COORDINATION SCIENTIFIC INFORMATION CENTER

GLOBAL NAVIGATION SATELLITE SYSTEM

GLONASS

INTERFACE CONTROL DOCUMENT

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по космическим средствам

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ГЛОБАЛЬНАЯ НАВИГАЦИОННАЯ СПУТНИКОВАЯ СИСТЕМА ГЛОНАСС

ИНТЕРФЕЙСНЫЙ КОНТРОЛЬНЫЙ ДОКУМЕНТ

(редакция четвертая)

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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
ICD	Interface Control Document
KNITs	Coordination Scientific Information Center
MT	Moscow Time
msd	mean-solar day
NPO PM	Scientific and Production Association of Applied Mechanics
PR	Pseudo random
RF	Radio frequency
RNII KP	Research Institute of Space Device Engineering
UTC	Coordinated Universal Time

1. INTRODUCTION

1.1 GLONASS purpose

The purpose of the Global Navigation Satellite System GLONASS is to provide unlimited number of air, marine, and any other type of users with all-weather three-dimensional positioning, velocity measuring and timing anywhere in the world or near-earth space.

1.2 GLONASS components

GLONASS includes three components:

- Constellation of satellites (space segment);
- Ground-based control facilities (control segment);
- 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 uploading.

User equipment consists of receives 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 passive measurements of pseudoranges and pseudorange rate of 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 navigation message includes the data that allows planning observations, and selecting and tracking the necessary constellation of satellites.

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.

2.2 ICD approval and revision

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:

- Scientific and Production Association of Applied Mechanics (NPO PM) as developer of GLONASS system as a whole including the satellites and software for control segment. (Russian Space Agency);
- Research Institute of Space Device Engineering (RNII KP) as developer of GLONASS system including control segment, satellite onboard equipment and user equipment (Russian Space Agency);
- Coordination Scientific Information Center (KNITs) (Ministry of Defence),

and approved by duly authorized representatives of Ministry of Defence and Russian Space Agency.

Some GLONASS parameters may be changed in the process of development and modernization of the system. Each of above organizations may suggest amendments and additions to the previously agreed version of ICD. The developer of control interface is responsible for coordinating the proposed amendments and additions by all authorized organizations, and for the further developing (if necessary) a new version of the document.

Current version of ICD takes into account users' comments and suggestions related to the previous version of the document. It includes some parameters to be implemented on stage-by-stage basis in interface between GLONASS-M satellites and user equipment.

KNITs (Ministry of Defence) is authorized for official distribution 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

Interface between space segment and user equipment consists of radio links of L-band (see Fig. 3.1). Each GLONASS satellite transmits navigation signals in two sub-bands of L-band (L1 ~ 1.6 GHz and L2 ~ 1.2 GHz).

GLONASS uses Frequency Division Multiple Access (FDMA) technique in both L1 and L2 sub-bands. This means that each satellite transmits navigation signal on its own carrier frequency in the L1 and L2 sub-bands. Two GLONASS satellites may transmit navigation signals on the same carrier frequency if they are located in antipodal slots of a single orbital plane.

GLONASS satellites provide two types of navigation signals in the L1 and L2 sub-bands: standard accuracy signal and high accuracy signal.

The standard accuracy signal with clock rate 0.511 MHz is designed for using by civil users worldwide.

The high accuracy code with clock 5.11 MHz is modulated by special code, and its unauthorized use (without permission of Ministry of Defence) is not recommended.

ICD provides structure and characteristics of the standard accuracy signal of both L1 and L2(1) sub-bands.

The standard accuracy signal is available for any users equipped with proper receivers and having visible GLONASS satellites above the horizon.

An intentional degradation of the standard accuracy signal is not applied.

Note (1): In GLONASS-M satellite, it is planned to provide users with the standard accuracy code in L2 sub-band.

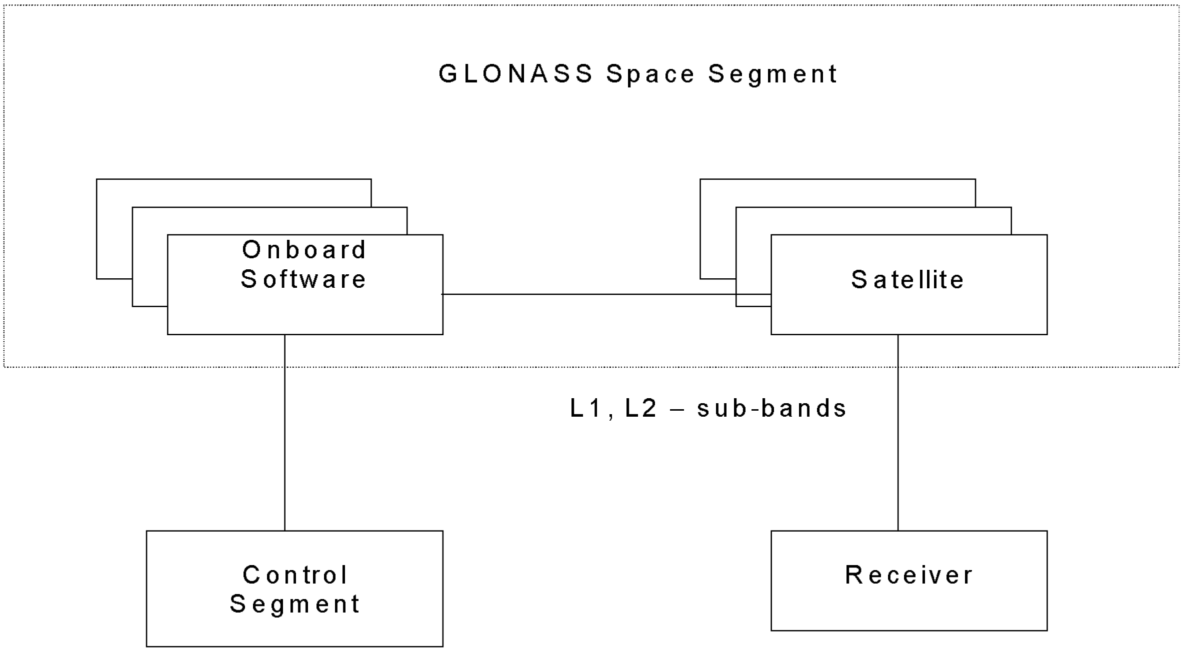


Figure 3.1 Satellite/Receiver Interface

3.2 Navigation signal structure

Navigation signal being transmitted in particular carrier frequency of L1 and L2 sub-bands is a multi-component one using a bipolar phase-shift key (BPSK) modulated binary train. 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 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.

The carrier of L2 sub-band is modulated by the Modulo-2 addition of the following binary signals: PR ranging code 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 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 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:

$$\mathbf{f_{K1} = f_{01} + K\Delta f_1,}$$

$$\mathbf{f_{K2} = f_{02} + K\Delta f_2,} \text{ where}$$

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

$\mathbf{f_{01} = 1602\ MHz;}$ $\mathbf{\Delta f_1 = 562.5\ kHz,}$ for L1 sub-band;

$\mathbf{f_{02} = 1246\ MHz;}$ $\mathbf{\Delta f_2 = 437.5\ kHz,}$ for L2 sub-band.

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

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

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 $\Delta f/f = -4.36 * 10^{-10}$

or $\Delta f = -2.18*10^{-3}$ 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 values of the carrier frequencies of a GLONASS satellite are within ±2 x 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
13	1609.3125	13	1251.6875
12	1608.75	12	1251.25
11	1608.1875	11	1250.8125
10	1607.625	10	1250.375
09	1607.0625	09	1249.9375
08	1606.5	08	1249.5
07	1605.9375	07	1249.0625
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

The following staged shift of the GLONASS frequency plan is stipulated:

1998 - 2005

At this stage GLONASS satellites will use frequency channels K = 0...12 without any restrictions. The channel numbers K = 0 and13 may be used for technical purposes.

GLONASS satellites that are launched during 1998 to 2005 will use filters, limiting out-of-band emissions to the harmful interference limit contained in CCIR Recommendation 769 for the (1660…1670) MHz band.

Beyond 2005

At this stage GLONASS satellites will use frequency channels K = (-7...+6), where the channel numbers K = +5 and K = +6 may be used for only technical purposes over the Russian Federation (for instance, when performing replacements within space segment).

GLONASS satellites that are launched beyond 2005 will use filters, limiting out-of-band emissions to the harmful interference limit contained in CCIR Recommendation 769 for the (1610.6 ... 1613.8) MHz and (1660 ... 1670) MHz bands.

3.3.1.2 Correlation loss

Correlation loss is defined as a difference between transmitted signal power in (1598.0625…1605.375) MHz ± 0,511 MHz and (1242.9375…1248.625) MHz ± 0.511 MHz bands and received signal power in ideal correlation-type receiver and in the same frequency bands. The worst case of correlation loss occurs when receiving RF signal at channel number K = -7 or K = 12. For this case correlation loss is defined by the following components:

- Satellite modulation imperfections..................…........0.6 dB;
- User receiver waveform distortion, not more than....0.2 dB.

For all other frequency channels the correlation loss, caused by waveform distortion, is decreased as it moves away from edges of the GLONASS L1 and L2 sub-bands.

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 0.1 radian (1σ).

3.3.1.4 Spurious emissions

Power of transmitted 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.

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 not more than (-48 dB) provided that the satellites transmitting signals on adjacent frequencies are simultaneously visible for an user.

3.3.1.6 Received power level

The level of the received RF signal at the output of a 3dBi linearly polarized antenna is not less than (-161) dBW for L1 sub-band and (-167) dBW for L2 sub band provided that the satellite is observed at an 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 an user since it has no effect on the GLONASS time computations. The undetermined component does not exceed 8 nanoseconds.

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 is not worse than 0.7 (for both L1 and L2 sub-bands) for the angular range ±19° from boresight.

3.3.2 Modulation

The modulating sequence used for modulation of carrier frequencies in L1 sub-band (when generating standard accuracy signals) 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
- 100 Hz auxiliary meander sequence.

The modulating sequence used for modulation of carrier frequencies in L2 sub-band (when generating standard accuracy signals) is generated by the Modulo-2 addition of the following two binary signals:

- PR ranging code transmitted at 511 kbps;
- 100 Hz auxiliary meander sequence.

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 7th stage of the 9-stage shift register. 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

$$\mathbf{G(x) = 1 + x^5 + x^9}$$

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

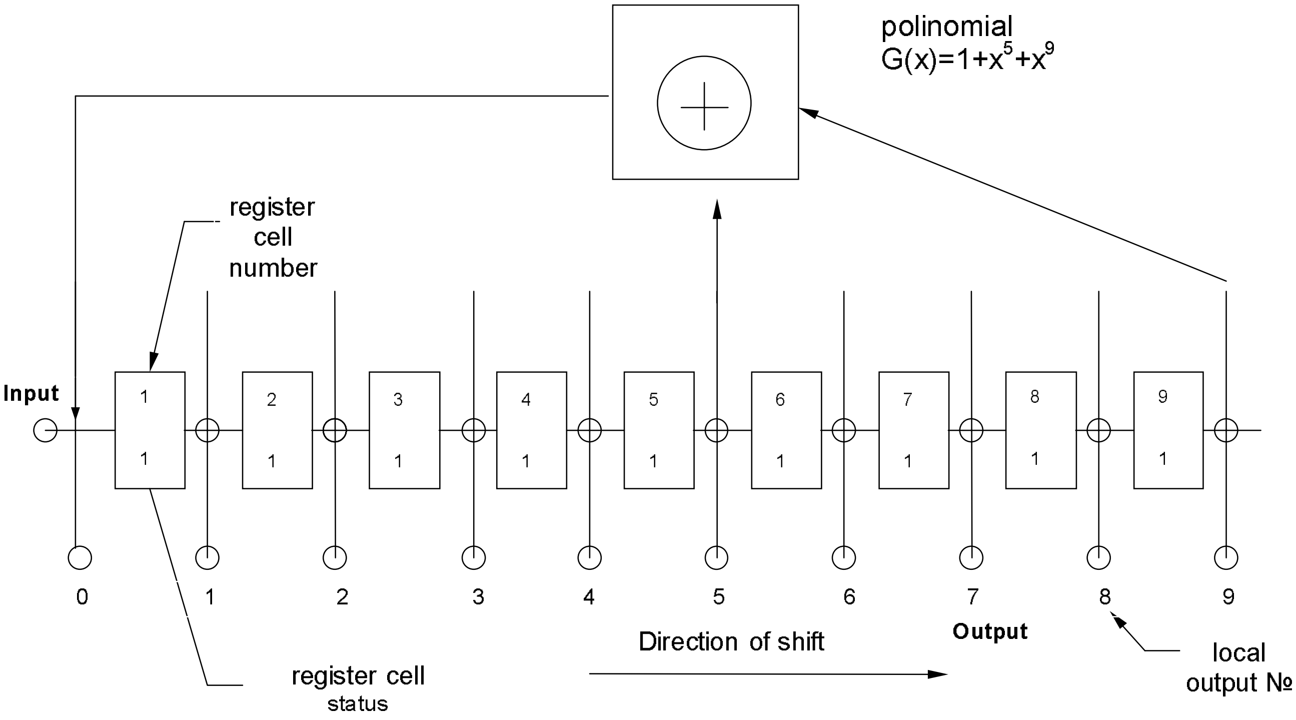


Figure 3.2 Structure of shift register used for ranging code generation

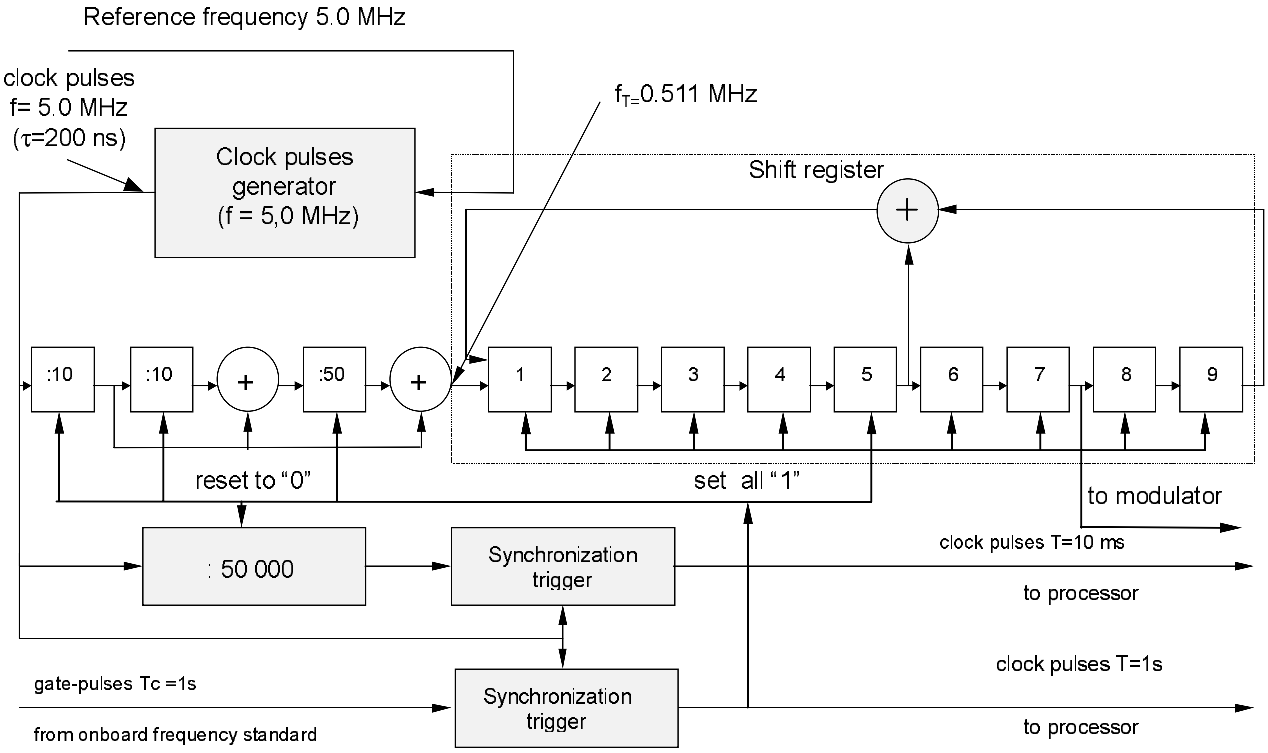


Figure 3.3 Simplified diagram of PR ranging code and clock pulse generation

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 (in the beginning of each string) 85 bits of navigation data are transmitted. During the last 0.3 second within this two-second interval (in the end of each string) 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:

$$\mathbf{g(x) = 1 + x^3 + x^5,}$$

or may be shown as

111110001101110101000010010110.

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

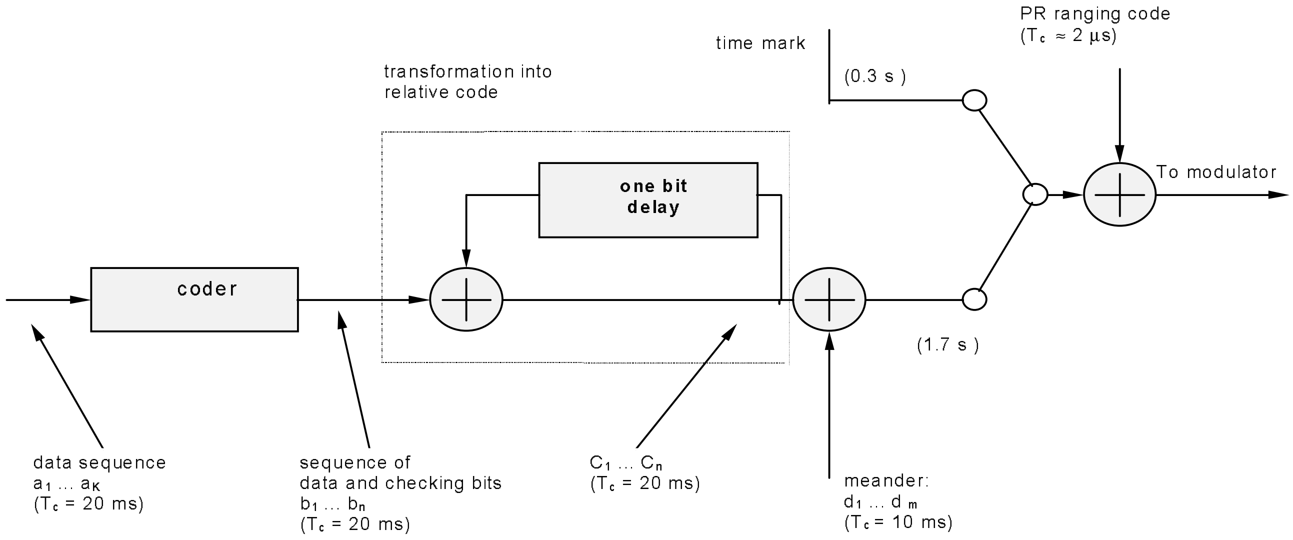


Figure 3.4 Simplified block-diagram of data sequence generation

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.

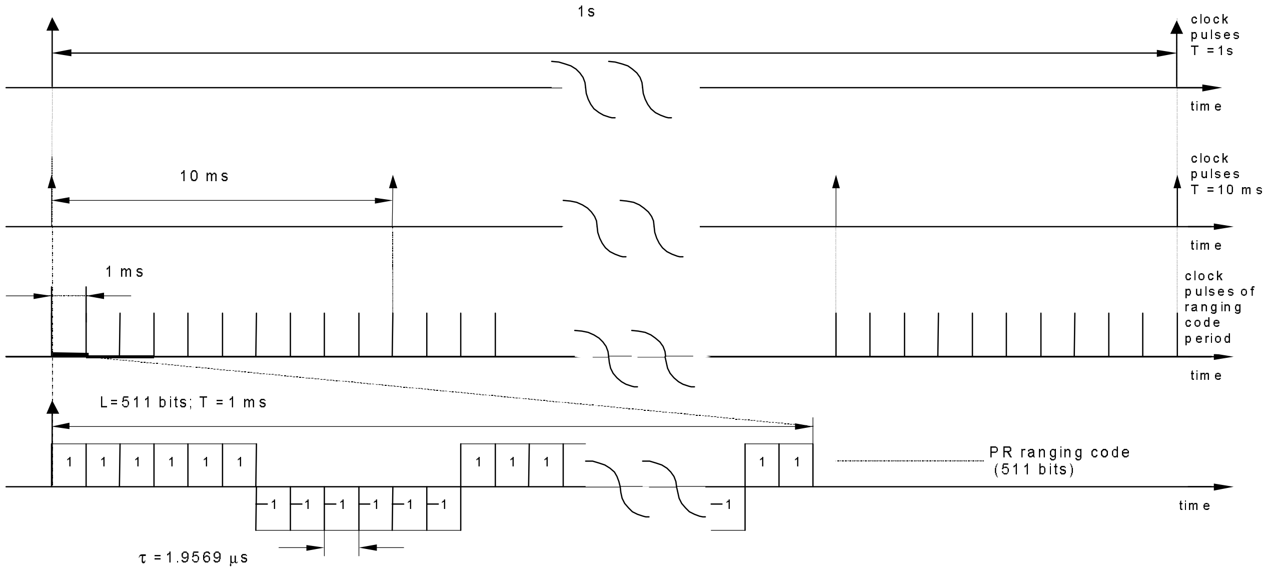


Figure 3.5 Time relationship between clock pulses and PR ranging code

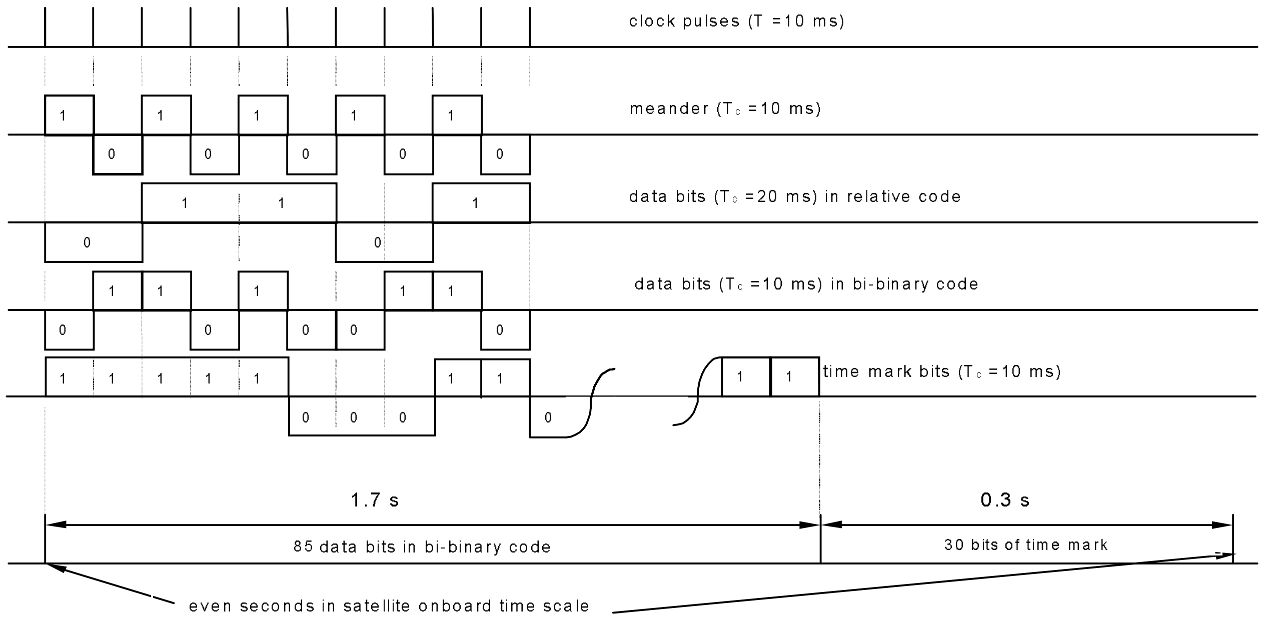


Figure 3.6 Data sequence generation in onboard processor

3.3.3 GLONASS time

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

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 $5{*}10^{-14}$.

Difference between GLONASS time and National Reference Time UTC(SU) shall be within 1 millisecond. The navigation message contains the requisite data to relate GLONASS time to UTS (SU) within 1 microsecond.

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) are computed and uploaded to the satellites twice a day by control segment.

An accuracy of comparisons between onboard time scales and CS time does not exceed 10 nanoseconds at epoch of measurement.

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 00 hours 00 minutes 00 seconds UTC at midnight from December 31 to January 1 (or from March 31 to April 1 or from June 30 to July 1 or from September 30 to October 1) by all UTC users.

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 (1).

During the leap second correction, GLONASS time is also corrected by changing enumeration of second pulses of onboard clocks of all GLONASS satellites. Here the time mark within navigation message changes its position (in a continuous time scale) to become synchronized with two-second epochs of corrected UTC time scale. This change occurs at 00 hours 00 minutes 00 seconds UTC (2).

Note (1): - 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).

*Note (2): - 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:

$$t_{GLONASS} = \text{UTC(SU)} + 03 \text{ hours } 00 \text{ minutes}$$

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

$$t_{UTC(SU)} + 03 \text{ hours } 00 \text{ minutes} = t + \tau_c + \tau_n(t_b) - \gamma_n(t_b)(t - t_b), \text{ where}$$

t – time of transmission of navigation signal in onboard time scale (parameters τ_c, τ_n, γ_n, and t_b are given in Sections 4.4 and 4.5).

3.3.4 Coordinate system

The GLONASS broadcast ephemeris describes a position of transmitting antenna phase center of given satellite in the PZ-90 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 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 point M is defined as angle between plane of the initial (zero) meridian and plane of a meridian passing through the point M. Positive direction of the longitude count from the initial meridian to east.

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

Fundamental geodetic constants and other significant parameters of the common terrestrial ellipsoid PZ-90 are given in Table 3.2.

Table 3.2 Geodetic constants and parameters of PZ-90 common terrestrial ellipsoid

Earth rotation rate	7.292115×10^{-5} radian/s
Gravitational constant	$398\ 600.44 \times 10^{9}$ 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	1/298.257 839 303
Equatorial acceleration of gravity	978 032.8 mgal
Correction to acceleration of gravity at sea-level due to Atmosphere	-0.9 mgal
Second zonal harmonic of the geopotential (J_2^0)	1082625.7×10^{-9}
Fourth zonal harmonic of the geopotential (J_4^0)	$(-\ 2370.9 \times 10^{-9})$
Normal potential at surface of common terrestrial ellipsoid (U_0)	62 636 861.074 $м^2/s^2$

4. NAVIGATION MESSAGE

A content and a format of the GLONASS navigation message are given in this Section.

4.1 Navigation message purpose

The navigation message transmitted by the GLONASS 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.

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).

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 superframes. A superframe consists of the frames, and a frame consists of the strings.

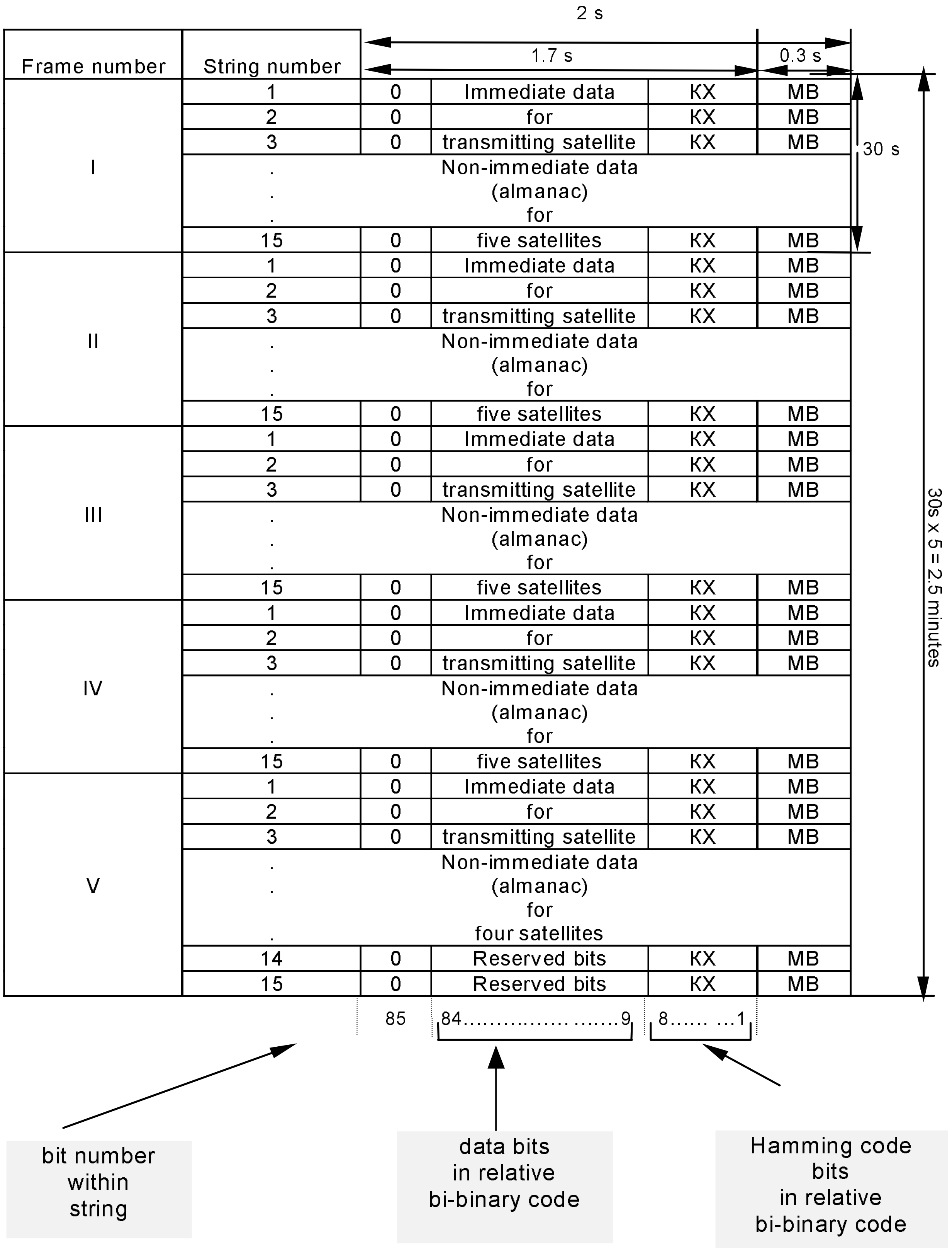
The boundaries of strings, frames and superframes of navigation messages from different GLONASS satellites are synchronized within 2 milliseconds.

4.3.1 Superframe structure

The superframe has duration 2.5 minutes and consists of 5 frames. Each frame has duration 30 seconds and consists of 15 strings. Each string has duration 2 seconds.

Within each frame a total content of non-immediate data (almanac for 24 GLONASS 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.



Frame number	String number				
I	1	0	Immediate data	KX	MB
	2	0	for	KX	MB
	3	0	transmitting satellite	KX	MB
	. . .		Non-immediate data (almanac) for		
	15	0	five satellites	KX	MB
II	1	0	Immediate data	KX	MB
	2	0	for	KX	MB
	3	0	transmitting satellite	KX	MB
	. . .		Non-immediate data (almanac) for		
	15	0	five satellites	KX	MB
III	1	0	Immediate data	KX	MB
	2	0	for	KX	MB
	3	0	transmitting satellite	KX	MB
	. . .		Non-immediate data (almanac) for		
	15	0	five satellites	KX	MB
IV	1	0	Immediate data	KX	MB
	2	0	for	KX	MB
	3	0	transmitting satellite	KX	MB
	. . .		Non-immediate data (almanac) for		
	15	0	five satellites	KX	MB
V	1	0	Immediate data	KX	MB
	2	0	for	KX	MB
	3	0	transmitting satellite	KX	MB
	. . .		Non-immediate data (almanac) for four satellites		
	14	0	Reserved bits	KX	MB
	15	0	Reserved bits	KX	MB

Figure 4.1 Superframe structure

4.3.2 Frame structure

The superframe has duration 2.5 minutes and consists of 5 frames. Each frame has duration 30 seconds and consists of 15 strings. Each string has duration 2 seconds.

Within each frame the total content of immediate data for given satellite and a part of non-immediate data are transmitted.

Frame structure within superframe is given in Fig. 4.2.

The frames 1…4 are identical. Shaded area in Fig. 4.2 indicates reserved bits are to be utilized in future modernization of the navigation message structure.

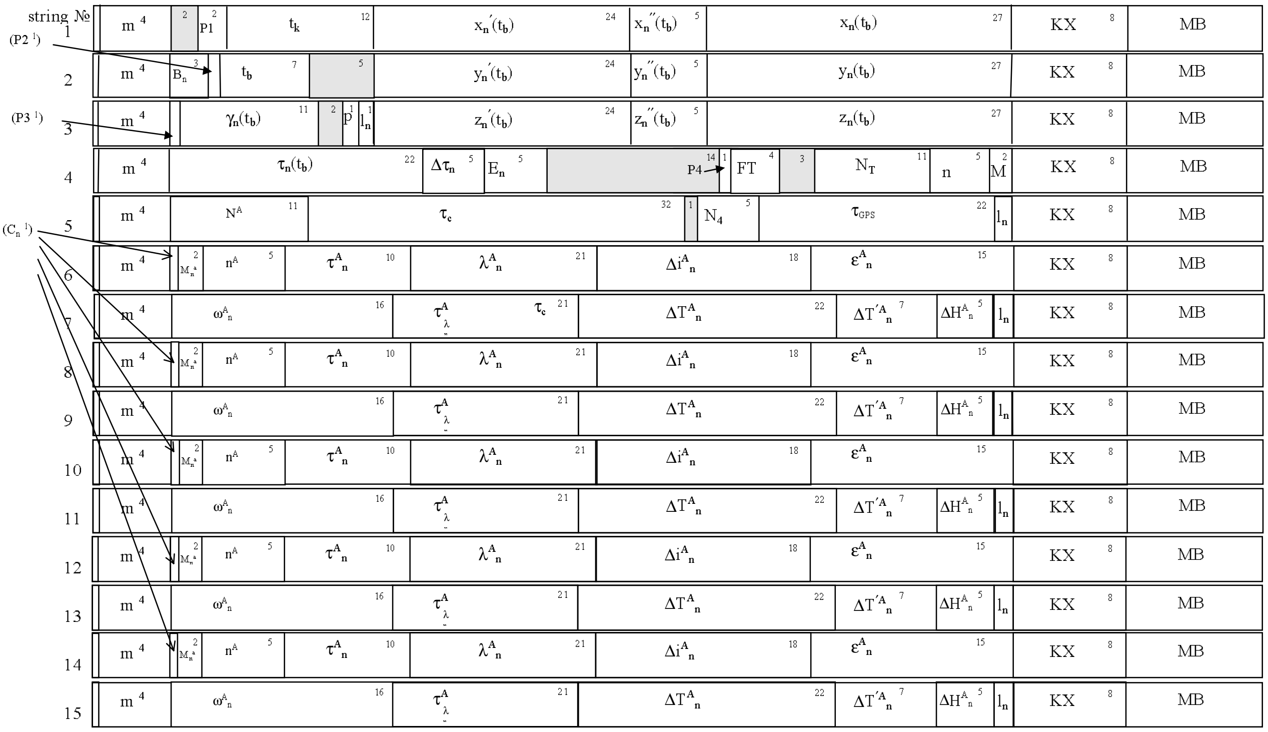
The data contained in strings 1…4 of each frame relate to the satellite that transmits given navigation message (immediate data). The immediate data are the same within one superframe.

The strings 6…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 5th frame contains remainder of almanac for 4 satellites. Non-immediate data (almanac) for one satellite occupy two strings. Data contained in 5th 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.

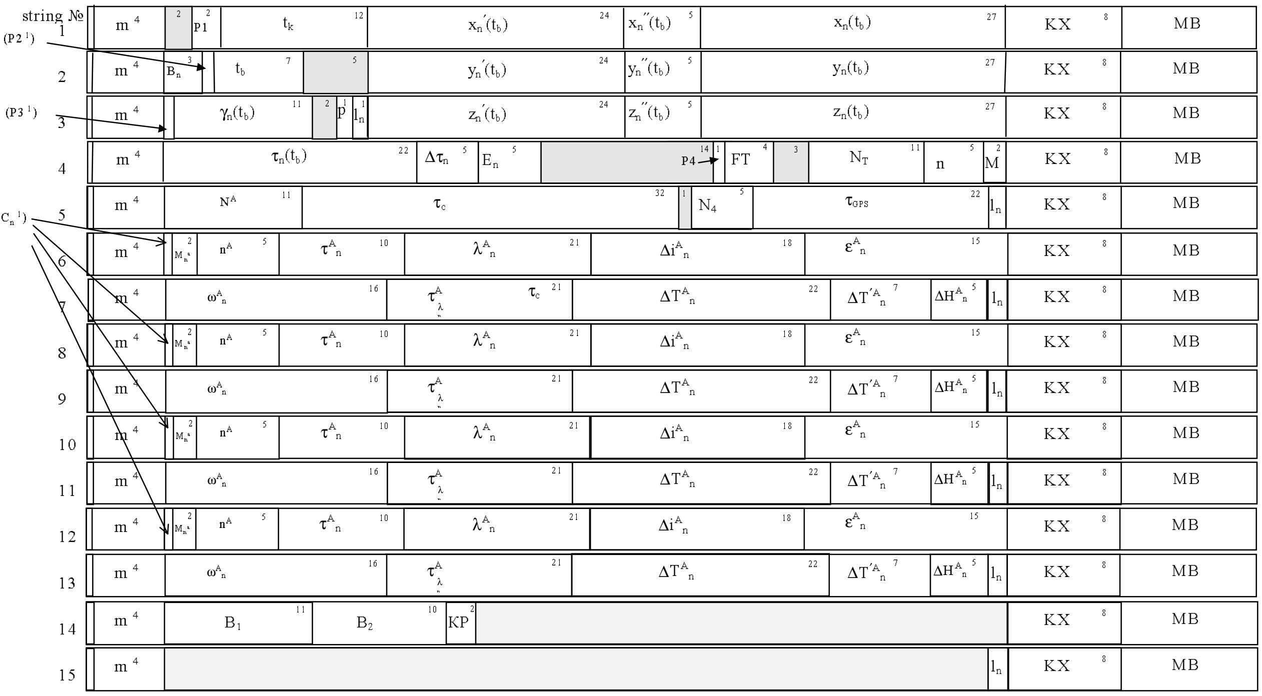
Table 4.1 Arrangement of GLONASS almanac within superframe

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



string №												
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			
3	m 4	$\gamma_n(t_b)$ 11	2	p 1	l_n	$z_n'(t_b)$ 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	FT 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			
6	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
7	m 4	ω^A_n 16	τ^A_λ τ_c 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
8	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
9	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
10	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
11	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
12	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
13	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
14	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
15	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			

Figure 4.2a Frame structure, 1st – 4th frames



string №												
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			
3	m 4	$\gamma_n(t_b)$ 11	2	p 1	l_n	$z_n'(t_b)$ 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	FT 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			
6	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
7	m 4	ω^A_n 16	τ^A_λ τ_c 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
8	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
9	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
10	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
11	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 5	l_n	KX 8	MB			
12	m 4	M_n^A 2	n^A 5	τ^A_n 10	λ^A_n 21	Δi^A_n 18	ε^A_n 15	KX 8	MB			
13	m 4	ω^A_n 16	τ^A_λ 21	ΔT^A_n 22	$\Delta T'^A_n$ 7	ΔH^A_n 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, 5th 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 9…84) 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.

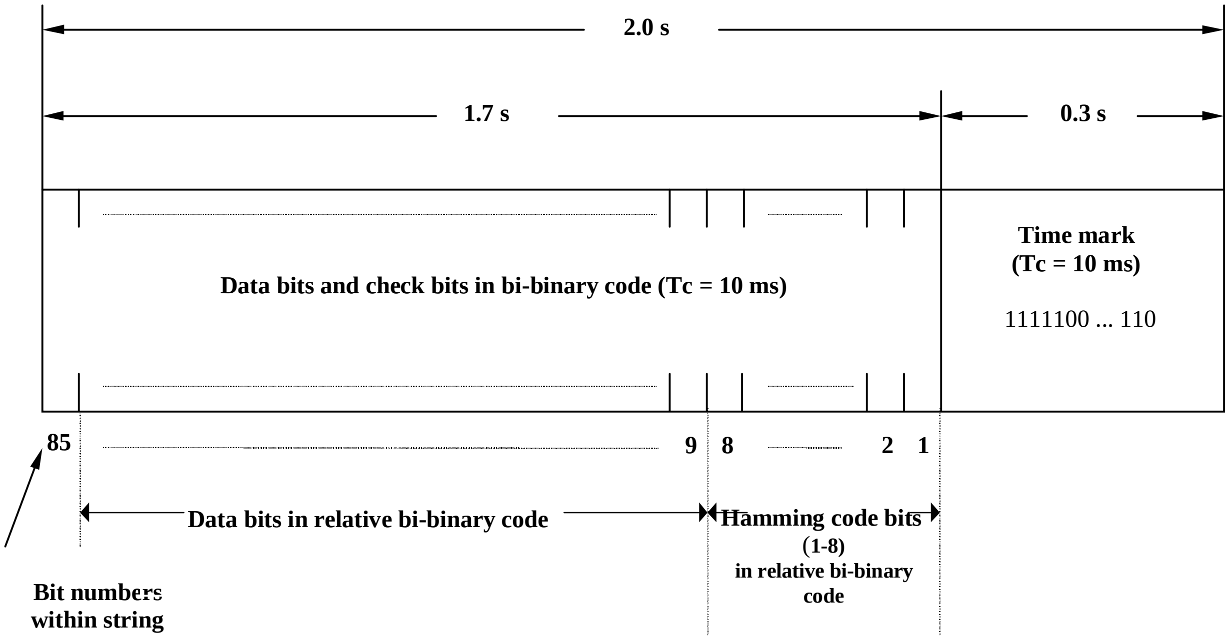


Figure 4.3 String structure

4.4 Immediate information and ephemeris parameters

Characteristics of words of immediate information (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 GLONASS satellites by control segment.

Mean square errors of daily-predicted coordinates and velocities of the satellites are given in Table 4.2.

Table 4.2 Accuracy of determination of coordinates and velocity for GLONASS satellite

Error component	Mean square error	
	predicted coordinates (m)	velocity (cm/s)
Along track component	20	0.05
Cross track component	10	0.1
Radial component	5	0.3

The designations and explanations of the navigation message words are given below.

Word **m** is the string number within the frame;

Word $\mathbf{t_K}$ 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;

Word $\mathbf{B_n}$ 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 $\mathbf{t_b}$ is an index of a time interval within current day according to UTC(SU) + 03 hours 00 min. The immediate data transmitted within the frame are referred to the middle of t_b- time interval. 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 flag that indicates a mode of computation of frequency/time correction parameters (1). If P = 1 then the data are computed by satellite onboard processor; if P = 0 then the data are computed and uploaded to the satellite by control segment.

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 of ephemeris parameters updating. "1" indicates that updated ephemeris and frequency/time parameters are transmitted within given frame (1);

Word **N_T** is current date, calendar number of day within four-year interval starting from a leap year (1);

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 indicator of accuracy of measurements. It is given as an equivalent error of data set received within navigation message at a time t_b, as indicated in Table 4.4 (1);

Table 4.4 Word F_T

Value of word F_T	Accuracy of measurements σ, 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 **$\Delta\tau_n$** – time difference between navigation RF signal transmitted in L2 sub-band and navigation RF signal transmitted in L1 sub-band by nth satellite.

$$\Delta\tau_n = t_{f2} - t_{f1}, \text{ where}$$

t_{f1}, t_{f2} – equipment delays in L1 and L2 sub-bands correspondingly, expressed in units of time;

Word **M** is modification flag for the satellite transmitting given navigation signal. "00" indicates GLONASS satellite, "01" – GLONASS-M satellite (1);

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

$$\gamma_n(t_b) = \frac{f_n(t_b) - f_{Nn}}{f_{Nn}}, \text{ where}$$

$f_n(t_b)$ 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 nth 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 nth 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 nth satellite; $l_n = 1$ indicates malfunction of this nth satellite.

Table 4.5 Characteristics of words of immediate information (ephemeris parameters)

Word*	No. of bits	Scale factor (LSB)	Effective range	Units
m	4	1	0...15	dimensionless
t_k	5	1	0...23	hours
	6	1	0...59	minutes
	1	30	0;30	seconds
t_b	7	15	15...1425	minutes
M (1)	2	1	0;1	dimensionless
$\gamma_n(t_b)$ (2)	11	2^{-40}	$\pm 2^{-30}$	dimensionless
$\tau_n(t_b)$ (2)	22	2^{-30}	$\pm 2^{-9}$	seconds
$x_n(t_b)$, $y_n(t_b)$, $z_n(t_b)$ (2)	27	2^{-11}	$\pm 2{,}7*10^4$	kilometers
$\dot{x}_n(t_b)$, $\dot{y}_n(t_b)$, $\dot{z}_n(t_b)$ (2)	24	2^{-20}	$\pm 4{,}3$	km/s
$\ddot{x}_n(t_b)$, $\ddot{y}_n(t_b)$, $\ddot{z}_n(t_b)$ (2)	5	2^{-30}	$\pm 6{,}2*10^{-9}$	km/s^2
B_n	3	1	0…7	dimensionless
P (1)	1	1	0;1	dimensionless
N_T (1)	11	1	0…2048	days
F_T (1)	4	(see Table 4.4)		
n (1)	5	1	0…31	dimensionless
$\Delta\tau_n$ (2)	5	2^{-30}	$\pm 13{,}97*10^{-9}$	seconds
E_n	5	1	0...31	days
P1	2	(see Table 4.3)		
P2	1	1	0;1	dimensionless
P3	1	1	0;1	dimensionless
P4 (1)	1	1	0;1	dimensionless
l_n (1)	1	1	0;1	dimensionless

Note (1): - These words are planned to insert into navigation message of GLONASS-M satellite.
Note (2): - 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 "-".

Arrangement of immediate information within frame is given in Table 4.6.

Table 4.6 Arrangement of immediate information within frame

Word	**No. of bits**	**String number within the frame**	**Bit number within the frame**
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	1	3	66
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 (3rd string), 9 (5th, 7th ,9th, 11th ,13th ,15th strings)

Words **X_n (t_b), Y_n (t_b), Z_n (t_b)** are the coordinates of n-satellite in PZ-90 coordinate system at the instant t_b;

Words **$\dot{X}_n$ (t_b), $\dot{Y}_n$ (t_b), $\dot{Z}_n$ (t_b)** are the velocity vector components of n-satellite in PZ-90 coordinate system at the instant t_b;

Words **$\ddot{X}_n$ (t_b), $\ddot{Y}_n$ (t_b), $\ddot{Z}_n$ (t_b)** are the acceleration components of n-satellite in PZ-90 coordinate system at the instant t_b, which are caused by effect of the sun and the moon;

Word $\mathbf{E_n}$ indicates the "age" of the immediate information that is a time interval elapsed since the instant of its calculation (uploading) until the instant t_b for n-satellite. This word is generated on the board of satellite.

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 $\boldsymbol{\tau_c}$ 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 ;

Word $\mathbf{N_4}$ is four-year interval number starting from 1996 (1) ;

Word $\boldsymbol{\tau_{GPS}}$ is correction to GPS time relative to GPS time or difference between these time scales T_{GPS} and T_{GL} as indicated in the following equation:

$$T_{GPS} - T_{GL} = \Delta T + \tau_{GPS}\,, \text{ where}$$

ΔT is integer part, and τ_{GPS} is fractional part of the difference between the system time scales expressed in seconds. The integer part ΔT is determined from GPS navigation message in user receiver (1);

Word $\mathbf{N^A}$ 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 $\boldsymbol{\lambda_n^A}$ is longitude of the first (within the N^A -day) ascending node of n^A -satellite orbit in PZ-90 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 $\boldsymbol{\varepsilon_n^A}$ is eccentricity of n^A -satellite at instant of $t_{\lambda n}^A$;

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

Word $\mathbf{M_n}^{\mathbf{A}}$ is a flag of modification of n^A -satellite (1); "00" indicates GLONASS satellite, "01" indicates GLONASS-M satellite;

Word **B1** is coefficient to determine ΔUT1, it is equal to difference between UT1 and UTC at beginning of current day (1);

Word **B2** is coefficient to determine ΔUT1, it is equal to daily change of difference ΔUT1 (1);

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

Table 4.7 Word KP

KP	Information on UTC leap second correction
00	There will not be UTC leap second correction in the end of current quarter.
01	There will be UTC leap second correction (+1 s) in the end of current quarter.
11	There will be UTC leap second correction (-1 s) in 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 values of the word KP is transmitted in the beginning of current quarter (the first five weeks). Otherwise KP = 10 is transmitted.

Word $\boldsymbol{\tau}_{\mathbf{n}}^{\mathbf{A}}$ 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 $\mathbf{C_n}^{\mathbf{A}}$ 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)	28	2^{-27}	±1	s
τ_{GPS} (1) (2)	22	2^{-30}	$\pm 1.9 * 10^{-3}$	day
N_4 (1)	5	1	0…31	4-year interval
N^A	11	1	1...1461	days
n^A	5	1	1...24	dimensionless
H_n^A (3)	5	1	1...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
$\Delta \dot{T}_n^A$ (2)	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	0.1	dimensionless
B1 (1) (2)	11	2^{-10}	±0.9	s
B2 (1) (2)	10	2^{-16}	$(-4{,}5 \ldots 3{,}5) * 10^{-3}$	s/msd
KP (1)	2	1	0,1	dimensionless
τ_n^A (4)	10	2^{-18}	$\pm 1{,}9 * 10^{-3}$	s
C_n^A	1	1	0...1	dimensionless

Note (1): - These words are planned to insert 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): - It is planned to increase scale factor (LSB) of the word τ_c 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	String number within frame (1)	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

Note (1): - String numbers of the first four frames within superframe are given. There are no almanac parameters in 14th and 15th strings of 5th frame.

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 superframe

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	67 – 68	2
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: - Position of reserved bits is given taking into account Notes 1 and 4 to Tables 4.5 and 4.10.

4.7 Data verification algorithm

This algorithm allows correcting an error in one bit within the string and detecting an error in two or more 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 to zero 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:

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

$\beta 1, \beta 2, \ldots, \beta 8$ – check bits of Hamming code (1-8);
b77,b76,…,b2, b1 – data bits (9-85);
$C_1, C_2, \ldots, C_7, C_\Sigma$ - checksums;

$C_1 = \beta_1 \oplus [\ \Sigma_i\ b_i]_{\text{mod }2}$

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.

$C_2 = \beta_2 \oplus [\ \Sigma_j\ b_j]_{\text{mod }2}$

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.

$C_3 = \beta_3 \oplus [\Sigma_k\ b_k]_{\text{mod }2}$

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

$C_4 = \beta_4 \oplus [\Sigma_l\ b_l]_{\text{mod }2}$

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

$C_5 = \beta_5 \oplus [\Sigma_m\ b_m]_{\text{mod }2}$

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

$C_6 = \beta_6 \oplus [\sum_{n=35}^{65} b_n]_{\text{mod }2}$ $C_7 = \beta_7 \oplus [\sum_{p=66}^{85} b_p]_{\text{mod }2}$

$C_\Sigma = [\sum_{q=1}^{8} \beta_q]_{\text{mod }2} \oplus [\sum_{q=9}^{85} b_q]_{\text{mod }2}$

5 GLONASS SPACE SEGMENT

A structure of GLONASS space segment and orbital parameters of GLONASS satellites are given in this Section.

5.1 Constellation structure

Completely deployed GLONASS constellation consists of 24 satellites.

GLONASS satellites are placed in three orbital planes. There are 8 satellites in each plane. 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:

$$\mathbf{251^\circ\ 15'\ 00'' + 120^\circ\ (i - 1),}$$

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 and are equal to:

$$\mathbf{145^\circ\ 26'\ 37'' + 15^\circ\ (27 - 3j + 25j^*),}$$

(as was fixed at 00 hours 00 minutes 00 seconds MT (UTC + 03 hours 00 minutes 00 seconds on January 1st, 1983)

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

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

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 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 five-year period.

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, 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.

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. This word will be transmitted within navigation message every 4 seconds.*

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 (GLONASS-M) satellites:

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

Each GLONASS satellite transmits the first type of flag within immediate data (ephemeris) the second type of flag within non-immediate data (almanac).

A time that is required for generation and providing users with B_n flag (to 1 minute) is much less than time required for C_n generation and transmission (to 16 hours), but generation of C_n is based on more profound analysis of GLONASS performance. GLONASS 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 B_n (l_n), C_n and operability of satellite

Value of flags		Operability of satellite
B_n (l_n)	C_n	
0	0	-
01	1	+
1	0	-
1	1	-

APPENDIX 1

RECEIVED POWER LEVEL

A guaranteed minimum signal power level (in L1 sub-band) 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 Fig.A1. 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 his orbital slot.

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).

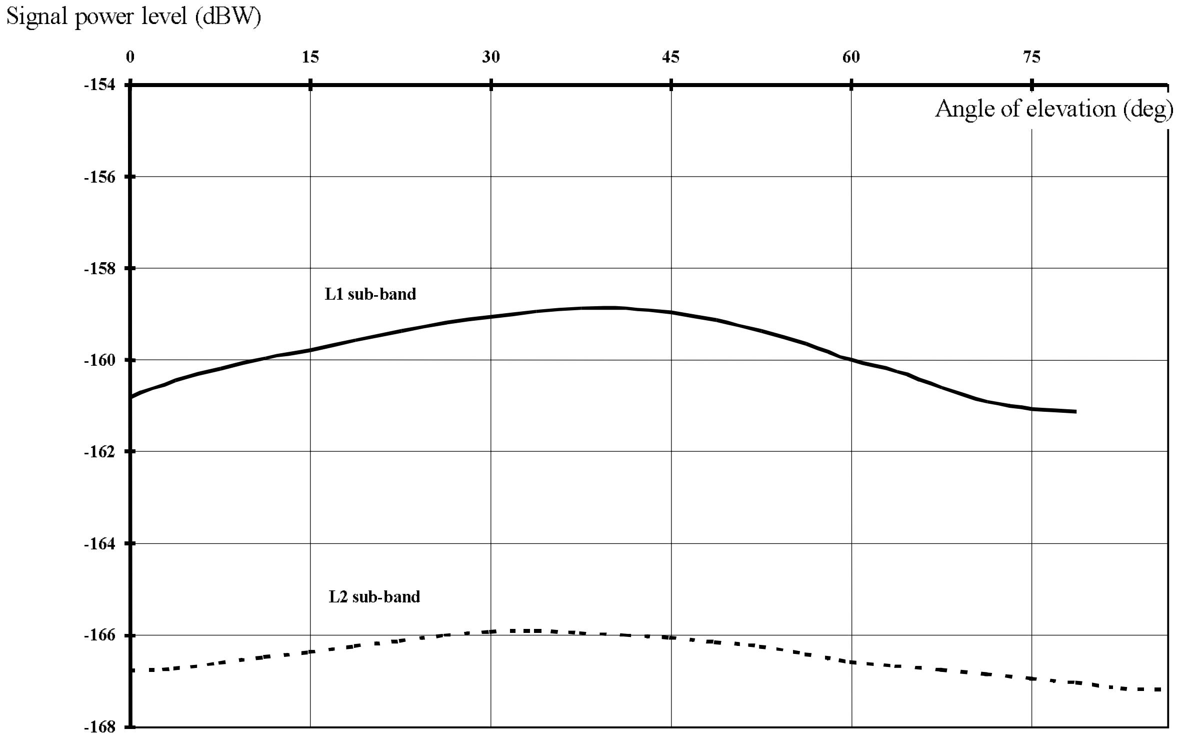


Figure A.1 Relationship between minimum received power level and angle of elevation

APPENDIX 2

RECOMMENDATIONS FOR USERS ON OPERATION OF RECEIVER 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 satellites.

Upon UTC leap second correction, the GLONASS 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).

An information on date/time and value of the UTC correction is either introduced by operator or received from (GLONASS or GPS) navigation message.

At 1 second before the UTC correction, the receiver starts operation of an algorithm of control and utilization of corrected GLONASS time. The algorithm should operate in the following time interval:

- until the end of correcting the onboard clocks of all observed satellites and the receiver clocks (when checking a correctness of pseudoranges computation);
- until the end of receiving new ephemeris parameters from all observed satellites, that are ephemeris parameters at instant t_b = 00 hours 15 minutes 00 seconds in updated UTC scale (when computing satellite ephemeris).

To obtain correct values of measured pseudoranges the receiver should track the moments of both transmission and reception of navigation signals. If both these events are registered using different time references (UTC_{old} and UTC_{new}), then measured pseudorange should be corrected by factor equal to product of values of UTC correction and speed of light. The value of pseudorange should refer to an instant of time in UTC_{old}.(UTS prior to the correction).

To compute current positions of GLONASS satellites until a moment of receiving new ephemeris parameters, the ephemeris data received before UTC correction is used. All computations are performed in UTC_{old}.

After receiving new ephemeris parameters from given satellite the coordinates of the satellite are computed using new ephemeris data and corrected UTC.

Result of positioning and all data provided by the receiver through its interface after the leap second correction should refer to UTC_{new} (corrected GLONASS time).

APPENDIX 3

EXAMPLES OF ALGORITHMS FOR CALCULATION OF COORDINATES AND VELOCITY

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

A.3.1 Example of 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 C_{20}, (that characterizes polar flattening of Earth), and accelerations due to luni-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:

$$\left.\begin{array}{l}
dx_a/dt = Vx_a \qquad dy_a/dt = Vy_a \qquad dz_a/dt = Vz_a \\
dVx_a/dt = -\bar{\mu} * \bar{X}_a + 3/2 * C_{20} * \bar{\mu} * \bar{X}_a * \rho^2 * (1 - 5 * \bar{Z}_a^2) + Jx_am + Jx_as \\
dVy_a/dt = -\bar{\mu} * \bar{Y}_a + 3/2 * C_{20} * \bar{\mu} * \bar{Y}_a * \rho^2 * (1 - 5 * \bar{Z}_a^2) + Jy_am + Jy_as \\
dVz_a/dt = -\bar{\mu} * \bar{Z}_a + 3/2 * C_{20} * \bar{\mu} * \bar{Z}_a * \rho^2 * (1 - 5 * \bar{Z}_a^2) + Jz_am + Jz_as
\end{array}\right\} \qquad (1)$$

where $\bar{\mu} = \mu / r^2, \quad \bar{X}_a = x_a/r, \quad \bar{Y}_a = y_a / r, \quad \bar{Z}_a = z_a/r, \quad \rho = a_e / r,$

$$r = \sqrt{X_a^2 + Y_a^2 + Z_a^2}.$$

Jx_as, Jy_as, Jz_as	-	Accelerations due to solar gravitational perturbation;
Jx_am, Jy_am, Jz_am	-	Accelerations due to lunar gravitational perturbations;
a_e	-	Equatorial radius of Earth, 6378.136 km [PZ-90 Reference document, KNITs, 1998];
μ	-	Gravitational constant, (398600.44 km^3/s^2) [PZ-90];
C_{20}	-	Second zonal coefficient of spherical harmonic expansion, ($-1082.63*10^{-6}$); ($C_{20} = \sqrt{5} * \bar{C}_{20}$, where $\bar{C}_{20}$ – normalized value of harmonic coefficient ($-484.165*10^{-6}$)) [PZ-90]).

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

$$\left.\begin{aligned}
Jx_{ak} &= \bar{\mu}_k \, [\, (\xi_к - \bar{X}_{ak}) / \Delta^3_к - \xi_к \,] , \\
Jy_{ak} &= \bar{\mu}_k \, [\, (\eta_к - \bar{Y}_{ak}) / \Delta^3_к - \eta_к \,] , \\
Jz_{ak} &= \bar{\mu}_k \, [\, (\zeta_k - \bar{Z}_{ak}) / \Delta^3_к - \zeta_к \,] ,
\end{aligned}\right\} \qquad (2)$$

where: $\bar{\mu}_k = \mu_k / r^2_k$, $\bar{X}_{ak} = X_a / r_k$, $\bar{Y}_{ak} = Y_a / r_k$, $\bar{Z}_{ak} = Z_a / r_k$,

$$\Delta^2_k = (\xi_k - \bar{X}_{ak})^2 + (\eta_k - \bar{Y}_{ak})^2 + (\zeta_k - \bar{Z}_{ak})^2,$$

k - Index for a perturbing body; k = m indicates “lunar”, and k = s indicates “solar”;

$\xi_k, \eta_k, \zeta_k, r_k$ - Directive cosines and radius-vector of perturbing bodies in $OX_aY_aZ_a$ coordinate system at instant t_e

$\mu_л$ - Lunar gravitational constant (4902.835 km^3/s^2);

μ_c - Solar gravitational constant ($0.1325263 * 10^{12}$ km/s^2).

The parameters $\xi_k, \eta_k, \zeta_k, r_k$ 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]:

$$\left.\begin{aligned}
\xi_m &= \sin(\upsilon_m + \Gamma') \, \xi_{11} + \cos(\upsilon_m + \Gamma') \, \xi_{12} , \\
\eta_m &= \sin(\upsilon_m + \Gamma') \, \eta_{11} + \cos(\upsilon_m + \Gamma') \, \eta_{12} , \\
\zeta_m &= \sin(\upsilon_m + \Gamma') \, \zeta_{11} + \cos(\upsilon_m + \Gamma') \, \zeta_{12} , \\
\xi_{se} &= \cos \upsilon_s * \cos \omega_s - \sin \upsilon_s * \sin \omega_s , \\
\eta_s &= (\sin \upsilon_s * \cos \omega_s + \cos \upsilon_s * \sin \omega_s) \, \cos \varepsilon , \\
\zeta_s &= (\sin \upsilon_s * \cos \omega_s + \cos \upsilon_s * \sin \omega_s) \, \sin \varepsilon , \\
r_k &= a_k \, (1 - e_k * \cos E_k), \qquad (k = m, s)
\end{aligned}\right\} \qquad (3)$$

where: $E_k = g_k + e_k * \sin E_k,$

$$\begin{aligned}
\sin \upsilon_k &= \sqrt{1 - e_k^2} * \sin E_k * (1 - e_k * \cos E_k)^{-1} , \\
\cos \upsilon_k &= (\cos E_k - e_k) * (1 - e_k * \cos E_k)^{-1} , \\
\xi_{11} &= \sin \Omega_m * \cos \Omega_m * (1 - \cos i_m) , \\
\xi_{12} &= 1 - \sin^2 \Omega_m * (1 - \cos i_m) , \\
\eta_{11} &= \xi^* * \cos \varepsilon - \zeta^* * \sin \varepsilon , \\
\eta_{12} &= \xi_{11} * \cos \varepsilon + \eta^* * \sin \varepsilon , \\
\zeta_{11} &= \xi^* * \sin \varepsilon + \zeta^* * \cos \varepsilon , \\
\zeta_{12} &= \xi_{11} * \sin\varepsilon - \eta^* * \cos\varepsilon , \\
\xi^* &= 1 - \cos^2 \Omega_m \, (1 - \cos i_m) , \\
\eta^* &= \sin \Omega_m * \sin i_m , \\
\zeta^* &= \cos \Omega_m * \sin i_m , \\
g_k &= g_{ok} + g_{1k} * T, \\
\Omega_m &= \Omega_{om} + \Omega_{1m} * T,
\end{aligned}$$

$\Gamma' = \Gamma'_0 + \Gamma'_1 * T,$

$T = (27392.375 + \Sigma_{day} + t_e / 86400) / 36525$

where:

a_m - Semi-major axis of lunar orbit ($3.84385243 * 10^5$ km);
A_s - Semi-major axis of solar “orbit” ($1.49598 * 10^8$ 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 ($5^\circ 08' 43.4''$);
ε - Mean inclination of ecliptic to equator ($23^\circ 26' 33''$).
$g_{om} = -63^\circ\ 53'\ 43.41''$
$g_{1m} = 477198^\circ\ 50'\ 56.79''$
$\Omega_{om} = 259^\circ\ 10'\ 59.79''$
$\Omega_{1m} = -1934^\circ\ 08'\ 31.23''$
$\Gamma'_o = -334^\circ\ 19'\ 46.40''$
$\Gamma'_1 = 4069^\circ\ 02'\ 02.52''$
$\omega_s = 281^\circ\ 13'\ 15.00'' + 6189.03'' * T;$
$g_{om} = 358^\circ\ 28'\ 33.04'';$
$g_{om} = 129596579.10''.$

T is a time from the epoch 5 January 1900 (GMT) to time reference t_e of ephemeris parameters (in Julian centuries of 36525 ephemeris days);

27392.375 is a number of days from the epoch 5 January 1900 to the epoch 0 January 1975 (Moscow Time or MT) taking into account the three-hour offset between MT and GMT when re-computing t_e into GMT;

Σ_{days} - sum of days from the epoch at 00 hours MT on 0 January 1975 to the epoch at 00 hours MT of current date within which the instant t_e is.

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) to an absolute coordinate system $OX_aY_aZ_a$ using the following formulae:

$$
\begin{aligned}
X_a(t_e) &= X(t_e) * \cos S - Y(t_e) * \sin S,\\
Y_a(t_e) &= Y(t_e) * \sin S + Y(t_e) * \cos S,\\
Z_a(t_e) &= Z(t_e),\\
Vx_a(t_e) &= Vx(t_e) * \cos S - Vy(t_e) * \sin S - \omega_E * Y_a(t_e),\\
Vy_a(t_e) &= Vx(t_e) * \sin S + Vy(t_e) * \cos S + \omega_E * X_a(t_e),\\
Vz_a(t_e) &= V_z(t_e),
\end{aligned}
$$

$$S = s + \omega_E\ (t - 3^h).$$

Where:

ω_E- Earth's rotation rate ($0.7292115 * 10^{-4}\ s^{-1}$);
s - true sidereal time at midnight GMT of a date within which the instant t_e is specified.

Notes:

1. *Accelerations Jx_as, Jx_am, Jy_as, Jy_am, Jz_as, Jz_am in equation (1) can be either adopted constant and computed once per an instant te using the formulae (2) or excluded from (1) and then added the results of integration of corrections:*

$$\Delta X = (Jx_am + Jx_as) * \tau^2/2, \ \Delta Y = (Jy_am + Jy_as) * \tau^2/2, \ \Delta Z = (Jz_am + Jz_as) \tau^2/2 ,$$
$$\Delta Vx = (Jx_am + Jx_as) * \tau , \quad \Delta Vy = (Jy_am + Jy_as) * \tau , \quad \Delta Vz =(Jz_am + Jz_as) \tau ,$$

where $\tau = t_i - t_e$.

2. *Directive cosines ξ_k , η_k , ζ_k can be computed using the formulae (3) or taken from an external source.*

3. *The origin of Greenwich (right-hand) coordinate system is in the center of Earth's body; OZ-axis is directed to northern pole along Earth's rotation axis; OX- axis is directed to the point of intersection of Greenwich meridian and equatorial plane.*

4. *If to exclude luni-solar accelerations when integrating system (1) and take into them account by addition of them to the results of integration*

$$\Delta X = (Jx_am + Jx_as) * \tau^2/2, \ \Delta Y = (Jy_am + Jy_as) * \tau^2/2, \ \Delta Z = (Jz_am + Jz_as) \tau^2/2 ,$$
$$\Delta Vx = (Jx_am + Jx_as) * \tau , \quad \Delta Vy = (Jy_am + Jy_as) * \tau , \quad \Delta Vz = (Jz_am + Jz_as)\tau ,$$

then increasing, due to this, of ephemeris extrapolation errors does not exceed 10%. Here $(Jx_am + Jx_as)$, $(Jy_am + Jy_as)$, $(Jz_am + Jz_as)$ are projection of luni-solar accelerations to axes of $OX_aY_aZ_a$ system at instant t_e to which ephemeris parameters are referenced, they are computed using the formulae (2).

5. *To calculate ephemeris parameters at instant t_j the projections of luni-solar accelerations to axes of Greenwich geocentric coordinate system $X''(t_e)$, $Y''(t_e)$, $Z''(t_e)$ can be used; they are transmitted within navigation message. Prior to the integration of the system (1) these accelerations should be transformed into an absolute Cartesian geocentric coordinate system $OX_aY_aZ_a$ using the following formulae:*

$$(Jx_am + Jx_as) = X''(t_e) * \cos S - Y''(t_e) * \sin S ,$$
$$(Jy_am + Jy_as) = X''(t_e) * \sin S + Y''(t_e) * \cos S ,$$
$$(Jz_am + Jz_as) = Z''(t_e)$$

An accuracy of ephemeris data multiplication is given in the following table:

Step of integration, minutes	Interval of integration		
	5 minutes	10 minutes	15 minutes
1	0.42	0.56	0.77
2.5	0.42	0.56	0.77
5	0.45	0.61	0.83
7.5	-	-	1.21

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

The algorithm is used when selecting optimal constellation, calculating satellite position to provide acquisition and tracking the selected satellite. The algorithm allows calculating the coordinates and velocity vector components of a satellite at instant of acquisition t_i.

A.3.2.1 Almanac data

GLONASS almanac contains orbital parameters specified for each satellite at an instant $t_{\lambda j}$ (see paragraph 4.5).

A list of the parameters for each satellite is as indicated below:

N_{Aj} - Calendar number of a day within four-year interval starting from latest leap year; almanac data for j-satellite are referenced to N_{Aj};

λ_j - Greenwich longitude of ascending node of orbit of j-satellite at instant $t_{\lambda j}$ (in radians);

$t_{\lambda j}$ - An instant of a first ascending node passage of j-satellite within N_{Aj} – day (in seconds);

Δi_j - Correction to the mean value of inclination of j-satellite at instant $t_{\lambda j}$ (mean value of inclination is equal to 63°);

ΔTj - Correction to the mean value of Draconian period of j-satellite at instant $t_{\lambda j}$ (mean value of Draconian period T is equal to 43200 seconds);

$\Delta T'_j$ - Rate of change of orbital period for j-satellite;

ε_j - Eccentricity of j-satellite orbit at instant $t_{\lambda j}$;

ω_j - Argument of perigee of j-satellite orbit at instant $t_{\lambda j}$ (in radians).

A.3.2.2 Algorithm of calculation

Calculation of satellite and velocity vector components at instant t_i (MT) of a day N_0 within four-year interval, and in absolute geocentric coordinate system $OX_aY_aZ_a$ (which origin and Z-axis coincide with origin and Z-axis of OXYZ system, offset between XOZ-plane and X_aOZ_a is equal to true sidereal time, and OY_a - axis completes the system to the right-handed one) is performed in two steps.

At the first step the time t_k of ascending node passage at k-orbital period and corresponding longitude λ_k are calculated using the almanac parameters ΔT, $\Delta T'$ and λ. Here the specified instant t_i is within the following interval: $(t_i - t_k < T_{mean} + \Delta T)$. Other parameters are assumed constant and equal to the corresponding parameters of almanac.

Then osculating elements are re-computed from the instant t_k to the instant t_i using analytic formulae and taking into account secular and periodic perturbations of the orbital elements caused by second zonal harmonic C_{20}.

Then the osculating elements at instant t_i are transformed into kinematic parameters, as indicated below.

1) semi-major axis "a" of orbit is calculated using technique of successive approximations:

$$a^{(n+1)} = [\mu * (T / 2\pi)^2]^{1/3},$$
$$T_{osc}^{(n+1)} = T_{dr} *\{ 1+3/2\ C_{20}\ (a_e/p^{(n)})^2 *$$
$$* [(2 - 5/2\sin^2 i) * (1-e^2)^{3/2} / (1 + e*\cos \omega)^2 + (1+ e* \cos \upsilon)^3 / (1-e^2)]\}^{-1},$$
$$p^{(n)} = a^{(n)} * (1- e^2),\quad n = 0, 1, 2...,$$

where: $\upsilon = -\omega$, $i = i_{mean} + \Delta i$ and $T_{dr} = T_{mean} + \Delta T$.

An initial approximation $a^{(0)} = [\mu * (T_{dr} / 2\pi)^2]^{1/3}$,

The process of approximation ends when fulfilling the following condition:
$| a^{(n-1)} - a^{(n)} | < 10^{-3}$ km.
Usually it is enough to make three iterations for it.

2) The time t_k of ascending node passage on k-orbital period (within which the instant t_i is located) and respective longitude λ_k are calculated:

$$t\lambda_k = [\overline{t\lambda_k}]_{\text{mod } 86400}$$

$$\overline{t\lambda_k} = t\lambda + T_{dr} * W + \Delta T' * W^2$$

$W_k = t^* / T_{dr}$, W is integer part of W_k,

$$t^* = t_i - t\lambda + 86400 * (N_o - N_A) ,$$

$$\lambda_k = \lambda + (\Omega' - \omega_3) * (W * T_{dr} + \Delta T' * W^2),$$

$$\Omega' = 3/2 * C_{20} * n * (a_e / a)^2 * \cos i * (1-e^2)^{-2},$$

$n = 2\pi / T_{dr}$, $\Omega = \lambda_k + S$, $S = S_0 + \omega_E (t\lambda_k - 10800)$.

where:

C_{20} - Second zonal harmonic of geopotential ($-1082.63 * 10^{-6}$);
a_e - Equatorial radius of Earth (6378.136 km);
S_0 - True sidereal time at Greenwich midnight on day N_0, within which the instant t_i is located;
ω_E - Earth's rotation rate ($0.7392115 * 10^{-4}\ s^{-1}$);
μ - Gravitational constant ($398600.44\ km^3 / s^2$).

3) Constant parameters of integration at the instant t_{λ_k} are computed:

$$\left.\begin{aligned}
\delta a^{(m)} / a \ &= \ 2 * J * (a_e / a)^2 * (1 - 3/2 \sin^2 i) * (l * \cos L) + J * (a_e/a)^2 * \sin i * (1/2 * \\
&\quad * h * \sin L - 1/2 * l * \cos L + \cos 2\lambda + 7/2 * l * \cos 3L + 7/2 * h * \sin 3L) \\[1ex]
\delta h^{(m)} \ &= \ J*(a_e / a)^2*(1-3/ 2\sin^2 i)*[l*n* \tau + \sin 3L + 3/2 * l * \sin 2L - 3/2*h*\cos 2L]- \\
&\quad -1/4*J*(a_e / a)^2*\sin^2 i*[\sin L - 7/3*\sin 3L + 5*l*\sin 2L -17/2 * l * \sin 4L + \\
&\quad +17/2*h*\cos 4L + h*\cos 2L] + J*(a_e / a)^2*\cos^2 i*(l*n* \tau- 1/2 * l * \sin 2L) \\[1ex]
\delta l^{(m)} \ &= \ J*(a_e / a)^2*(1-3/2 \sin^2 i)*[-h*n*\tau + \cos L + 3/2 * l * \cos 2L + 3/2*h*\sin 2L]- \\
&\quad -1/4*J*(a_e / a)^2*\sin^2 i*[-\cos L - 7/3*\cos 3L - 5*h*\sin 2L - 17/2 * l * \cos 4L- \\
&\quad -17/2*h*\sin 4L + l*\cos 2L] + J*(a_e / a)^2*\cos^2 i*(-h*n*\tau + 1/2 *h * \sin 2L) \\[1ex]
\delta \Omega^{(m)} \ &= \ J*(a_e / a)^2*\cos i*(n*\tau + 7/2 * l * \sin L - 7/2*h*\cos L -1/2\sin 2L -7/6*\sin 3L + \\
&\quad + 7/6*h*\cos 3L) \\[1ex]
\delta i^{(m)} \ &= \ 1/2*J*(a_e / a)^2*\sin i * \cos i * (-1 *\cos L +h*\sin L +\cos 2L +7/3*l*\cos 3L + \\
&\quad + 7/3*h*\sin 3L) \\[1ex]
\delta L^{(m)} \ &= \ 2*J*(a_e / a)^2*(1 - 3/2*\sin i)*(n*\tau + 7/4 * l * \sin L - 7/4 * h * \cos L) + \\
&\quad +3*J*(a_e / a)^2*\sin i * (-7/24 * h * \cos L - 7/24 * l * \sin L -49/72* h *\cos 3L+ \\
&\quad + 49/72* l *\sin 3L + 1/4 * \sin 2L) + J * (a_e / a)^2* \cos i * (n*\tau + \\
&\quad + 7/2 * l * \sin L - 5/2\, h \cos L - 1/2 * \sin 2L -7/6 * l*\sin 3L + 7/6 * h*\cos 3L)
\end{aligned}\right] \quad (1)$$

where: $L = M + \omega$, $M = E - \varepsilon * \sin E$, $\mathrm{tg}(E/2) = [(1 - \varepsilon) / (1 + \varepsilon)]^{1/2} *\mathrm{tg}(\upsilon/2)$,

$h = \varepsilon * \sin \omega$, $l = \varepsilon * \cos \omega$, $m = 1$,

$\tau = 0$, $J = 3/2 * C_{20}$, $a = a^{(n)}$ from item 1).

4) Corrections to orbital elements at instant t_i due to effect of C_{20} are computed:

$$\begin{aligned}
\delta a &= \delta a^{(2)} - \delta a^{(1)} \\
\delta h &= \delta h^{(2)} - \delta h^{(1)} \\
\delta l &= \delta l^{(2)} - \delta l^{(1)} \\
\delta \Omega &= \delta \Omega^{(2)} - \delta \Omega^{(1)} \\
\delta i &= \delta i^{(2)} - \delta i^{(1)} \\
\delta L^* &= \delta L^{(2)} - \delta L^{(1)}
\end{aligned}$$

Parameters $\delta a^{(2)}$, $\delta h^{(2)}$, $\delta l^{(2)}$, $\delta \Omega^{(2)}$, $\delta i^{(2)}$, $\delta L^{(2)}$ are computed for $\tau = t_i - t_{\lambda_k}$ and $m =2$ using the formulae (1), where $L = M + \omega + n * \tau$.

5) Perturbing orbital elements of satellites at instant t_i are computed:

$$a_i = a + \delta a,$$
$$h_i = h + \delta h,$$
$$l_i = l + \delta l,$$
$$\varepsilon_i = (h_i * h_i + l_i * l_i)^{1/2},$$

$$\omega_i = \begin{cases} \mathrm{arctg}\,(h_i / l_i), & \text{if } \varepsilon_i \neq 0 \text{ and } l_i \neq 0 \\ 0, & \text{if } \varepsilon_i = 0, \\ \pi / 2, & \text{if } \varepsilon_i \neq 0 \text{ and } l_i = \varepsilon_i, \\ -\pi / 2, & \text{if } \varepsilon_i \neq 0 \text{ and } l_i = -\varepsilon_i, \end{cases}$$

$$\Omega_i = \Omega + \delta\Omega$$
$$i_i = i + \delta i$$
$$M_i = L^* - \omega_i , \qquad L^* = M + \omega + n * (t_i - t_{\lambda k}) + \delta L^*.$$

Here "i" indicates reference to instant t_i,

6) Coordinates and velocity vector components at instant t_i in $OX_aY_aZ_a$ coordinate system are computed:

$$E_i^{(n)} = M_i + \varepsilon_i * \sin E_i^{(n-1)}, \qquad E_i^{(0)} = M_i, \qquad | E_i^{(n)} - E_i^{(n-1)} | \leq 10^{-8},$$
$$\mathrm{tg}(\upsilon_i/2) = [(1 + \varepsilon_i) / (1 - \varepsilon_i)]^{1/2} * \mathrm{tg}(E_i^{(n)}/2), \qquad u_i = \upsilon_i + \omega_i,$$
$$r_i = a_i * (1 - \varepsilon_i * \cos E_i^{(n)}),$$
$$Vr_i = (\mu / a_i)^{1/2} * (\varepsilon_i - \sin \upsilon_i) / (1 - \varepsilon_i * \varepsilon_i)^{-1},$$
$$Vu_i = (\mu / a_i)^{1/2} * (1 + \varepsilon_i * \cos \upsilon_i) / (1 - \varepsilon_i * \varepsilon_i)^{-1},$$

$$X_i = r_i * (\cos u_i * \cos \Omega_i - \sin u_i * \sin \Omega_i * \cos i_i),$$

$$Y_i = r_i * (\cos u_i * \sin \Omega_i + \sin u_i * \cos \Omega_i * \cos i_i),$$

$$Z_i = r_i * \sin u_i * \sin i_i,$$

$$Vx_i = Vr_i * (\cos u_i * \cos \Omega_i - \sin u_i * \sin \Omega_i * \cos i_i) - \\ -Vu_i * (\sin u_i * \cos \Omega_i + \cos u_i * \sin \Omega_i * \cos i_i),$$

$$Vy_i = Vr_i * (\cos u_i * \sin \Omega_i + \sin u_i * \cos \Omega_i * \cos i_i) - \\ -Vu_i * (\sin u_i * \sin \Omega_i - \cos u_i * \cos \Omega_i * \cos i_i),$$

$$Vz_i = Vr_i * \sin u_i * \sin i_i + Vu_i * \cos u_i * \sin i_i.$$

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