BeiDou Navigation Satellite System Signal In Space Interface Control Document

Open Service Signal B2a (Version 1.0)

China Satellite Navigation Office

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Table of Contents

1 Statement

China Satellite Navigation Office is responsible for the preparation, revision, distribution, and retention of BeiDou Navigation Satellite System Signal In Space Interface Control Document (hereinafter referred to as ICD), and reserves the right for final explanation of this ICD.

2 Scope

The construction and development of BeiDou Navigation Satellite System (BDS) is divided into three phases: BDS-1, BDS-2, and BDS-3 in sequence.

This document defines the characteristics of the open service signal B2a transmitted from the BDS space segment to the BDS user segment. Furthermore, the B2a signal is transmitted by the Medium Earth Orbit (MEO) satellites and the Inclined GeoSynchronous Orbit (IGSO) satellites of BDS-3 for providing open services, and shall not be transmitted by the Geostationary Earth Orbit (GEO) satellites.

3 BDS Overview

3.1 Space Constellation

The basic space constellation of BDS-3 consists of 3 GEO satellites, 3 IGSO satellites, and 24 MEO satellites. According to actual situation, spare satellites may be deployed in orbit. The GEO satellites operate in orbit at an altitude of 35,786 kilometers and are located at 80°E, 110.5°E, and 140°E respectively. The IGSO satellites operate in orbit at an altitude of 35,786 kilometers and an inclination of the orbital planes of 55 degrees with reference to the equatorial plane. The MEO satellites operate in orbit at an altitude of 21,528 kilometers and an inclination of the orbital planes of 55 degrees with reference to the equatorial plane.

3.2 Coordinate System

The BeiDou Coordinate System is adopted by BDS, with the abbreviation as BDCS. The definition of BDCS is in accordance with the specifications of the International Earth Rotation and Reference System Service (IERS), and it is consistent with the definition of the China Geodetic Coordinate System 2000 (CGCS2000). BDCS and CGCS2000 have the same ellipsoid parameters, which is defined as follows:

(1) Definition of origin, axis and scale

The origin is located at the Earth’s center of mass. The Z-Axis is the direction of the IERS Reference Pole (IRP). The X-Axis is the intersection of the IERS Reference Meridian (IRM) and the plane passing through the origin and normal to the Z-Axis. The Y-Axis, together with Z-Axis and X-Axis, constitutes a right-handed orthogonal coordinate system.

The length unit is the international system of units (SI) meter.

(2) Definition of the BDCS Ellipsoid

The geometric center of the BDCS Ellipsoid coincides with the Earth’s center of mass, and the rotational axis of the BDCS Ellipsoid is the Z-Axis. The parameters of the BDCS Ellipsoid are shown in Table 3-1.

Table 3-1 Parameters of the BDCS Ellipsoid

No.	Parameter	Definition
1	Semi-major axis	a=6378137.0 m
2	Geocentric gravitational constant	$\mu=3.986004418\times10^{14}\ \mathrm{m^3/s^2}$
3	Flattening	f=1/298.257222101
4	Earth's rotation rate	$\dot{\Omega}_e=7.2921150\times10^{-5}$ rad/s

3.3 Time System

The BeiDou Navigation Satellite System Time (BDT) is adopted by the BDS as time reference. BDT adopts the international system of units (SI) second as the base unit, and accumulates continuously without leap seconds. The start epoch of BDT is 00:00:00 on January 1, 2006 of Coordinated Universal Time (UTC). BDT connects with UTC via UTC (NTSC), and the deviation of BDT to UTC is maintained within 50 nanoseconds (modulo 1 second). The leap second information is broadcast in the navigation message.

4 Signal Characteristics

The signal characteristics described in this chapter pertain to the B2a signal contained within the 20.46MHz bandwidth with a center frequency of 1176.45 MHz.

4.1 Signal Structure

The carrier frequencies, modulations, and symbol rates of the B2a signal are shown in Table 4-1.

Table 4-1 Structure of the B2a signal

Signal	Signal component	Carrier frequency (MHz)	Modulation	Symbol rate (sps)
B2a	Data component B2a_data	1176.45	BPSK(10)	200
	Pilot component B2a_pilot		BPSK(10)	0

4.2 Signal Modulation

4.2.1 Modulation

In the following sections, a power normalized complex envelope is used to describe a modulated signal.

Assume that the complex envelope expression of a modulated signal is

$$s_X(t) = s_{X1}(t) + \mathrm{j} s_{X2}(t) \tag{4-1}$$

where, j is an imaginary unit, $s_{X1}(t)$ is the real part of the complex envelope, which represents the in-phase component of the signal; $s_{X2}(t)$ is the imaginary part of complex envelope, which represents the quadrature component of the signal. $s_X(t)$ is the baseband form of the signal, describing the structure and content of the signal before carrier modulation.

The expression of the modulated signal can be also described as

$$S_X(t) = \sqrt{2P_X}\left[s_{X1}(t)\cos(2\pi f_X t) - s_{X2}(t)\sin(2\pi f_X t)\right] \tag{4-2}$$

where, f_X is the carrier frequency, and P_X is the signal power. $S_X(t)$ completely expresses a carrier-modulated bandpass signal.

Therefore, $s_X(t)$ and $S_X(t)$ are the different expressions of the same signal, and they can be transformed from one to the other.

4.2.2 B2a Signal

The complex envelope of the B2a signal is expressed as

$$s_{\mathrm{B2a}}(t) = s_{\mathrm{B2a\_data}}(t) + \mathrm{j}\, s_{\mathrm{B2a\_pilot}}(t) \tag{4-3}$$

where, the data component $s_{\mathrm{B2a\_data}}(t)$ is generated from the navigation message data $D_{\mathrm{B2a\_data}}(t)$ modulated with the ranging code $C_{\mathrm{B2a\_data}}(t)$, while the pilot component $s_{\mathrm{B2a\_pilot}}(t)$ contains the ranging code $C_{\mathrm{B2a\_pilot}}(t)$ only. They both adopt BPSK(10) modulation. The power ratio of the data component to the pilot component is 1:1. The expressions of these two components are shown below, respectively:

$$s_{\mathrm{B2a\_data}}(t) = \frac{1}{\sqrt{2}} D_{\mathrm{B2a\_data}}(t) \cdot C_{\mathrm{B2a\_data}}(t) \tag{4-4}$$

$$s_{\mathrm{B2a\_pilot}}(t) = \frac{1}{\sqrt{2}} C_{\mathrm{B2a\_pilot}}(t) \tag{4-5}$$

where, $D_{\mathrm{B2a\_data}}(t)$ is defined as follows:

$$D_{\mathrm{B2a\_data}}(t) = \sum_{k=-\infty}^{\infty} d_{\mathrm{B2a\_data}}[k]\, p_{T_{\mathrm{B2a\_data}}}\left(t - kT_{\mathrm{B2a\_data}}\right) \tag{4-6}$$

where, $d_{\mathrm{B2a\_data}}$ is the navigation message data of the B2a signal, and $T_{\mathrm{B2a\_data}}$ is the chip width of the corresponding data.

The expressions of $C_{\mathrm{B2a\_data}}(t)$ and $C_{\mathrm{B2a\_pilot}}(t)$ are given as follows:

$$C_{\mathrm{B2a\_data}}(t) = \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_{\mathrm{B2a\_data}}-1} c_{\mathrm{B2a\_data}}[k] p_{T_{\mathrm{c\_B2a}}}\left(t - \left(N_{\mathrm{B2a\_data}} n + k\right) T_{\mathrm{c\_B2a}}\right) \tag{4-7}$$

$$C_{\mathrm{B2a\_pilot}}(t) = \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_{\mathrm{B2a\_pilot}}-1} c_{\mathrm{B2a\_pilot}}[k] p_{T_{\mathrm{c\_B2a}}}\left(t - \left(N_{\mathrm{B2a\_pilot}} n + k\right) T_{\mathrm{c\_B2a}}\right) \tag{4-8}$$

where, $c_{\text{B2a\_data}}$ and $c_{\text{B2a\_pilot}}$ are the ranging code sequences (with the values of ±1) of the data component and the pilot component respectively. $N_{\text{B2a\_data}}$ and $N_{\text{B2a\_pilot}}$ are the ranging code length of the corresponding components with the same values of 10230. $T_{\text{c\_B2a}}=1/R_{\text{c\_B2a}}$ is the chip width of the B2a ranging code. $R_{\text{c\_B2a}}$ =10.23 Mbps is the chip rate of the B2a ranging code.

Table 4-2 shows the components of the B2a signal as well as the modulation, phase relationship and power ratio of each component.

Table 4-2 Modulation characteristics of the B2a signal

Component	Modulation	Phase relationship	Power ratio
$s_{\text{B2a\_data}}(t)$	BPSK(10)	0	1/2
$s_{\text{B2a\_pilot}}(t)$	BPSK(10)	90	1/2

4.3 Logic Levels

The correspondence between the logic level code bits used to modulate the signal and the signal level is shown in Table 4-3.

Table 4-3 Logic to signal level assignment

Logic level	Signal level
1	-1.0
0	+1.0

4.4 Signal Polarization

The transmitted signals are Right-Hand Circularly Polarized (RHCP).

4.5 Carrier Phase Noise

The phase noise spectral density of the un-modulated carrier will allow a third-order phase locked loop with 10 Hz one-sided noise bandwidth to track the carrier to an accuracy of 0.1 radians RMS.

4.6 Spurious

The transmitted spurious signal shall not exceed -50dBc.

4.7 Correlation Loss

The correlation loss due to payload distortions shall not exceed 0.6dB.

4.8 Data/Code Coherence

The edge of each data symbol is aligned with the edge of the corresponding ranging code chip. The start of the first chip of the periodic ranging codes is aligned with the start of a data symbol.

The edge of each secondary chip is aligned with the edge of a primary code chip. The start of the first chip of the primary codes is aligned with the start of a secondary code chip.

4.9 Signal Coherence

The time difference between the ranging code phases of all signal components shall not exceed 10 nanoseconds.

4.10 Received Power Levels on Ground

The minimum received power levels on ground are shown in Table 4-4. They are measured at the output of a 0 dBi RHCP user receiving antenna (or 3 dBi linearly polarized user receiving antenna) when the satellites are above a 5-degree elevation angle.

Table 4-4 Minimum received power levels on ground

Signal	Satellite type	Minimum received power (dBW)*
B2a	MEO satellite	-156
	IGSO satellite	-158
*For the signal that contains a data component and a pilot component, the minimum received power is the combined power of the data component and the pilot component. The power distribution between the data component and the pilot component is defined by the modulation method. The effective power ratio offset between the components shall be less than 0.5 dB.		

The BDS satellites shall provide the B2a signal with the following characteristics: the off-axis relative power shall not decrease by more than 2dB from the edge of the Earth to nadir.

5 Ranging Code Characteristics

5.1 Ranging Code Structure

The B2a ranging codes are the tiered codes which are generated by XORing the primary codes with secondary codes. The chip width of the secondary code has the same length as one period of a primary code, and the start of a secondary code chip is strictly aligned with the start of the first chip of a primary code. The timing relationships are shown in Figure 5-1.

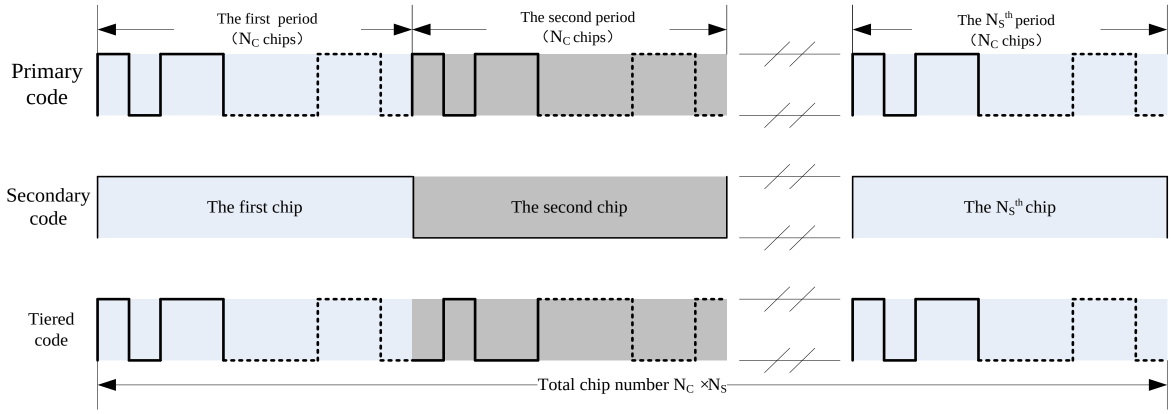


Figure 5-1 Timing relationships of the primary code and secondary code

The characteristics of the B2a ranging codes are shown in Table 5-1.

Table 5-1 Characteristics of the B2a ranging codes

Signal component	Primary code type	Primary code length (chip)	Primary code period (ms)	Secondary code type	Secondary code length (chip)	Secondary code period (ms)
B2a data component	Gold	10230	1	Fixed sequence	5	5
B2a pilot component	Gold	10230	1	Truncated Weil	100	100

For a given MEO/IGSO satellite, a unique pseudo-random noise (PRN) ranging code number is assigned to all operational signals. Furthermore, the B1C and B2a signals transmitted by one satellite have the same PRN number.

5.2 B2a Ranging Codes

5.2.1 B2a Primary Codes

The B2a primary codes (for both data and pilot components) have the same chip rate of 10.23Mcps, and have the same length of 10230 chips. Each primary code is obtained by expanding the Gold code that is generated by shifting and modulo-2 addition based on two 13-stage linear feedback shift registers. The generator polynomials for each B2a data component primary code are

$$\begin{aligned} g_1(x) &= 1 + x + x^5 + x^{11} + x^{13} \\ g_2(x) &= 1 + x^3 + x^5 + x^9 + x^{11} + x^{12} + x^{13} \end{aligned} \tag{5-1}$$

And, the generator polynomials for each B2a pilot component primary code are

$$\begin{aligned} g_1(x) &= 1 + x^3 + x^6 + x^7 + x^{13} \\ g_2(x) &= 1 + x + x^5 + x^7 + x^8 + x^{12} + x^{13} \end{aligned} \tag{5-2}$$

The implementations of the primary code generators for the B2a data and pilot components are shown in Figure 5-2 and Figure 5-3, respectively.

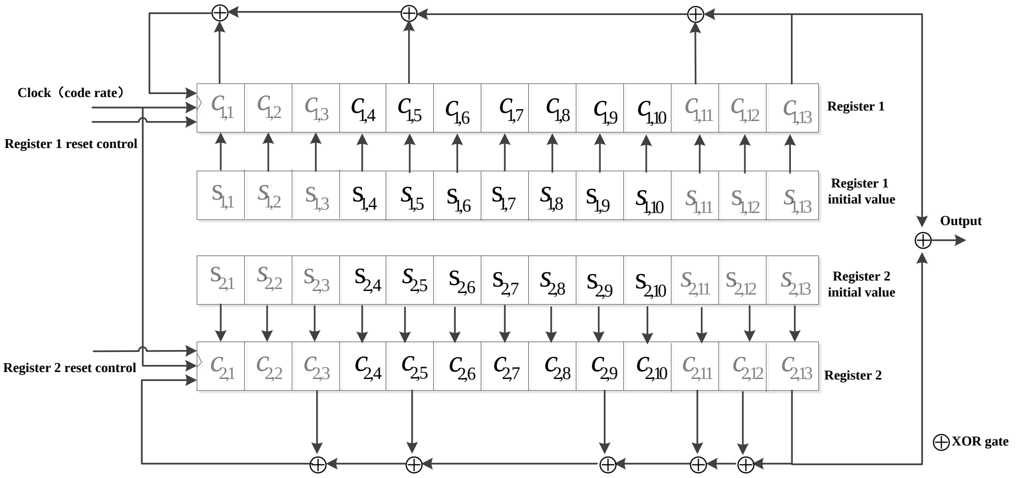


Figure 5-2 Primary code generator of the B2a data components

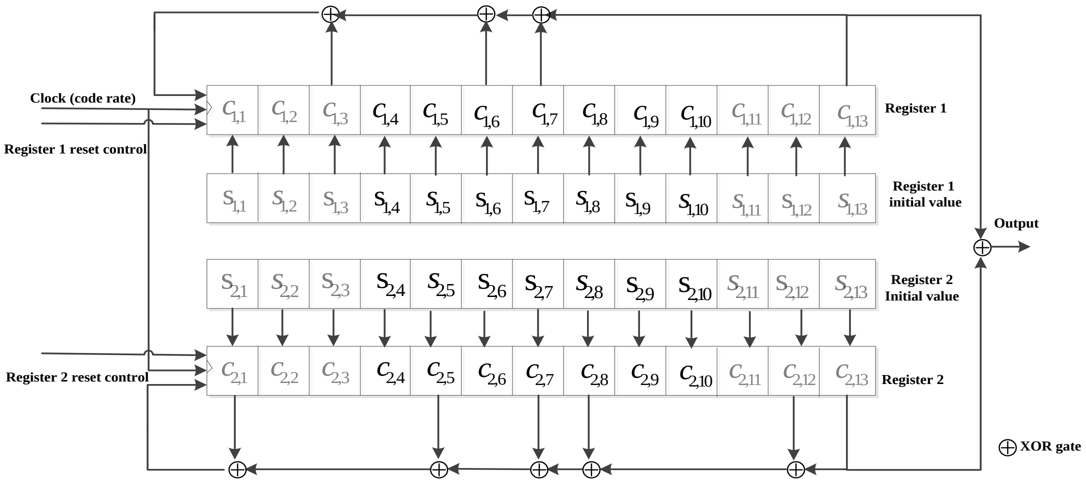


Figure 5-3 Primary code generator of the B2a pilot components

For a given satellite, the primary code generators for the B2a data and pilot components use different polynomials, but they start with the same initial bit values. In a code generator whether for a data component or for a pilot component, the initial bit values of register 1 are all “1”, and the initial bit values of register 2 are given in Table 5-2 and Table 5-3, arranged as $\left[s_{2,1},s_{2,2},s_{2,3},\ldots,s_{2,13}\right]$. At the start of each primary code period, both register 1 and register 2 are simultaneously reset to their corresponding initial bit values. Furthermore, register 1 is reset at the end of the 8190th chip in each period of a primary code. A primary code with the length of 10230 chips is finally obtained by repeating the above procedure.

There are a total of 126 B2a primary codes, of which 63 codes are for the data components and the other 63 codes for the pilot components. The detailed parameters are shown in Table 5-2 and Table 5-3, in which, the values of both the first 24 chips and the last 24 chips are expressed in an octal form. The MSB (i.e., the first chip of the primary codes) is transmitted first.

Table 5-2 Primary code parameters of the B2a data components

PRN	Initial bit values of register 2 (binary)	The first 24 chips (octal)	The last 24 chips (octal)
1	1 0 0 0 0 0 0 1 0 0 1 0 1	26771056	42646672
2	1 0 0 0 0 0 0 1 1 0 1 0 0	64771737	43261240
3	1 0 0 0 0 1 0 1 0 1 1 0 1	22570544	22122147
4	1 0 0 0 1 0 1 0 0 1 1 1 1	03270060	37130044
5	1 0 0 0 1 0 1 0 1 0 1 0 1	25270173	62604441
6	1 0 0 0 1 1 0 1 0 1 1 1 0	42473731	32223757
7	1 0 0 0 1 1 1 1 0 1 1 1 0	42073211	75444074
8	1 0 0 0 1 1 1 1 1 1 0 1 1	10070275	72155517
9	1 0 0 1 1 0 0 1 0 1 0 0 1	32630236	23340625
10	1 0 0 1 1 1 1 0 1 1 0 1 0	51032336	70730557
11	1 0 1 0 0 0 0 1 1 0 1 0 1	24751346	12470110
12	1 0 1 0 0 0 1 0 0 0 1 0 0	67350347	43367447
13	1 0 1 0 0 0 1 0 1 0 1 0 1	25350426	42740075
14	1 0 1 0 0 0 1 0 1 1 0 1 1	11351730	26275034
15	1 0 1 0 0 0 1 0 1 1 1 0 0	61353105	77007136
16	1 0 1 0 0 1 0 1 0 0 0 1 1	16553042	21516371
17	1 0 1 0 0 1 1 1 1 0 1 1 1	04152767	57170016
18	1 0 1 0 1 0 0 0 0 0 0 0 1	37653046	73363551
19	1 0 1 0 1 0 0 1 1 1 1 1 0	40653671	01726764
20	1 0 1 0 1 1 0 1 0 1 0 1 1	12450445	65504556
21	1 0 1 0 1 1 0 1 1 0 0 0 1	34450556	30230153

PRN	Initial bit values of register 2 (binary)	The first 24 chips (octal)	The last 24 chips (octal)
22	1 0 1 1 0 0 1 0 1 0 0 1 1	15311110	06600771
23	1 0 1 1 0 0 1 1 0 0 0 1 0	56310431	10770505
24	1 0 1 1 0 1 0 0 1 1 0 0 0	71511012	76447734
25	1 0 1 1 0 1 0 1 1 0 1 1 0	44511144	05425133
26	1 0 1 1 0 1 1 1 1 0 0 1 0	54112361	44374741
27	1 0 1 1 0 1 1 1 1 1 1 1 1	00112147	77505753
28	1 0 1 1 1 0 0 0 1 0 0 1 0	55611514	30732736
29	1 0 1 1 1 0 0 1 1 1 1 0 0	60611442	43750131
30	1 0 1 1 1 1 0 1 0 0 0 0 1	36413134	24525367
31	1 0 1 1 1 1 1 0 0 1 0 0 0	73011377	41152341
32	1 0 1 1 1 1 1 0 1 0 1 0 0	65011630	73304761
33	1 0 1 1 1 1 1 1 0 1 0 1 1	12011007	01741554
34	1 0 1 1 1 1 1 1 1 0 0 1 1	14012245	35421025
35	1 1 0 0 0 0 1 0 1 0 0 0 1	35360637	50337664
36	1 1 0 0 0 1 0 0 1 0 1 0 0	65561423	44445660
37	1 1 0 0 0 1 0 1 1 0 1 1 1	04561753	04256075
38	1 1 0 0 1 0 0 0 1 0 0 0 1	35662052	50515704
39	1 1 0 0 1 0 0 0 1 1 0 0 1	31663710	53542760
40	1 1 0 0 1 1 0 1 0 1 0 1 1	12463151	71045216
41	1 1 0 0 1 1 0 1 1 0 0 0 1	34463042	24771613
42	1 1 0 0 1 1 1 0 1 0 0 1 0	55063612	23705725
43	1 1 0 1 0 0 1 0 1 0 1 0 1	25322050	75623014
44	1 1 0 1 0 0 1 1 1 0 1 0 0	64321071	54464775
45	1 1 0 1 0 1 1 0 0 1 0 1 1	13121416	45712211
46	1 1 0 1 1 0 1 0 1 0 1 1 1	05223044	53232723
47	1 1 1 0 0 0 0 1 1 0 1 0 0	64742223	57720500
48	1 1 1 0 0 1 0 0 0 0 0 1 1	17543106	45401000
49	1 1 1 0 0 1 0 0 0 1 0 1 1	13542644	46456064
50	1 1 1 0 0 1 0 1 0 0 0 1 1	16542346	52156646
51	1 1 1 0 0 1 0 1 0 1 0 0 0	72542534	06245671
52	1 1 1 0 1 0 0 1 1 1 0 1 1	10643011	42540225
53	1 1 1 0 1 1 0 0 1 0 1 1 1	05440046	33645207
54	1 1 1 1 0 0 1 0 0 1 0 0 0	73302166	16264764
55	1 1 1 1 0 1 0 0 1 0 1 0 0	65502351	00166336
56	1 1 1 1 0 1 0 0 1 1 0 0 1	31502177	33717324
57	1 1 1 1 0 1 1 0 1 1 0 1 0	51103567	23234454
58	1 1 1 1 0 1 1 1 1 1 0 0 0	70101476	55337366
59	1 1 1 1 0 1 1 1 1 1 1 1 1	00103243	04145264
60	1 1 1 1 1 1 0 1 1 0 1 0 1	24403035	66364214

PRN	Initial bit values of register 2 (binary)	The first 24 chips (octal)	The last 24 chips (octal)
61	0 0 1 0 0 0 0 0 0 0 0 1 0	57754771	16642116
62	1 1 0 1 1 1 1 1 1 0 1 0 1	24021305	46402740
63	0 0 0 1 1 1 1 0 1 0 0 1 0	55037136	06147764

Table 5-3 Primary code parameters of the B2a pilot components

PRN	Initial bit values of register 2 (binary)	The first 24 chips (octal)	The last 24 chips (octal)
1	1 0 0 0 0 0 0 1 0 0 1 0 1	26772435	05133452
2	1 0 0 0 0 0 0 1 1 0 1 0 0	64771100	32506731
3	1 0 0 0 0 1 0 1 0 1 1 0 1	22573033	46030461
4	1 0 0 0 1 0 1 0 0 1 1 1 1	03272567	46247217
5	1 0 0 0 1 0 1 0 1 0 1 0 1	25270312	25242712
6	1 0 0 0 1 1 0 1 0 1 1 1 0	42471450	30604612
7	1 0 0 0 1 1 1 1 0 1 1 1 0	42073477	46162133
8	1 0 0 0 1 1 1 1 1 1 0 1 1	10071171	01037517
9	1 0 0 1 1 0 0 1 0 1 0 0 1	32631672	70661477
10	1 0 0 1 1 1 1 0 1 1 0 1 0	51030525	11057614
11	1 0 1 0 0 0 0 1 1 0 1 0 1	24752054	60410454
12	1 0 1 0 0 0 1 0 0 0 1 0 0	67350376	57214270
13	1 0 1 0 0 0 1 0 1 0 1 0 1	25353643	60621113
14	1 0 1 0 0 0 1 0 1 1 0 1 1	11350203	05270220
15	1 0 1 0 0 0 1 0 1 1 1 0 0	61350565	55150062
16	1 0 1 0 0 1 0 1 0 0 0 1 1	16550214	30076625
17	1 0 1 0 0 1 1 1 1 0 1 1 1	04153006	40344732
18	1 0 1 0 1 0 0 0 0 0 0 0 1	37653767	46567772
19	1 0 1 0 1 0 0 1 1 1 1 1 0	40650022	62054544
20	1 0 1 0 1 1 0 1 0 1 0 1 1	12453537	12272230
21	1 0 1 0 1 1 0 1 1 0 0 0 1	34451342	71277735
22	1 0 1 1 0 0 1 0 1 0 0 1 1	15311341	56036234
23	1 0 1 1 0 0 1 1 0 0 0 1 0	56311044	17154331
24	1 0 1 1 0 1 0 0 1 1 0 0 0	71513035	43013023
25	1 0 1 1 0 1 0 1 1 0 1 1 0	44513245	50115176
26	1 0 1 1 0 1 1 1 1 0 0 1 0	54110251	56313110
27	1 0 1 1 0 1 1 1 1 1 1 1 1	00112144	13102726
28	1 0 1 1 1 0 0 0 1 0 0 1 0	55613763	37225071
29	1 0 1 1 1 0 0 1 1 1 1 0 0	60613513	24323124
30	1 0 1 1 1 1 0 1 0 0 0 0 1	36410413	20375533
31	1 0 1 1 1 1 1 0 0 1 0 0 0	73012122	15635105

PRN	**Initial bit values of register 2 (binary)**	**The first 24 chips (octal)**	**The last 24 chips (octal)**
32	1 0 1 1 1 1 1 0 1 0 1 0 0	65013702	67011450
33	1 0 1 1 1 1 1 1 0 1 0 1 1	12010047	43522666
34	1 0 1 1 1 1 1 1 1 0 0 1 1	14010654	41666474
35	1 1 0 0 0 0 1 0 1 0 0 0 1	35362324	06151354
36	1 1 0 0 0 1 0 0 1 0 1 0 0	65563410	76525270
37	1 1 0 0 0 1 0 1 1 0 1 1 1	04561575	20632513
38	1 1 0 0 1 0 0 0 1 0 0 0 1	35663035	26643303
39	1 1 0 0 1 0 0 0 1 1 0 0 1	31663420	52433060
40	1 1 0 0 1 1 0 1 0 1 0 1 1	12463063	04062730
41	1 1 0 0 1 1 0 1 1 0 0 0 1	34461616	67067235
42	1 1 0 0 1 1 1 0 1 0 0 1 0	55061754	47416277
43	1 1 0 1 0 0 1 0 1 0 1 0 1	25322640	51407764
44	1 1 0 1 0 0 1 1 1 0 1 0 0	64322743	66451710
45	1 1 0 1 0 1 1 0 0 1 0 1 1	13120015	75211676
46	1 1 0 1 1 0 1 0 1 0 1 1 1	05223510	66732705
47	1 1 1 0 0 0 0 1 1 0 1 0 0	64741454	24716231
48	1 1 1 0 0 1 0 0 0 0 0 1 1	17543717	43326034
49	1 1 1 0 0 1 0 0 0 1 0 1 1	13543302	37156357
50	1 1 1 0 0 1 0 1 0 0 0 1 1	16540127	35671252
51	1 1 1 0 0 1 0 1 0 1 0 0 0	72541267	61241434
52	1 1 1 0 1 0 0 1 1 1 0 1 1	10642411	56632466
53	1 1 1 0 1 1 0 0 1 0 1 1 1	05441614	13706174
54	1 1 1 1 0 0 1 0 0 1 0 0 0	73300134	71335154
55	1 1 1 1 0 1 0 0 1 0 1 0 0	65502720	42104070
56	1 1 1 1 0 1 0 0 1 1 0 0 1	31500435	07315646
57	1 1 1 1 0 1 1 0 1 1 0 1 0	51103347	51233462
58	1 1 1 1 0 1 1 1 1 1 0 0 0	70102511	46425113
59	1 1 1 1 0 1 1 1 1 1 1 1 1	00102277	16705351
60	1 1 1 1 1 1 0 1 1 0 1 0 1	24401515	23126772
61	1 0 1 0 0 1 0 0 0 0 1 1 0	47551324	77540116
62	0 0 1 0 1 1 1 1 1 1 0 0 0	70057625	31062540
63	0 0 0 1 1 0 1 0 1 0 1 0 1	25236023	01076040

5.2.2 B2a Secondary Codes

For different satellites, the secondary codes of the B2a data components are the same, while the secondary codes of the B2a pilot components are different.

The secondary codes of the B2a data components are the fixed 5-bit sequences with the bit values of 00010 in binary. The MSB is transmitted first.

The secondary codes for the B2a pilot components are generated by truncating the Weil codes, and the process is described as follows:

In general, a Weil code sequence of length N is defined as

$$W(k;\ w) = L(k) \oplus L((k+w) \bmod \mathrm{N}),\ k = 0,1,2,\ldots,\mathrm{N}-1 \tag{5-3}$$

where, $L(k)$ is a legendre sequence of length N, and w represents the phase difference between two legendre sequences. A legendre sequence $L(k)$ of length N is defined as

$$L(k) = \begin{cases} 0,\ k = 0 \\ 1,\ k \neq 0, \text{ and if there exists an integer } x \text{ which makes } k = (x^2 \bmod \mathrm{N}) \\ 0,\ else \end{cases} \tag{5-4}$$

where， mod is a modulo division operation.

Finally, a ranging code of length N_0 is obtained by cyclically truncating the Weil code of length N. The truncated sequence is given as

$$c(n;w;p) = W((n+p-1) \bmod \mathrm{N};w),\ n = 0,1,2,\ldots,\mathrm{N}_0-1 \tag{5-5}$$

where， p is the truncation point in the range of 1 to N, which means the Weil code is truncated from the p^{th} bit.

The secondary codes for the B2a pilot components have the same length of 100 chips. The secondary codes are generated by truncating the Weil codes which have a length of 1021 chips. The value of w is in the range of 1 to 510.

Specific parameters of the secondary codes of the B2a pilot components are shown in Table 5-4. In this table, both the first 24 chips and the last 24 chips are expressed in an octal form. The MSB is transmitted first.

Table 5-4 Secondary code parameters of the B2a pilot components

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
1	123	138	32063050	65322167
2	55	570	51032554	16507723
3	40	351	26031355	03244075
4	139	77	00016672	51467525
5	31	885	43414712	46604555
6	175	247	03313653	56202042
7	350	413	41103653	71007450
8	450	180	42370454	34256747
9	478	3	06231051	40430077
10	8	26	37047570	06442617
11	73	17	36242432	16314440
12	97	172	62600563	05321123
13	213	30	77411542	56573352
14	407	1008	41654772	55730776
15	476	646	63255352	01324146
16	4	158	16034451	17500531
17	15	170	56753432	66634453
18	47	99	62660722	37240150
19	163	53	11300714	32673101
20	280	179	46564670	76643076
21	322	925	51453710	41236437
22	353	114	75520773	47126073
23	375	10	55105576	24605443
24	510	584	31050323	07347067
25	332	60	76030274	41470462
26	7	3	61576715	07552423
27	13	684	21353627	15306360
28	16	263	11326621	43507041
29	18	545	77304426	12537651
30	25	22	26565352	32362347
31	50	546	34135261	14550406
32	81	190	30407566	60014143
33	118	303	52113374	61116102

PRN	**Phase difference (*w*)**	**Truncation point (*p*)**	**The first 24 chips (octal)**	**The last 24 chips (octal)**
34	127	234	54145235	20702236
35	132	38	63100104	23455231
36	134	822	35317452	17352571
37	164	57	10714032	07417741
38	177	668	43602423	47415564
39	208	697	13700511	36550046
40	249	93	67442654	41615230
41	276	18	42621301	70270411
42	349	66	25413532	73527103
43	439	318	73475715	20344205
44	477	133	60600610	33470052
45	498	98	22362271	73213175
46	88	70	73341370	21175624
47	155	132	76412463	71174640
48	330	26	10475522	77336306
49	3	354	31662361	52645772
50	21	58	72164341	10166636
51	84	41	03600703	62442252
52	111	182	12734207	47205776
53	128	944	66744236	67053707
54	153	205	66354613	12103375
55	197	23	42710457	01304276
56	199	1	72744364	62223707
57	214	792	76720625	03111453
58	256	641	46643276	34250037
59	265	83	53525215	71514224
60	291	7	42453402	36620001
61	324	111	26604754	70502406
62	326	96	35027021	07344636
63	340	92	12073317	30264212

5.3 Non-standard Codes

The non-standard codes are used to protect the user from tracking the anomalous navigation signals, which are not for utilization by the user. Therefore, they are not defined in this document.

6 Navigation Message Structure

6.1 Navigation Message Overview

6.1.1 Navigation Message Types

The B2a signal broadcasts the B-CNAV2 navigation message.

6.1.2 Cyclic Redundancy Check

The B-CNAV2 navigation message uses a cyclic redundancy check (CRC), and more specifically, CRC-24Q. The generator polynomial of CRC-24Q is

$$g(x)=\sum_{i=0}^{24} g_i x^i \tag{6-1}$$

where, $g_i=\begin{cases}1, & i=0,1,3,4,5,6,7,10,11,14,17,18,23,24\\ 0, & else\end{cases}$.

Furthermore, $g(x)$ can be expressed as follows:

$$g(x)=(1+x)p(x) \tag{6-2}$$

where, $p(x)=x^{23}+x^{17}+x^{13}+x^{12}+x^{11}+x^{9}+x^{8}+x^{7}+x^{5}+x^{3}+1$.

A message sequence m_i $(i=1\sim k)$ of length k can be expressed as a polynomial below:

$$m(x)=m_k+m_{k-1}x+m_{k-2}x^2+\cdots+m_1x^{k-1} \tag{6-3}$$

Through dividing polynomial $m(x)x^{24}$ with the generator polynomial $g(x)$, the residue is supposed to be the following polynomial:

$$R(x)=p_{24}+p_{23}x+p_{22}x^2+\cdots+p_1x^{23} \tag{6-4}$$

where, p_1 p_2 …… p_{24} is the corresponding output sequence regarded as the CRC check sequence.

During the implementation, the initial bit values of the register are set to all “0”.

6.2 B-CNAV2 Navigation Message

6.2.1 Brief Description

The B-CNAV2 navigation message is broadcast on the B2a signal. More specifically, the B-CNAV2 message data are modulated on the B2a data component. The basic frame structure of B-CNAV2 is defined in Figure 6-1. Each frame has a length of 600 symbols, and its symbol rate is 200sps, so the transmission of one frame lasts for 3 seconds.

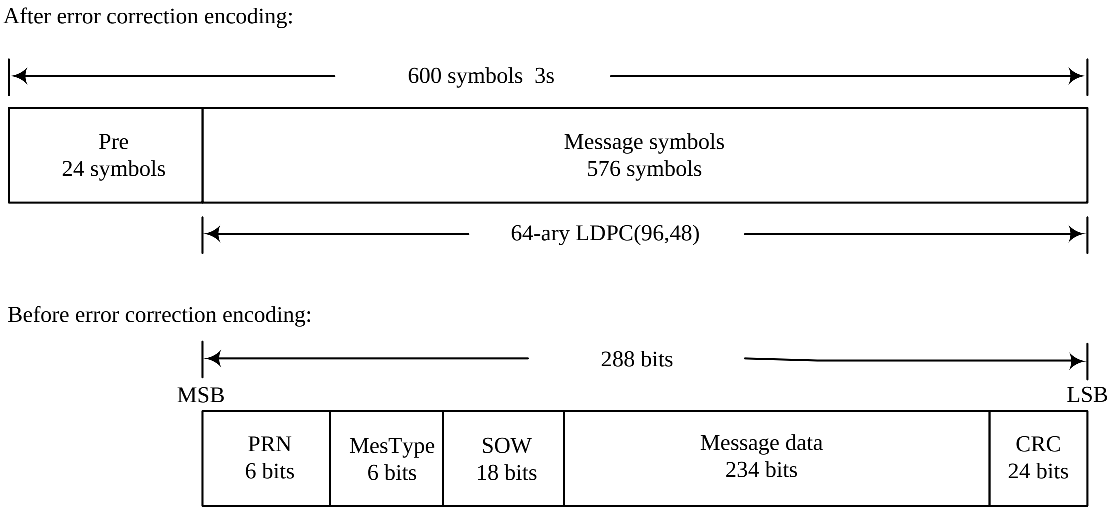


Figure 6-1 B-CNAV2 frame structure

The first 24 symbols of each frame is preamble (Pre) with the value of 0xE24DE8 in hexadecimal (i.e., 111000100100110111101000 in binary). The MSB is transmitted first.

Each frame before error correction encoding has a length of 288 bits, containing PRN (6 bits), Message Type (Mestype, 6 bits), Seconds Of Week

(SOW, 18 bits), message data (234 bits), and CRC check bits (24 bits). PRN, MesType, SOW, and message data participate in the CRC calculation. As a result of 64-ary LDPC(96, 48) encoding, the frame length becomes 576 symbols.

6.2.2 Coding Methods

The B-CNAV2 navigation messages are encoded with 64-ary LDPC(96, 48) code. Each codeword symbol is composed of 6 bits and defined in GF(2^6) domain with a primitive polynomial of $p(x)=1+x+x^6$. A vector representation (MSB first) is used to describe the mapping relationship between non-binary symbols and binary bits. The message length k is equal to 48 codeword symbols, i.e., 288 bits. The check matrix is a sparse matrix $\mathrm{H}_{48,96}$ of 48 rows and 96 columns defined in GF(2^6) domain with the primitive polynomial of $p(x)=1+x+x^6$, of which the first 48×48 part corresponds to the information symbols and the last 48×48 part corresponds to the check symbols. The locations of its non-zero elements are defined as follows:

$\mathbf{H}_{48,\ 96,\ \mathrm{index}}$= [

19	46	49	76	5	29	53	71	17	30	64	72	22	36	59	82
22	41	68	94	20	44	54	75	9	41	61	86	6	47	60	89
8	40	60	87	15	26	66	81	19	24	67	95	2	26	50	72
5	38	70	89	16	34	64	92	21	45	55	74	0	24	48	78
23	37	58	83	15	43	56	91	18	47	48	77	14	42	57	90
6	30	54	76	14	27	67	80	17	35	65	93	7	46	61	88
1	25	49	79	12	45	69	79	18	25	66	94	23	40	69	95
8	36	51	84	3	38	56	86	0	29	62	85	2	39	57	87
11	33	59	81	20	43	74	93	13	32	63	91	11	35	52	83
16	31	65	73	4	28	52	70	1	28	63	84	12	33	62	90
21	42	75	92	7	31	55	77	9	37	50	85	10	34	53	82
4	39	71	88	13	44	68	78	3	27	51	73	10	32	58	80

]

where, each element is a non-binary symbol in GF(2^6) domain. The elements are described by a vector representation as follows:

$$\mathbf{H}_{48,\,96,\,\text{element}} = \left[\begin{array}{cccc|cccc|cccc|cccc}
1 & 45 & 15 & 6 & 1 & 44 & 53 & 24 & 45 & 15 & 6 & 1 & 30 & 24 & 1 & 44 \\
18 & 15 & 32 & 61 & 3 & 55 & 9 & 34 & 35 & 31 & 50 & 44 & 45 & 15 & 6 & 1 \\
24 & 1 & 44 & 53 & 30 & 24 & 1 & 44 & 32 & 42 & 47 & 37 & 6 & 1 & 45 & 15 \\
44 & 53 & 24 & 1 & 39 & 36 & 34 & 33 & 44 & 53 & 24 & 1 & 44 & 53 & 24 & 1 \\
45 & 15 & 6 & 1 & 6 & 1 & 45 & 15 & 24 & 1 & 44 & 53 & 9 & 41 & 57 & 58 \\
32 & 61 & 18 & 40 & 1 & 45 & 15 & 6 & 22 & 14 & 2 & 50 & 24 & 1 & 44 & 30 \\
30 & 24 & 1 & 44 & 15 & 46 & 45 & 44 & 45 & 15 & 6 & 1 & 1 & 44 & 30 & 24 \\
24 & 1 & 44 & 53 & 15 & 6 & 1 & 45 & 53 & 24 & 1 & 44 & 7 & 38 & 23 & 54 \\
1 & 45 & 15 & 6 & 44 & 53 & 24 & 1 & 57 & 25 & 9 & 41 & 35 & 13 & 51 & 60 \\
33 & 45 & 36 & 34 & 6 & 1 & 45 & 15 & 6 & 1 & 45 & 15 & 6 & 1 & 45 & 15 \\
44 & 35 & 31 & 50 & 26 & 27 & 37 & 5 & 24 & 1 & 44 & 30 & 33 & 42 & 14 & 5 \\
24 & 1 & 44 & 30 & 24 & 1 & 44 & 30 & 1 & 44 & 53 & 24 & 1 & 44 & 30 & 24
\end{array} \right]$$

The above matrix shall be read from top to bottom in the same column, and from left to right column after column. In the same column, the four numbers of each row correspond to four non-zero elements in the matrix. The reading rules for $H_{48,\,96}$ are shown in Figure 6-2.

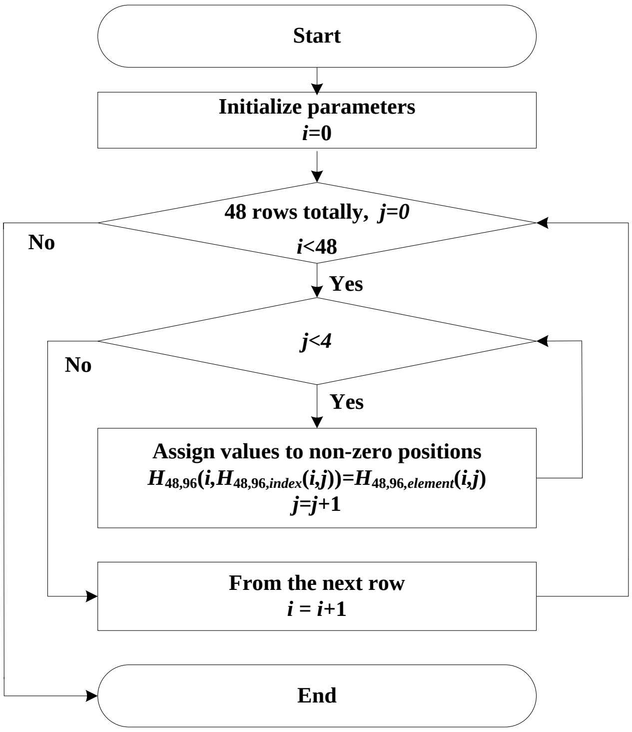


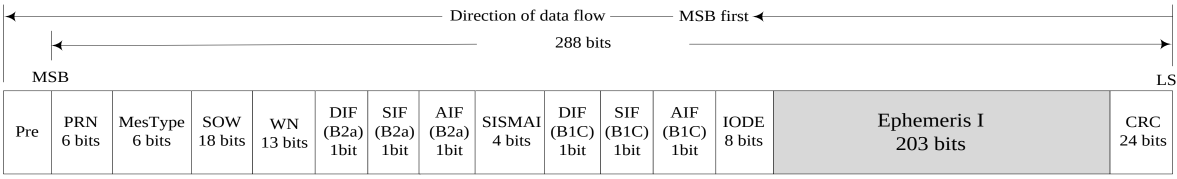
Figure 6-2 $H_{48,96}$ reading flow chart

For more information about the encoding and decoding methods, please refer to Annex.

6.2.3 Data Format

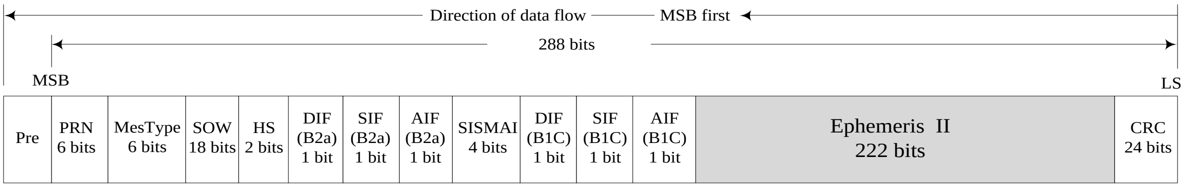
At most 63 message types can be defined for the B-CNAV2 navigation message. Currently, eight valid message types have been defined, i.e., Message Type 10, 11, 30, 31, 32, 33, 34, and 40. Their bit allocation formats are shown in Figure 6-3 ~ Figure 6-10.

The broadcast order of the B-CNAV2 message types may be dynamically adjusted, however Message Types 10 and 11 shall be broadcast continuously together. The user should recognize its MesType every time when a B-CNAV2 navigation message is received.



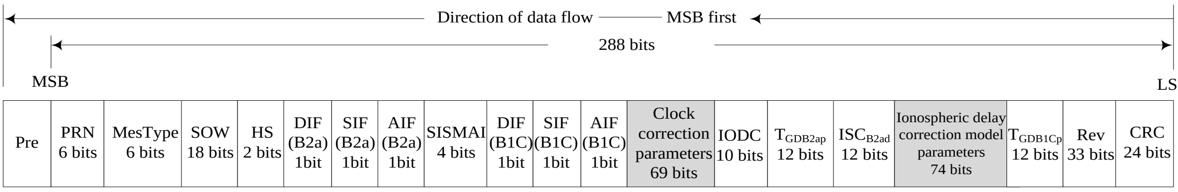
Pre	PRN	MesType	SOW	WN	DIF (B2a)	SIF (B2a)	AIF (B2a)	SISMAI	DIF (B1C)	SIF (B1C)	AIF (B1C)	IODE	Ephemeris I	CRC
	6 bits	6 bits	18 bits	13 bits	1bit	1bit	1bit	4 bits	1bit	1bit	1bit	8 bits	203 bits	24 bits

Figure 6-3 Bit allocation for B-CNAV2 Message Type 10



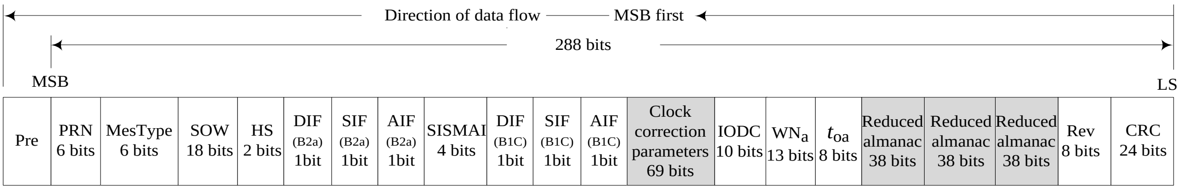
Pre	PRN	MesType	SOW	HS	DIF (B2a)	SIF (B2a)	AIF (B2a)	SISMAI	DIF (B1C)	SIF (B1C)	AIF (B1C)	Ephemeris II	CRC
	6 bits	6 bits	18 bits	2 bits	1 bit	1 bit	1 bit	4 bits	1 bit	1 bit	1 bit	222 bits	24 bits

Figure 6-4 Bit allocation for B-CNAV2 Message Type 11



Pre	PRN	MesType	SOW	HS	DIF (B2a)	SIF (B2a)	AIF (B2a)	SISMAI	DIF (B1C)	SIF (B1C)	AIF (B1C)	Clock correction parameters	IODC	T_{GDB2ap}	ISC_{B2ad}	Ionospheric delay correction model parameters	T_{GDB1Cp}	Rev	CRC
	6 bits	6 bits	18 bits	2 bits	1bit	1bit	1bit	4 bits	1bit	1bit	1bit	69 bits	10 bits	12 bits	12 bits	74 bits	12 bits	33 bits	24 bits

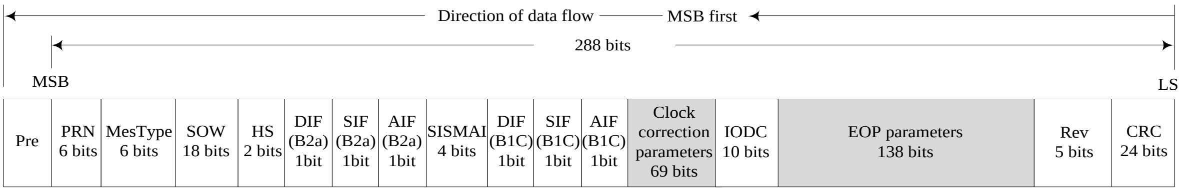
Figure 6-5 Bit allocation for B-CNAV2 Message Type 30



Pre	PRN	MesType	SOW	HS	DIF (B2a)	SIF (B2a)	AIF (B2a)	SISMAI	DIF (B1C)	SIF (B1C)	AIF (B1C)	Clock correction parameters	IODC	WN_a	t_{oa}	Reduced almanac	Reduced almanac	Reduced almanac	Rev	CRC
	6 bits	6 bits	18 bits	2 bits	1bit	1bit	1bit	4 bits	1bit	1bit	1bit	69 bits	10 bits	13 bits	8 bits	38 bits	38 bits	38 bits	8 bits	24 bits

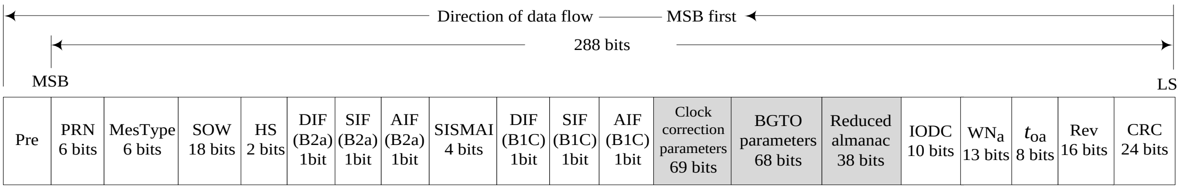
Figure 6-6 Bit allocation for B-CNAV2 Message Type 31

(Note: Each Message Type 31 broadcasts reduced almanac parameters for three satellites, while WN_a and t_{oa} in this frame are the reference time of these reduced almanacs)



Pre	PRN	MesType	SOW	HS	DIF (B2a)	SIF (B2a)	AIF (B2a)	SISMAI	DIF (B1C)	SIF (B1C)	AIF (B1C)	Clock correction parameters	IODC	EOP parameters	Rev	CRC
	6 bits	6 bits	18 bits	2 bits	1bit	1bit	1bit	4 bits	1bit	1bit	1bit	69 bits	10 bits	138 bits	5 bits	24 bits

Figure 6-7 Bit allocation for B-CNAV2 Message Type 32



Pre	PRN	MesType	SOW	HS	DIF (B2a)	SIF (B2a)	AIF (B2a)	SISMAI	DIF (B1C)	SIF (B1C)	AIF (B1C)	Clock correction parameters	BGTO parameters	Reduced almanac	IODC	WN_a	t_{oa}	Rev	CRC
	6 bits	6 bits	18 bits	2 bits	1bit	1bit	1bit	4 bits	1bit	1bit	1bit	69 bits	68 bits	38 bits	10 bits	13 bits	8 bits	16 bits	24 bits

Figure 6-8 Bit allocation for B-CNAV2 Message Type 33

(Note: Each Message Type 33 broadcasts reduced almanac parameters for one satellite, while WN_a and t_{oa} in this frame are the reference time of this reduced almanac)

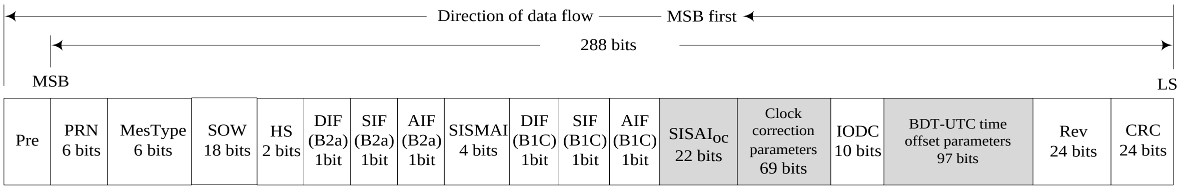


Figure 6-9 Bit allocation for B-CNAV2 Message Type 34

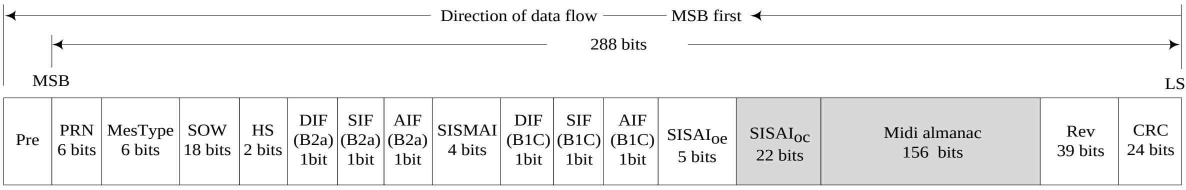


Figure 6-10 Bit allocation for B-CNAV2 Message Type 40

Among the parameters in the above message types, "ephemeris I", "ephemeris II", "clock correction parameters", "SISAI$_{oc}$", "ionospheric delay correction model parameters", "BDT-UTC time offset parameters", "reduced almanac", "EOP parameters", "BGTO parameters", and “midi almanac” are data blocks further constituted of a set of parameters. Data blocks "ephemeris I" and "ephemeris II" constitute a complete set of ephemeris parameters together. The detailed bit allocations of 10 data blocks are shown in Figure 6-11 ~ Figure 6-20.

MSB LSB

t_{oe}	SatType	ΔA	$\dot{A}$	Δn_0	$\Delta \dot{n}_0$	M_0	e	ω
11 bits	2 bits	26 bits	25 bits	17 bits	23 bits	33 bits	33 bits	33 bits

Figure 6-11 Bit allocation for ephemeris I (203bits)

MSB LSB

Ω_0	i_0	$\dot{\Omega}$	$\dot{i}_0$	C_{is}	C_{ic}	C_{rs}	C_{rc}	C_{us}	C_{uc}
33 bits	33 bits	19 bits	15 bits	16 bits	16 bits	24 bits	24 bits	21 bits	21 bits

Figure 6-12 Bit allocation for ephemeris II (222 bits)

MSB LSB

t_{oc}	a_0	a_1	a_2
11 bits	25 bits	22 bits	11 bits

Figure 6-13 Bit allocation for clock correction parameters (69 bits)

MSB LSB

t_{op}	SISAI_{ocb}	SISAI_{oc1}	SISAI_{oc2}
11 bits	5 bits	3 bits	3 bits

Figure 6-14 Bit allocation for SISAI_{oc} (22 bits)

MSB LSB

α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	α_9
10 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits	8 bits

Figure 6-15 Bit allocation for ionospheric delay correction model parameters (74 bits)

MSB LSB

$A_{0\mathrm{UTC}}$	$A_{1\mathrm{UTC}}$	$A_{2\mathrm{UTC}}$	Δt_{LS}	t_{ot}	WN_{ot}	$\mathrm{WN}_{\mathrm{LSF}}$	DN	Δt_{LSF}
16 bits	13 bits	7 bits	8 bits	16 bits	13 bits	13 bits	3 bits	8 bits

Figure 6-16 Bit allocation for BDT-UTC time offset parameters (97 bits)

MSB LSB

PRN_a	SatType	δ_A	Ω_0	Φ_0	Health
6 bits	2 bits	8 bits	7 bits	7 bits	8 bits

Figure 6-17 Bit allocation for reduced almanac parameters (38 bits)

MSB LSB

t_{EOP}	PM_X	$\dot{PM}\_X$	PM_Y	$\dot{PM}\_Y$	$\Delta UT1$	$\Delta \dot{UT}1$
16 bits	21 bits	15 bits	21 bits	15 bits	31 bits	19 bits

Figure 6-18 Bit allocation for EOP parameters (138 bits)

MSB LSB

GNSS ID	$\mathrm{WN}_{0\mathrm{BGTO}}$	$t_{0\mathrm{BGTO}}$	$A_{0\mathrm{BGTO}}$	$A_{1\mathrm{BGTO}}$	$A_{2\mathrm{BGTO}}$
3 bits	13 bits	16 bits	16 bits	13 bits	7 bits

Figure 6-19 Bit allocation for BGTO parameters (68 bits)

MSB LSB

PRN_a	SatType	WN_a	t_{oa}	e	δ_i	$\sqrt{A}$	Ω_0	$\dot{\Omega}$	ω	M_0	a_{f0}	a_{f1}	Health
6 bits	2 bits	13 bits	8 bits	11 bits	11 bits	17 bits	16 bits	11 bits	16 bits	16 bits	11 bits	10 bits	8 bits

Figure 6-20 Bit allocation for midi almanac parameters (156 bits)

The message parameters in the B-CNAV2 navigation message will be described in the corresponding sections listed in Table 6-1.

Table 6-1 Descriptions of parameters in the B-CNAV2 navigation message

No.	Message parameter	Parameter description
1	PRN	See Section 7.1 for details
2	MesType	See Section 7.2 for details
3	SOW	See Section 7.3 for details
4	IODE	See Section 7.4.1 for details
5	IODC	See Section 7.4.2 for details
6	Clock correction parameters	See Section 7.5 for details
7	T_{GDB2ap}	See Section 7.6 for details
8	ISC_{B2ad}	See Section 7.6 for details
9	T_{GDB1Cp}	See Section 7.6 for details
10	Ephemeris parameters (Ephemeris I, Ephemeris II)	See Section 7.7 for details
11	Ionospheric delay correction model parameters	See Section 7.8 for details
12	Midi almanac parameters	See Section 7.9 for details
13	WN_a	See Section 7.10 for details
14	t_{oa}	See Section 7.10 for details
15	Reduced almanac parameters	See Section 7.10 for details
16	EOP parameters	See Section 7.11 for details
17	BDT-UTC time offset parameter	See Section 7.12 for details

18	BGTO parameters	See Section 7.13 for details
19	HS	See Section 7.14 for details
20	DIF	See Section 7.15 for details
21	SIF	See Section 7.15 for details
22	AIF	See Section 7.15 for details
23	$SISAI_{oe}$	See Section 7.16 for details
24	$SISAI_{oc}$	See Section 7.16 for details
25	SISMAI	See Section 7.17 for details
26	CRC	See Section 6.1.2 for details

7 Navigation Message Parameters and Algorithms

7.1 Ranging Code Number

PRN broadcasted in the navigation messages is an unsigned integer with a length of 6 bits. Its effective value is in the range of 1 to 63.

7.2 Message Types

MesType is used to identify the message types of the B-CNAV2 frames. It is an unsigned integer with a length of 6 bits. Its definition is shown in Table 7-1.

Table 7-1 Message type definition

MesType (Binary)	Message type
000000	Invalid
001010	Message Type 10
001011	Message Type 11
011110	Message Type 30
011111	Message Type 31
100000	Message Type 32

100001	Message Type 33
100010	Message Type 34
101000	Message Type 40
Others	Reserved

7.3 System Time Parameters

The system time parameters broadcasted in B-CNAV2 contain Seconds Of Week (SOW) and Week Number (WN). The definitions of the system time parameters are shown in Table 7-2.

Table 7-2 Definitions of the system time parameters

Parameter	Definition	No. of bits	Scale factor	Effective range	Unit
SOW	Seconds of week	18	3	0~604797	s
WN	Week number	13	1	0~8191	week

SOW is broadcast in all message types of B-CNAV2. The epoch denoted by SOW corresponds to the rising edge of the first chip of the current frame preamble. SOW counts from zero at 00:00:00 each Sunday in BDT and is reset to zero at the end of each week.

WN is the week number of BDT and is broadcast in B-CNAV2 Message Type 10. WN counts from zero at the origin of BDT (i.e., 00:00:00, January 1, 2006 UTC).

7.4 Issue Of Data

7.4.1 Issue Of Data, Ephemeris

Issue Of Data, Ephemeris (IODE) has a length of 8 bits. It has the following two meanings.

(1) IODE indicates the issue number of a set of ephemeris parameters. The IODE value will be updated when any ephemeris parameter is updated. The user can recognize whether any ephemeris parameter has changed by checking any change in IODE.

(2) The IODE values indicate the range of the ephemeris data age. The ephemeris data age is the extrapolated time interval of the ephemeris parameters. It is defined as the offset between the ephemeris parameters reference time (t_{oe}) and the last measured time for generating the ephemeris parameters. The relationship between the IODE values and the ephemeris data age is shown in Table 7-3.

Table 7-3 Relationship between the IODE values and the ephemeris data age

IODE value	**Ephemeris data age***
0~59	Less than 12 hours
60~119	12 hours ~ 24 hours
120~179	1day ~ 7days
180~239	Reserved
240~255	More than 7 days

7.4.2 Issue Of Data, Clock

Issue Of Data, Clock (IODC) has a length of 10 bits. It has the following two meanings.

(1) IODC indicates the issue number of a set of clock correction parameters. The IODC value will be updated when any clock correction

parameter is updated. The user can recognize whether any clock correction parameter has changed by checking any change in IODC.

(2) The IODC values indicate the range of the clock correction data age. The clock correction data age is the extrapolated time interval of the clock correction parameters. It is defined as the offset between the clock correction parameters reference time (t_{oc}) and the last measured time for generating the clock correction parameters. The range of the clock correction data age is defined by the 2 MSBs of IODC together with the 8 LSBs of IODC. The relationship between the IODC values and the clock correction data age is shown in Table 7-4.

Table 7-4 Relationship between the IODC values and the clock correction data age

2 MSBs of IODC	**8 LSBs of IODC**	**Clock correction data age***
0	0~59	Less than 12 hours
	60~119	12 hours ~ 24 hours
	120~179	1day ~ 7days
	180~239	Reserved
	240~255	More than 7 days
1	0~59	Less than 12 tours
	60~119	Less than 12 hours
	120~179	Less than 1 day
	180~239	Reserved
	240~255	No more than 7 days
2	0~59	More than 12 hours
	60~119	More than 24 hours
	120~179	More than 7 days
	180~239	Reserved
	240~255	More than 7 days
3	Reserved	Reserved

7.4.3 IODE and IODC Usage Constraints

For a matched pair of ephemeris data and clock correction data, IODE and the 8 LSBs of IODC keep consistent with each other and are updated synchronously.

When the IODE value received by the user is the same as the 8 LSBs of IODC, i.e., the ephemeris data match with the clock correction data in the current navigation message, the user can use this matched pair of ephemeris data and clock correction data whose issue number can be identified by the IODE.

The IODE value received by the user may be different from the 8 LSBs of IODC during the update of the ephemeris and clock correction data, due to the the time delay of message transmission. The user shall use the preceding matched pair of ephemeris data and clock correction data until the updated IODE and the 8 LSBs of IODC are the same. The values of IODE and IODC shall not be repeated within one day, except that the data age is more than seven days.

7.5 Clock Correction Parameters

7.5.1 Parameters Description

A set of clock correction parameters identified by an IODC contains four parameters: t_{oc}, a_0, a_1, and a_2. The definitions and characteristics of the clock correction parameters are shown in Table 7-5.

Table 7-5 Definitions of the clock correction parameters

No.	**Parameter**	**Definition**	**No. of bits**	**Scale factor**	**Effective range****	**Unit**
1	t_{oc}	Clock correction parameters reference time	11	300	0~604500	s
2	a_0	Satellite clock time bias correction coefficient	25*	2^{-34}	--	s
3	a_1	Satellite clock time drift correction coefficient	22*	2^{-50}	--	s/s
4	a_2	Satellite clock time drift rate correction coefficient	11*	2^{-66}	--	s/s^2
* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB. ** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.						

7.5.2 User Algorithm

The user shall compute the BDT time of signal transmission as

$$t = t_{\mathrm{sv}} - \Delta t_{\mathrm{sv}} \tag{7-1}$$

where, t is the BDT time of signal transmission (in seconds), t_{sv} is the effective satellite ranging code phase time at time of signal transmission (in seconds), Δt_{sv} is the satellite ranging code phase time offset which is computed by the equation (in seconds):

$$\Delta t_{\mathrm{sv}} = a_0 + a_1\left(t - t_{\mathrm{oc}}\right) + a_2\left(t - t_{\mathrm{oc}}\right)^2 + \Delta t_r \tag{7-2}$$

where, the sensitivity of t_{sv} to t is negligible, which allow the user to approximate t by t_{sv}. Δt_r is the relativistic correction term (in seconds) which is defined as follows:

$$\Delta t_r = \mathrm{F} \cdot e \cdot \sqrt{A} \cdot \sin E_k \tag{7-3}$$

where, e is the eccentricity of the satellite orbit, which is given in the ephemeris parameters;

$\sqrt{A}$ is the square root of semi-major axis of the satellite orbit, which is computed from the ephemeris parameters;

E_k is the eccentric anomaly of the satellite orbit, which is computed from the ephemeris parameters;

$\mathrm{F}=-2\mu^{1/2}/\mathrm{C}^2$;

$\mu=3.986004418\times10^{14}\ \mathrm{m}^3/\mathrm{s}^2$, is the geocentric gravitational constant;

$\mathrm{C}=2.99792458\times10^8\ \mathrm{m/s}$, is the speed of light.

7.6 Group Delay differential Parameters

7.6.1 Parameters Description

The satellite equipment group delay is defined as the delay between the signal radiated output of a specific satellite (measured at the antenna phase center) and the output of that satellite’s on-board frequency source. The ranging code phase offset caused by the satellite equipment group delay can be compensated with clock correction parameter a_0 and group delay differential parameters.

The equipment group delay of the B3I signal is included in the clock correction parameter a_0 broadcasted in the navigation message, which is the reference equipment group delay for the B1C and B2a signals.

$\mathrm{T}_{\mathrm{GDB1Cp}}$ is group delay differential between the B1C pilot component and the B3I signal, and $\mathrm{T}_{\mathrm{GDB2ap}}$ is group delay differential between the B2a pilot component and the B3I signal. Both $\mathrm{T}_{\mathrm{GDB1Cp}}$ and $\mathrm{T}_{\mathrm{GDB2ap}}$ are broadcast in the B-CNAV2 message, which are used to compensate for the equipment group delay of the B1C pilot component and the B2a pilot component respectively.

$\mathrm{ISC_{B2ad}}$ is broadcast in the B-CNAV2 message to compensate for the group delay differential between the B2a data component and the B2a pilot component.

The definition and characteristics of the group delay differential parameters are shown in Table 7-6.

Table 7-6 Definitions of the group delay differential parameters

No.	**Parameter**	**Definition**	**No. of bits**	**Scale factor**	**Effective range****	**Unit**
1	$\mathrm{T_{GDB1Cp}}$	Group delay differential of the B1C pilot component	12^*	2^{-34}	--	s
2	$\mathrm{T_{GDB2ap}}$	Group delay differential of the B2a pilot component	12^*	2^{-34}	--	s
3	$\mathrm{ISC_{B2ad}}$	Group delay differential between the B2a data and pilot components	12^*	2^{-34}	--	s
* Parameters so indicated are two’s complement, with the sign bit (+ or -)occupying the MSB. ** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.						

7.6.2 User Algorithm

The single frequency user processing pseudorange from the B2a pilot component shall further correct the ranging code phase with the equation as follows:

$$\left(\Delta t_{\mathrm{SV}}\right)_{\mathrm{B2ap}} = \Delta t_{\mathrm{SV}} - \mathrm{T_{GDB2ap}} \tag{7-4}$$

The single frequency user processing pseudorange from the B2a data component shall further correct the ranging code phase with the equation as follows:

$$\left(\Delta t_{\mathrm{SV}}\right)_{\mathrm{B2ad}} = \Delta t_{\mathrm{SV}} - \mathrm{T_{GDB2ap}} - \mathrm{ISC_{B2ad}} \tag{7-5}$$

where, Δt_{SV} is the satellite ranging code phase offset which is defined in Section 7.5.

7.7 Ephemeris Parameters

7.7.1 Parameters Description

A set of satellite ephemeris parameters identified by an IODE consists of a satellite orbit type parameter and 18 quasi-Keplerian orbital parameters.

The descriptions of the ephemeris parameters are shown in Table 7-7.

Table 7-7 Descriptions of the ephemeris parameters

No.	Parameter	Definition
1	t_{oe}	Ephemeris reference time
2	SatType	Satellite orbit type
3	ΔA	Semi-major axis difference at reference time
4	$\dot{A}$	Change rate in semi-major axis
5	Δn_0	Mean motion difference from computed value at reference time
6	$\Delta \dot{n}_0$	Rate of mean motion difference from computed value at reference time
7	M_0	Mean anomaly at reference time
8	e	Eccentricity
9	ω	Argument of perigee
10	Ω_0	Longitude of ascending node of orbital plane at weekly epoch
11	i_0	Inclination angle at reference time
12	$\dot{\Omega}$	Rate of right ascension
13	$\dot{i}_0$	Rate of inclination angle
14	C_{is}	Amplitude of sine harmonic correction term to the angle of inclination
15	C_{ic}	Amplitude of cosine harmonic correction term to the angle of inclination
16	C_{rs}	Amplitude of sine harmonic correction term to the orbit radius

17	C_{rc}	Amplitude of cosine harmonic correction term to the orbit radius
18	C_{us}	Amplitude of sine harmonic correction to the argument of latitude
19	C_{uc}	Amplitude of cosine harmonic correction to the argument of latitude

The definitions of the ephemeris parameters are shown in Table 7-8.

Table 7-8 Definitions of the ephemeris parameters

No.	Parameter	No. of bits	Scale factor	Effective range**	Unit
1	t_{oe}	11	300	0~604500	s
2	SatType****	2	--	--	--
3	ΔA***	26*	2^{-9}	--	m
4	$\dot{A}$	25*	2^{-21}	--	m/s
5	Δn_0	17*	2^{-44}	--	π/s
6	$\Delta\dot{n}_0$	23*	2^{-57}	--	π/s^2
7	M_0	33*	2^{-32}	--	π
8	e	33	2^{-34}	--	dimensionless
9	ω	33*	2^{-32}	--	π
10	Ω_0	33*	2^{-32}	--	π
11	i_0	33*	2^{-32}	--	π
12	$\dot{\Omega}$	19*	2^{-44}	--	π/s
13	$\dot{i}_0$	15*	2^{-44}	--	π/s
14	C_{is}	16*	2^{-30}	--	rad
15	C_{ic}	16*	2^{-30}	--	rad
16	C_{rs}	24*	2^{-8}	--	m
17	C_{rc}	24*	2^{-8}	--	m
18	C_{us}	21*	2^{-30}	--	rad
19	C_{uc}	21*	2^{-30}	--	rad

* Parameters so indicated are two’s complement, with the sign bit (+ or -)occupying the MSB.

** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

*** Semi-major axis reference value:

$A_{\text{ref}} = 27906100$ m（MEO）， $A_{\text{ref}} = 42162200$ m（IGSO/GEO）.

**** Meaning of SatType (in binary): 01 indicates the GEO satellite, 10 indicates the IGSO satellite, 11 indicates the MEO satellite, and 00 is reserved.

7.7.2 User Algorithm

The user shall compute the corresponding coordinate of the satellite antenna phase center in BDCS, according to the ephemeris parameters. The related user algorithms are shown in Table 7-9.

Table 7-9 User algorithms for the ephemeris parameters

Formula	Description
$\mu=3.986004418\times10^{14}\ \mathrm{m}^3/\mathrm{s}^2$	Geocentric gravitational constant of BDCS
$\dot{\Omega}_\mathrm{e}=7.2921150\times10^{-5}\ \mathrm{rad/s}$	Earth’s rotation rate of BDCS
$\pi=3.1415926535898$	Ratio of a circle’s circumference to its diameter
$t_k=t-t_\mathrm{oe}$ **	Time from ephemeris reference time
$A_0=A_\mathrm{ref}+\Delta A$ *	Semi-major axis at reference time
$A_k=A_0+(\dot{A})t_k$	Semi-major axis
$n_0=\sqrt{\frac{\mu}{A_0^3}}$	Computed mean motion (rad/s) at reference time
$\Delta n_A=\Delta n_0+1/2\Delta\dot{n}_0t_k$	Mean motion difference from computed value
$n_A=n_0+\Delta n_A$	Corrected mean motion
$M_k=M_0+n_At_k$	Mean anomaly
$M_k=E_k-e\sin E_k$	Kepler’s equation for eccentric anomaly (may be solved by iteration)
$\begin{cases}\sin\nu_k=\frac{\sqrt{1-e^2}\sin E_k}{1-e\cos E_k}\\ \cos\nu_k=\frac{\cos E_k-e}{1-e\cos E_k}\end{cases}$	True anomaly
$\phi_k=\nu_k+\omega$	Argument of latitude

$\begin{cases} \delta u_k = C_{\mathrm{us}} \sin(2\phi_k) + C_{\mathrm{uc}} \cos(2\phi_k) \\ \delta r_k = C_{\mathrm{rs}} \sin(2\phi_k) + C_{\mathrm{rc}} \cos(2\phi_k) \\ \delta i_k = C_{\mathrm{is}} \sin(2\phi_k) + C_{\mathrm{ic}} \cos(2\phi_k) \end{cases}$	Argument of latitude correction Radius correction Inclination correction
$u_k = \phi_k + \delta u_k$	Corrected argument of latitude
$r_k = A_k (1 - e \cos E_k) + \delta r_k$	Corrected radius
$i_k = i_0 + \dot{i}_0 \cdot t_k + \delta i_k$	Corrected inclination
$\begin{cases} x_k = r_k \cos u_k \\ y_k = r_k \sin u_k \end{cases}$	Position in orbital plane
$\Omega_k = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_{\mathrm{e}}) t_k - \dot{\Omega}_{\mathrm{e}} t_{\mathrm{oe}}$	Corrected longitude of ascending node
$\begin{cases} X_k = x_k \cos \Omega_k - y_k \cos i_k \sin \Omega_k \\ Y_k = x_k \sin \Omega_k + y_k \cos i_k \cos \Omega_k \\ Z_k = y_k \sin i_k \end{cases}$	Coordinate of the MEO/IGSO satellite antenna phase center in BDCS
* Semi-major axis reference value: $A_{\mathrm{ref}} = 27906100\mathrm{m}$（MEO） $A_{\mathrm{ref}} = 42162200\mathrm{m}$（IGSO/GEO）. ** In the equation, t is the BDT time of signal transmission, i.e., the BDT time corrected for transit time; t_k is the total time difference between t and the ephemeris reference time t_{oe} after taking account of the beginning or end of week crossovers, that is, if $t_k > 302400$, subtract 604800 seconds from t_k, else if $t_k < -302400$, add 604800 seconds to t_k.	

7.8 Ionospheric Delay Correction Model Parameters

7.8.1 Parameters Description

The BeiDou Global Ionospheric delay correction Model (BDGIM) contains nine parameters which are used to correct the effect of ionospheric delay for the single frequency user. Descriptions of these parameters are shown in Table 7-10.

For the dual frequency user applying the B1C and B2a signals, the effect of the ionospheric delay shall be corrected by using the dual frequency ionosphere-free pseudorange.

Table 7-10 Descriptions of the ionospheric delay correction model parameters

Parameter	No. of bits	Scale factor	Effective range**	Unit
α_1	10	2^{-3}	--	TECu
α_2	8^*	2^{-3}	--	TECu
α_3	8	2^{-3}	--	TECu
α_4	8	2^{-3}	--	TECu
α_5	8	-2^{-3}	--	TECu
α_6	8^*	2^{-3}	--	TECu
α_7	8^*	2^{-3}	--	TECu
α_8	8^*	2^{-3}	--	TECu
α_9	8^*	2^{-3}	--	TECu
* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB. ** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.				

7.8.2 Single Frequency Algorithm

The BeiDou Global Ionospheric delay correction Model (BDGIM) is based on the modified spherical harmonics method. According to BDGIM, the user shall compute the ionospheric delay correction by using the equation as follows:

$$T_{ion} = M_{\mathrm{F}} \cdot \frac{40.28 \times 10^{16}}{f^2} \cdot \left[A_0 + \sum_{i=1}^{9} \alpha_i A_i \right] \tag{7-6}$$

Where, T_{ion} is the line-of-sight (LOS) ionospheric delay along the signal propagation path from satellite to receiver (in meters). M_{F} is the ionospheric mapping function for the conversion between vertical and slant total electron contents (TEC), which is referred to Equation (7-17); f is the carrier frequency of the current signal (in Hertz); $\alpha_i\left(i=1\sim 9\right)$ are the BDGIM parameters (in TECu) which are defined in Table 7-10; $A_i\left(i=1\sim 9\right)$ are calculated by Equation (7-11); A_0 is the predictive ionospheric delay (in TECu) which is calculated by Equation (7-14).

According to BDGIM, the specific steps for the user to calculate the LOS ionospheric delay along the signal propagation path from satellite to receiver are listed as follows:

(1) Calculation of the ionospheric pierce point (IPP) position

ψ indicates the Earth's central angle between the user position and IPP (in radians), which is given by

$$\psi=\frac{\pi}{2}-E-\arcsin\left(\frac{\mathrm{Re}}{\mathrm{Re}+\mathrm{H}_{\mathrm{ion}}}\cdot\cos E\right) \tag{7-7}$$

where, E is the elevation angle between the user and satellite (in radians); $\mathrm{H}_{\mathrm{ion}}$ is the altitude of the ionospheric single-layer shell; Re is the mean radius of the Earth.

The geographic latitude φ_g and longitude λ_g of the Earth projection of IPP are calculated as

$$\begin{cases}\varphi_g=\arcsin(\sin\varphi_u\cdot\cos\psi+\cos\varphi_u\cdot\sin\psi\cdot\cos A)\\ \lambda_g=\lambda_u+\arctan\left(\dfrac{\sin\psi\cdot\sin A\cdot\cos\varphi_u}{\cos\psi-\sin\varphi_u\cdot\sin\varphi_g}\right)\end{cases} \tag{7-8}$$

where, φ_u and λ_u are the user geographic latitude and longitude, respectively; A is the azimuth angle between the user and satellite (in radians).

In the Earth-fixed reference frame, the geomagnetic latitude φ_m and longitude λ_m of the Earth projection of IPP are calculated as follows:

$$\begin{cases} \varphi_m = \arcsin\left(\sin\varphi_{\mathrm{M}}\cdot\sin\varphi_g + \cos\varphi_{\mathrm{M}}\cdot\cos\varphi_g\cdot\cos(\lambda_g-\lambda_{\mathrm{M}})\right) \\ \lambda_m = \arctan\left(\dfrac{\cos\varphi_g\cdot\sin(\lambda_g-\lambda_{\mathrm{M}})\cdot\cos\varphi_{\mathrm{M}}}{\sin\varphi_{\mathrm{M}}\cdot\sin\varphi_m-\sin\varphi_g}\right) \end{cases} \tag{7-9}$$

where φ_{M} and λ_{M} are the geographic latitude and longitude of the north magnetic pole (both in radians), respectively.

In the solar-fixed reference frame, the geomagnetic latitude φ' and longitude λ' of IPP are calculated as

$$\begin{cases} \varphi' = \varphi_m \\ \lambda' = \lambda_m - \arctan\left(\dfrac{\sin(S_{lon}-\lambda_{\mathrm{M}})}{\sin\varphi_{\mathrm{M}}\cdot\cos(S_{lon}-\lambda_{\mathrm{M}})}\right) \end{cases} \tag{7-10}$$

where, S_{lon} is the mean geographic longitude of the sun (in radians), which is calculated as $S_{lon} = \pi\cdot\left(1-2\cdot\left(t-\mathrm{int}(t)\right)\right)$, t is the time (in days) of calculation epoch expressed by Modified Julian Date (MJD), and $\mathrm{int}(\cdot)$ means rounding down.

(2) Calculation of $A_i\,(i=1\sim 9)$

A_i is calculated as follows:

$$A_i = \begin{cases} \tilde{P}_{|n_i|,|m_i|}(\sin\varphi')\cdot\cos(m_i\cdot\lambda') & m_i \ge 0 \\ \tilde{P}_{|n_i|,|m_i|}(\sin\varphi')\cdot\sin(-m_i\cdot\lambda') & m_i < 0 \end{cases} \tag{7-11}$$

where, the values of n_i and m_i are shown in Table 7-11.

Table 7-11 Values of n_i and m_i

i	1	2	3	4	5	6	7	8	9
n_i/m_i	0/0	1/0	1/1	1/-1	2/0	2/1	2/-1	2/2	2/-2

φ' and λ' are calculated by Equation (7-10); $\tilde{P}_{n,m}$ is the normalized Legendre function with degree n and order m, which is calculated as

$\tilde{P}_{n,m} = N_{n,m} \cdot P_{n,m}$ (both n and m are taken the absolute values); $N_{n,m}$ is the normalization function, which is calculated as

$$\begin{cases} N_{n,m} = \sqrt{\dfrac{(n-m)! \cdot (2n+1) \cdot (2-\delta_{0,m})}{(n+m)!}} \\ \delta_{0,m} = \begin{cases} 1, & m = 0 \\ 0, & m > 0 \end{cases} \end{cases} \tag{7-12}$$

$P_{n,m}$ is the classic, un-normalized Legendre function, which is calculated as

$$\begin{cases} P_{n,n}(\sin\varphi') = (2n-1)!!\left(1-(\sin\varphi')^2\right)^{n/2}, & n = m \\ P_{n,m}(\sin\varphi') = \sin\varphi' \cdot (2m+1) \cdot P_{m,m}(\sin\varphi'), & n = m+1 \\ P_{n,m}(\sin\varphi') = \dfrac{(2n-1)\cdot\sin\varphi'\cdot P_{n-1,m}(\sin\varphi') - (n+m-1)\cdot P_{n-2,m}(\sin\varphi')}{n-m}, & else \end{cases} \tag{7-13}$$

where, $(2n-1)!! = (2n-1)\cdot(2n-3)\cdots 1$, and $P_{0,0}(\sin\varphi') = 1$.

(3) Calculation of the predictive ionospheric delay A_0

A_0 is calculated as follows:

$$\begin{cases} A_0 = \sum_{j=1}^{17} \beta_j \cdot B_j, \\ B_j = \begin{cases} \tilde{P}_{|n_j|,|m_j|}(\sin\varphi') \cdot \cos(m_j \cdot \lambda') & m_j \ge 0 \\ \tilde{P}_{|n_j|,|m_j|}(\sin\varphi') \cdot \sin(-m_j \cdot \lambda') & m_j < 0 \end{cases} \end{cases} \tag{7-14}$$

where, the values of n_j and m_j are shown in Table 7-11; $\tilde{P}_{|n_j|,|m_j|}(\sin\varphi')$ is calculated by Equation (7-12) and (7-13); $\beta_j\ (j = 1 \sim 17)$ are calculated as follows:

$$\begin{cases} \beta_j = a_{0,j} + \sum_{k=1}^{12}\left(a_{k,j} \cdot \cos(\omega_k \cdot t_p) + b_{k,j} \cdot \sin(\omega_k \cdot t_p)\right) \\ \omega_k = \dfrac{2\pi}{T_k} \end{cases} \tag{7-15}$$

where, $a_{k,j}$ and $b_{k,j}$ are the non-broadcast coefficients of BDGIM as shown in

Table 7-12 (in TECu); T_k is the period for prediction corresponding to the individual non-broadcast coefficients as shown in Table 7-12; t_p is an odd hour (in days) of the corresponding day (01:00:00, 03:00:00, 05:00:00..., or 23:00:00 in MJD), while the user should choose a t_p which is nearest to the time of the calculation epoch.

(4) Calculation of the vertical ionospheric delay of IPP

The vertical ionospheric delay (in TECu) of IPP is calculated as

$$VTEC = A_0 + \sum_{i=1}^{9} \alpha_i A_i \tag{7-16}$$

(5) Calculation of the ionospheric mapping function M_{F} of IPP

The ionospheric mapping function M_{F} of IPP is calculated as follows:

$$M_{\mathrm{F}} = \frac{1}{\sqrt{1 - \left(\frac{\mathrm{Re}}{\mathrm{Re} + \mathrm{H}_{\mathrm{ion}}} \cdot \cos(E) \right)^2}} \tag{7-17}$$

where, Re, $\mathrm{H}_{\mathrm{ion}}$, and E have been defined in Equation (7-7).

(6) Calculation of the LOS ionospheric delay along the signal propagation path

According to the calculated *VTEC* and M_{F}, the LOS ionospheric delay along the signal propagation path from satellite to receiver can be calculated by Equation (7-6).

In the above equations, the related parameter values are suggested as

Altitude of the ionospheric single-layer shell: $\mathrm{H}_{\mathrm{ion}} = 400\ \mathrm{km}$;

Mean radius of the Earth: $\mathrm{Re} = 6378\ \mathrm{km}$;

Geographic longitude of the north magnetic pole: $\lambda_{\mathrm{M}} = \frac{-72.58°}{180°} \cdot \pi \ \mathrm{rad}$;

Geographic latitude of the north magnetic pole: $\varphi_{\mathrm{M}} = \frac{80.27°}{180°} \cdot \pi \ \mathrm{rad}$.

Table 7-12 BDGIM non-broadcast coefficients and periods for prediction

Parameter No. k	**No. j**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**Period T_k / day**
	n_j/m_j	**3/0**	**3/1**	**3/-1**	**3/2**	**3/-2**	**3/3**	**3/-3**	**4/0**	**4/1**	**4/-1**	**4/2**	**4/-2**	**5/0**	**5/1**	**5/-1**	**5/2**	**5/-2**	
0	$a_{0,j}$	-0.61	-1.31	-2.00	-0.03	0.15	-0.48	-0.40	2.28	-0.16	-0.21	-0.10	-0.13	0.21	0.68	1.06	0	-0.12	-
1	$a_{k,j}$	-0.51	-0.43	0.34	-0.01	0.17	0.02	-0.06	0.30	0.44	-0.28	-0.31	-0.17	0.04	0.39	-0.12	0.12	0	1
	$b_{k,j}$	0.23	-0.20	-0.31	0.16	-0.03	0.02	0.04	0.18	0.34	0.45	0.19	-0.25	-0.12	0.18	0.40	-0.09	0.21	
2	$a_{k,j}$	-0.06	-0.05	0.06	0.17	0.15	0	0.11	-0.05	-0.16	0.02	0.11	0.04	0.12	0.07	0.02	-0.14	-0.14	0.5
	$b_{k,j}$	0.02	-0.08	-0.06	-0.11	0.15	-0.14	0.01	0.01	0.04	-0.14	-0.05	0.08	0.08	-0.01	0.01	0.11	-0.12	
3	$a_{k,j}$	0.01	-0.03	0.01	-0.01	0.05	-0.03	0.05	-0.03	-0.01	0	-0.08	-0.04	0	-0.02	-0.03	0	-0.03	0.33
	$b_{k,j}$	0	-0.02	-0.03	-0.05	-0.01	-0.07	-0.03	-0.01	0.02	-0.01	0.03	-0.10	0.01	0.05	-0.01	0.04	0.00	
4	$a_{k,j}$	-0.01	0	0.01	0	0.01	0	-0.01	-0.01	0	0	0	0	0	0	0	0	0	14.6
	$b_{k,j}$	0	-0.02	0.01	0	-0.01	0.01	0	-0.02	0	0	0	0	0	0	0	0	0	
5	$a_{k,j}$	0	0	0.03	0.01	0.02	0.01	0	-0.02	0	0	0	0	0	0	0	0	0	27.0
	$b_{k,j}$	0.01	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	
6	$a_{k,j}$	-0.19	-0.02	0.12	-0.10	0.06	0	-0.02	-0.08	-0.02	-0.07	0.01	0.03	0.15	0.06	-0.05	-0.03	-0.10	121.6
	$b_{k,j}$	-0.09	0.07	0.03	0.06	0.09	0.01	0.02	0	-0.04	-0.02	-0.01	0.01	-0.10	0	-0.01	0.02	0.05	
7	$a_{k,j}$	-0.18	0.06	-0.55	-0.02	0.09	-0.08	0	0.86	-0.18	-0.05	-0.07	0.04	0.14	-0.03	0.37	-0.11	-0.12	182.51
	$b_{k,j}$	0.15	-0.31	0.13	0.05	-0.09	-0.03	0.06	-0.36	0.08	0.05	0.06	-0.02	-0.05	0.06	-0.20	0.04	0.07	
8	$a_{k,j}$	1.09	-0.14	-0.21	0.52	0.27	0	0.11	0.17	0.23	0.35	-0.05	0.02	-0.60	0.02	0.01	0.27	0.32	365.25
	$b_{k,j}$	0.50	-0.08	-0.38	0.36	0.14	0.04	0	0.25	0.17	0.27	-0.03	-0.03	-0.32	-0.10	0.20	0.10	0.30	
9	$a_{k,j}$	-0.34	-0.09	-1.22	0.05	0.15	-0.29	-0.17	1.58	-0.06	-0.15	0.00	0.13	0.28	-0.08	0.62	-0.01	-0.04	4028.71
	$b_{k,j}$	0	-0.11	-0.22	0.01	0.02	-0.03	-0.01	0.49	-0.03	-0.02	0.01	0.02	0.04	-0.04	0.16	-0.02	-0.01	
10	$a_{k,j}$	-0.13	0.07	-0.37	0.05	0.06	-0.11	-0.07	0.46	0.00	-0.04	0.01	0.07	0.09	-0.05	0.15	-0.01	0.01	2014.35
	$b_{k,j}$	0.05	0.03	0.07	0.02	-0.01	0.03	0.02	-0.04	-0.01	-0.01	0.02	0.03	0.02	-0.04	-0.04	-0.01	0	
11	$a_{k,j}$	-0.06	0.13	-0.07	0.03	0.02	-0.05	-0.05	0.01	0	0	0	0	0	0	0	0	0	1342.90
	$b_{k,j}$	0.03	-0.02	0.04	-0.01	-0.03	0.02	0.01	0.04	0	0	0	0	0	0	0	0	0	
12	$a_{k,j}$	-0.03	0.08	-0.01	0.04	0.01	-0.02	-0.02	-0.04	0	0	0	0	0	0	0	0	0	1007.18
	$b_{k,j}$	0.04	-0.02	-0.04	0.00	-0.01	0	0.01	0.07	0	0	0	0	0	0	0	0	0	

7.8.3 Dual Frequency Algorithm

For the dual frequency user applying the B1C and B2a signals, the effect of the ionospheric delay shall be corrected by using the dual frequency ionosphere-free pseudorange.

The dual frequency user processing pseudorange from the B1C pilot component and B2a pilot component shall correct the ionospheric delay with the equation as follows:

$$PR_{\mathrm{B1Cp\text{-}B2ap}} = \frac{PR_{\mathrm{B2ap}} - k_{12} \cdot PR_{\mathrm{B1Cp}}}{1 - k_{12}} - \frac{\mathrm{C} \cdot (\mathrm{T}_{\mathrm{GDB2ap}} - k_{12} \cdot \mathrm{T}_{\mathrm{GDB1Cp}})}{1 - k_{12}} \qquad (7\text{-}18)$$

The dual frequency user processing pseudorange from the B1C pilot component and B2a data component shall correct the ionospheric delay with the equation as follows:

$$PR_{\mathrm{B1Cp\text{-}B2ad}} = \frac{PR_{\mathrm{B2ad}} - k_{12} \cdot PR_{\mathrm{B1Cp}}}{1 - k_{12}} - \frac{\mathrm{C} \cdot (\mathrm{T}_{\mathrm{GDB2ap}} + \mathrm{ISC}_{\mathrm{B2ad}} - k_{12} \cdot \mathrm{T}_{\mathrm{GDB1Cp}})}{1 - k_{12}} \qquad (7\text{-}19)$$

The dual frequency user processing pseudorange from the B1C data component and B2a pilot component shall correct the ionospheric delay with the equation as follows:

$$PR_{\mathrm{B1Cd\text{-}B2ap}} = \frac{PR_{\mathrm{B2ap}} - k_{12} \cdot PR_{\mathrm{B1Cd}}}{1 - k_{12}} - \frac{\mathrm{C} \cdot (\mathrm{T}_{\mathrm{GDB2ap}} - k_{12} \cdot \mathrm{T}_{\mathrm{GDB1Cp}} - k_{12} \cdot \mathrm{ISC}_{\mathrm{B1Cd}})}{1 - k_{12}} \qquad (7\text{-}20)$$

The dual frequency user processing pseudorange from the B1C data component and B2a data component shall correct the ionospheric delay with the equation as follows:

$$PR_{\text{B1Cd-B2ad}} = \frac{PR_{\text{B2ad}} - k_{12} \cdot PR_{\text{B1Cd}}}{1 - k_{12}} - \frac{\text{C} \cdot (\text{T}_{\text{GDB2ap}} + \text{ISC}_{\text{B2ad}} - k_{12} \cdot \text{T}_{\text{GDB1Cp}} - k_{12} \cdot \text{ISC}_{\text{B1Cd}})}{1 - k_{12}} \tag{7-21}$$

where, $k_{12} = \left(\frac{1575.42}{1176.45}\right)^2$, is the factor associated with frequency;

$PR_{\text{B1Cp-B2ap}}$ is the dual frequency ionosphere-free pseudorange between the B1C pilot component and the B2a pilot component;

$PR_{\text{B1Cp-B2ad}}$ is the dual frequency ionosphere-free pseudorange between the B1C pilot component and the B2a data component;

$PR_{\text{B1Cd-B2ap}}$ is the dual frequency ionosphere-free pseudorange between the B1C data component and the B2a pilot component;

$PR_{\text{B1Cd-B2ad}}$ is the dual frequency ionosphere-free pseudorange between the B1C data component and the B2a data component;

PR_{B1Cp} is the measured pseudorange of the B1C pilot component (corrected by the clock correction but not corrected by T_{GDB1Cp});

PR_{B1Cd} is the measured pseudorange of the B1C data component (corrected by the clock correction but not corrected by T_{GDB1Cp} and ISC_{B1Cd});

PR_{B2ap} is the measured pseudorange of the B2a pilot component (corrected by the clock correction but not corrected by T_{GDB2ap});

PR_{B2ad} is the measured pseudorange of the B2a data component (corrected by the clock correction but not corrected by T_{GDB2ap} and ISC_{B2ad});

T_{GDB1Cp} is the group delay differential of the B1C pilot component;

T_{GDB2ap} is the group delay differential of the B2a pilot component;

ISC_{B1Cd} is the group delay differential between the B1C data component and the B1C pilot component, referring to *BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal B1C (Version 1.0)*;

ISC_{B2ad} is the group delay differential between the B2a data component and the B2a pilot component;

$C = 2.99792458 \times 10^8$ m/s is the speed of light.

7.9 Midi Almanac Parameters

7.9.1 Parameters Description

The midi almanac contains 14 parameters. The definitions of the midi almanac parameters are described in Table 7-13.

Table 7-13 Definitions of the midi almanac parameters

No.	Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
1	PRN_a	PRN number of the corresponding almanac data	6	1	1~63	--
2	SatType***	Satellite orbit type	2	--	--	--
3	WN_a	Almanac reference week number	13	1	--	week
4	t_{oa}	Almanac reference time	8	2^{12}	0~602112	s
5	e	Eccentricity	11	2^{-16}	--	--
6	δ_i	Correction of inclination angle relative to reference value at reference time	11*	2^{-14}	--	π

7	$\sqrt{A}$	Square root of semi-major axis	17	2^{-4}	--	$m^{1/2}$
8	Ω_0	Longitude of ascending node of orbital plane at weekly epoch	16*	2^{-15}	--	π
9	$\dot{\Omega}$	Rate of right ascension	11*	2^{-33}	--	π/s
10	ω	Argument of perigee	16*	2^{-15}	--	π
11	M_0	Mean anomaly at reference time	16*	2^{-15}	--	π
12	a_{f0}	Satellite clock time bias correction coefficient	11*	2^{-20}	--	s
13	a_{f1}	Satellite clock time drift correction coefficient	10*	2^{-37}	--	s/s
14	Health	Satellite health information	8	—	—	—

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB.

** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

*** Meaning of SatType (in binary): 01 indicates the GEO satellite, 10 indicates the IGSO satellite, 11 indicates the MEO satellite, and 00 is reserved.

The parameter Health indicates the satellite health status with a length of 8 bits. The definitions of the satellite health information are described in Table 7-14.

Table 7-14 Definitions of the satellite health information

Information bit	Value	Definition
The 8th bit (MSB)	0	Satellite clock is healthy
	1	*
The 7th bit	0	B1C signal is normal
	1	B1C signal is abnormal**
The 6th bit	0	B2a signal is normal
	1	B2a signal is abnormal **

The 5th ~ 1st bit	0	Reserved
	1	Reserved
* When the 8th bit is 1, that the last 7 bits are “0000000” represents the satellite clock is not available and that the last 7 bits are “1111111” represents the satellite is abnormal or permanent shutdown. **The abnormal signal indicates that the signal power is over 10dB lower than the rated value.		

7.9.2 User Algorithm

The user shall compute the BDT time of signal transmission as

$$t = t_{\mathrm{sv}} - \Delta t_{\mathrm{sv}} \tag{7-22}$$

where, t is the BDT time of signal transmission (in seconds), t_{sv} is the satellite ranging code phase time at time of signal transmission (in seconds), Δt_{sv} is the satellite ranging code phase time offset which is computed by the equation (in seconds):

$$\Delta t_{\mathrm{sv}} = a_{f0} + a_{f1}\left(t - t_{\mathrm{oa}}\right) \tag{7-23}$$

where, the almanac reference time t_{oa} counts from the start of the almanac reference week number ($\mathrm{WN_a}$).

The user calculates the satellite position by using the midi almanac parameters. The related user algorithms are shown in Table 7-15.

Table 7-15 User algorithms for the midi almanac parameters

Formula	**Description**
$\mu = 3.986004418 \times 10^{14}\ \mathrm{m^3/s^2}$	Geocentric gravitational constant of BDCS
$\dot{\Omega}_{\mathrm{e}} = 7.2921150 \times 10^{-5}\ \mathrm{rad/s}$	Earth’s rotation rate of BDCS
$\pi = 3.1415926535898$	Ratio of a circle’s circumference to its diameter

$A = \left(\sqrt{A}\right)^2$	Semi-major axis
$n_0 = \sqrt{\dfrac{\mu}{A^3}}$	Computed mean motion (rad/s) at reference time
$t_k = t - t_{\mathrm{oa}}{}^*$	Time from ephemeris reference time
$M_k = M_0 + n_0 t_k$	Mean anomaly
$M_k = E_k - e\sin E_k$	Kepler's equation for eccentric anomaly (may be solved by iteration)
$\begin{cases} \sin\nu_k = \dfrac{\sqrt{1-e^2}\sin E_k}{1-e\cos E_k} \\ \cos\nu_k = \dfrac{\cos E_k - e}{1-e\cos E_k} \end{cases}$	True anomaly
$\phi_k = \nu_k + \omega$	Argument of latitude
$r_k = A(1-e\cos E_k)$	radius
$\begin{cases} x_k = r_k\cos\phi_k \\ y_k = r_k\sin\phi_k \end{cases}$	Position in orbital plane
$\Omega_k = \Omega_0 + \left(\dot{\Omega} - \dot{\Omega}_{\mathrm{e}}\right)t_k - \dot{\Omega}_{\mathrm{e}} t_{\mathrm{oa}}$	Corrected longitude of ascending node
$i = i_0 + \delta_i{}^{**}$	Inclination at reference time
$\begin{cases} X_k = x_k\cos\Omega_k - y_k\cos i\sin\Omega_k \\ Y_k = x_k\sin\Omega_k + y_k\cos i\cos\Omega_k \\ Z_k = y_k\sin i \end{cases}$	Coordinate of the satellite antenna phase center in BDCS

* In the equation, t is the BDT time of signal transmission, i.e., the BDT time corrected for transit time; t_k is the total time difference between t and the almanac reference time t_{oa} after taking account of the beginning or end of week crossovers, that is, if $t_k > 302400$, subtract 604800 seconds from t_k, else if $t_k < -302400$, add 604800 seconds to t_k.

** For the MEO/IGSO satellites, $i_0 = 0.30\pi$; for the GEO satellites, $i_0 = 0.00$.

7.10 Reduced Almanac parameters

7.10.1 Parameters Description

The definitions and characteristics of the reduced almanac parameters are shown in Table 7-16.

Table 7-16 Definitions of the reduced almanac parameters

No.	Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
1	PRN_a	PRN number of the corresponding almanac data	6	1	1~63	--
2	SatType*****	Satellite orbit type	2	--	--	--
3	δ_A***	Correction of semi-major axis relative to reference value at reference time	8*	2^9	--	m
4	Ω_0	Longitude of ascending node of orbital plane at weekly epoch	7*	2^{-6}	--	π
5	Φ_0****	Argument of latitude at reference time	7*	2^{-6}	--	π
6	Health	Satellite health information	8	—	—	—

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB.

** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

*** Semi-major axis reference value:

$$A_{\mathrm{ref}} = 27906100\mathrm{m}\text{（MEO）} \quad A_{\mathrm{ref}} = 42162200\mathrm{m}\text{（IGSO/GEO）}.$$

**** $\Phi_0 = M_0 + \omega$, relative to the following reference values:

$e = 0$;

$\delta_i = 0$, $i = 55$ degrees (MEO/IGSO), $i = 0$ degree (GEO).

***** Meaning of SatType (in binary): 01 indicates the GEO satellite, 10 indicates the IGSO satellite, 11 indicates the MEO satellite, and 00 is reserved.

7.10.2 User Algorithm

The user algorithm for the reduced almanac parameters is the same as the user algorithm for the midi almanac specified in Table 7-15. Other parameters appearing in the equations of Table 7-15, but not provided by the reduced almanac with the reference values, are set to zero for satellite position determination.

The definitions of the almanac reference week number $\mathrm{WN_a}$ and the almanac reference time t_{oa} corresponding to the reduced almanac are shown in Table 7-17.

Table 7-17 Definitions of the almanac reference time parameters

No.	Parameter	Definition	No. of bits	Scale factor	Effective range	Unit
1	$\mathrm{WN_a}$	Almanac reference week number	13	1	0~8191	week
2	t_{oa}	Almanac reference time	8	2^{12}	0~602112	s

7.11 Earth Orientation Parameters

7.11.1 Parameters Description

The definitions of the Earth Orientation Parameters are shown in Table 7-18.

Table 7-18 Definitions of the Earth Orientation Parameters

Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
t_{EOP}	EOP data reference time	16	2^4	0~604784	s
PM_X	X-Axis polar motion value at reference time	21*	2^{-20}	--	arc-seconds
$\dot{PM}\_X$	X-Axis polar motion drift at reference time	15*	2^{-21}	--	arc-seconds/day
PM_Y	Y-Axis polar motion value at reference time	21*	2^{-20}	--	arc-seconds
$\dot{PM}\_Y$	Y-Axis polar motion drift at reference time	15*	2^{-21}	--	arc-seconds/day

$\Delta UT1$	UT1-UTC difference at reference time	31^{*}	2^{-24}	--	s
$\Delta \dot{U}T1$	Rate of UT1-UTC difference at reference time	19^{*}	2^{-25}	--	s/day
* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB. ** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.					

7.11.2 User Algorithm

The BDCS coordinate of the satellite antenna phase center is calculated by using the ephemeris parameters. If the user needs to convert it to the corresponding Earth Centered Inertial (ECI) coordinate, the related transformation matrix shall be calculated by using the algorithms which are shown in Table 7-19.

The full coordinate transformation algorithms can be accomplished in accordance with the IERS specifications.

Table 7-19 User algorithms for the EOP parameters

Formula	Description
$\mathrm{UT1} - \mathrm{UTC} = \Delta UT1 + \Delta \dot{U}T1(t - t_{\mathrm{EOP}})$	UT1-UTC difference at time t
$x_p = PM\_X + \dot{PM}\_X\ (t - t_{\mathrm{EOP}})$ $y_p = PM\_Y + \dot{PM}\_Y\ (t - t_{\mathrm{EOP}})$	Polar motion in the X-Axis at time t Polar motion in the Y-Axis at time t
Note: t is the BDT time of signal transmission.	

7.12 BDT-UTC Time Offset Parameters

7.12.1 Parameters Description

The BDT-UTC time offset parameters represent the relationship between BDT and UTC time. The definitions and characteristics of the BDT-UTC time offset parameters are shown in Table 7-20.

Table 7-20 Definitions of the BDT-UTC time offset parameters

No.	Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
1	$A_{0\mathrm{UTC}}$	Bias coefficient of BDT time scale relative to UTC time scale	16*	2^{-35}	--	s
2	$A_{1\mathrm{UTC}}$	Drift coefficient of BDT time scale relative to UTC time scale	13*	2^{-51}	--	s/s
3	$A_{2\mathrm{UTC}}$	Drift rate coefficient of BDT time scale relative to UTC time scale	7*	2^{-68}	--	s/s^2
4	Δt_{LS}	Current or past leap second count	8*	1	--	s
5	t_{ot}	Reference time of week	16	2^4	0~604784	s
6	$\mathrm{WN}_{\mathrm{ot}}$	Reference week number	13	1	--	week
7	$\mathrm{WN}_{\mathrm{LSF}}$	Leap second reference week number	13	1	--	week
8	DN	Leap second reference day number	3	1	0~6	day
9	Δt_{LSF}	Current or future leap second count	8*	1	--	s
* Parameters so indicated are two’s complement, with the sign bit (+ or -) occupying the MSB. ** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.						

7.12.2 User Algorithm

Three different cases of calculating BDT-UTC time offset are listed as follows:

(1) Whenever the leap second time indicated by $\mathrm{WN}_{\mathrm{LSF}}$ and DN is not in the past (relative to the user’s present time) and the user’s present time does not fall in the time span which starts six hours prior to the leap second time and ends six hours after the leap second time, t_{UTC} is

calculated according to the following equations:

$$t_{\mathrm{UTC}} = (t_{\mathrm{E}} - \Delta t_{\mathrm{UTC}}) \bmod 86400 \tag{7-24}$$

$$\begin{aligned}\Delta t_{\mathrm{UTC}} = \Delta t_{\mathrm{LS}} + A_{0\mathrm{UTC}} + A_{1\mathrm{UTC}}\left(t_{\mathrm{E}} - t_{\mathrm{ot}} + 604800\left(\mathrm{WN} - \mathrm{WN}_{\mathrm{ot}}\right)\right) + \\ A_{2\mathrm{UTC}}\left(t_{\mathrm{E}} - t_{\mathrm{ot}} + 604800\left(\mathrm{WN} - \mathrm{WN}_{\mathrm{ot}}\right)\right)^2\end{aligned} \tag{7-25}$$

where, t_{E} is the BDT time as estimated by the user.

(2) Whenever the user’s present time falls within the time span which starts six hours prior to the leap second time and ends six hours after the leap second time, t_{UTC} is calculated according to the following equations:

$$t_{\mathrm{UTC}} = \mathrm{W} \bmod (86400 + \Delta t_{\mathrm{LSF}} - \Delta t_{\mathrm{LS}}) \tag{7-26}$$

$$\mathrm{W} = \left((t_{\mathrm{E}} - \Delta t_{\mathrm{UTC}} - 43200) \bmod 86400\right) + 43200 \tag{7-27}$$

where, the calculation method of Δt_{UTC} is shown in Equation (7-25).

(3) Whenever the leap second time indicated by $\mathrm{WN}_{\mathrm{LSF}}$ and DN is in the past (relative to the user’s present time) and the user’s present time does not fall in the time span which starts six hours prior to the leap second time and ends six hours after the leap second time, t_{UTC} is calculated according to the following equations:

$$t_{\mathrm{UTC}} = (t_{\mathrm{E}} - \Delta t_{\mathrm{UTC}}) \bmod 86400 \tag{7-28}$$

$$\begin{aligned}\Delta t_{\mathrm{UTC}} = \Delta t_{\mathrm{LSF}} + A_{0\mathrm{UTC}} + A_{1\mathrm{UTC}}\left(t_{\mathrm{E}} - t_{\mathrm{ot}} + 604800\left(\mathrm{WN} - \mathrm{WN}_{\mathrm{ot}}\right)\right) + \\ A_{2\mathrm{UTC}}\left(t_{\mathrm{E}} - t_{\mathrm{ot}} + 604800\left(\mathrm{WN} - \mathrm{WN}_{\mathrm{ot}}\right)\right)^2\end{aligned} \tag{7-29}$$

7.13 BDT-GNSS Time Offset Parameters

7.13.1 Parameters Description

The BDT-GNSS Time Offset (BGTO) parameters are used to calculate the time offsets between BDT and other GNSS time. The definitions and characteristics of the BGTO parameters are shown in Table 7-21.

Table 7-21 Definitions of the BGTO parameters

No.	Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
1	GNSS ID	GNSS type identification	3	--	--	dimensionless
2	WN_{0BGTO}	Reference week number	13	1	--	week
3	t_{0BGTO}	Reference time of week	16	2^4	0~604784	s
4	A_{0BGTO}	Bias coefficient of BDT time scale relative to GNSS time scale	16*	2^{-35}	--	s
5	A_{1BGTO}	Drift coefficient of BDT time scale relative to GNSS time scale	13*	2^{-51}	--	s/s
6	A_{2BGTO}	Drift rate coefficient of BDT time scale relative to GNSS time scale	7*	2^{-68}	--	s/s^2
* Parameters so indicated are two's complement, with the sign bit (+ or -)occupying the MSB. ** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.						

GNSS ID is used to identify different navigation satellite systems, and its definition is as follows:

000 indicates that the present BGTO parameters are not available;

001 indicates GPS;

010 indicates Galileo;

011 indicates GLONASS;

100 to 111 are reserved.

The $\mathrm{WN}_{0\mathrm{BGTO}}$, $t_{0\mathrm{BGTO}}$, $A_{0\mathrm{BGTO}}$, $A_{1\mathrm{BGTO}}$,and $A_{2\mathrm{BGTO}}$ broadcasted in the same frame correspond to the system identified by GNSS ID. The BGTO parameters broadcasted in different frames may be different, and the user should recognize GNSS ID every time when the BGTO parameters are received.

7.13.2 User Algorithm

The relationship between BDT and other GNSS time is given by the equation as follows:

$$\begin{aligned}\Delta t_{\mathrm{Systems}} = t_{\mathrm{BD}} - t_{\mathrm{GNSS}} = A_{0\mathrm{BGTO}} + A_{1\mathrm{BGTO}}\left[t_{\mathrm{BD}} - t_{0\mathrm{BGTO}} + 604800\left(\mathrm{WN} - \mathrm{WN}_{\mathrm{BGTO}}\right)\right] + \\ A_{2\mathrm{BGTO}}\left[t_{\mathrm{BD}} - t_{0\mathrm{BGTO}} + 604800\left(\mathrm{WN} - \mathrm{WN}_{\mathrm{BGTO}}\right)\right]^2\end{aligned} \quad (7\text{-}30)$$

where, $\Delta t_{\mathrm{Systems}}$ is in seconds; t_{BD} and t_{GNSS} are the BDT time and other GNSS time, respectively.

7.14 Satellite Health Status

Satellite Health Status (HS) is an unsigned integer with a length of 2 bits, which indicates the health status of the transmitting satellite. The definitions of the satellite health status parameter are shown in Table 7-22.

Table 7-22 Definitions of the satellite health status parameter

HS value	Definition	Description
0	The satellite is healthy	The satellite provides services
1	The satellite is unhealthy or in the test	The satellite does not provide services
2	Reserved	Reserved
3	Reserved	Reserved

7.15 Satellite Integrity Status Flag

The satellite integrity status flag contains three parameters: data integrity flag (DIF), signal integrity flag (SIF), and accuracy integrity flag (AIF). Each of them has a length of 1 bit, and their definitions are shown in Table 7-23.

Table 7-23. Definitions of the satellite integrity status flag parameters

Parameter	Value	Definition
DIF	0	The error of message parameters broadcasted in this signal does not exceed the predictive accuracy
	1	The error of message parameters broadcasted in this signal exceeds the predictive accuracy
SIF	0	This signal is normal
	1	This signal is abnormal
AIF	0	SISMAI* value of this signal is valid
	1	SISMAI value of this signal is invalid
* The definitions of SISMAI will be shown in Section 7.17.		

The B2a integrity status flag parameters ($DIF_{(B2a)}$, $SIF_{(B2a)}$, $AIF_{(B2a)}$) are only broadcast in B-CNAV2. The B1C integrity status flag parameters ($DIF_{(B1C)}$, $SIF_{(B1C)}$, $AIF_{(B1C)}$) are broadcast in B-CNAV2, as well as in the B1C navigation message.

Because of the higher update rate of the B-CNAV2 message, it is recommended that the dual frequency user, using the B1C and B2a signals, applies the integrity status flag parameters which are broadcast by the B2a signal preferentially.

The specific definitions of the signal integrity status flag parameters will be published in a future update of this ICD.

7.16 Signal In Space Accuracy Index

The signal in space accuracy describes the predictive accuracy of the orbital parameters and clock correction parameters broadcasted in the navigation message. It contains the along-track and cross-track accuracy of the satellite orbit ($SISA_{oe}$) and the satellite orbital radius and satellite clock correction accuracy ($SISA_{oc}$).

The signal in space accuracy index parameters broadcasted in the navigation message are used to calculate $SISA_{oe}$ and $SISA_{oc}$, which contain five parameters as follows:

(1) $SISAI_{oe}$: satellite orbit along-track and cross-track accuracy ($SISA_{oe}$) index;

(2) $SISAI_{ocb}$: satellite orbit radius and fixed satellite clock bias accuracy ($SISA_{ocb}$) index;

(3) $SISAI_{oc1}$: satellite clock bias accuracy ($SISA_{oc1}$) index;

(4) $SISAI_{oc2}$: satellite clock drift accuracy ($SISA_{oc2}$) index;

(5) t_{op}: time of week for data prediction.

The specific definitions of the signal in space accuracy index parameters will be published in a future update of this ICD.

7.17 Signal In Space Monitoring Accuracy Index

The estimated error of the signal in space accuracy is described by the zero-mean Gaussian distribution model. The signal in space monitoring accuracy (SISMA) is the variance of the Gaussian distribution, which is indicated by the signal in space monitoring accuracy index (SISMAI).

The specific definitions of the signal in space monitoring accuracy index parameters will be published in a future update of this ICD.

8 Acronyms

BDCS	BeiDou Coordinate System
BDGIM	BeiDou Global Ionospheric delay correction Model
BDS	BeiDou Navigation Satellite System
BDT	BeiDou Navigation Satellite System Time
BGTO	BDT-GNSS Time Offset
bps	bits per second
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CGCS2000	China Geodetic Coordinate System 2000
CRC	Cyclic Redundancy Check
ECI	Earth Centered Inertial
EOP	Earth Orientation Parameters
GEO	Geostationary Earth Orbit
GF	Galois Field
GLONASS	GLObal NAvigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
IERS	International Earth Rotation and Reference Systems Service
IGSO	Inclined GeoSynchronous Orbit
IODC	Issue Of Data, Clock
IODE	Issue Of Data, Ephemeris
IPP	Ionoshperic Pierce Point
IRM	IERS Reference Meridian
IRP	IERS Reference Pole
LDPC	Low Density Parity Check
LOS	Line Of Sight
LSB	Least Significant Bit

Mcps	Mega chips per second
MEO	Medium Earth Orbit
MJD	Modified Julian Date
MSB	Most Significant Bit
NTSC	National Time Service Center
PRN	Pseudo-Random Noise
RHCP	Right-Hand Circular Polarization
RMS	Root Mean Square
SOW	Seconds Of Week
sps	symbols per second
TEC	Total Electron Content
TECu	Total Electron Content unit
UT	Universal Time
UTC	Universal Time Coordinated
WN	Week Number

Annex: Non-binary LDPC Encoding and Decoding Methods

1. Non-binary LDPC Encoding

The generator matrix G is obtained from the parity-check matrix $\mathbf{H}=[\mathbf{H}_1,\mathbf{H}_2]$ of the non-binary LDPC(*n*, *k*) code. And then, the codeword **c** of length n can be generated by encoding the input information sequence **m** of length *k* with the generator matrix **G**, i.e., $\mathbf{c=(c_0,c_1,\ldots,c_{n\text{-}1})=m}\cdot\mathbf{G}=[\mathbf{m},\mathbf{p}]$, where, $\mathbf{c}_j\ (0\le j<n)$ is the j^{th} codeword symbol, and $\mathbf{p}=\mathbf{m}\cdot(\mathbf{H}_2^{-1}\cdot\mathbf{H}_1)^{\mathrm{T}}$ is the check sequence.

The method for generating the generator matrix **G** is given as follows:

Step 1: The matrix **H** of size (*n*-*k*) × *n* is expressed as: $\mathbf{H}=[\mathbf{H}_1,\mathbf{H}_2]$, where the size of $\mathbf{H}_1$ is (*n*-*k*) × *k*, and the size of $\mathbf{H}_2$ is (*n*- *k*) × (*n*-*k*).

Step 2: Convert the matrix **H** into the systematic form, i.e., multiply **H** with $\mathbf{H}_2^{-1}$ from the left to generate a parity-check matrix $\hat{\mathbf{H}}=[\mathbf{H}_2^{-1}\cdot\mathbf{H}_1,\mathbf{I}_{n-k}]$, where $\mathbf{I}_{n-k}$ is a unit matrix of size (*n*-*k*) × (*n*-*k*).

Step 3: The generator matrix is computed as $\mathbf{G}=[\mathbf{I}_k,(\mathbf{H}_2^{-1}\cdot\mathbf{H}_1)^{\mathrm{T}}]$, where $\mathbf{I}_k$ is a unit matrix of size *k*×*k*.

(1) Encoding Example

The B-CNAV2 message data are encoded by one 64-ary LDPC(96, 48) code. Assume that the input information is

[001010 110010 010011 100001 001010 100110 010000 101001 101100 101111
011100 000101 001110 111010 001001 110100 100010 111111 000101 011100

000110 111101 000000 110001 110100 110111 000101 011001 010000 110011
011011 111010 001011 010000 001001 001000 110111 100101 100011 001001
110110 100111 010110 100000 011001 000100 001111 000111]

after encoding, the output codeword is

[001010 110010 010011 100001 001010 100110 010000 101001 101100 101111
011100 000101 001110 111010 001001 110100 100010 111111 000101 011100
000110 111101 000000 110001 110100 110111 000101 011001 010000 110011
011011 111010 001011 010000 001001 001000 110111 100101 100011 001001
110110 100111 010110 100000 011001 000100 001111 000111 100000 001000
101101 111001 001011 110111 101101 111111 000000 100011 000110 101110
101011 001100 100001 100101 010111 010010 000101 000010 111011 001010
101111 101100 011000 101010 010011 000001 000001 001101 111000 001100
111001 110101 100111 110100 101111 010111 111010 111111 101100 011111
101011 000010 000110 000001 110000 101100]

(2) Mapping Relationship

After 64-ary LDPC encoding, each codeword symbol is composed of 6 bits, which is defined over GF(2^6) domain with the primitive polynomial of $p(x)=1+x+x^6$. Each element in Galois field can be described by the vector representation and power representation.

The mapping from the vector representation of 64 field elements to the power representation is shown as follows:

[∞ 0 1 6 2 12 7 26 3 32 13 35 8 48 27 18
4 24 33 16 14 52 36 54 9 45 49 38 28 41 19 56
5 62 25 11 34 31 17 47 15 23 53 51 37 44 55 40
10 61 46 30 50 22 39 43 29 60 42 21 20 59 57 58]

The mapping from the power representation of 63 non-zero elements to the vector representation is shown as follows:

[1 2 4 8 16 32 3 6 12 24 48 35 5 10 20 40
19 38 15 30 60 59 53 41 17 34 7 14 28 56 51 37
9 18 36 11 22 44 27 54 47 29 58 55 45 25 50 39
13 26 52 43 21 42 23 46 31 62 63 61 57 49 33]

2. Non-binary LDPC Decoding

One codeword $\mathbf{c}=(\mathbf{c_0},\mathbf{c_1},\ldots,\mathbf{c_{n-1}})$ generated by the non-binary LDPC encoding is transmitted over a channel with the modulation. On the receiving side, the corresponding sequence $\mathbf{y}=(\mathbf{y_0},\mathbf{y_1},\ldots,\mathbf{y_{n-1}})$ is received, where $\mathbf{y_j}=(y_{j,0},y_{j,1},\ldots,y_{j,r\text{-}1})$ is the received information corresponding to the j^{th} codeword symbol $\mathbf{c}_j$ ($\mathbf{c}_j\in\mathrm{GF}(q)$, q=2^r and $0\le j<n$).

The parity-check matrix $\mathbf{H}$ of the non-binary LDPC code can be used to check the correctness of the received sequence **y**. The specific method is described as follows:

A hard decision codeword $\hat{\mathbf{c}}=(\hat{\mathbf{c}}_\mathbf{0},\hat{\mathbf{c}}_\mathbf{1},\ldots,\hat{\mathbf{c}}_\mathbf{n\text{-}1})$ is obtained by making hard decision on the received sequence **y** bit by bit. The check sum is calculated as $\mathbf{s}=\hat{\mathbf{c}}\mathbf{H}^{\mathrm{T}}$. If $\mathbf{s}=\mathbf{0}$ (for any i, $0\le i<m$, $\sum_{j\in N_i}\hat{c}_j h_{i,j}=0$, in the Galois field), $\hat{\mathbf{c}}$ is the correct output, otherwise $\hat{\mathbf{c}}$ is erroneous.

The parity-check matrix $\mathbf{H}$ describes the connection relationship of the check node CN and the variable node VN, i.e., the reliability information can be transmitted between the connected CN and VN. For the parity-check matrix $\mathbf{H}$ of size $m\times n$, each element $h_{i,j}$ is an element in $\mathrm{GF}(q)$, while each row corresponds to a check node CN and each column corresponds to a variable node VN.

Two index sets are given as follows:

$$M_j = \{i : 0 \le i < m, h_{i,j} \ne 0\}, 0 \le j < n$$

$$N_i = \{j : 0 \le j < n, h_{i,j} \ne 0\}, 0 \le i < m$$

If $h_{i,j} \ne 0$, the check node CN_i is connected to the variable node VN_j. The reliability vector transmitted from the variable node VN_j to the connected check node CN_i ($i \in M_j$) is denoted as $\mathrm{V2C}_{j \to i}$, and can be used to calculate the check sum of CN_i. The reliability vector transmitted from the check node CN_i to the connected variable node VN_j ($j \in N_i$) is denoted as $\mathrm{C2V}_{i \to j}$, and can be used to estimate the symbol value of VN_j. $\mathrm{V2C}_{j \to i}$ and $\mathrm{C2V}_{i \to j}$ are iterated by using the reliability transmitting decoding algorithm to correct the received sequence $\mathbf{y}$, and then the codeword **c** is correctly estimated.

Two iterative reliability transmitting decoding algorithms used to estimate the codeword **c** are listed in the following contents.

(1) Extended Min-Sum Method

Set the mean noise value of the additive white Gaussian noise channel as zero and the variance as σ^2. The reliability vector $\mathbf{L}_\mathrm{j}$ is calculated according to the received symbol vector $\mathbf{y}_\mathrm{j}$ corresponding to each codeword symbol $\mathbf{c}_j$. The reliability vector $\mathbf{L}_\mathrm{j}$ consists of all q Galois field elements $x \in \mathrm{GF}(q)$ and their logarithmic likelihood ratio (LLR) values $\mathrm{LLR}(x)$, where the l^{th} ($0 \le l < q$) element of $\mathbf{L}_\mathrm{j}$ consists of the l^{th} Galois field symbol x_l and its LLR value. The logarithmic likelihood ratio of the Galois field element x in the reliability vector $\mathbf{L_j}$ is

$$\mathrm{LLR}(x) = \log(\frac{P(\mathbf{y}_j \mid \hat{x})}{P(\mathbf{y}_j \mid x)}) = \frac{2\sum_{b=0}^{r-1} | y_{j,b} | \Delta_{j,b}}{\sigma^2}$$

where $\hat{x}$ is the element in $\mathrm{GF}(q)$ which maximizes the probability $P(\mathbf{y}_j \mid x)$, i.e., the hard decision symbol of $\mathbf{y}_j$. The bit sequences of the Galois field elements x and $\hat{x}$ are $x = (x_0, x_1, ..., x_{r-1})$ and $\hat{x} = (\hat{x}_0, \hat{x}_1, ..., \hat{x}_{r-1})$, respectively. $\Delta_{j,b} = x_b \text{ XOR } \hat{x}_b$, where XOR is exclusive-OR operation, that is, if x_b and $\hat{x}_b$ are the same, $\Delta_{j,b} = 0$, otherwise, $\Delta_{j,b} = 1$.

In the extended Min-Sum decoding algorithm, the length of each reliability vector $\mathbf{L_j}$ is reduced from q to n_m $(n_m \ll q)$, i.e., truncating the n_m most reliable field elements (i.e., the smallest LLR values) from the reliability vector. The extended Min-Sum decoding algorithm is shown as follows:

Initialization: Set the maximum number of iterations as $\mathrm{itr}_{\max}$ and the current iteration number itr as zero. The reliability vector $\mathbf{L_j}$ $(0 \le j < n)$ is calculated from the received vector $\mathbf{y_j}$. Initialize all $\mathrm{V2C}_{j \to i}$ vectors of each variable node VN_j with $\mathbf{L_j}$.

Step 1: For each variable node VN_j $(0 \le j < n)$, the decision symbol $\hat{c}_j$ and the reliability vector $\mathrm{V2C}_{j \to i}$ are calculated according to the variable node updating rule.

Step 2: Calculate the check sum $\mathbf{s} = \hat{\mathbf{c}}\mathbf{H}^{\mathrm{T}}$. If $\mathbf{s} = \mathbf{0}$, output the decision sequence and exit the decoding, otherwise, go into Step 3.

Step 3: For each check node CN_i ($0 \le i < m$), the reliability vector $\mathrm{C2V}_{i \to j}$ is calculated according to the check node updating rule.

Step 4: Let itr=itr+1. If $\mathrm{itr} = \mathrm{itr}_{\max}$, exit decoding and declare a decoding failure, otherwise, go into Step 1.

1) Updating Rules of Variable Nodes

If the current iteration number itr=0, the reliability vector $\mathbf{L_j}$ of each codeword symbol is arranged in ascending order according to its LLR values of the *q* field elements. The first n_m elements in the sorted $\mathbf{L_j}$ constitute the truncated reliability vector $\mathbf{L_{j,n_m}} = (\mathbf{x_{n_m}}, \mathrm{LLR}(\mathbf{x_{n_m}}))$. Initialize $\mathrm{V2C}_{j \to i}$ as $\mathbf{L}'_{\mathbf{j,n_m}}$:

$$\mathrm{V2C}_{j \to i} = \mathbf{L}'_{\mathbf{j,n_m}} = \mathbf{L_{j,n_m}} .\, h_{i,j} = (\mathbf{x_{n_m}} \,\mathbf{.}\, h_{i,j}, \mathrm{LLR}(\mathbf{x_{n_m}}))$$

where $\mathbf{x_{n_m}}$ is the vector containing the n_m truncated Galois field elements, and $\mathbf{x_{n_m}} \cdot h_{i,j}$ is the Galois field multiplication of $h_{i,j}$ and n_m Galois field elements in $\mathbf{x_{n_m}}$.

If the current iteration number $\mathrm{itr} \ne 0$, it is assumed that $\mathrm{C2V}_{f \to j}$ is the reliability vector of length n_m which is transmitted from the connected CN_f to VN_j and then the reliability vector $\mathrm{V2C}_{j \to i}$ can be calculated by using all the received reliability vector $\mathrm{C2V}_{f \to j}(f \in M_j, f \ne i)$ as follows:

$$\mathrm{V2C}_{j \to i} = h_{i,j} .\, \Big(\sum_{f \in M_j, f \ne i} \mathrm{C2V}_{f \to j} .\, h_{f,j}^{-1} + \mathbf{L}_j \Big)_{n_m} = (\mathbf{Rs}_{j \to i}, \mathbf{R}_{j \to i})$$

where the Galois field element $h_{f,j}^{-1}$ is the inverse element of $h_{f,j}$, i.e.,

$h_{f,j}^{-1}.h_{f,j}=1$. In the above equation, the sum operation adds the LLR values of the same elements in each reliability vector $\mathrm{C2V}_{i\to j}$. $(\bullet)_{n_m}$ operation indicates that the field elements in the reliability vector are sorted by ascending order and then the first n_m different Galois field elements are truncated. $\mathbf{Rs}_{j\to i}$ is a vector consisting of the first n_m Galois field elements, and $\mathbf{R}_{j\to i}$ is a vector consisting of the corresponding LLR values. The LLR of the $q-n_m$ Galois field elements discarded from the reliability vector $\mathrm{C2V}_{i\to j}$ is set as the sum of the maximum LLR value in $\mathrm{C2V}_{i\to j}$ and a fixed offset. After each reliability vector $\mathrm{V2C}_{j\to i}$ is calculated, the LLR value of each element in the reliability vector subtracts $\mathrm{LLR}_{\min}$ which is the minimum LLR value in this reliability vector.

In addition, a decision should be made on each variable node in each iteration. The Galois field element corresponding to $\mathrm{LLR}_{\min}$ in the reliability vector $\{\sum_{f\in M_j}\mathrm{C2V}_{f\to j}.\,h_{f,j}^{-1}+\mathbf{L}_j\}$ of length q is selected as a decision value. The related decision formula is

$$\hat{c}_j=\arg\min_{x\in\mathrm{GF}(q)}\{\sum_{f\in M_j}\mathrm{C2V}_{f\to j}.\,h_{f,j}^{-1}+\mathbf{L}_j\},0\le j<n$$

The decision symbol $\hat{c}_j$ is transmitted together with the reliability vector $\mathrm{V2C}_{j\to i}$ to the corresponding check node. It is checked whether the current iteration decoding vector $\hat{\mathbf{c}}=(\hat{c}_0,\hat{c}_1,....,\hat{c}_{n-1})$ satisfies that $\mathbf{s}=\hat{\mathbf{c}}\mathbf{H}^{\mathrm{T}}$ is a zero vector.

2) Updating Rules of Check Nodes

For each check node CN_i $(0 \le i < m)$, all reliability vectors $\mathrm{V2C}_{j\to i}$ from the connected variable nodes are received. The reliability vector $\mathrm{C2V}_{i\to j}$ is calculated by

$$\mathrm{C2V}_{i\to j} = \sum_{\gamma\in N_i, \gamma\ne j} \mathrm{V2C}_{\gamma\to i}$$

where, each sum operation is defined as the basic calculation of the check node; when two reliability vectors containing n_m Galois field elements and their LLR vectors are inputted, the candidate element is obtained by the sum of the Galois field elements of different reliability vectors, and their LLR values are calculated at the same time. The LLR values of the candidate elements are sorted by ascending order and then the first n_m LLR values are truncated. The output reliability vector consists of the n_m LLR values and their Galois field elements.

The two input reliability vectors of the check nodes is given as $(\mathbf{U}_\mathrm{s}, \mathbf{U})$ and $(\mathbf{Q}_\mathrm{s}, \mathbf{Q})$, and the output reliability vector is given as $(\mathbf{V}_\mathrm{s}, \mathbf{V})$, where $\mathbf{U}$, $\mathbf{Q}$, $\mathbf{V}$ are the LLR vectors of length n_m arranged in ascending order, and $\mathbf{U}_\mathrm{s}$, $\mathbf{Q}_\mathrm{s}$, $\mathbf{V}_\mathrm{s}$ are the corresponding Galois field element vectors. According to the input reliability vectors, the reliability matrix $\mathbf{M}$ of size $n_m \times n_m$ and the Galois field element matrix $\mathbf{M}_\mathrm{s}$ are constructed as follows:

$$M_s[d,\rho] = U_s[d] \oplus Q_s[\rho]$$

$$M[d,\rho] = U[d] + Q[\rho]$$

where, $d,\rho \in \{0,1,...,n_m-1\}$ and $\oplus$ is the Galois field addition operation.

The basic formula for the check node is

$$V[\varepsilon] = \min_{d,\rho\in[0,1,...,n_m-1]} \{M[d,\rho]\}_{V_s[\varepsilon]=M_s[d,\rho]}, 0 \le \varepsilon < n_m$$

The implementation of the above equation can be completed by operating the register **S** of size n_m as follows:

Initialize: Store the first column of **M** into **S**, and let $S[\zeta] = M[\zeta, 0]$, $\zeta \in \{0,1,...,n_m-1\}$. Let $\varepsilon = 0$.

Step 1: Find the minimum value in **S**. (Suppose $M[d,\rho]$ is the smallest value of the corresponding **S**.)

Step 2: If the Galois field element corresponding to the found minimum value does not exist in $\mathbf{V}_s$, $V[\varepsilon]$ is filled with the minimum value in **S**, and $V_s[\varepsilon]$ is filled with the corresponding Galois field element, and $\varepsilon = \varepsilon + 1$. Otherwise, no action.

Step 3: Replace the minimum value in **S** by $M[d,\rho+1]$, i.e., the element on the right of the corresponding element in **M.**

Step 4: Go to Step 1 until $\varepsilon = n_m$.

(2) Fixed Path Decoding Method

The fixed path decoding method is an efficient decoding algorithm, and its algorithm procedure is consistent with that of the extended Min-Sum method, except that the check node updating rules is different. Take check nodes with row weight d_c=4 (i.e., each check node receives four input reliability vectors) as an example, the check node updating rules of the fixed path decoding method are described as follows:

For each check node CN_i ($0 \le i < m$), the fixed path deviation value vector $\mathbf{E_i} = (\mathbf{Rs_i}, \mathbf{R_i})$ of length 8+2 n_m is calculated by using four received reliability vectors $\mathrm{V2C}_{j\to i} = (\mathbf{Rs}_{j\to i}, \mathbf{R}_{j\to i})$ ($j \in N_i$) transmitted from the connected variable nodes, where $\mathbf{Rs_i}$ is the Galois field element vector of length 8+2 n_m (the vector may contain the same Galois field elements), and $\mathbf{R_i}$ is the corresponding LLR vector.

In order to compute each fixed path deviation value, the four reliability vectors $\mathrm{V2C}_{j\to i}$ are sorted in ascending order according to the LLR values $R_{j\to i}[1]$ of the second elements $\mathrm{V2C}_{j\to i}[1] = (Rs_{j\to i}[1], R_{j\to i}[1])$ (i.e., its subscript is “1”) of $\mathrm{V2C}_{j\to i}$. The four sorted vectors are defined as $(\mathbf{Rs_{\iota,i}}, \mathbf{R_{\iota,i}})$, $0 \le \iota < 4$, i.e., $R_{0,i}[1] \le R_{1,i}[1] \le R_{2,i}[1] \le R_{3,i}[1]$, where $\mathbf{Rs}_{\iota,\mathbf{i}}$ is the Galois field element vector of length n_m, and $\mathbf{R}_{\iota,\mathbf{i}}$ is the corresponding LLR vector. Then, the fixed path deviation value vector $\mathbf{E_i} = (\mathbf{Rs_i}, \mathbf{R_i})$ is computed according to $\mathbf{Rs}_{\iota,\mathbf{i}}$ and $\mathbf{R}_{\iota,\mathbf{i}}$ which are calculated by the equations as follows:

$$Rs_i[e] = \begin{cases} \sum\limits_{0\le\iota<4} Rs_{\iota,i}[0], & e = 0 \\ Rs_{e-1,i}[1] \oplus \sum\limits_{0\le\iota<4,\iota\ne e-1} Rs_{\iota,i}[0], & 1 \le e \le 4 \\ Rs_{0,i}[1] \oplus Rs_{e-4,i}[1] \oplus \sum\limits_{1\le\iota<4,\iota\ne e-4} Rs_{\iota,i}[0], & 5 \le e \le 7 \\ Rs_{0,i}[0] \oplus Rs_{1,i}[1] \oplus Rs_{2,i}[1] \oplus Rs_{3,i}[0], & e = 8 \\ Rs_{0,i}[0] \oplus Rs_{1,i}[1] \oplus Rs_{2,i}[0] \oplus Rs_{3,i}[1], & e = 9 \\ Rs_{e-10,i}[2] \oplus \sum\limits_{0\le\iota<4,\iota\ne e-10} Rs_{\iota,i}[0], & 10 \le e < 14 \\ Rs_{\theta,i}[e-11] \oplus \sum\limits_{0\le\iota<4,\iota\ne\theta} Rs_{\iota,i}[0], & 14 \le e < 11 + n_m \\ Rs_{\beta,i}[e-8-n_m] \oplus \sum\limits_{0\le\iota<4,\iota\ne\beta} Rs_{\iota,i}[0], & 11 + n_m \le e < 8 + 2n_m \end{cases}$$

$$R_i\left[e\right]=\begin{cases}0, & e=0\\ R_{e-1,i}\left[1\right], & 1\le e\le 4\\ R_{0,i}\left[1\right]+R_{e-4,i}\left[1\right], & 5\le e\le 7\\ R_{1,i}\left[1\right]+R_{e-6,i}\left[1\right], & 8\le e\le 9\\ R_{e-10,i}\left[2\right], & 10\le e\le 14\\ R_{\theta,i}\left[e-11\right], & 14\le e<11+n_m\\ R_{\beta,i}\left[e-8-n_m\right], & 11+n_m\le e<8+2n_m\end{cases}$$

Where, θ and β represent the subscripts l of the vectors $(\mathbf{Rs}_{\iota,\mathbf{i}},\mathbf{R}_{\iota,\mathbf{i}})$ whose $(\lfloor n_m/2\rfloor+1)^{\mathrm{th}}$ LLR values (i.e., its subscript is $\lfloor n_m/2\rfloor$) are the minimum and second smallest values, respectively. The sum operation and $\oplus$ in the above equation are the Galois field addition operation.

Set two flag vectors **T** and $\bar{\mathbf{T}}$ of length 8+2n_m and initialize them to all “1” vectors. The updating rules for the first $0\le k_R<8+2n_m$ values of the flag vectors **T** and $\bar{\mathbf{T}}$ is defined by the following equations:

$$T[k_R]=\begin{cases}1, R_i[k_R]\le R_{\theta,i}[\lfloor n_m/2\rfloor]\\ 0, R_i[k_R]>R_{\theta,i}[\lfloor n_m/2\rfloor]\end{cases}$$

$$\bar{T}[k_R]=\begin{cases}1, R_i[k_R]\le R_{\beta,i}[\lfloor n_m/2\rfloor]\\ 0, R_i[k_R]>R_{\beta,i}[\lfloor n_m/2\rfloor]\end{cases}$$

According to the fixed path deviation vector and the flag vectors, Four output reliability vectors $(\mathbf{Us}_{\mathbf{i},\iota},\mathbf{U}_{\mathbf{i},\iota})$ of length n_m are updated by the following equations:

$$\mathbf{U}s_{i,\iota}=(Rs_i\left[w\right]\oplus Rs_{\iota,i}\left[0\right])_{n_m}$$

$$\mathbf{U}_{i,\iota}=(R_i\left[w\right])_{n_m}$$

where, $0\le l<4$, and the value range of w is determined by the different cases. In the case of $l=0$, if $\theta\ne 0$, the value range of w is

$$\{w \mid T[w]=1\} \cap \{\{w=0\} \cup \{1<w\le 4\} \cup \{8\le w<10\} \cup \{10<w<11+n_m\}\}$$

otherwise, the value range of *w* is

$$\{w \mid T[w]=1\} \cap \{\{w=0\} \cup \{1<w\le 4\} \cup \{8\le w<10\} \cup \{10<w<14\} \cup \{w\ge 11+n_m\}\}$$

In the case of $1\le l<4$, if $l=\theta$, the value range of *w* is

$$\{w \mid \bar{T}[w]=1\} \cap \{\{0\le w\le 7\} \cup \{10\le w<14\} \cup \{w\ge 11+n_m\}\} \cap \{\{w\ne \imath+1\} \cap \{w\ne 4+\imath\} \cap \{w\ne 10+\imath\}\}$$

otherwise, the value range of *w* is

$$\{w \mid T[w]=1\} \cap \{\{0\le w\le 7\} \cup \{10\le w<11+n_m\}\} \cap \{\{w\ne \imath+1\} \cap \{w\ne 4+\imath\} \cap \{w\ne 10+\imath\}\}$$

$Us_{i,\imath}[z]$ $(0\le z<n_m)$ corresponds to $Rs_i[w]\oplus Rs_{\imath,i}[0]$ calculated by the n_m smallest values of *w*, which doesn’t need to eliminate the same symbols of $Us_{i,\imath}[z]$. Meanwhile, $U_{i,\imath}[z]$ is the corresponding LLR value of $Us_{i,\imath}[z]$.

The order of the four reliability vectors $(\mathbf{Us}_{\mathbf{i},\boldsymbol{\imath}},\mathbf{U}_{\mathbf{i},\boldsymbol{\imath}})$ is aligned with the four sorted input vectors $(\mathbf{Rs}_{\boldsymbol{\imath},\mathbf{i}},\mathbf{R}_{\boldsymbol{\imath},\mathbf{i}})$. Each input vector $(\mathbf{Rs}_{\boldsymbol{\imath},\mathbf{i}},\mathbf{R}_{\boldsymbol{\imath},\mathbf{i}})$ corresponds to a $\mathrm{C2V}_{i\to j}$ vector and a $\mathrm{V2C}_{j\to i}$ vector. According to the same method as calculating $(\mathbf{Rs}_{\boldsymbol{\imath},\mathbf{i}},\mathbf{R}_{\boldsymbol{\imath},\mathbf{i}})$ from $\mathrm{V2C}_{j\to i}$, each reliability vector $\mathrm{C2V}_{i\to j}=(\mathbf{Us}_{\mathbf{i},\boldsymbol{\imath}},\mathbf{U}_{\mathbf{i},\boldsymbol{\imath}})$ can be updated by using the four reliability vectors $(\mathbf{Us}_{\mathbf{i},\boldsymbol{\imath}},\mathbf{U}_{\mathbf{i},\boldsymbol{\imath}})$.