\,cos\,\Gamma' + cos\,\vartheta_m\,sin\,\Gamma')\xi_{11} +$$
$$+ (cos\,\vartheta_m\,cos\,\Gamma' - sin\,\vartheta_m\,sin\,\Gamma')\xi_{12} \quad,$$
$$\eta_m = (sin\,\vartheta_m\,cos\,\Gamma' + cos\,\vartheta_m\,sin\,\Gamma')\eta_{11} +$$
$$+ (cos\,\vartheta_m\,cos\,\Gamma' - sin\,\vartheta_m\,sin\,\Gamma')\eta_{12} \quad,$$
$$\Im_m = (sin\,\vartheta_m\,cos\,\Gamma' + cos\,\vartheta_m\,sin\,\Gamma')\Im_{11} +$$
$$+ (cos\,\vartheta_m\,cos\,\Gamma' - sin\,\vartheta_m\,sin\,\Gamma')\Im_{12} \quad,$$
$$\xi_s = cos\,\vartheta_s \cdot cos\,\omega_s - sin\,\vartheta_s \cdot sin\,\omega_s \quad,$$
$$\eta_s = (sin\,\vartheta_s \cdot cos\,\omega_s + cos\,\vartheta_s \cdot sin\,\omega_s)cos\,\varepsilon \quad,$$
$$\Im_s = (sin\,\vartheta_s \cdot cos\,\omega_s + cos\,\vartheta_s \cdot sin\,\omega_s)sin\,\varepsilon \quad,$$
$$r_\kappa = a_\kappa \cdot (1 - e_\kappa\,cos\,E_\kappa) \quad, \quad (\kappa = m,\ s) \quad, \tag{3}$$

where:

$$sin\,\vartheta_\kappa = \frac{\sqrt{1 - e_\kappa^2}\,sin\,E_\kappa}{1 - e_\kappa\,cos\,E_\kappa} \quad,$$

$$cos\,\vartheta_\kappa = \frac{cos\,E_\kappa - e_\kappa}{1 - e_\kappa\,cos\,E_\kappa} \quad,$$

$E_\kappa = q_\kappa + e_\kappa\,sin\,E_\kappa$ –Kepler's Equation for Eccentric Anomaly, may be solved by iteration, until $\left|E_\kappa - E_\kappa(prev)\right|$ will be less 10^{-8},

$$\xi_{11} = \sin\Omega_m \cdot \cos\Omega_m (1 - \cos i_m) \quad,$$

$$\xi_{12} = 1 - \sin^2\Omega_m (1 - \cos i_m) \quad,$$

$$\eta_{11} = \xi * \cos\varepsilon - \Im * \sin\varepsilon \quad,$$

$$\eta_{12} = \xi_{11} \cos\varepsilon + \eta * \sin\varepsilon \quad,$$

$$\Im_{11} = \xi * \sin\varepsilon + \Im * \cos\varepsilon \quad,$$

$$\Im_{12} = \xi_{11} \sin\varepsilon - \eta * \cos\varepsilon \quad,$$

$$\xi* = 1 - \cos^2\Omega_m (1 - \cos i_m) \quad,$$

$$\eta* = \sin\Omega_m \cdot \sin i_m \quad,$$

$$\Im* = \cos\Omega_m \cdot \sin i_m \quad.$$

Where:

a_m - Semi-major axis of lunar orbit ($3.84385243 \cdot 10^5$ km);

a_s - Semi-major axis of solar "orbit" ($1.49598 \cdot 10^8$ km);

e_m - Eccentricity of lunar orbit (0.054900489)

e_s – Eccentricity of solar "orbit" (0.016719);

i_m – Inclination of lunar orbit to ecliptic plane (0.089803977 radians);

Mean anomaly of the Moon, radians
$q_л = 2.3555557435 + 8328.6914257190 \cdot T + 0.0001545547 \cdot T^2$;
Mean Anomaly of the Sun, radians
$q_c = 6.2400601269 + 628.3019551714 \cdot T - 0.0000026820 \cdot T^2$;
Mean longitude of the ascending node of the Moon, radians
$\Omega_л = 2.1824391966 - 33.7570459536 \cdot T + 0.0000362262 \cdot T^2$;
Mean longitude perigee of the Moon orbit, radians
$\Gamma' = 1.4547885346 + 71.0176852437 \cdot T - 0.0001801481 \cdot T^2$;
Mean tropical longitude perigee of the Sun orbit, radians
$\omega_c = -7.6281824375 + 0.0300101976 \cdot T + 0.0000079741 \cdot T^2$;
Mean inclination of ecliptic to equator, radians,
$\varepsilon = 0{,}4090926006 - 0{,}0002270711 \cdot T$;

T - is a time from the epoch 2000 г., 1 January, 12h (UTC) to time reference t_e of GLONASS ephemeris parameters (in Julian centuries of 36525 ephemeris days),

calculated as:

$T = (JD + (t_э - 10800) /86400 - 2451545.0) / 36525;$

where: JD – current Julian date at 0 hours UTC, calculated by the algorithm A 3.1.3;

$t_э$ – time reference t_e of GLONASS ephemeris parameters, (Moscow standard Time or MT);

10800 – difference between Moscow standard time (MT) and the World Greenwich Mean Time (UTC), in seconds;

2451545.0 - Julian date to January 1, 12:00 (UTC) 2000.

Coordinates $X(t_e)$, $Y(t_e)$, $Z(t_e)$ and velocity vector components $V_x(t_e)$, $V_y(t_e)$, $V_z(t_e)$ are initial conditions for integration of the system (1); they are taken from a navigation message and then re-computed from Greenwich coordinate system (PZ-90.11) to an absolute coordinate system $OX_aY_aZ_a$ using the following formulae:

$$X_o(t_э) = x(t_э) \cos S(t_э) - y(t_э) \sin S(t_э),$$
$$Y_o(t_э) = x(t_э) \sin S(t_э) + y(t_э) \cos S(t_э),$$
$$Z_o(t_э) = z(t_э),$$
$$Vx_o(t_э) = Vx(t_э) \cos S(t_э) - Vy(t_э) \sin S(t_э) - \omega_3 Y_o(t_э), \qquad (4)$$
$$Vy_o(t_э) = Vx(t_э) \sin S(t_э) + Vy(t_э) \cos S(t_э) + \omega_3 X_o(t_э),$$
$$Vz_o(t_э) = Vz(t_э),$$
$$S(t_э) = s + \omega_3(t_э - 10800)$$

Where:
ω – Earth's rotation rate ($7.2921151467 \cdot 10^{-5}$ radians/sec);
s – true sidereal time(GST) at midnight UTC of a date within which the instant t_e is specified.

After integration received in an absolute system of units of co-ordinates $OX_0Y_0Z_0$ of co-ordinate $X_o(t_i)$, $Y_o(t_i)$, $Z_o(t_i)$ and components of velocity vector of space vehicle $Vx_o(t_i)$, $Vy_o(t_i)$, $Vz_o(t_i)$ can be translated in an earth-referenced Greenwich geocentric conception of coordinates PZ-90.11 Oxyz under formulas:

$$
\begin{aligned}
x(t_i) &= X_o(t_i)\cos S(t_i) + Y_o(t_i)\sin S(t_i),\\
y(t_i) &= -X_o(t_i)\sin S(t_i) + Y_o(t_i)\cos S(t_i),\\
z(t_i) &= Z_o(t_i),\\
Vx(t_i) &= Vx_o(t_i)\cos S(t_i) + Vy_o(t_i)\sin S(t_i) + \omega_3\, Y(t_i),\\
Vy(t_i) &= -Vx_o(t_i)\sin S(t_i) + Vy_o(t_i)\cos S(t_i) - \omega_3\, X(t_i),\\
Vz(t_i) &= Vz_o(t_i),\\
S(t_i) &= s + \omega_3(t_i - 10800).
\end{aligned}
\qquad (5)
$$

   Note: Instead of the true sidereal time (GST) in formulae (4) and (5) is allowed to use the mean sidereal time(GMST), calculated by the equations given in the IERS Convention 2010:

$$
\begin{aligned}
\text{GMST}= {}&\text{ERA} + 0.0000000703270726 + 0.0223603658710194 \cdot T_\Delta +\\
&+ 0.0000067465784654 \cdot T_\Delta^2 - 0.0000000000021332 \cdot T_\Delta^3 -\\
&- 0.000000001452308 \cdot T_\Delta^4 - 0.0000000000001784 \cdot T_\Delta^5 ;
\end{aligned}
$$

where   ERA – Earthrotation angle, radians,
$\text{ERA} = 2\pi(0.7790572732640 + 1.00273781191135448 \cdot (JD - 2451545.0))$;
$T_\Delta = (JD - 2451545.0) / 36525$;

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Example of satellite ephemeris conversion at the current time:

Set GLONASS ephemeris (connected with the Earth in Greenwich geocentric coordinate system PZ-90.11 Oxyz at time $t_e = $ 6:15:00 date 15.11.2007:

$x(t_e) = $ -14081,752701 km	$y(t_e) = $ 18358,958252 km	$z(t_e) = $ 10861,302124 km
$Vx(t_e) = $ -1,02576358 km/s	$Vy(t_e) = $ 1,08672147 km/s	$Vz(t_e) = $ -3,15732343 km/s

Required to calculate the satellite ephemeris (connected with the Earth in Greenwich geocentric coordinate system PZ-90.11 Oxyz on time $t_i = $ 06:30:00 date 15.11.2007.

Result:

$x(t_i) = $ -14836,563872 km	$y(t_i) = $ 19249,935476 km	$z(t_i) = $ 7924,017196 km
$Vx(t_i) = $ -0,65397782 km/s	$Vy(t_i) = $ 0,88262958 km/s	$Vz(t_i) = $ -3,49667707 km/s

Components of lunar (m) and solar (s) accelerations at time t_i in absolute geocentric rectangular coordinate system $OX_oY_oZ_o$:

$Jx_o m(t_i) = 1{,}7156 \cdot 10^{-9}$ km/s^2	$Jy_o m(t_i) = 1{,}0278 \cdot 10^{-9}$ km/s^2	$Jz_o m(t_i) = -1{,}0368 \cdot 10^{-9}$ km/s^2
$Jx_o s(t_i) = -9{,}2581 \cdot 10^{-10}$ km/s^2	$Jy_o s(t_i) = -1{,}0343 \cdot 10^{-9}$ km/s^2	$Jz_o s(t_i) = -1{,}1260 \cdot 10^{-9}$ km/s^2

A.3.1.2. Simplified algorithm for re-calculation of ephemeris to current time

Re-calculation of ephemeris within the interval of measurement is performed using technique of numerical integration of differential equations that describe motion of the satellites in coordinate system PZ -90.11:

$$\frac{dx}{dt} = V_x \quad,$$

$$\frac{dy}{dt} = V_y \quad,$$

$$\frac{dz}{dt} = V_z \quad,$$

$$\frac{dV_x}{dt} = -\frac{\mu}{r^3}x - \frac{3}{2}J_2^0\frac{\mu a_e^2}{r^5}x(1-5\frac{z^2}{r^2}) + \omega^2 x + 2\omega V_x + x'' \quad,$$

$$\frac{dV_y}{dt} = -\frac{\mu}{r^3}y - \frac{3}{2}J_2^0\frac{\mu a_e^2}{r^5}y(1-5\frac{z^2}{r^2}) + \omega^2 y - 2\omega V_y + y'' \quad,$$

$$\frac{dV_z}{dt} = -\frac{\mu}{r^3}z - \frac{3}{2}J_2^0\frac{\mu a_e^2}{r^5}z(3-5\frac{z^2}{r^2}) + z'' \quad,$$

where:

$$r = \sqrt{x^2 + y^2 +}$$

μ= 398600.44*109 m3 / s2 - Gravitational constant;
a_e = 6 378 136 m- Semi-major axis of Earth ;
J_2^0 = 1082625.75*10 –9 – Second zonal harmonic of the geopotential;
ω= 7.292115 10 -5 radian/s - Earth rotation rate.
Initial conditions of integration of reduced equations set are co-ordinates and components of velocity vector of n th SV $x_n(t_b)$, $y_n(t_b)$, $z_n(t_b)$, $x'_n(t_b) = Vx$, $y'_n(t_b) = Vy$, $z'_n(t_b) = Vz$.

Accelerations due to lunar-solar gravitational perturbations
are constant in the integration interval ±15 minutes and can be extracted from a navigation frame: $\ddot{x}_n(t_b), \ddot{y}_n(t_b), \ddot{z}$

A.3.1.3. Algorithm of transformation of current four-year cycle data into common form

Satellite navigation message contains current date information (N_T) in the four-year cycle, and the number of cycles (N_4). It could be transformed into a common form by the following algorithm:

1. Calculate the current Julian date to 0 hours (UTC):

$JD = 1461 \cdot (N_4 - 1) + N_T + 2450082.5;$

2. Calculate the Julian day number for the current date:

$JDN = JD + 0.5;$

3. Calculate the intermediate factors:

$a = JDN + 32044;$
$b = (4a + 3) / 146097;$
$c = a - (146097b) / 4;$
$d = (4c + 3) / 1461;$
$e = c - (1461d) / 4;$
$m = (5e + 2) / 153;$

4. You can then calculate the day, month and year in the Gregorian calendar:

$Day = e - (153m + 2) / 5 + 1;$
$Month = m + 3 - 12 \cdot (m / 10);$
$Year = 100b + d - 4800 + (m / 10);$

   All division operation is integer, the fractional part is discarded. That's why
   $12 \cdot (m / 10)$ in the formula for the month should not be calculated as $(12m) / 10$.

   5. The day of the week can be determined from the Julian day number by dividing by 7, the remainder (JDN mod 7) indicates the day, starting with Monday as 0.

A.3.2 Algorithm of calculation of satellite motion parameters using almanac

The algorithm is used when selecting optimal constellation, calculating satellite position to ensure start of communication with the selected satellite.
The algorithm and almanac accuracy allows calculating the coordinates at the interval at least 30 days. MSE of satellites coordinates is less than 1 km when using almanac data.

Calculation order:

1. Specify the interval, in seconds:
$$\Delta t_p = (N_s - N_s^A) \cdot 86400 + (t - t^A)$$, where

N_s^A - calendar number of a day within four-year interval starting from latest leap year with a preset instant t_i. One should check the case when N_s and N_s^A are different four years intervals.

2. Determined by the number of turns Win the interval:
$$W = \left[\frac{\Delta t_p}{\Delta T^A + T_{cp}} \right],$$
where [X] is integer part of X, T_{av}=43200 s

3. Defines the current inclination:
$$i = \left(\frac{i_{cp}}{180^o} + \Delta i^A \right) \cdot \pi \ \text{рад}.,$$
where i_{av}=63°, Δi^A - correction to the mean value of inclination

4. Identifies the current draconic period, mean motion at turn W+1:
$$T_{\partial p} = \Delta T^A + T_{cp} + (2W + 1) \cdot \Delta \dot{T}^A$$
$$n = 2\pi / T_{\partial p}$$; where
ΔT^A- correction to the mean value of Draconian period of turn and half rate of change of draconian period

5. By iteration method m=0, 1, 2…:

$$a^{(n+1)} = \sqrt[3]{\left(\frac{T_{оск}^{(n)}}{2\pi}\right)^2 \cdot \mu}\;;$$

$$p^{(n+1)} = a^{(n+1)}(1-e^2)\;;$$

$$T_{оск}^{(n+1)} = \frac{T_{др}}{1 - \dfrac{3}{2}\cdot J_2 \left(\dfrac{a_e}{p^{(n+1)}}\right)^2 \left[\left(2 - \dfrac{5}{2}\cdot \sin^2 i\right)\cdot \dfrac{(1-e^2)^{3/2}}{(1+e\cdot\cos\omega^A)^2} + \dfrac{(1+e\cdot\cos\omega^A)^3}{1-e^2}\right]}\;;$$

where

GM=398600,4418 km^3/s^2 ‾ geocentric constant of gravitational field given atmosphere

e^A - Eccentricity at instant $t_{\lambda j}$

a_e = 6378.136 km – major semiaxis of all-Earth ellipsoid PZ-90-11

J_2 = 1082.62575·10^{-6} ‾ second zone harmonic of geopotential

ω^A - Argument of perigee at instant $t_{\lambda j}$ (in radians)

Initial data $T_{оск}^{(0)} = T_{др}$.

Iteration is over when $\left|a^{(n+1)} - a^{(n)}\right| \le 1 м$.

6. The current value of the longitude of the ascending node of the orbit and the argument of perigee given their secular movement influenced by Earth elipticity:

$$\lambda = \lambda^A - \left\{\Omega_3 + \frac{3}{2}J_2\cdot n\cdot\left(\frac{a_e}{p}\right)^2 \cos i\right\}\Delta t_p\;;$$

$$\omega = \omega^A - \frac{3}{4}J_2 n\left(\frac{a_e}{p}\right)^2 (1-5\cos^2 i)\cdot\Delta t_p$$

ω_3 = 7, 2921150 * 10^{-5} rad/s – angular velocity of Earth rotation

7. The current value of mean longitude at the ascending node

$$L_1 = \omega + E_0 - e\sin E_0, \quad где\; E_0 = -2\cdot atan\left(\sqrt{\frac{1-e}{1+e}}\cdot tan\frac{\omega}{2}\right)$$

8. The current value of the mean longitude of SC:

$$L = L_1 + n(\Delta t_p - (\Delta T^A + T_{ср})W - \Delta\dot{T}^A W^2)\;.$$

9. Parameters $a, e, i, \lambda, \omega, L$ are corrected by followed equations:

$$a' = a + \delta a_2 - \delta a_1$$

$$e' = \sqrt{h'^2 + l'^2}$$

$$i' = i + \delta i_2 - \delta i_1$$

$$\lambda' = \lambda + \delta\lambda_2 - \delta\lambda_1$$

$$\omega' = a\,tan\,\frac{h'}{l'}$$

$$L' = L + \delta L_2 - \delta L_2$$

where

$$h' = h + \delta h_2 - \delta h_1$$

$$l' = l + \delta l_2 - \delta l_1$$

$$h = e\,sin\,\omega$$

$$l = e\,cos\,\omega \qquad ;$$

Calculate $\delta a_k, \delta h_k, \delta l_k, \delta i_k, \delta\lambda_k, \delta L_k, \quad for\ k = 1,2;$ by:

$$\frac{\delta a_k}{a} = \ 2B\left(1 - \frac{3}{2}\sin^2 i\right)(l \cdot \cos L_k + h \cdot \sin L_k) +$$

$$+ B\sin^2 i\left(\frac{1}{2}h \cdot \sin L_k - \frac{1}{2}l \cdot \cos L_k + \cos 2L_k + \frac{7}{2}l \cdot \cos 3L_k + \frac{7}{2}h \cdot \sin 3L_k\right);$$

$$\delta h_k = \ B\left(1 - \frac{3}{2}\sin^2 i\right)\left[\sin L_k + \frac{3}{2}l \cdot \sin 2L_k - \frac{3}{2}h \cdot \cos 2L_k\right] -$$

$$- \frac{1}{4}B\sin^2 i\left[\sin L_k - \frac{7}{3}\sin 3L_k + 5l \cdot \sin 2L_k - \frac{17}{2}l \cdot \sin 4L_k + \frac{17}{2}h \cdot \cos 4L_k + h \cdot \cos 2L_k\right] -$$

$$- \frac{1}{2}B\cos^2 i \cdot l \cdot \sin 2L_k$$

$$\delta l_k = \ B\left(1 - \frac{3}{2}\sin^2 i\right)\left[\cos L_k + \frac{3}{2}l \cdot \cos 2L_k + \frac{3}{2}h \cdot \sin 2L_k\right] -$$

$$- \frac{1}{4}B\sin^2 i\left[-\cos L_k - \frac{7}{3}\cos 3L_k - 5h \cdot \sin 2L_k - \frac{17}{2}l \cdot \cos 4L_k - \frac{17}{2}h \cdot \sin 4L_k + l \cdot \cos 2L_k\right] +$$

$$+ \frac{1}{2}B\cos^2 i \cdot h \cdot \sin 2L_k$$

$$\delta\lambda_k = -B\cos i\left(\frac{7}{2}l \cdot \sin L_k - \frac{5}{2}h \cdot \cos L_k - \frac{1}{2}\sin 2L_k - \frac{7}{6}l \cdot \sin 3L_k + \frac{7}{6}h \cdot \cos 3L_k\right)$$

$$\delta i_k = \frac{1}{2}B\sin i \cdot \cos i\left(-l \cdot \cos L_k + h \cdot \sin L_k + \cos 2L_k + \frac{7}{3}l \cdot \cos 3L_k + \frac{7}{3}h \cdot \sin 3L_k\right)$$

$$\delta L_k = 2B\left(1-\frac{3}{2}\sin^2 i\right)\left(\frac{7}{4}l\cdot\sin L_k - \frac{7}{4}h\cdot\cos L_k\right)+$$

$$+3B\sin^2 i\cdot\left(-\frac{7}{24}h\cdot\cos L_k - \frac{7}{24}l\cdot\sin L_k - \frac{49}{72}h\cdot\cos 3L_k + \frac{49}{72}l\cdot\sin 3L_k + \frac{1}{4}\sin 2L_k\right)+$$

$$+B\cos^2 i\cdot\left(\frac{7}{2}l\cdot\sin L_k - \frac{5}{2}h\cdot\cos L_k - \frac{1}{2}\sin 2L_k + \frac{7}{6}l\cdot\sin 3L_k + \frac{7}{6}h\cdot\cos 3L_k\right)$$

where $B = \frac{3}{2}J_2\left(\frac{a_e}{a}\right)^2$.

Calculate these formulae by using the value $L_k, k = 1,2$, where $L_2 = L$ stepwise.

Note: At this step the algorithm calculates short-term perturbations in SC orbits caused by the second zone harmonic of geopotential. Amplitude of short-term perturbations in GLONASS SC orbits shall be less than 1.5 …2 km Greenwich. In practice these almanac errors are insufficient to a major part of the GLONASS users. These users may skip step 9 of the algorithm which allows reduce by 2…3 times method error in Greenwich coordinates calculation.

The next steps, namely 10…12, describe how to calculate using a, ε, i, λ, ω, L Greenwich coordinates and SC speed. In case step 9 is applied, use adjusted $a', e', i', \lambda', \omega', L'$ parameters.

10. Eccentric anomaly is defined by solving the Kepler equation:
$L - \omega = E - e\sin E$.

As a rule the pattern of progressive approximations is applied m=0, 1, 2…

$E^{(n+1)} = L - \omega + e\sin E^{(n)}$,

with initial $E^{(0)} = L - \omega$.

Iteration process stops when $\left|E^{(m+1)} - E^{(m)}\right| \le 10^{-9}$

11. Calculate the true anomaly and the argument of latitude:
$\upsilon = 2\arctan\left(\sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}\right)$;

$u = \upsilon + \omega$.

12. Calculation of Greenwich coordinates of SC:

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$$p = a(1 - e^2)$$

$$r = \frac{p}{1 + e\cos\upsilon} ;$$

$$X = r(\cos\lambda\cos u - \sin\lambda\sin u\cos i) ;$$

$$Y = r(\sin\lambda\cos u + \cos\lambda\sin u\cos i) ;$$

$$Z = r\sin u\sin i .$$

13. Calculation of Greenwich velocity:

$$v_r = \sqrt{\frac{\mu}{p}}\ \varepsilon^A \sin\upsilon ;$$

$$v_u = \sqrt{\frac{\mu}{p}}(1 + \varepsilon^A \cos\upsilon) ;$$

$$\dot{x}(t_i) = v_r(\cos\lambda\cos u - \sin\lambda\sin u\cos i) - v_u(\cos\lambda\sin u + \sin\lambda\cos u\cos i) + \omega_3 y(t_i);$$

$$\dot{y}(t_i) = v_r(\sin\lambda\cos u + \cos\lambda\sin u\cos i) - v_u(\sin\lambda\sin u - \cos\lambda\cos u\cos i) - \omega_3 x(t_i);$$

$$\dot{z}(t_i) = v_r\sin u\sin i + v_u\cos u\sin i .$$

A 3.2.3 An example of how to calculate coordinates and velocity of a SC using GLONASS almanac

1. The following parameters are assigned :

$N_S^A = 1452$

$t^A = 33571.625$

$\Delta T^A = -2655.98046875$

$\varDelta \dot{T}^A = 6.103515625\text{E-}05$

$\lambda^A = -0.293967247009277$

$\omega^A = 0.57867431640625$

$e^A = 0.000432968139648438$

$\Delta i^A = 0.00987052917480469$

The task is to calculate co-ordinates and components of velocity vector in *OXYZ* co-ordinate system at an instant:

$N_S = 1453$ (four-year period)

$t = 51300$

Calculation order:

1. Calculate the interval, in seconds:

$\Delta t_P = 104128.375$

2. Calculate number of circulations at the interval:

$W = 2$

3. Calculate current inclination:

$i = 1.1305666106990377$

4. Calculate current draconic period, mean motion:

$T_{др} = 40544.019836425781$

$n = 0.00015497193747756143$

5. By iteration method calculate major semiaxis of the orbit:

m	a	p	T_{ock}
0	25508.047485485004	25508.042703710456	40547.946040115967
1	25509.694225238574	25509.689443155326	40547.945533182959
2	25509.694012622691	25509.689230539483	40547.945533248407
3	25509.694012650143	25509.689230566935	40547.945533248399

6. Calculate the current value of the longitude of the ascending node of the orbit and the argument of perigee given their secular motion influenced by Earth ellipticity :

$\lambda = -8.5173843140309469$

$\omega = 1.8178836298808301$

7. Calculate current value of mean longitude at the ascending node:

$E_0 = -1.8174637892065451$

$L_1 = 0.00083970352771615942$

8. The current value of the mean longitude:

$L = 3.5714451660610322$

9. Parameters $a, e, i, \lambda, \omega, L$ are corrected by followed equations:

$a' = 25508.955431086055$

$\varepsilon' = 0.00042419917873569112$

$i' = 1.1305597941298686$

$\lambda' = -8.5173680227942352$

$\omega' = 1.9658015187961821$

$L' = 3.5714854290812852$

$h' = 0.00039153353705544239$

$l' = -0.00016323735050805419$

$h = 0.00041981843111904164$

$l = -0.00010589567905904274$

$B = 0.00010151884398503961$

k	1	2
L_k	0.00083970352771615942	3.5714451660610322
$\dfrac{\delta a_k}{a}$	8.3061556356548271e-005	5.4108580138128547e-005
δh_k	1.6920305123187429e-008	-2.8267973758476053e-005
δl_k	4.6117590145455587e-005	-1.1224081303555874e-005
$\delta \lambda_k$	6.0543507136053742e-008	1.6351780218807089e-005
δi_k	1.9565821919218402e-005	1.2749252750088746e-005
δL_k	1.1021945852191378e-008	4.0274042199185228e-005

10. Eccentric anomaly is calculated by solving the Kepler:

m	$E^{(m)}$
0	1.6056839102851030
1	1.6061078513343894
2	1.6061078450235415
3	1.6061078450236359

11. Calculate the true anomaly and the argument of latitude:

υ = 1.6065317766004903

u = 3.5723332953966724

12. Calculate Greenwich coordinate:

p = 25508.950840878515

r = 25509.337453312484

$x(t_i)$ = 10697.116424527978

$y(t_i)$ = 21058.292414091822

$z(t_i)$ = −9635.6794316575106

13. Calculate Greenwich velocity:

v_r = 0.0016757724716836881

v_u = 3.9529016345992583

$$\dot{x}(t_i) = -0.68610081793104882$$

$$\dot{y}(t_i) = -1.1365486509759850$$

$$\dot{z}(t_i) = -3.2499858708515017$$

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