BeiDou Navigation Satellite System

Signal In Space

Interface Control Document

Open Service Signal B1C (Version 1.0)

China Satellite Navigation Office

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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 B1C transmitted from the BDS space segment to the BDS user segment. Furthermore, the B1C 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	$\mu=3.986004418\times10^{14}$ 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 B1C signal contained within the 32.736MHz bandwidth with a center frequency of 1575.42MHz.

4.1 Signal Structure

The carrier frequencies, modulations, and symbol rates of the B1C signal are shown in Table 4-1.

Table 4-1 Structure of the B1C signal

Signal	Signal component	Carrier frequency (MHz)	Modulation	Symbol rate (sps)
B1C	Data component B1C_data	1575.42	BOC(1, 1)	100
	Pilot component B1C_pilot		QMBOC(6, 1, 4/33)	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 B1C Signal

The complex envelope of the B1C signal is expressed as

$$s_{\mathrm{B1C}}(t) = s_{\mathrm{B1C\_data}}(t) + \mathrm{j}\, s_{\mathrm{B1C\_pilot}}(t) \tag{4-3}$$

where, $s_{\mathrm{B1C\_data}}(t)$ is the data component, which is generated from the navigation message data $D_{\mathrm{B1C\_data}}(t)$ and the ranging code $C_{\mathrm{B1C\_data}}(t)$ modulated with the sine-phased BOC(1,1) subcarrier $sc_{\mathrm{B1C\_data}}(t)$. $s_{\mathrm{B1C\_pilot}}(t)$ is the pilot component, which is generated from the ranging code $C_{\mathrm{B1C\_pilot}}(t)$ modulated with the QMBOC(6, 1, 4/33) subcarrier $sc_{\mathrm{B1C\_pilot}}(t)$. The power ratio of the data component to the pilot component is 1:3. The expressions of the two components are as follows:

$$s_{\mathrm{B1C\_data}}(t) = \frac{1}{2} D_{\mathrm{B1C\_data}}(t) \cdot C_{\mathrm{B1C\_data}}(t) \cdot sc_{\mathrm{B1C\_data}}(t) \tag{4-4}$$

$$s_{\mathrm{B1C\_pilot}}(t) = \frac{\sqrt{3}}{2} C_{\mathrm{B1C\_pilot}}(t) \cdot sc_{\mathrm{B1C\_pilot}}(t) \tag{4-5}$$

The expression of $D_{\mathrm{B1C\_data}}(t)$ in the data component $s_{\mathrm{B1C\_data}}(t)$ is given as follows:

$$D_{\mathrm{B1C\_data}}(t) = \sum_{k=-\infty}^{\infty} d_{\mathrm{B1C\_data}}[k]\, p_{T_{\mathrm{B1C\_data}}}\left(t - kT_{\mathrm{B1C\_data}}\right) \tag{4-6}$$

where, $d_{\mathrm{B1C\_data}}$ is the navigation message data of the B1C signal, and $T_{\mathrm{B1C\_data}}$ is the chip width of the corresponding data. $p_T(t) = \begin{cases} 1, & 0 \le t < T \\ 0, & else \end{cases}$, is a rectangular pulse function of width *T*.

The expressions of ranging codes $C_{\mathrm{B1C\_data}}(t)$ and $C_{\mathrm{B1C\_pilot}}(t)$ are given as follows:

$$C_{\mathrm{B1C\_data}}(t)=\sum_{n=-\infty}^{\infty}\sum_{k=0}^{N_{\mathrm{B1C\_data}}-1} c_{\mathrm{B1C\_data}}[k]p_{T_{\mathrm{c\_B1C}}}\left(t-\left(N_{\mathrm{B1C\_data}}n+k\right)T_{\mathrm{c\_B1C}}\right) \quad (4\text{-}7)$$

$$C_{\mathrm{B1C\_pilot}}(t)=\sum_{n=-\infty}^{\infty}\sum_{k=0}^{N_{\mathrm{B1C\_pilot}}-1} c_{\mathrm{B1C\_pilot}}[k]p_{T_{\mathrm{c\_B1C}}}\left(t-\left(N_{\mathrm{B1C\_pilot}}n+k\right)T_{\mathrm{c\_B1C}}\right) \quad (4\text{-}8)$$

where, $c_{\mathrm{B1C\_data}}$ and $c_{\mathrm{B1C\_pilot}}$ are the ranging code sequences (with the values of ±1) of the data component and the pilot component respectively. $N_{\mathrm{B1C\_data}}$ and $N_{\mathrm{B1C\_pilot}}$ are the ranging code length of the corresponding components with the same values of 10230. $T_{\mathrm{c\_B1C}}=1/R_{\mathrm{c\_B1C}}$ is the chip width of the B1C ranging code. $R_{\mathrm{c\_B1C}}$=1.023 Mbps is the chip rate of the B1C ranging code.

The B1C data component subcarrier $sc_{\mathrm{B1C\_data}}(t)$ is expressed as

$$sc_{\mathrm{B1C\_data}}(t)=\mathrm{sign}\left(\sin\left(2\pi f_{\mathrm{sc\_B1C\_a}}t\right)\right) \quad (4\text{-}9)$$

where, $f_{\mathrm{sc\_B1C\_a}}$ is 1.023 MHz.

The B1C pilot component subcarrier $sc_{\mathrm{B1C\_pilot}}(t)$ is the QMBOC(6, 1, 4/33) composite subcarrier. It is composed of a BOC(1, 1) subcarrier and a BOC(6, 1) subcarrier, which are in phase quadrature with each other and have a power ratio of 29:4. The expression of $sc_{\mathrm{B1C\_pilot}}(t)$ is defined as follows:

$$sc_{\mathrm{B1C\_pilot}}(t)=\sqrt{\frac{29}{33}}\mathrm{sign}\left(\sin\left(2\pi f_{\mathrm{sc\_B1C\_a}}t\right)\right)-\mathrm{j}\sqrt{\frac{4}{33}}\mathrm{sign}\left(\sin\left(2\pi f_{\mathrm{sc\_B1C\_b}}t\right)\right) \quad (4\text{-}10)$$

where, $f_{\mathrm{sc\_B1C\_b}}$ is 6.138 MHz。

Since $sc_{\mathrm{B1C\_pilot}}(t)$ is a complex waveform, the B1C signal contains three components as shown in the following equation:

$$s_{\mathrm{B1C}}(t)=\underbrace{\frac{1}{2}D_{\mathrm{B1C\_data}}(t)\cdot C_{\mathrm{B1C\_data}}(t)\cdot \mathrm{sign}\left(\sin\left(2\pi f_{\mathrm{sc\_B1C\_a}}t\right)\right)}_{s_{\mathrm{B1C\_data}}(t)} +\underbrace{\sqrt{\frac{1}{11}}C_{\mathrm{B1C\_pilot}}(t)\cdot \mathrm{sign}\left(\sin\left(2\pi f_{\mathrm{sc\_B1C\_b}}t\right)\right)}_{s_{\mathrm{B1C\_pilot\_b}}(t)} +j\underbrace{\sqrt{\frac{29}{44}}C_{\mathrm{B1C\_pilot}}(t)\cdot \mathrm{sign}\left(\sin\left(2\pi f_{\mathrm{sc\_B1C\_a}}t\right)\right)}_{s_{\mathrm{B1C\_pilot\_a}}(t)} \tag{4-11}$$

Table 4-2 shows the components of the B1C signal as well as the modulation, phase relationship and power ratio of each component.

Table 4-2 Modulation characteristics of the B1C signal

Component	Modulation		Phase relationship	Power ratio
$s_{\mathrm{B1C\_data}}(t)$	Sine BOC(1, 1)		0	1/4
$s_{\mathrm{B1C\_pilot\_a}}(t)$	QMBOC(6, 1, 4/33)	Sine BOC(1, 1)	90	29/44
$s_{\mathrm{B1C\_pilot\_b}}(t)$		Sine BOC(6, 1)	0	1/11

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 0.3dB.

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)*
B1C	MEO satellite	-159
	IGSO satellite	-161
*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 B1C 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 B1C 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.

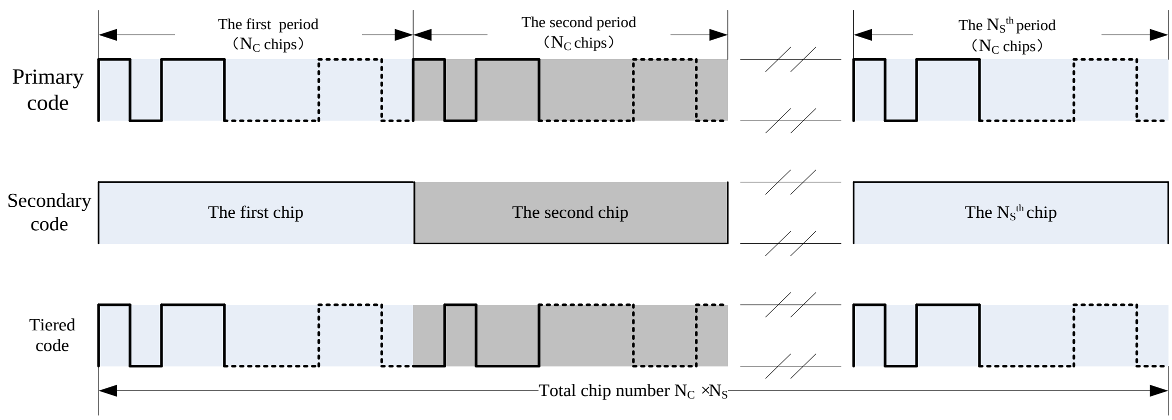

Figure 5-1 Timing relationships of the primary code and secondary code

The characteristics of the B1C ranging codes are shown in Table 5-1.

Table 5-1 Characteristics of the B1C 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)
B1C data component	Truncated Weil	10230	10	--*	--*	--*
B1C pilot component	Truncated Weil	10230	10	Truncated Weil	1800	18000
* The B1C data component shall not contain a secondary code.						

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 B1C Ranging Codes

5.2.1 B1C Primary Codes

The B1C primary codes 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

$$W(k;\ w) = L(k) \oplus L((k+w) \bmod \mathrm{N}),\ k = 0,1,2,\dots,\mathrm{N}-1 \qquad (5\text{-}1)$$

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

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

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

$$c(n;w;p)=W((n+p-1)\bmod \mathrm{N};w),\ n=0,1,2,...,\mathrm{N}_0-1 \qquad (5\text{-}3)$$

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 B1C primary codes (for both data and pilot components) have the same chip rate of 1.023Mcps, and have the same length of 10230 chips. Each primary code is generated by truncating a Weil code which has a length of 10243 chips. The value of w is in the range of 1 to 5121.

There are a total of 126 B1C 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. For example, the first 24 chips of the B1C data component primary code of PRN 1 are 101011111111011001001110 in binary, or equivalently, 53773116 in octal. The Most Significant Bit (MSB), i.e., the first binary number 1 in this example, corresponds to the first chip of the ranging code. The MSB is transmitted first.

Table 5-2 Primary code parameters of the B1C data components

PRN	Phase difference (w)	Truncation point (p)	The first 24 chips (octal)	The last 24 chips (octal)
1	2678	699	53773116	42711657
2	4802	694	32235341	17306122
3	958	7318	17633713	01145221
4	859	2127	41551514	05307430
5	3843	715	17205134	46341377

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
6	2232	6682	04254545	60604443
7	124	7850	70663435	50500234
8	4352	5495	16701045	27476454
9	1816	1162	32132263	70555612
10	1126	7682	25432015	43004057
11	1860	6792	31711760	07100551
12	4800	9973	25604267	15703521
13	2267	6596	65705054	12615632
14	424	2092	24700370	14267226
15	4192	19	72405456	25330122
16	4333	10151	02621063	15741134
17	2656	6297	00506754	62665617
18	4148	5766	44317266	07251312
19	243	2359	14463723	26526763
20	1330	7136	70234110	33737311
21	1593	1706	62002462	34564677
22	1470	2128	52312612	30142557
23	882	6827	34500023	52015335
24	3202	693	77312776	56550366
25	5095	9729	03712305	04531416
26	2546	1620	02501573	00717773
27	1733	6805	66632544	65070030
28	4795	534	00447425	65742570
29	4577	712	50643132	47674377
30	1627	1929	75652754	45534064
31	3638	5355	40610704	03636755
32	2553	6139	60523643	52040645
33	3646	6339	30522043	36645510
34	1087	1470	06337743	54551553
35	1843	6867	41375664	26065254
36	216	7851	20200053	03373656
37	2245	1162	22017103	15754234
38	726	7659	67327102	36032344
39	1966	1156	07154144	00456573
40	670	2672	45367715	20772116
41	4130	6043	46775773	04657766
42	53	2862	37123271	11652043
43	4830	180	34054132	63673657
44	182	2663	36632600	06140620
45	2181	6940	43776172	42103455

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
46	2006	1645	13675272	71143561
47	1080	1582	53755564	07122624
48	2288	951	60621674	32065524
49	2027	6878	22415634	47205733
50	271	7701	37363473	71732000
51	915	1823	77262176	11057010
52	497	2391	57132462	60447016
53	139	2606	13314107	77551540
54	3693	822	54474504	54256322
55	2054	6403	76023074	61777241
56	4342	239	60652454	37175533
57	3342	442	31371623	00254400
58	2592	6769	52134040	51277171
59	1007	2560	41013755	57767521
60	310	2502	20323763	60063316
61	4203	5072	52445270	12771226
62	455	7268	50735662	51142373
63	4318	341	27571255	47160627

Table 5-3 Primary code parameters of the B1C pilot components

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
1	796	7575	71676756	13053205
2	156	2369	60334021	46604773
3	4198	5688	24562714	60007065
4	3941	539	61011650	23616424
5	1374	2270	67337730	66243127
6	1338	7306	23762642	33630334
7	1833	6457	25365366	43456307
8	2521	6254	57226722	76521063
9	3175	5644	72643175	52465264
10	168	7119	00236125	76142064
11	2715	1402	12071371	60232627
12	4408	5557	61136116	05607727
13	3160	5764	36261215	77737367
14	2796	1073	13607013	16031533
15	459	7001	31010541	55416670
16	3594	5910	73163062	33076260
17	4813	10060	30250537	73355574

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
18	586	2710	56226421	42437243
19	1428	1546	26205736	66470710
20	2371	6887	02450570	54366756
21	2285	1883	66511327	23666556
22	3377	5613	06323465	74622250
23	4965	5062	10633350	16402734
24	3779	1038	10544206	54230354
25	4547	10170	43714115	37167223
26	1646	6484	55641056	56136734
27	1430	1718	26572456	62211315
28	607	2535	75123401	40615033
29	2118	1158	70041254	63213062
30	4709	526	53034467	03066540
31	1149	7331	50733517	30062510
32	3283	5844	73077145	34360276
33	2473	6423	55454316	45431517
34	1006	6968	37137206	47647044
35	3670	1280	45724432	33773217
36	1817	1838	55560467	77620561
37	771	1989	13467065	17327352
38	2173	6468	24245150	62223375
39	740	2091	22265044	67665257
40	1433	1581	10003471	27515010
41	2458	1453	36537736	37705710
42	3459	6252	57706617	76736116
43	2155	7122	76411007	77202566
44	1205	7711	61643153	25334277
45	413	7216	50125760	70220333
46	874	2113	66657234	22376763
47	2463	1095	01350500	31043217
48	1106	1628	43621551	20166102
49	1590	1713	42435620	16423062
50	3873	6102	74327566	31245527
51	4026	6123	44553226	37160613
52	4272	6070	52231514	03414402
53	3556	1115	46576047	04003162
54	128	8047	46312270	54703562
55	1200	6795	04717127	25225202
56	130	2575	50407031	31643432
57	4494	53	10044104	27063234

PRN	Phase difference (w)	Truncation point (p)	The first 24 chips (octal)	The last 24 chips (octal)
58	1871	1729	36610123	40756155
59	3073	6388	73470741	24774305
60	4386	682	24072445	51507057
61	4098	5565	07765425	12225744
62	1923	7160	32242545	62104320
63	1176	2277	03210227	56250500

5.2.2 B1C Secondary Codes

The secondary code for each B1C pilot component has the length of 1800 chips. The secondary codes are generated by truncating the Weil codes with the length of 3607 chips, which is in the same way as the primary codes. The value of w is in the range of 1 to 1803.

The specific parameters of the secondary codes of the B1C 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 B1C pilot components

PRN	Phase difference (w)	Truncation point (p)	The first 24 chips (octal)	The last 24 chips (octal)
1	269	1889	27516364	67377026
2	1448	1268	56523173	22276405
3	1028	1593	13575116	64256064
4	1324	1186	46450720	22541050
5	822	1239	12131561	65326055
6	5	1930	17464233	72132153
7	155	176	65053061	04514276
8	458	1696	71707375	63530655
9	310	26	34213032	35460510
10	959	1344	46160454	71144703
11	1238	1271	42153002	45741561
12	1180	1182	23004216	34642255
13	1288	1381	75723150	24051066
14	334	1604	31622150	02232734
15	885	1333	77044051	16722614

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
16	1362	1185	57236013	04521371
17	181	31	63564466	62033045
18	1648	704	70454263	21634063
19	838	1190	14276724	64030307
20	313	1646	34631517	36355573
21	750	1385	66647441	22662277
22	225	113	56655305	07135537
23	1477	860	44120321	13737416
24	309	1656	01401156	77676406
25	108	1921	71446113	33352240
26	1457	1173	65511011	24006552
27	149	1928	23206551	20557017
28	322	57	77770161	14726030
29	271	150	74540673	17203546
30	576	1214	71611373	23731232
31	1103	1148	37057206	37773355
32	450	1458	23025164	41547173
33	399	1519	41327640	70714166
34	241	1635	61120023	46232706
35	1045	1257	06234040	37305130
36	164	1687	74425523	00744320
37	513	1382	30506176	07273204
38	687	1514	42154245	43674256
39	422	1	11240471	71100451
40	303	1583	32430440	02111760
41	324	1806	45423343	17414124
42	495	1664	04254573	55250612
43	725	1338	00100444	43330066
44	780	1111	10223615	50630424
45	367	1706	47340430	06777411
46	882	1543	65721741	51654600
47	631	1813	56006024	65061571
48	37	228	42262216	27652771
49	647	2871	02226642	74310663
50	1043	2884	30472126	75564321
51	24	1823	44032145	72312644
52	120	75	54551571	06432203
53	134	11	40710042	74277066
54	136	63	01560736	51754340
55	158	1937	11725354	54647123
56	214	22	47676432	11456125
57	335	1768	25530310	66634346
58	340	1526	34717545	61553336
59	661	1402	51512234	40357216
60	889	1445	01645770	63375367

PRN	Phase difference (*w*)	Truncation point (*p*)	The first 24 chips (octal)	The last 24 chips (octal)
61	929	1680	05363453	73263151
62	1002	1290	76720135	37304627
63	1149	1245	24724407	27051216

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 B1C signal broadcasts the B-CNAV1 navigation message.

6.1.2 Cyclic Redundancy Check

The B-CNAV1 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:

$$m(x) = m_k + m_{k-1}x + m_{k-2}x^2 + \cdots + m_1 x^{k-1} \tag{6-3}$$

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

$$R(x) = p_{24} + p_{23}x + p_{22}x^2 + \cdots + p_1 x^{23} \tag{6-4}$$

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-CNAV1 Navigation Message

6.2.1 Brief Description

The B-CNAV1 navigation message is broadcast on the B1C signal, and the associated message data are modulated on the B1C data component. The basic frame structure of B-CNAV1 is defined in Figure 6-1. The length of each frame is 1800 symbols, and its symbol rate is 100sps, so the transmission of one frame lasts for 18 seconds.

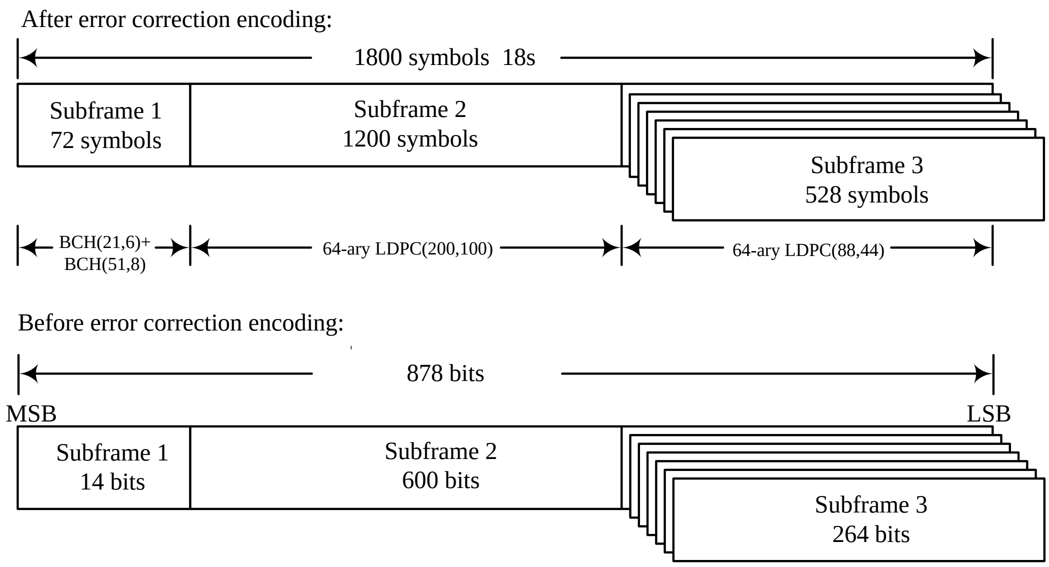

Figure 6-1 B-CNAV1 frame structure

Each frame consists of three subframes, and each subframe is described below:

Subframe 1 before error correction encoding has a length of 14 bits, containing PRN and Seconds Of Hour (SOH). As a result of BCH (21, 6) + BCH (51, 8) encoding, its length becomes 72 symbols. The detailed encoding method will be explained in Section 6.2.2.1.

The length of Subframe 2 before error correction encoding is 600 bits, containing information such as system time parameters, Issue Of Data, ephemeris parameters, clock correction parameters, group delay differential parameters, and so on. As a result of 64-ary LDPC(200, 100) encoding, its length becomes 1200 symbols. The detailed encoding method will be explained in Section 6.2.2.2.

The length of Subframe 3 before error correction encoding is 264 bits. Subframe 3 is divided into multiple pages, containing information such as ionospheric delay correction model parameters, Earth Orientation Parameters (EOP), BDT-UTC time offset parameters, BDT-GNSS time offset (BGTO) parameters, midi almanac, reduced almanac, satellite health status, satellite integrity status flag, signal in space accuracy index, signal in space monitoring accuracy index, and so on. As a result of 64-ary LDPC(88, 44) encoding, its length becomes 528 symbols. The detailed encoding method will be explained in Section 6.2.2.3.

Subframe 2 and Subframe 3 are separately encoded by using the LDPC codes and then interleaved. The interleaving method will be described in Section 6.2.2.4.

6.2.2 Coding Methods

6.2.2.1 BCH(21,6) + BCH(51,8)

Subframe 1 is encoded by using BCH(21, 6) and BCH(51, 8) codes. More specifically, the 6 MSBs are encoded by using BCH(21, 6) code, and the 8 LSBs are encoded by using BCH(51, 8) code. After encoding, the length of Subframe 1 becomes 72 symbols. The generator polynomials of these BCH encoders are shown in Table 6-1.

Table 6-1 The generator polynomials of BCH encoders

BCH code	Encoding characteristics			Optional generator polynomials g(x)
	n	k	t	
(21,6)	21	6	3	$x^6+x^4+x^2+x+1$
(51,8)	51	8	11	$x^8+x^7+x^4+x^3+x^2+x+1$

The BCH encoders mentioned above are implemented by using the k-stage registers as shown in Figure 6-2. Where, the gate 1 is closed during the first k clock periods and then disconnected; the gate 2 is disconnected during the first k periods and then closed.

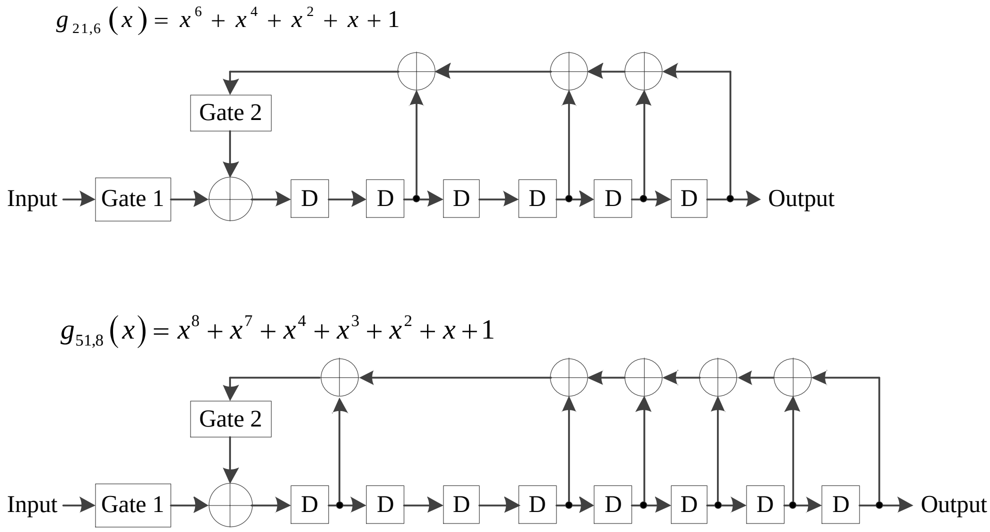

Figure 6-2 Diagram of the BCH encoder circuit

6.2.2.2 64-ary LDPC(200,100)

Subframe 2 is encoded by using 64-ary LDPC(200, 100) 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. For example, the symbol "0" corresponds to the binary vector [000000], and the symbol "1" corresponds to the binary vector [000001]. The message length k is equal to 100 codeword symbols, i.e., 600 bits. The check matrix is a sparse matrix $\mathbf{H}_{100,\,200}$ of 100 rows and 200 columns defined in GF(2^6) domain with the primitive polynomial of $p(x) = 1 + x + x^6$, of which the first

100×100 part corresponds to the information symbols and the last 100×100 part corresponds to the check symbols. The locations of its non-zero elements are defined as follows:

$\mathbf{H}_{100,\ 200,\ index}$= [

11	62	102	150	9	60	100	148	0	51	142	197	22	80	116	154
4	90	131	177	47	95	138	191	51	79	146	195	44	75	142	190
13	57	135	198	24	65	120	173	6	88	129	179	7	89	130	176
6	58	106	158	8	60	108	160	44	92	139	188	4	56	104	156
10	61	101	149	39	87	123	168	15	67	105	167	50	78	145	194
17	98	151	187	46	94	137	190	14	66	104	166	7	59	107	159
21	83	119	153	31	87	114	167	2	49	140	199	12	64	106	164
40	53	132	159	19	96	149	185	16	68	112	168	14	58	132	199
34	69	125	162	23	75	119	175	42	96	144	192	8	63	103	151
23	81	117	155	24	93	111	182	20	72	116	172	17	69	113	169
34	82	130	182	1	53	101	153	46	73	140	188	13	65	107	165
2	54	102	154	18	70	114	170	26	67	122	175	29	77	125	177
36	84	120	169	25	94	108	183	39	89	137	185	21	73	117	173
28	76	124	176	36	90	138	186	33	68	124	161	12	56	134	197
29	85	112	165	45	93	136	189	27	64	123	172	28	84	115	164
25	66	121	174	37	85	121	170	3	50	141	196	48	76	147	192
35	70	126	163	32	80	128	180	0	52	100	152	43	52	135	158
35	83	131	183	10	62	110	162	19	71	115	171	15	59	133	196
33	81	129	181	41	54	133	156	20	82	118	152	38	86	122	171
30	78	126	178	9	61	109	161	26	95	109	180	45	72	143	191
1	48	143	198	40	98	146	194	18	99	148	184	5	57	105	157
41	99	147	195	31	79	127	179	3	55	103	155	22	74	118	174
37	91	139	187	5	91	128	178	30	86	113	166	43	97	145	193
16	97	150	186	11	63	111	163	32	71	127	160	42	55	134	157
38	88	136	184	47	74	141	189	49	77	144	193	27	92	110	181

]

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

$\mathbf{H}_{100,\ 200,\ element}$= [

35	13	51	60	1	44	53	24	1	45	15	6	45	15	6	1
1	44	53	24	1	45	15	6	35	46	56	15	6	1	45	15
15	6	1	45	44	53	24	1	24	1	44	30	1	45	15	6
30	24	1	44	24	1	44	30	45	15	6	1	17	38	49	11
24	1	44	30	24	1	44	53	24	1	44	53	30	24	1	44
33	42	14	24	33	42	14	24	45	15	6	1	1	45	15	6

30	24	1	44	24	1	44	53	1	44	30	24	57	25	9	41
1	45	15	6	1	45	15	6	42	36	12	57	6	1	45	15
24	1	44	53	24	1	44	30	1	45	15	6	1	45	15	6
44	53	24	1	30	24	1	44	1	44	30	24	53	24	1	44
1	44	53	24	27	28	30	31	53	24	1	44	24	1	44	30
45	15	6	1	30	24	1	44	1	45	15	6	26	22	14	2
35	13	18	60	45	15	6	1	30	1	44	7	6	1	45	15
6	1	45	15	53	24	1	44	24	1	44	53	30	24	1	44
1	44	30	24	44	53	24	1	53	24	1	44	44	30	24	1
30	24	1	44	1	44	30	24	1	44	30	24	41	16	29	51
1	44	30	24	38	23	22	7	44	53	24	1	1	45	15	6
30	24	1	44	53	24	1	44	6	1	45	15	24	1	44	53
35	46	56	15	5	33	42	14	54	7	38	23	1	45	15	6
44	30	24	1	6	1	45	15	53	24	1	44	44	53	24	1
1	44	53	24	1	44	30	24	44	30	24	1	1	44	53	24
45	15	6	1	6	1	45	15	1	44	53	24	42	47	37	32
51	60	35	13	29	28	30	31	6	1	45	15	24	1	44	53
44	53	24	1	44	30	24	1	38	49	11	17	44	30	24	1
24	1	44	30	24	1	44	30	1	44	53	24	53	24	1	44

]

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 $H_{100, 200}$ are shown in Figure 6-3.

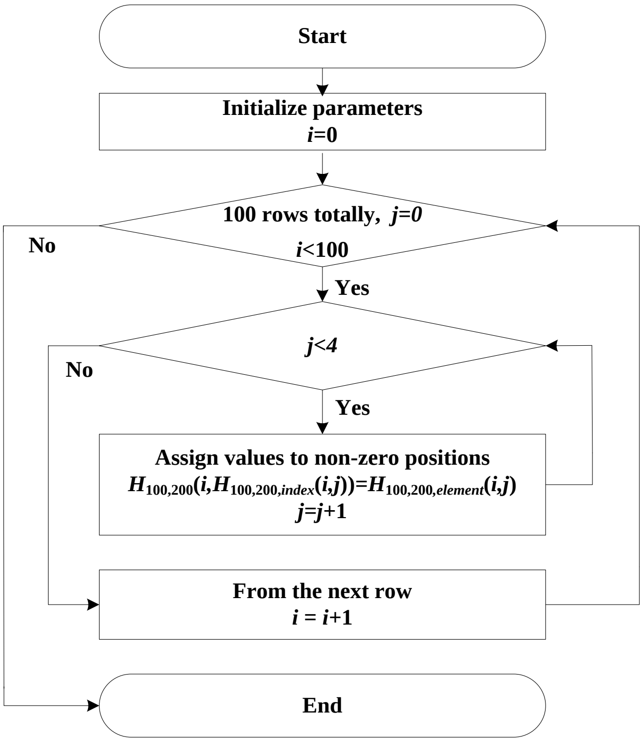

Figure 6-3 $H_{100,\ 200}$ reading flow chart

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

6.2.2.3 64-ary LDPC(88, 44)

Subframe 3 is encoded by using 64-ary LDPC(88, 44) code. Each codeword symbol is composed of 6 bits and defined in GF(2^6) domain with the 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 44 codeword symbols, i.e., 264 bits. The check matrix is a sparse matrix $\mathbf{H}_{44,\ 88}$ of 44 rows and 88 columns defined in GF(2^6) domain with the primitive polynomial of $p(x)=1+x+x^6$, of which the first 44×44 part corresponds to the information symbols and the last 44×44 part corresponds to the check symbols. The locations of its non-zero elements are defined as follows:

$\mathbf{H}_{44,\,88,\,\text{index}}$= [

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

]

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

$\mathbf{H}_{44,\,88,\,\text{element}}$= [

30	24	1	44	24	1	44	30	40	32	61	18	53	24	1	44
51	60	35	13	18	15	32	61	15	6	1	45	30	24	1	44
6	1	45	15	45	15	6	1	1	45	15	6	1	44	53	24
24	1	44	53	44	30	24	1	34	33	45	36	55	9	34	3
1	44	53	24	61	47	20	8	53	24	1	44	15	6	1	45
13	18	60	35	45	15	6	1	24	1	44	53	37	32	52	47
44	53	24	1	39	36	34	33	44	35	31	50	12	25	36	14
15	35	46	56	53	24	1	44	1	44	53	24	24	1	44	30
44	30	24	1	15	6	1	45	30	24	1	44	2	50	22	14
33	42	14	5	34	3	55	9	44	35	61	50	15	6	1	45
45	15	6	1	1	44	30	24	6	1	45	15	1	44	53	24

]

The reading rules for $\mathbf{H}_{44,\,88}$ are the same as that for $\mathbf{H}_{100,\,200}$. For more information about the encoding and decoding methods, please refer to Annex.

6.2.2.4 Interleaving

The LDPC encoded symbols of Subframe 2 and Subframe 3 are combined and interleaved by using a block interleaver. The block interleaver is conceptually described by using a two-dimensional array of M = 36 rows and N = 48 columns, which is shown in Figure 6-4.

The 1200 encoded Subframe 2 symbols and the 528 encoded Subframe 3 symbols are written into the block interleaver with a staggered writing method. The Subframe 2 symbols are written first (MSB first) into the array from left to right starting at Row 1, and Row 2 is also filled with Subframe 2 symbols from left to right. After Row 2 is filled, Row 3 is filled with Subframe 3 symbols from left to right. One row of Subframe 3 symbols are written following the two rows of Subframe 2 symbols, and this process continues until the 528th symbol of Subframe 3 (i.e., LSB of Subframe 3) is written into the last cell of the 33th row in Column 48. Finally, the last 3 rows are filled with the remaining 144 symbols of Subframe 2.

Once all 1728 symbols are written into the array, the symbols are sequentially read out of the array from top to bottom starting at Column 1. After reading out of the last symbol of the 36th row in Column 1, Column 2 symbols are read out from top to bottom and this process continues until the last symbol of the 36th row in Column 48 is read out.

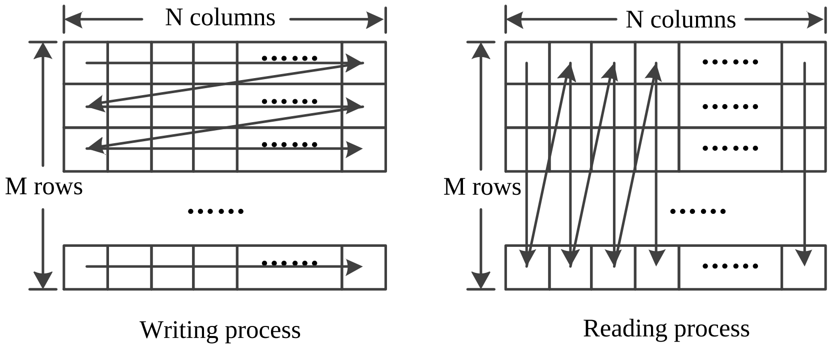

Figure 6-4 Diagram of a block interleaving process

6.2.3 Data Format

6.2.3.1 Subframe 1

Subframe 1 has a length of 14 bits, containing a 6-bit PRN and an 8-bit SOH. The bit allocation of Subframe 1 is shown in Figure 6-5.

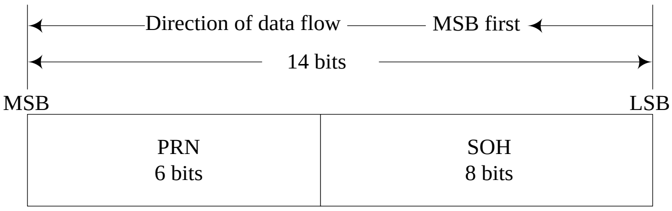

Figure 6-5 Bit allocation for B-CNAV1 Subframe 1

For more information about PRN and SOH, please refer to Section 7.1 and Section 7.3 respectively.

6.2.3.2 Subframe 2

Subframe 2 has a length of 600 bits, containing system time parameters, Issue Of Data, ephemeris parameters, clock correction parameters, group delay differential parameters, and so on. The bit allocation of Subframe 2 is shown in Figure 6-6. Among them, "ephemeris I", "ephemeris II", and "clock correction parameters" are data blocks further constituted of a set of parameters, and "ephemeris I" and "ephemeris II" constitute a complete set of ephemeris parameters together. The detailed bit allocation of each data block is described in Section 6.2.3.4.

The 576 MSBs of Subframe 2 participate in the CRC calculation, and the 24 LSBs are the corresponding CRC check bits.

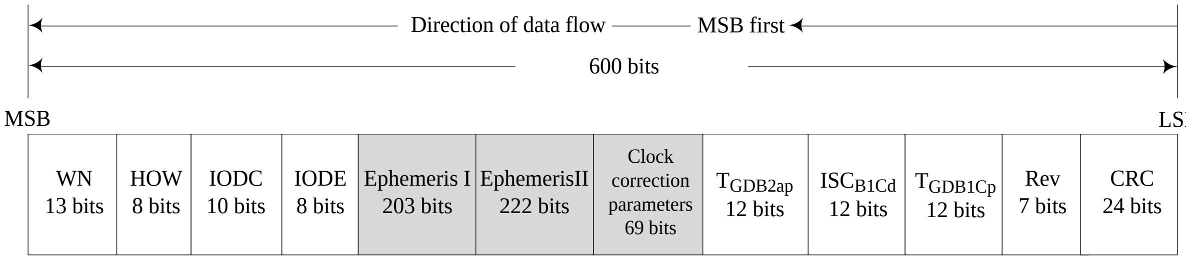

Figure 6-6 Bit allocation for B-CNAV1 Subframe 2

The message parameters in Subframe 2 will be described in the corresponding sections listed in Table 6-2.

Table 6-2 Descriptions of parameters in Subframe 2

No.	Message parameter	Parameter description
1	WN	See Section 7.3 for details
2	HOW	See Section 7.3 for details
3	IODE	See Section 7.4.1 for details
4	IODC	See Section 7.4.2 for details
5	Clock correction parameters	See Section 7.5 for details
6	T_{GDB2ap}	See Section 7.6 for details
7	ISC_{B1Cd}	See Section 7.6 for details
8	T_{GDB1Cp}	See Section 7.6 for details
9	Ephemeris parameters (Ephemeris I, Ephemeris II)	See Section 7.7 for details
10	CRC	See Section 6.1.2 for details

6.2.3.3 Subframe 3

The frame structure of Subframe 3 is shown in Figure 6-7. Subframe 3 has a length of 264 bits, of which the 6 MSBs are page type (PageID), the 24 LSBs are CRC bits, and the remaining 234 bits are message data. PageID and message data participate in the CRC calculation.

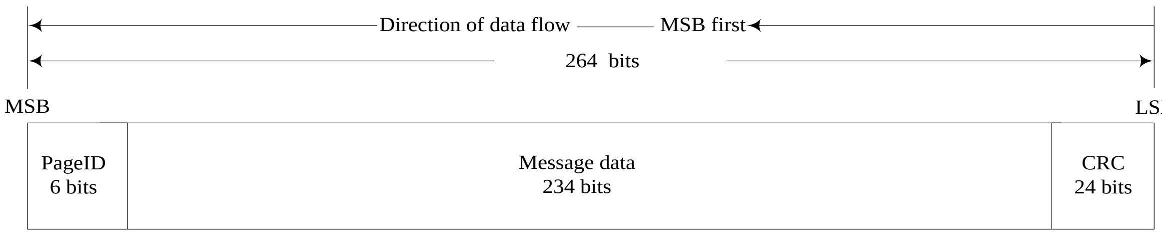

Figure 6-7 Frame structure for B-CNAV1 Subframe 3

At most 63 page types can be defined for Subframe 3. Currently, four valid page types have been defined, i.e., Page Type 1, 2, 3, and 4. Their bit allocation formats are shown in Figure 6-8 ~ Figure 6-11. Among them, "$SISAI_{oc}$", "ionospheric delay correction model parameters", "BDT-UTC time offset parameters", "reduced almanac", "midi almanac", "EOP parameters", and "BGTO parameters" are data blocks further constituted of a set of parameters. The detailed bit allocation of each data block is described in Section 6.2.3.4.

The broadcast order of the Subframe 3 pages may be dynamically adjusted. The user should recognize its PageID every time when Subframe 3 is received.

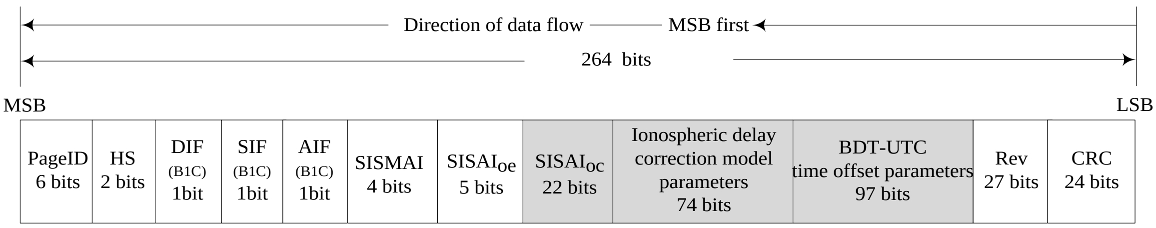

Figure 6-8 Bit allocation for Page Type 1 of B-CNAV1 Subframe 3

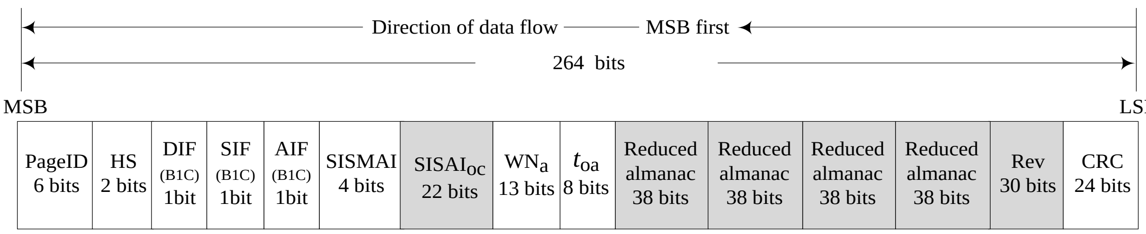

Figure 6-9 Bit allocation for Page Type 2 of B-CNAV1 Subframe 3

(Note: Each Page Type 2 broadcasts reduced almanac parameters for four satellites, while WN_a and t_{oa} in this page are the reference time of these reduced almanacs)

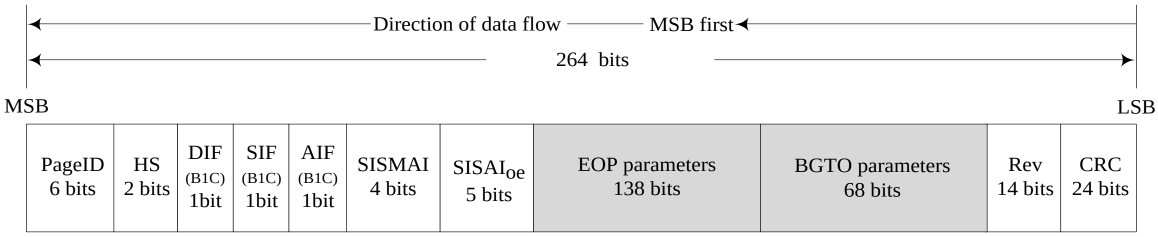

Figure 6-10 Bit allocation for Page Type 3 of B-CNAV1 Subframe 3

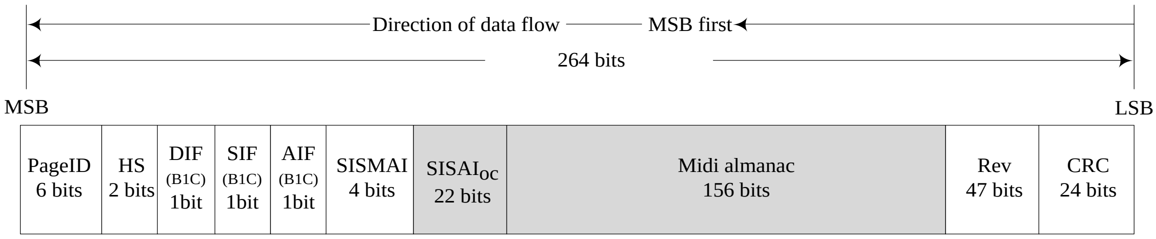

Figure. 6-11 Bit allocation for Page Type 4 of B-CNAV1 Subframe 3

The message parameters in Subframe 3 will be described in the corresponding sections listed in Table 6-3.

Table 6-3 Descriptions of parameters in Subframe 3

No.	Message parameter	Parameter description
1	PageID	See Section 7.2 for details
2	Ionospheric delay correction model parameters	See Section 7.8 for details
3	Midi almanac parameters	See Section 7.9 for details
4	WN_a	See Section 7.10 for details
5	t_{oa}	See Section 7.10 for details
6	Reduced almanac parameters	See Section 7.10 for details
7	EOP parameters	See Section 7.11 for details
8	BDT-UTC time offset parameters	See Section 7.12 for details
9	BGTO parameters	See Section 7.13 for details
10	HS	See Section 7.14 for details
11	DIF	See Section 7.15 for details
12	SIF	See Section 7.15 for details
13	AIF	See Section 7.15 for details
14	$SISAI_{oe}$	See Section 7.16 for details
15	$SISAI_{oc}$	See Section 7.16 for details
16	SISMAI	See Section 7.17 for details
17	CRC	See Section 6.1.2 for details

6.2.3.4 Data Blocks

The detailed bit allocations of 10 data blocks, i.e., "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 shown in Figure 6-12 ~ Figure 6-21.

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 6-12 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 6-13 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 6-14 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 6-15 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 6-16 Bit allocation for ionospheric delay correction model parameters (74 bits)

MSB → LSB

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

Figure 6-17 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 6-18 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 6-19 Bit allocation for EOP parameters (138 bits)

MSB → LSB

GNSS ID	WN_{0BGTO}	t_{0BGTO}	A_{0BGTO}	A_{1BGTO}	A_{2BGTO}
3 bits	13 bits	16 bits	16 bits	13 bits	7 bits

Figure 6-20 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 6-21 Bit allocation for midi almanac parameters (156 bits)

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 Page Types

PageID is used to identify the page types of Subframe 3 in B-CNAV1. It is an unsigned integer with a length of 6 bits. Its definition is shown in Table 7-1.

Table 7-1 Page type definition

PageID (Binary)	Page type
000000	Invalid
000001	Page Type 1
000010	Page Type 2
000011	Page Type 3
000100	Page Type 4
Others	Reserved

7.3 System Time Parameters

The system time parameters broadcasted in B-CNAV1 contain Seconds Of Hour (SOH), Hours Of Week (HOW), 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
SOH	Seconds of hour	8	18	0~3582	s
HOW	Hours of week	8	1	0~167	hour
WN	Week number	13	1	0~8191	week

SOH is broadcast in Subframe 1 of B-CNAV1. The epoch denoted by SOH corresponds to the rising edge of the first chip at the beginning of the current Subframe 1. SOH counts from zero at the origin of each hour of BDT and is reset to zero at the end of each hour (i.e., the origin of the next hour).

HOW is broadcast in Subframe 2 of B-CNAV1. HOW represents the number of hours in the current week and 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-CNAV1 Subframe 2.

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

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

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):

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

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;

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

$\mu = 3.986004418 \times 10^{14}\ \mathrm{m^3/s^2}$, is the geocentric gravitational constant;

$\mathrm{C} = 2.99792458 \times 10^{8}\ \mathrm{m/s}$, 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 signal.

T_{GDB1Cp} is group delay differential between the B1C pilot component and the B3I signal, and T_{GDB2ap} is group delay differential between the B2a pilot component and the B3I signal. Both T_{GDB1Cp} and T_{GDB2ap} are broadcast in the B-CNAV1 message, which are used to compensate for the equipment group delay of the B1C pilot component and the B2a pilot component respectively.

ISC_{B1Cd} is broadcast in the B-CNAV1 message to compensate for the group delay differential between the B1C data component and the B1C 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	T_{GDB1Cp}	Group delay differential of the B1C pilot component	12*	2^{-34}	--	s
2	T_{GDB2ap}	Group delay differential of the B2a pilot component	12*	2^{-34}	--	s
3	ISC_{B1Cd}	Group delay differential between the B1C 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 B1C pilot component shall further correct the ranging code phase with the equation as follows:

$$\left(\Delta t_{\mathrm{SV}}\right)_{\mathrm{B1Cp}} = \Delta t_{\mathrm{SV}} - \mathrm{T}_{\mathrm{GDB1Cp}} \tag{7-4}$$

The single frequency user processing pseudorange from the B1C data component shall further correct the ranging code phase with the equation as follows:

$$\left(\Delta t_{\mathrm{SV}}\right)_{\mathrm{B1Cd}} = \Delta t_{\mathrm{SV}} - \mathrm{T}_{\mathrm{GDB1Cp}} - \mathrm{ISC}_{\mathrm{B1Cd}} \tag{7-5}$$

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:
$A_{ref} = 27906100$ m（MEO）， $A_{ref} = 42162200$ 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
$\dot{\Omega}_e = 7.2921150\times10^{-5}$ rad/s	Earth's rotation rate of BDCS
$\pi = 3.1415926535898$	Ratio of a circle's circumference to its diameter
$t_k = t - t_{oe}$ **	Time from ephemeris reference time
$A_0 = A_{ref} + \Delta A$ *	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
$\Delta n_A = \Delta n_0 + 1/2\,\Delta\dot{n}_0 t_k$	Mean motion difference from computed value
$n_A = n_0 + \Delta n_A$	Corrected mean motion

$M_k = M_0 + n_A t_k$	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
$\begin{cases} \delta u_k = C_{us}\sin(2\phi_k) + C_{uc}\cos(2\phi_k) \\ \delta r_k = C_{rs}\sin(2\phi_k) + C_{rc}\cos(2\phi_k) \\ \delta i_k = C_{is}\sin(2\phi_k) + C_{ic}\cos(2\phi_k) \end{cases}$	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
$\Omega_k = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_e)t_k - \dot{\Omega}_e t_{oe}$	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: $A_{ref} = 27906100\text{m}$（MEO） $A_{ref} = 42162200\text{m}$（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

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

where, E is the elevation angle between the user and satellite (in radians); $\mathrm{H_{ion}}$ 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:

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

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

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

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

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

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:

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

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); $\beta_j\left(j=1 \sim 17\right)$ are calculated as follows:

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

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:

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

where, Re, $\mathrm{H_{ion}}$, 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: $\mathrm{H_{ion}} = 400\ \mathrm{km}$;

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

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

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

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:

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

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

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

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

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

$PR_{\mathrm{B1Cd\text{-}B2ad}}$ 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 $\mathrm{T}_{\mathrm{GDB1Cp}}$);

PR_{B1Cd} is the measured pseudorange of the B1C data component (corrected by the clock correction but not corrected by $\mathrm{T}_{\mathrm{GDB1Cp}}$ and $\mathrm{ISC}_{\mathrm{B1Cd}}$);

PR_{B2ap} is the measured pseudorange of the B2a pilot component (corrected by the clock correction but not corrected by $\mathrm{T}_{\mathrm{GDB2ap}}$);

PR_{B2ad} is the measured pseudorange of the B2a data component (corrected by the clock correction but not corrected by $\mathrm{T}_{\mathrm{GDB2ap}}$ and $\mathrm{ISC}_{\mathrm{B2ad}}$);

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;

ISC_{B2ad} is the group delay differential between the B2a data component and the B2a pilot component, referring to *BeiDou Navigation Satellite System Signal In Space Interface Control Document Open Service Signal B2a (Version 1.0)*;

$C = 2.99792458 \times 10^8$ 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

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

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):

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

where, the almanac reference time t_{oa} counts from the start of the almanac reference week number (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**
$\mu=3.986004418\times10^{14}\ \text{m}^3/\text{s}^2$	Geocentric gravitational constant of BDCS
$\dot{\Omega}_e = 7.2921150\times10^{-5}\ \text{rad/s}$	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
$n_0=\sqrt{\frac{\mu}{A^3}}$	Computed mean motion (rad/s) at reference time
$t_k=t-t_{oa}$ *	Time from ephemeris reference time
$M_k=M_0+n_0t_k$	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
$r_k=A(1-e\cos E_k)$	radius
$\begin{cases}x_k=r_k\cos\phi_k\\ y_k=r_k\sin\phi_k\end{cases}$	Position in orbital plane
$\Omega_k=\Omega_0+\left(\dot{\Omega}-\dot{\Omega}_e\right)t_k-\dot{\Omega}_e t_{oa}$	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:

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

**** $\Phi_0 = M_0 + \omega$, 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
$x_p = PM\_X + P\dot{M}\_X \ (t - t_{\mathrm{EOP}})$ $y_p = PM\_Y + P\dot{M}\_Y \ (t - t_{\mathrm{EOP}})$	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_{0UTC}	Bias coefficient of BDT time scale relative to UTC time scale	16*	2^{-35}	--	s
2	A_{1UTC}	Drift coefficient of BDT time scale relative to UTC time scale	13*	2^{-51}	--	s/s
3	A_{2UTC}	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	WN_{ot}	Reference week number	13	1	--	week
7	WN_{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 WN_{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:

$$t_{UTC} = (t_E - \Delta t_{UTC}) \bmod 86400 \quad (7\text{-}24)$$

$$\Delta t_{UTC} = \Delta t_{LS} + A_{0UTC} + A_{1UTC}\left(t_E - t_{ot} + 604800\left(\mathrm{WN} - \mathrm{WN}_{ot}\right)\right) + A_{2UTC}\left(t_E - t_{ot} + 604800\left(\mathrm{WN} - \mathrm{WN}_{ot}\right)\right)^2 \quad (7\text{-}25)$$

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:

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

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

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

(3) Whenever the leap second time indicated by WN_{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:

$$t_{UTC} = (t_E - \Delta t_{UTC}) \bmod 86400 \quad (7\text{-}28)$$

$$\Delta t_{UTC} = \Delta t_{LSF} + A_{0UTC} + A_{1UTC}\left(t_E - t_{ot} + 604800\left(\mathrm{WN} - \mathrm{WN}_{ot}\right)\right) + A_{2UTC}\left(t_E - t_{ot} + 604800\left(\mathrm{WN} - \mathrm{WN}_{ot}\right)\right)^2 \quad (7\text{-}29)$$

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 B1C integrity status flag parameters ($DIF_{(B1C)}$, $SIF_{(B1C)}$, $AIF_{(B1C)}$) are broadcast in Subframe 3 of B-CNAV1, as well as in the B2a navigation message.

Because of the higher update rate of the B2a navigation 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
BOC	Binary Offset Carrier
bps	bits per second
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
HOW	Hours Of Week
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
QMBOC	Quadrature Multiplexed Binary Offset Carrier
RHCP	Right-Hand Circular Polarization
RMS	Root Mean Square
SOH	Seconds Of Hour
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., $\mathbf{c} = (\mathbf{c_0}, \mathbf{c_1}, \ldots, \mathbf{c_{n-1}}) = \mathbf{m} \cdot \mathbf{G} = [\mathbf{m}, \mathbf{p}]$, 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 $k \times k$.

(1) Encoding Examples

The B-CNAV1 Subframe 2 is encoded by one 64-ary LDPC(200,100) 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 001011 001111
011010 000011 111001 111100 011111 011111 010101 111001 010111 000111
110001 011000 001111 011001 000110 001000 111100 111101 100100 000011
001111 010110 110100 000000 000010 001010 101001 101110 101001 011100
100011 010010 101111 001100 101011 001011 010111 101000 110001 000101
111011 110001 011111 011011 011100 010011 100000 100000 110100 110010]

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 001011 001111
011010 000011 111001 111100 011111 011111 010101 111001 010111 000111
110001 011000 001111 011001 000110 001000 111100 111101 100100 000011
001111 010110 110100 000000 000010 001010 101001 101110 101001 011100
100011 010010 101111 001100 101011 001011 010111 101000 110001 000101
111011 110001 011111 011011 011100 010011 100000 100000 110100 110010
100110 000000 110110 011100 111101 101001 101010 100111 000001 111101
011100 100101 111110 101100 100000 000000 111001 010100 101101 110010
101000 000100 111100 110000 101011 000101 100011 110111 000111 101000
010100 110011 011011 000000 110110 001110 001001 111111 001000 010100
011100 010111 011010 001111 011001 100011 100100 001111 010001 100101
100000 011011 101101 110010 101000 001100 010101 111000 001110 101101
111011 011010 110111 110111 011011 101010 011001 011011 100011 101011
110001 101001 011111 100010 010000 010111 101011 111101 000011 010110
100111 111000 000111 100101 001100 111011 111011 110111 011111 010010
011110 100000 011101 011011 110110 111100 111100 001101 001000 101111]

The B-CNAV1 Subframe 3 is encoded by one 64-ary LDPC(88, 44) 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]

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 101001 101000 101011 011101 111000 100000
000001 001111 110111 010101 100111 001100 000010 101001 001000 100110
000011 101000 110101 110110 010101 001000 010100 011110 111110 101001
000001 000001 101110 100000 101001 110101 110001 011111 001001 000011
010010 011011 101100 010111 100001 000001 000110 000101]

(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 $\mathbf{c} = (\mathbf{c_0}, \mathbf{c_1}, \ldots, \mathbf{c_{n\text{-}1}})$ generated by the non-binary LDPC encoding is transmitted over a channel with the modulation. On the receiving side, the corresponding sequence $\mathbf{y} = (\mathbf{y_0}, \mathbf{y_1}, \ldots, \mathbf{y_{n\text{-}1}})$ 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 $\mathbf{c}_j$ ($\mathbf{c}_j \in \text{GF}(q)$, 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 $\mathbf{y}$. 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 $\mathbf{y}$ 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 $\mathbf{L_j}$ is calculated according to the received symbol vector $\mathbf{y_j}$ corresponding to each codeword symbol $\mathbf{c}_j$. The reliability vector $\mathbf{L_j}$ 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 $\mathbf{L_j}$ 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

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

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. $\Delta_{j,b} = x_b \ \mathrm{XOR}\ \hat{x}_b$, 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 $\mathrm{itr} = \mathrm{itr}_{\mathrm{max}}$, 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 $\mathbf{L}'_{\mathbf{j,n_m}}$:

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

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:

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

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

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

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+2n_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:

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

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

where, θ and β represent the subscripts l of the vectors $(\mathbf{Rs}_{\iota,\mathbf{i}},\mathbf{R}_{\iota,\mathbf{i}})$ whose $(\lfloor n_m/2\rfloor+1)^{th}$ 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 $\mathbf{T}$ 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 $\mathbf{T}$ 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:

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

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

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

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

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

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

otherwise, the value range of w is

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

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

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