BeiDou Navigation Satellite System
Signal In Space
Interface Control Document
Open Service Signal B2b
(Version 1.0)

China Satellite Navigation Office

July, 2020

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 Statement

China Satellite Navigation Office is responsible for the preparation, revision, distribution, and retention of the BeiDou Navigation Satellite System (BDS) Signal In Space Interface Control Documents (hereinafter referred to as SIS ICD), and reserves the rights for final interpretation of this document.

2   Scope

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

This document defines the characteristics of positioning, navigation and timing services provided by the open service signal B2b transmitted by the BDS-3 satellites in Medium Earth Orbits (MEO) and Inclined Geo-Synchronous Orbits (IGSO). Other services provided by the signal B2b will be regulated in other documents.

3　BDS Overview

3.1　Space Constellation

The nominal space constellation of BDS-3 consists of 3 Geostationary Earth Orbit
（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

BDS adopts the BeiDou Coordinate System (BDCS) whose definition complies with the standards of the International Earth Rotation and Reference System Service (IERS). The definition is also consistent with that of the China Geodetic Coordinate System 2000(CGCS2000). BDCS and CGCS2000 have the same reference 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 Reference Ellipsoid

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

Table 3-1　Parameters of the BDCS Reference 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 second of the international system of units (SI) 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

This chapter specifies the signal characteristics of the I-component of the B2b signal with a center frequency of 1207.14MHz and a bandwidth of 20.46MHz.

4.1　Signal Structure

The carrier frequency, modulation, and symbol rate of the B2b I –component (B2b_I) are shown in Table 4-1.

<p align="center">Table 4-1　Structure of the B2b_I</p>

Signal	Carrier frequency(MHz)	Modulation	Symbol rate (sps)
B2b_I	1207.14	BPSK(10)	1000

4.2　Signal Modulation

The B2b_I signal $s_{\mathrm{B2b\_I}}(t)$ is generated by modulating the navigation message data $D_{\mathrm{B2b\_I}}(t)$ and the range code $C_{\mathrm{B2b\_I}}(t)$. The mathematical expression of $s_{\mathrm{B2b\_I}}(t)$ is as follows:

$$s_{\mathrm{B2b\_I}}(t) = \frac{1}{\sqrt{2}} D_{\mathrm{B2b\_I}}(t) \cdot C_{\mathrm{B2b\_I}}(t) \tag{4-1}$$

where $D_{\mathrm{B2b\_I}}(t)$ is as follows:

$$D_{\mathrm{B2b\_I}}(t) = \sum_{k=-\infty}^{\infty} d_{\mathrm{B2b\_I}}[k] p_{T_{\mathrm{B2b\_I}}}\left(t - kT_{\mathrm{B2b\_I}}\right) \tag{4-2}$$

where $d_{\mathrm{B2b\_I}}$ is the navigation message data code; $T_{\mathrm{B2b\_I}}$ is the chip width of the corresponding data code; and $p_{T_{\mathrm{B2b\_I}}}(t)$ is a rectangle pulse with width of $T_{\mathrm{B2b\_I}}$.

The mathematical expression of range code $c_{\mathrm{B2b\_I}}$ is as follows:

$$C_{\mathrm{B2b\_I}}(t) = \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_{\mathrm{B2b\_I}}-1} c_{\mathrm{B2b\_I}}[k] p_{T_{c\_\mathrm{B2b\_I}}}\left(t - \left(N_{\mathrm{B2b\_I}}n + k\right)T_{c\_\mathrm{B2b\_I}}\right) \tag{4-3}$$

where $c_{\mathrm{B2b\_I}}$ is a B2b_I ranging code sequence (possible values are ± 1); $N_{\mathrm{B2b\_I}}$ is the ranging code length with a value of 10230; $T_{c\_\mathrm{B2b\_I}} = 1/R_{c\_\mathrm{B2b\_I}}$ is the B2b_I chip period of the ranging code, and $R_{c\_\mathrm{B2b\_I}} = 10.23$ Mbps is the B2b_I chipping rate; and $p_{T_{c\_\mathrm{B2b\_I}}}(t)$ is a rectangle pulse with duration of $T_{c\_\mathrm{B2b\_I}}$.

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 4-2.

Table 4-2 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 satellite-transmitted signal distortions shall not exceed 0.6dB.

4.8 Data/Code Coherence

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

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 4-3. 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 4-3　Minimum received power levels on ground

Signal	Satellite type	Minimum received power (dBW)
B2b_I	MEO satellite	-160
	IGSO satellite	-162

The BDS satellites provide the B2b_I 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

The B2b_I ranging code chip rate is 10.23 Mcps, and the code length is 10230 chips. Each ranging code is obtained by expanding the Gold code that is generated by the modulo-2 addition of the shifted output of the two 13-stage linear feedback shift registers. The generator polynomials for each B2b_I ranging code are

$$g_1(x) = 1 + x + x^9 + x^{10} + x^{13}$$
$$g_2(x) = 1 + x^3 + x^4 + x^6 + x^9 + x^{12} + x^{13}$$

(5-1)

The implementation of the B2b_I ranging code generators is shown in Figure 5-1.
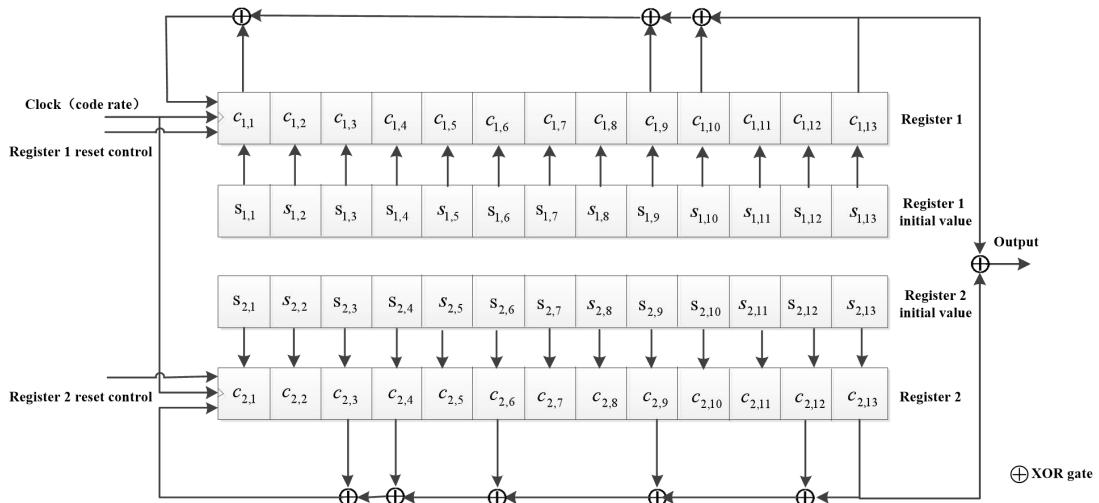
Figure 5-1　Ranging code generator of the B2b_I

In a code generator, the initial bit values of register 1 are all "1", and the initial bit values of register 2 are given in Table 5-1, arranged as $\left[s_{2,1}, s_{2,2}, s_{2,3}, \ldots, s_{2,13} \right]$. At the start of each ranging code period, both register 1 and register 2 are simultaneously reset to their corresponding initial bit values. Furthermore, register 1 is reset at the end of the 8190th chip in each period of a ranging code. A ranging code with the length of 10230 chips is finally obtained by repeating the above procedure.

There are a total of 53 ranging codes for the B2b_I. The detailed parameters are shown in Table 5-1, in which, the values of both the first 24 chips and the last 24 chips are expressed in an octal form. The MSB (i.e., the first chip of the ranging codes) is transmitted first.

Table 5-1   Ranging code parameters of the B2b_I

PRN	Initial bit values of register 2 (binary)	The first 24 chips (octal)	The last 24 chips (octal)
6	1 0 0 0 1 1 0 1 0 1 1 1 0	42471422	44530033
7	1 0 0 0 1 1 1 1 0 1 1 1 0	42071026	63454537
8	1 0 0 0 1 1 1 1 1 1 0 1 1	10070621	52114120
9	1 0 0 1 1 0 0 1 0 1 0 0 1	32631660	15654621
10	1 0 0 1 1 1 1 0 1 1 0 1 0	51031210	12615765
11	1 0 1 0 0 0 0 1 1 0 1 0 1	24752203	23740542
12	1 0 1 0 0 0 1 0 0 0 1 0 0	67353533	07467654
13	1 0 1 0 0 0 1 0 1 0 1 0 1	25353617	52575257
14	1 0 1 0 0 0 1 0 1 1 0 1 1	11351722	55226274
15	1 0 1 0 0 0 1 0 1 1 1 0 0	61351343	01160270
16	1 0 1 0 0 1 0 1 0 0 0 1 1	16550441	50756326
17	1 0 1 0 0 1 1 1 1 0 1 1 1	04153547	27542214
18	1 0 1 0 1 0 0 0 0 0 0 0 1	37651752	10640254
19	1 0 1 0 1 0 0 1 1 1 1 1 0	40652553	14350465
20	1 0 1 0 1 1 0 1 0 1 0 1 1	12451253	57452211
21	1 0 1 0 1 1 0 1 1 0 0 0 1	34450664	00071604
22	1 0 1 1 0 0 1 0 1 0 0 1 1	15313657	10263607
23	1 0 1 1 0 0 1 1 0 0 0 1 0	56312563	13020015
24	1 0 1 1 0 1 0 0 1 1 0 0 0	71510447	47474176
25	1 0 1 1 0 1 0 1 1 0 1 1 0	44513562	16076344
26	1 0 1 1 0 1 1 1 1 0 0 1 0	54112445	55540654
27	1 0 1 1 0 1 1 1 1 1 1 1 1	00111432	62507667
28	1 0 1 1 1 0 0 0 1 0 0 1 0	55610115	63416213
29	1 0 1 1 1 0 0 1 1 1 1 0 0	60613030	32014021
30	1 0 1 1 1 1 0 1 0 0 0 0 1	36410161	43533653
31	1 0 1 1 1 1 1 0 0 1 0 0 0	73013021	61313161
32	1 0 1 1 1 1 1 0 1 0 1 0 0	65010372	03246551
33	1 0 1 1 1 1 1 1 0 1 0 1 1	12013173	07756360
34	1 0 1 1 1 1 1 1 1 0 0 1 1	14011703	01251744
35	1 1 0 0 0 0 1 0 1 0 0 0 1	35360744	27367153
36	1 1 0 0 0 1 0 0 1 0 1 0 0	65561461	77223601
37	1 1 0 0 0 1 0 1 1 0 1 1 1	04561533	11666400
38	1 1 0 0 1 0 0 0 1 0 0 0 1	35661303	35322566
39	1 1 0 0 1 0 0 0 1 1 0 0 1	31661552	07107560
40	1 1 0 0 1 1 0 1 0 1 0 1 1	12463623	46612101
41	1 1 0 0 1 1 0 1 1 0 0 0 1	34462214	11231514
42	1 1 0 0 1 1 1 0 1 0 0 1 0	55062742	50710211

PRN	Initial bit values of register 2 (binary)	The first 24 chips (octal)	The last 24 chips (octal)
43	1 1 0 1 0 0 1 0 1 0 1 0 1	25323543	34555532
44	1 1 0 1 0 0 1 1 1 0 1 0 0	64320656	03034702
45	1 1 0 1 0 1 1 0 0 1 0 1 1	13121550	75766350
46	1 1 0 1 1 0 1 0 1 0 1 1 1	05221747	50550432
47	1 1 1 0 0 0 0 1 1 0 1 0 0	64741521	45030464
48	1 1 1 0 0 0 1 0 0 0 0 0 1 1	17540076	01547030
49	1 1 1 0 0 0 1 0 0 0 1 0 1 1	13540627	33762036
50	1 1 1 0 0 0 1 0 1 0 0 0 1 1	16541066	57616221
51	1 1 1 0 0 0 1 0 1 0 1 0 0 0	72540775	55327237
52	1 1 1 0 1 0 0 1 1 1 0 1 1	10640752	16072557
53	1 1 1 0 1 1 0 0 1 0 1 1 1	05442537	64716537
54	1 1 1 1 0 0 1 0 0 1 0 0 0	73301542	21130334
55	1 1 1 1 0 1 0 0 1 0 1 0 0	65500312	16343063
56	1 1 1 1 0 1 0 0 1 1 0 0 1	31503365	21304050
57	1 1 1 1 0 1 1 0 1 1 0 1 0	51102623	36574544
58	1 1 1 1 0 1 1 1 1 1 0 0 0	70100474	31701764

6 Navigation Message Structure

6.1 Navigation Message Overview

6.1.1 Navigation Message Types

The B2b_I broadcasts the B-CNAV3 navigation message.

6.1.2 Cyclic Redundancy Check

The B-CNAV3 navigation message shall use 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-CNAV3 Navigation Message

6.2.1 Brief Description

The B-CNAV3 navigation message includes basic navigation information and basic integrity information. Each frame has a length of 1000 symbols, with a symbol rate of 1000sps, therefore the transmission of each frame lasts for 1 second. The basic frame structure of B-CNAV3 is defined in Figure 6-1.

After error correction encoding:
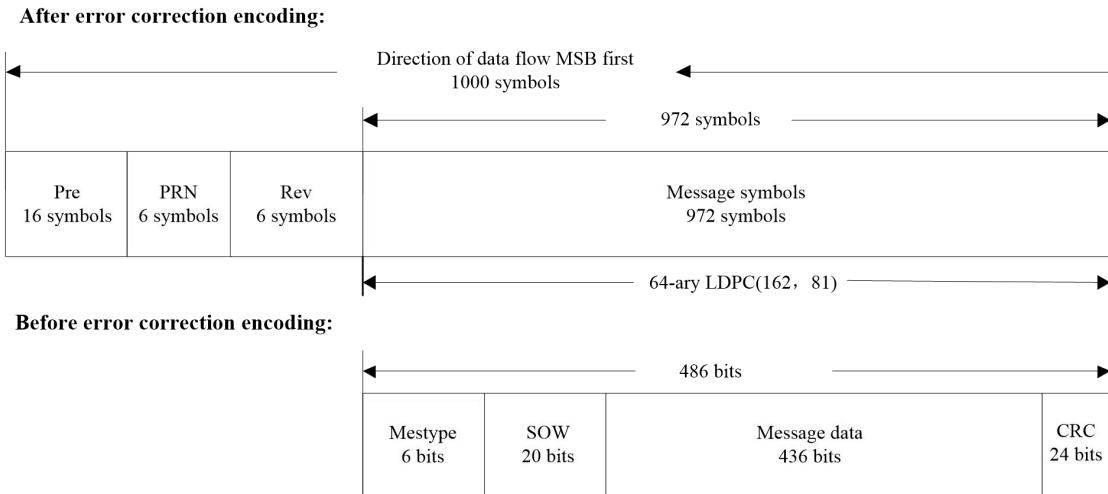
Figure 6-1   B-CNAV3 frame structure

The first 16 symbols of each frame is preamble (Pre) with the value of 0xEB90 in hexadecimal (i.e., 1110 1011 1001 0000 in binary). The MSB is transmitted first. The PRN for ranging code is 6 bits with unsigned integer.

Each frame before error correction encoding has a length of 486 bits, containing Message Type (Mestype, 6 bits), Seconds Of Week (SOW, 20 bits), message data (436 bits), and CRC check bits (24 bits). MesType, SOW, and message data participate in the CRC calculation. After 64-ary LDPC(162, 81) encoding, the frame length shall be 972 symbols.

6.2.2   Coding Methods

The B-CNAV3 navigation messages are encoded with 64-ary LDPC(162,81) code. Each codeword symbol is composed of 6 bits and defined in $GF(2^6)$ domain with a primitive polynomial of $p(x)=1+x+x^6$. A vector representation (MSB first) is used to describe the mapping relationship between non-binary symbols and binary bits. The message length k is equal to 81 code word symbols, i.e., 486 bits. The check matrix is a sparse matrix $\mathbf{H}_{81,162}$ of 81 rows and 162 columns defined in $GF(2^6)$ domain with the primitive polynomial of $p(x)=1+x+x^6$, of which the first 81×81 part corresponds to the information symbols and the last 81×81 part corresponds to the check symbols. The locations of its non-zero elements are defined as follows:

$\mathbf{H}_{81,162,index}=[$

19	67	109	130	27	71	85	161	31	78	96	122	2	44	83	125
26	71	104	132	30	39	93	154	4	46	85	127	21	62	111	127
13	42	101	146	18	66	108	129	27	72	100	153	29	70	84	160
23	61	113	126	8	50	89	131	34	74	111	157	12	44	100	145

22	60	112	128	0	49	115	151	6	47	106	144	33	53	82	140
3	45	84	126	38	80	109	147	9	60	96	141	1	43	82	124
20	77	88	158	37	54	122	159	3	65	104	149	5	47	86	128
0	42	81	123	32	79	97	120	35	72	112	158	15	57	93	138
22	75	107	143	24	69	102	133	1	50	116	152	24	57	119	135
17	59	95	140	7	45	107	145	34	51	83	138	14	43	99	144
21	77	106	142	16	58	94	139	20	68	110	131	2	48	114	150
10	52	91	133	25	70	103	134	32	41	95	153	14	56	91	137
33	73	113	156	28	73	101	154	4	63	102	147	6	48	87	129
8	46	105	146	30	80	98	121	41	68	119	150	35	52	81	139
16	63	114	124	13	55	90	136	31	40	94	155	10	61	97	142
36	56	121	161	29	74	99	155	5	64	103	148	18	75	89	156
36	78	110	148	19	76	87	157	15	65	116	123	11	53	92	134
25	58	117	136	39	66	117	151	11	62	98	143	9	51	90	132
38	55	120	160	7	49	88	130	17	64	115	125				
28	69	86	159	23	76	105	141	12	54	92	135				
40	67	118	152	37	79	108	149	26	59	118	137				

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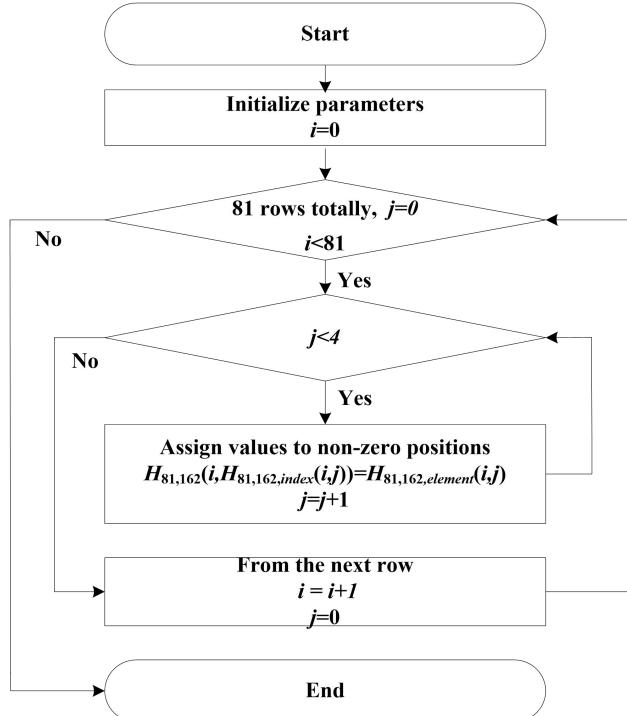
where, each element is a non-binary symbol in GF(2^6) domain. The elements are described by a vector representation as follows:

H$_{81,162,element}$=[

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

].

The above matrix shall be read from top to bottom in the same field, and from left to

13

right after reading each field. In the same field, the four numbers of each row correspond to four non-zero elements in the matrix. The reading rules for $\mathbf{H}_{81,162}$ are shown in Figure 6-2.

Figure 6-2 $\mathbf{H}_{81,162}$ reading flow chart

See Annex for more information about the encoding and decoding methods.

6.2.3   Data Format

At present, B-CNAV3 navigation message defines three valid message types, which are Message Type 10, 30 and 40. The bit allocation for these three message types are shown in Figure 6-3 - Figure 6-5.
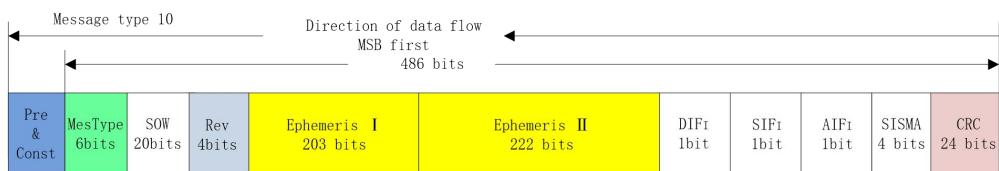
Figure 6-3   Bit allocation for B-CNAV3 Message Type 10
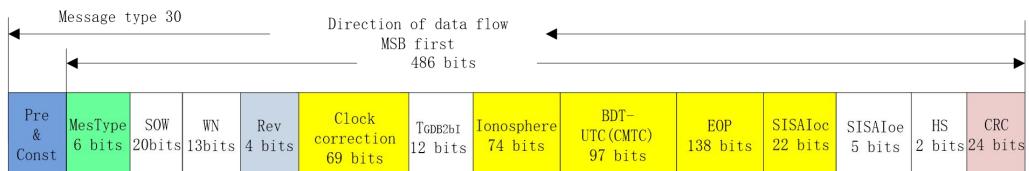
Figure 6-4   Bit allocation for B-CNAV3 Message Type 30

14
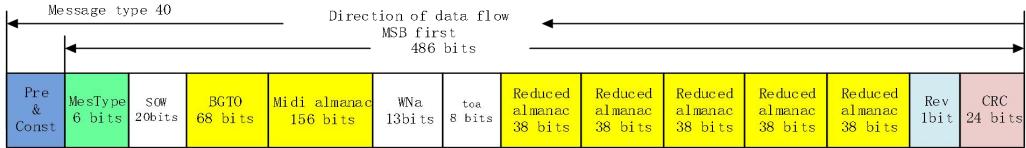
Figure 6-5   Bit allocation for B-CNAV3 Message Type 40

Among the parameters in the above message types, "ephemeris I", "ephemeris II", "clock correction parameters", "SISAI$_{oc}$", "ionospheric delay correction model parameters", "BDT-UTC time offset parameters", "reduced almanac", "EOP parameters", "BGTO parameters", and "midi almanac" are data blocks further constituted of a set of parameters. Data blocks "ephemeris I" and "ephemeris II" constitute a complete set of ephemeris parameters together. The detailed bit allocations of 10 data blocks are shown in Figure 6-6 ~ Figure 6-15.

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

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 6-7   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 6-8   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 6-9   Bit allocation for SISAIoc (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 6-10   Bit allocation for ionospheric delay correction model parameters (74 bits)

15

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 6-11   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 6-12   Bit allocation for reduced almanac parameters (38 bits)

MSB   LSB

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

Figure 6-13   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 6-14   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 6-15   Bit allocation for midi almanac parameters (156 bits)

The message parameters in the B-CNAV3 navigation message will be described in the corresponding sections listed in Table 6-1.

Table 6-1   Descriptions of parameters in the B-CNAV3 navigation message

No.	Message parameter	Parameter description
1	PRN	See Section 7.1 for details
2	MesType	See Section 7.2 for details
3	SOW	See Section 7.3 for details
4	WN	See Section 7.3 for details
5	Clock correction parameters	See Section 7.4 for details

16

No.	Message parameter	Parameter description
6	T_{GDB2bI}	See Section 7.5 for details
7	Ephemeris parameters (Ephemeris I, Ephemeris II)	See Section 7.6 for details
8	Ionospheric delay correction model parameters	See Section 7.7 for details
9	Midi almanac parameters	See Section 7.8 for details
10	WN_a	See Section 7.9 for details
11	t_{oa}	See Section 7.9 for details
12	Reduced almanac parameters	See Section 7.9 for details
13	EOP parameters	See Section 7.10 for details
14	BDT-UTC time offset parameter	See Section 7.11 for details
15	BGTO parameters	See Section 7.12 for details
16	HS	See Section 7.13 for details
17	DIF_I	See Section 7.14 for details
18	SIF_I	See Section 7.14 for details
19	AIF_I	See Section 7.14 for details
20	$SISAI_{oe}$	See Section 7.15 for details
21	$SISAI_{oc}$	See Section 7.15 for details
22	SISMA	See Section 7.16 for details
23	CRC	See Section 6.1.2 for details

7 Navigation Message Parameters and Algorithms

7.1 Ranging Code Number

PRN broadcast in the navigation messages is an unsigned integer with a length of 6 bits.

7.2 Message Types

MesType is used to identify the message types of the B-CNAV3 frames. It is an unsigned integer with a length of 6 bits. Its definition is shown in Table 7-1.

Table 7-1　Message type definition

MesType (Binary)	Message type
000000	Invalid
001010	Message Type 10
011110	Message Type 30
101000	Message Type 40
Others	Reserved

7.3 System Time Parameters

The system time parameters broadcast in B-CNAV3 contain Seconds Of Week (SOW) and Week Number (WN). The definitions of the system time parameters are shown in Table 7-2.

Table 7-2　Definitions of the system time parameters

Parameter	Definition	No. of bits	Scale factor	Effective range	Unit
SOW	Seconds of week	20	3	0~604799	s
WN	Week number	13	1	0~8191	week

SOW is broadcast in all message types of B-CNAV3. The epoch denoted by SOW corresponds to the rising edge of the first chip of the current frame preamble. SOW counts from zero at 00:00:00 each Sunday in BDT and is reset to zero at the end of each week.

WN is the week number of BDT and is broadcast in B-CNAV3 Message Type 30. WN counts from zero at the origin of BDT (i.e., 00:00:00, January 1, 2006 UTC).

7.4　Clock Correction Parameters

7.4.1　Parameters Description

A set of clock correction parameters 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 7-3.

Table 7-3　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.

7.4.2　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:

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

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

19

the ephemeris parameters;

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

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

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

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

7.5 Group Delay differential Parameters

7.5.1 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.

T_{GDB2bI} is the group delay differential between the B2b_I and the B3I signal. T_{GDB2bI} is broadcast in the B-CNAV3 message，which is used to compensate for the equipment group delay of the B2b_I.

The definition and characteristics of the group delay differential parameters are shown in Table 7-4.

Table 7-4   Definitions of the group delay differential parameters

Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
T_{GDB2bI}	Group delay differential of the B2b_I	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.					

7.5.2 User Algorithm

For single frequency receiver users using the B2b_I, the code phase correction is

$$\left(\Delta t_{SV}\right)_{B2bI} = \Delta t_{SV} - T_{GDB2bI} \tag{7-4}$$

7.6 Ephemeris Parameters

7.6.1 Parameters Description

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

The descriptions of the ephemeris parameters are shown in Table 7-5.

Table 7-5 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 7-6.

Table 7-6 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

No.	Parameter	No. of bits	Scale factor	Effective range**	Unit
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:

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

7.6.2 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 7-7.

Table 7-7   User algorithms for the ephemeris parameters

Formula	Description
$\mu = 3.986004418 \times 10^{14}\ \text{m}^3/\text{s}^2$	Geocentric gravitational constant in BDCS
$\dot{\Omega}_e = 7.2921150 \times 10^{-5}\ \text{rad/s}$	Earth's rotation rate in 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
$n_0 = \sqrt{\dfrac{\mu}{A_0^3}}$	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

Formula	Description
$n_A = n_0 + \Delta n_A$	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)
$\begin{cases} \sin v_k = \dfrac{\sqrt{1-e^2}\,\sin E_k}{1-e\cos E_k} \\[2ex] \cos v_k = \dfrac{\cos E_k - e}{1-e\cos E_k} \end{cases}$	True anomaly
$\phi_k = v_k + \omega$	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 the MEO/IGSO satellite 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.

7.7 Ionospheric Delay Correction Model Parameters

7.7.1 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 7-8.

Table 7-8   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

Parameter	No. of bits	Scale factor	Effective range**	Unit
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.				

7.7.2   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:

$$T_{ion} = M_{\text{F}} \cdot \frac{40.28 \times 10^{16}}{f^2} \cdot \left[A_0 + \sum_{i=1}^{9} \alpha_i A_i \right] \qquad (7\text{-}5)$$

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 (7-16); f is the carrier frequency of the current signal (in Hertz); $\alpha_i (i = 1 \sim 9)$ are the BDGIM parameters (in TECu) which are defined in Table 7-8; $A_i (i = 1 \sim 9)$ are calculated by Equation (7-10); A_0 is the predictive ionospheric delay (in TECu) which is calculated by Equation (7-13).

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

$$\psi = \frac{\pi}{2} - E - \arcsin\left(\frac{\text{Re}}{\text{Re} + \text{H}_{ion}} \cdot \cos E \right) \qquad (7\text{-}6)$$

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

altitude of the ionospheric single-layer shell; R_e 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

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

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:

$$\begin{cases} \varphi_m = \arcsin\left(\sin\varphi_M \cdot \sin\varphi_g + \cos\varphi_M \cdot \cos\varphi_g \cdot \cos(\lambda_g - \lambda_M)\right) \\ \lambda_m = \arctan\left(\dfrac{\cos\varphi_g \cdot \sin(\lambda_g - \lambda_M) \cdot \cos\varphi_M}{\sin\varphi_M \cdot \sin\varphi_m - \sin\varphi_g} \right) \end{cases} \tag{7-8}$$

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

$$\begin{cases} \varphi' = \varphi_m \\ \lambda' = \lambda_m - \arctan\left(\dfrac{\sin(S_{lon} - \lambda_M)}{\sin\varphi_M \cdot \cos(S_{lon} - \lambda_M)} \right) \end{cases} \tag{7-9}$$

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

(2) Calculation of $A_i\,(i=1\sim9)$

A_i is calculated as follows:

$$A_i = \begin{cases} \tilde{P}_{|n_i|,|m_i|}(\sin\varphi') \cdot \cos(m_i \cdot \lambda') & m_i \geq 0 \\ \tilde{P}_{|n_i|,|m_i|}(\sin\varphi') \cdot \sin(-m_i \cdot \lambda') & m_i < 0 \end{cases} \tag{7-10}$$

where, the values of n_i and m_i are shown in Table 7-9.

Table 7-9   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 (7-9); $\tilde{P}_{n,m}$ is the normalized Legendre function with degree n and order m, which is calculated as $\tilde{P}_{n,m} = N_{n,m} \cdot P_{n,m}$ (both n and m are taken the absolute values); $N_{n,m}$ is the normalization function, which is calculated as

$$
\begin{cases}
N_{n,m} = \sqrt{\dfrac{(n-m)! \cdot (2n+1) \cdot (2-\delta_{0,m})}{(n+m)!}} \\
\delta_{0,m} = \begin{cases} 1 , & m = 0 \\ 0 , & m > 0 \end{cases}
\end{cases}
\tag{7-11}
$$

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

$$
\begin{cases}
P_{n,n}(\sin\varphi') = (2n-1)!! \left(1 - (\sin\varphi')^2\right)^{n/2}, & n = m \\
P_{n,m}(\sin\varphi') = \sin\varphi' \cdot (2m+1) \cdot P_{m,m}(\sin\varphi'), & n = m+1 \\
P_{n,m}(\sin\varphi') = \dfrac{(2n-1) \cdot \sin\varphi' \cdot P_{n-1,m}(\sin\varphi') - (n+m-1) \cdot P_{n-2,m}(\sin\varphi')}{n-m}, & else
\end{cases}
\tag{7-12}
$$

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:

$$
\begin{cases}
A_0 = \sum_{j=1}^{17} \beta_j \cdot B_j, \\
B_j = \begin{cases} \tilde{P}_{|n_j|,|m_j|}(\sin\varphi') \cdot \cos(m_j \cdot \lambda') & m_j \geq 0 \\ \tilde{P}_{|n_j|,|m_j|}(\sin\varphi') \cdot \sin(-m_j \cdot \lambda') & m_j < 0 \end{cases}
\end{cases}
\tag{7-13}
$$

where, the values of n_j and m_j are shown in Table 7-10; $\tilde{P}_{|n_j|,|m_j|}(\sin\varphi')$ is calculated by Equation (7-11) and (7-12); $\beta_j (j=1\sim17)$ are calculated as follows:

$$
\begin{cases}
\beta_j = a_{0,j} + \sum_{k=1}^{12} \left(a_{k,j} \cdot \cos(\omega_k \cdot t_p) + b_{k,j} \cdot \sin(\omega_k \cdot t_p) \right) \\
\omega_k = \dfrac{2\pi}{T_k}
\end{cases}
\tag{7-14}
$$

where, $a_{k,j}$ and $b_{k,j}$ are the non-broadcast coefficients of BDGIM as shown in Table 7-10 (in TECu); T_k is the period for prediction corresponding to the individual non-broadcast coefficients as shown in Table 7-10; 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

$$VTEC = A_0 + \sum_{i=1}^{9} \alpha_i A_i \tag{7-15}$$

(5) Calculation of the ionospheric mapping function M_F of IPP

The ionospheric mapping function M_F of IPP is calculated as follows:

$$M_F = \frac{1}{\sqrt{1 - \left(\dfrac{Re}{Re + H_{ion}} \cdot \cos(E) \right)^2}} \tag{7-16}$$

where, Re, H_{ion}, and E have been defined in Equation (7-6).

(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 (7-5).

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

Altitude of the ionospheric single-layer shell: $H_{ion} = 400 \text{ km}$;
Mean radius of the Earth: $Re = 6378 \text{ km}$;

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

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

Table 7-10　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
	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	T_k/day
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   Midi Almanac Parameters

7.8.1   Parameters Description

The midi almanac contains 14 parameters. The definitions of the midi almanac parameters are described in Table 7-11.

Table 7-11   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 7-12.

Table 7-12   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 bit	0	B2b_I signal is normal
	1	B2b_I signal is abnormal**
The 4th ~ 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.		

7.8.2   User Algorithm

The user shall compute the BDT time of signal transmission as

$$t = t_{sv} - \Delta t_{sv} \tag{7-17}$$

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):

$$\Delta t_{sv} = a_{f0} + a_{f1}\left(t - t_{oa}\right) \tag{7-18}$$

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 7-13.

Table 7-13   User algorithms for the midi almanac parameters

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

Formula	Description
$A = \left(\sqrt{A}\right)^2$	Semi-major axis
$n_0 = \sqrt{\dfrac{\mu}{A^3}}$	Computed mean motion (rad/s) at reference time
$t_k = t - t_{\text{oa}}$ *	Time from ephemeris reference time
$M_k = M_0 + n_0 t_k$	Mean anomaly
$M_k = E_k - e \sin E_k$	Kepler's equation for eccentric anomaly (may be solved by iteration)
$\begin{cases} \sin v_k = \dfrac{\sqrt{1-e^2}\, \sin E_k}{1 - e \cos E_k} \\ \cos v_k = \dfrac{\cos E_k - e}{1 - e \cos E_k} \end{cases}$	True anomaly
$\phi_k = v_k + \omega$	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
$\Omega_k = \Omega_0 + \left(\dot{\Omega} - \dot{\Omega}_e\right) t_k - \dot{\Omega}_e t_{\text{oa}}$	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, $i_0 = 0.00$.

7.9 Reduced Almanac parameters

7.9.1 Parameters Description

The definitions and characteristics of the reduced almanac parameters are shown in Table 7-14.

Table 7-14   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	--	--	--

No.	Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
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} = 27906100m（MEO） A_{ref} = 42162200m（IGSO/GEO）.
**** Φ_0=M_0+ω, relative to the following reference values:
e = 0;
δ_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.

7.9.2 User Algorithm

The user algorithm for the reduced almanac parameters is the same as the user algorithm for the midi almanac. Other parameters appearing in the equations midi almanac, but not provided in reduced almanac, the reference values are set to 0.

The definitions of the almanac reference week number WN_a and the almanac reference time t_{oa} corresponding to the reduced almanac are shown in Table 7-15.

Table 7-15 Definitions of the almanac reference time parameters

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

7.10 Earth Orientation Parameters

7.10.1 Parameters Description

The definitions of the Earth Orientation Parameters are shown in Table 7-16.

Table 7-16   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
$\Delta\dot{UT1}$	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.

7.10.2   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 7-17.

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

Table 7-17   User algorithms for the EOP parameters

Formula	Description
$\mathrm{UT1} - \mathrm{UTC} = \Delta UT1 + \Delta\dot{UT1}(t - t_{EOP})$	UT1-UTC difference at time t
$x_p = PM\_X + \dot{PM}\_X\,(t - t_{EOP})$ $y_p = PM\_Y + \dot{PM}\_Y\,(t - t_{EOP})$	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.	

7.11   BDT-UTC Time Offset Parameters

7.11.1   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 7-18.

Table 7-18   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.						

7.11.2   User Algorithm

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

(1) Whenever the leap second time indicated by WNLSF 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:

$$t_{UTC} = (t_E - \Delta t_{UTC}) \bmod 86400 \qquad (7\text{-}19)$$

$$\Delta t_{\text{UTC}} = \Delta t_{\text{LS}} + A_{0\text{UTC}} + A_{1\text{UTC}} \left(t_{\text{E}} - t_{\text{ot}} + 604800 \left(\text{WN} - \text{WN}_{\text{ot}} \right) \right) +$$
$$A_{2\text{UTC}} \left(t_{\text{E}} - t_{\text{ot}} + 604800 \left(\text{WN} - \text{WN}_{\text{ot}} \right) \right)^2 \tag{7-20}$$

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:

$$t_{\text{UTC}} = \text{W mod} \left(86400 + \Delta t_{\text{LSF}} - \Delta t_{\text{LS}} \right) \tag{7-21}$$
$$\text{W} = \left((t_{\text{E}} - \Delta t_{\text{UTC}} - 43200) \bmod 86400 \right) + 43200 \tag{7-22}$$

where, the calculation method of Δt_{UTC} is shown in Equation (7-20).

(3) Whenever the leap second time indicated by WNLSF 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:

$$t_{\text{UTC}} = \left(t_{\text{E}} - \Delta t_{\text{UTC}} \right) \bmod 86400 \tag{7-23}$$
$$\Delta t_{\text{UTC}} = \Delta t_{\text{LSF}} + A_{0\text{UTC}} + A_{1\text{UTC}} \left(t_{\text{E}} - t_{\text{ot}} + 604800 \left(\text{WN} - \text{WN}_{\text{ot}} \right) \right) +$$
$$A_{2\text{UTC}} \left(t_{\text{E}} - t_{\text{ot}} + 604800 \left(\text{WN} - \text{WN}_{\text{ot}} \right) \right)^2 \tag{7-24}$$

7.12 BDT-GNSS Time Offset Parameters

7.12.1 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 7-19.

Table 7-19　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	$\text{WN}_{0\text{BGTO}}$	Reference week number	13	1	--	week
3	$t_{0\text{BGTO}}$	Reference time of week	16	2^4	0~604784	s
4	$A_{0\text{BGTO}}$	Bias coefficient of BDT time scale	16*	2^{-35}	--	s

35

No.	Parameter	Definition	No. of bits	Scale factor	Effective range**	Unit
		relative to GNSS time scale				
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 WN_{0BGTO}, t_{0BGTO}, A_{0BGTO}, A_{1BGTO}, and A_{2BGTO} broadcast in the same frame correspond to the system identified by GNSS ID. The BGTO parameters broadcast in different frames may be different, and the user should recognize GNSS ID every time when the BGTO parameters are received.

7.12.2   User Algorithm

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

$$\Delta t_{\mathrm{Systems}} = t_{\mathrm{BD}} - t_{\mathrm{GNSS}} = A_{0BGTO} + A_{1BGTO}\left[t_{\mathrm{BD}} - t_{0BGTO} + 604800\left(\mathrm{WN} - \mathrm{WN}_{0BGTO}\right)\right] + \\ A_{2BGTO}\left[t_{\mathrm{BD}} - t_{0BGTO} + 604800\left(\mathrm{WN} - \mathrm{WN}_{0BGTO}\right)\right]^2 \quad (7\text{-}25)$$

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

7.13   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 7-20.

Table 7-20   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

7.14   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 7-21.

Table 7-21   Definitions of the satellite integrity status flag parameters

Parameter	Value	Definition
DIF_I	0	The error of message parameters broadcast in this signal does not exceed the predictive accuracy
	1	The error of message parameters broadcast in this signal exceeds the predictive accuracy
SIF_I	0	This signal is normal
	1	This signal is abnormal
AIF_I	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 7.16.		

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

7.15   Signal In Space Accuracy Index

The signal in space accuracy describes the predictive accuracy of the orbital parameters

37

and clock correction parameters broadcast in the navigation message. It contains the along-track and cross-track accuracy of the satellite orbit ($SISA_{oe}$) and the satellite orbit radial and satellite clock correction accuracy ($SISA_{oc}$).

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

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

(2) $SISAI_{ocb}$: the combined satellite orbit radial and fixed satellite clock offset accuracy ($SISA_{ocb}$) index;

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

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

(5) t_{op}: the 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.

7.16   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 Abbreviations

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

MSB	Most Significant Bit
NTSC	National Time Service Center
PRN	Pseudo-Random Noise
RHCP	Right-Hand Circular Polarization
RMS	Root Mean Square
SOW	Seconds Of Week
sps	symbols per second
TEC	Total Electron Content
TECu	Total Electron Content unit
UT	Universal Time
UTC	Universal Time Coordinated
WN	Week Number

Annex   Non-binary LDPC Encoding and Decoding Methods

1. Non-binary LDPC Encoding

The generator matrix $\mathbf{G}$ 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 $\mathbf{c}$ of length n can be generated by encoding the input information sequence $\mathbf{m}$ of length k with the generator matrix $\mathbf{G}$, 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 jth codeword symbol, and $\mathbf{p} = \mathbf{m} \cdot (\mathbf{H}_2^{-1} \cdot \mathbf{H}_1)^{T}$ is the check sequence.

The method for generating the generator matrix $\mathbf{G}$ is given as follows:

Step 1: The matrix $\mathbf{H}$ 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 $\mathbf{H}$ into the systematic form, i.e., multiply $\mathbf{H}$ 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 $\mathbf{G} = [\mathbf{I}_k, (\mathbf{H}_2^{-1} \cdot \mathbf{H}_1)^{T}]$, where $\mathbf{I}_k$ is a unit matrix of size k×k.

(1) Encoding Example

The B-CNAV3 message data are encoded by one 64-ary LDPC(162, 81) 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];

The corresponding 64-ary information is

[10 50 19 33 10 38 16 41 44 47 28 5 14 58 9 52 34 63 5 28 6 61 0 49 52 55 5 25 16 51 27 58 11 16 9 8 55 37 35 9 54 39 22

32 25 4   15 7   11 15 26 3   57 60 31 31 21 57 23 7   49 24 15 25

6   8   60 61 36 3   15 22 52 0   2   10 41 46 41 28 35];

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 100100 101110 111001 000000 110111 000001 010110

101101 110010 001001 011011 001001 011010 000011 001011 101001 010101 011111

001101 101011 011110 001101 111101 011111 010100 001000 000110 100100 000011

101101 001100 111001 111011 010111 001010 101011 101101 111111 000001 111100

001111 101111 001010 000110 101000 111000 011000 000010 010011 010011 101110

101011 010011 111101 011010 000001 000111 111101 001011 110111 110000 101011

110001 101100 110010 011011 011111 011011 001100 111100 110011 111010 001111

000110 011101 111101 100111 100110 000101 110101 100010];

The corresponding 64-ary codeword is

[10 50 19 33 10 38 16 41 44 47 28 5   14 58 9   52 34 63 5   28 6   61

0   49 52 55 5   25 16 51 27 58 11 16 9   8   55 37 35 9   54 39 22

32 25 4   15 7   11 15 26 3   57 60 31 31 21 57 23 7   49 24 15 25

6   8   60 61 36 3   15 22 52 0   2   10 41 46 41 28 35 36 46 57 0

55 1   22 45 50 9   27 9   26 3   11 41 21 31 13 43 30 13 61 31 20

8   6   36 3   45 12 57 59 23 10 43 45 63 1   60 15 47 10 6   40 56

24 2   19 19 46 43 19 61 26 1   7   61 11 55 48 43 49 44 50 27 31

27 12 60 51 58 15 6   29 61 39 38 5   53 34];

(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

42

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:

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

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

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

2. Non-binary LDPC Decoding

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

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 $\hat{\mathbf{c}} = (\hat{c}_0, \hat{c}_1, \ldots, \hat{c}_{n-1})$ 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 $\mathbf{s} = \mathbf{0}$, $\hat{\mathbf{c}}$ is output as the correct decoding, 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 $h_{i,j} \in GF(q)$ is an element in $GF(q)$, 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 iteratively updated by using the reliability transmitting decoding algorithm to correct the received sequence $\mathbf{Y}$, and then the codeword $\mathbf{c}$ is correctly estimated.

Two iterative reliability transmitting decoding algorithms used to estimate the codeword $\mathbf{c}$ 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 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 lth ($0 \le l < q$) element of $\mathbf{L_j}$ consists of the lth Galois field symbol x and its LLR value. The logarithmic likelihood ratio of the Galois field element x in the reliability vector $\mathbf{L_j}$ is

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

where $\hat{x}$ is the element in $\mathrm{GF}(q)$ which maximizes the probability $P(\mathbf{y_j}|x)$, 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 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 ($0 \leq j < n$), the decision symbol $\hat{\mathbf{c}}_j$ 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 $\hat{\mathbf{c}}$ as decoding result and exit the decoding, otherwise, go into Step 3.

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

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

1) Updating Rules of Variable Nodes

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

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

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 $\mathrm{itr} \neq 0$, it is assumed that $\mathrm{C2V}_{f \to j}$ is the reliability vector of length n_m which is transmitted from the check node CN_f to the connecting variable node VN_j and then the reliability vector $\mathrm{V2C}_{j \to i}$ can be calculated by using all the received reliability vectors, $\mathrm{C2V}_{f \to j} (f \in M_j, f \neq i)$, as follows:

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

where the Galois field element $h_{f,j}^{-1}$ is the inverse element of $h_{f,j}$, i.e., $h_{f,j}^{-1} \cdot h_{f,j} = 1$. In the above equation, the sum operation adds the LLR values of the same elements in each reliability vector $\mathrm{C2V}_{f \to j} \cdot h_{f,j}^{-1}$. $(\bullet)_{n_m}$ 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 $\mathrm{C2V}_{f \to j}$ is set as the sum of the maximum LLR value in $\mathrm{C2V}_{f \to j}$ 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 $\{\sum_{f \in M_j} \mathrm{C2V}_{f \to j} \cdot h_{f,j}^{-1} + \mathbf{L_j}\}$ of length q is selected as a decision value. The related decision formula is

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

The decision symbol $\hat{\mathbf{c}}_{\mathbf{j}}$ 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 $\hat{\mathbf{c}} = (\hat{\mathbf{c}}_0, \hat{\mathbf{c}}_1, ..., \hat{\mathbf{c}}_{\mathbf{n\text{-}1}})$ satisfies that $\mathbf{s} = \hat{\mathbf{c}}\mathbf{H}^\mathrm{T}$ is a zero vector.

2) Updating Rules of Check Nodes

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

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

where, each sum operation is defined as the basic calculation of the check node; when two reliability vectors containing n_m Galois field elements and their LLR vectors are inputted, the candidate elements are 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 $(\mathbf{U_s}, \mathbf{U})$ and $(\mathbf{Q_s}, \mathbf{Q})$, and the output reliability vector is given as $(\mathbf{V_s}, \mathbf{V})$, where $\mathbf{U}$, $\mathbf{Q}$, $\mathbf{V}$ are the LLR vectors of length n_m arranged in ascending order, and $\mathbf{U_s}$, $\mathbf{Q_s}$, $\mathbf{V_s}$ 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 $\mathbf{M_s}$ 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

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

The implementation of the above equations 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 $S[\zeta] = M[\zeta,0]$, $\zeta \in \{0,1,\ldots,n_m-1\}$. 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 are 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+2n_m is calculated by using four received reliability vectors $V2C_{j \to i} = (\mathbf{Rs}_{j \to i}, \mathbf{R}_{j \to i})$ ($j \in N_i$) 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 $V2C_{j \to i}$ are sorted in ascending order according to the LLR values $R_{j \to i}[1]$ of the second elements $V2C_{j \to i}[1] = (Rs_{j \to i}[1], R_{j \to i}[1])$ (i.e., its subscript is "1") of $V2C_{j \to i}$. The four sorted vectors are defined as $(\mathbf{Rs_{l,i}}, \mathbf{R_{l,i}})$, $0 \le l < 4$, i.e., $R_{0,i}[1] \le R_{1,i}[1] \le R_{2,i}[1] \le R_{3,i}[1]$, where $\mathbf{Rs_{l,i}}$ is the Galois field element vector of length n_m, and $\mathbf{R_{l,i}}$ 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 $\mathbf{Rs_{l,i}}$ and $\mathbf{R_{l,i}}$ which

47

are calculated by the equations as follows:

$$Rs_i[e] = \begin{cases} \sum_{0 \leq l < 4} Rs_{l,i}[0], & e = 0 \\ Rs_{e-1,i}[1] \oplus \sum_{0 \leq l < 4, l \neq e-1} Rs_{l,i}[0], & 1 \leq e \leq 4 \\ Rs_{0,i}[1] \oplus Rs_{e-4,i}[1] \oplus \sum_{1 \leq l < 4, l \neq e-4} Rs_{l,i}[0], & 5 \leq e \leq 7 \\ Rs_{0,i}[0] \oplus Rs_{1,i}[1] \oplus Rs_{2,i}[1] \oplus Rs_{3,i}[0], & e = 8 \\ Rs_{0,i}[0] \oplus Rs_{1,i}[1] \oplus Rs_{2,i}[0] \oplus Rs_{3,i}[1], & e = 9 \\ Rs_{e-10,i}[2] \oplus \sum_{0 \leq l < 4, l \neq e-10} Rs_{l,i}[0], & 10 \leq e < 14 \\ Rs_{\theta,i}[e-11] \oplus \sum_{0 \leq l < 4, l \neq \theta} Rs_{l,i}[0], & 14 \leq e < 11 + n_m \\ Rs_{\beta,i}[e-8-n_m] \oplus \sum_{0 \leq l < 4, l \neq \beta} Rs_{l,i}[0], & 11 + n_m \leq e < 8 + 2n_m \end{cases}$$

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

Where, θ and β represent the subscripts l of the vector $\mathbf{R}_{l,i}$ 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 $\overline{\mathbf{T}}$ of length $8 + 2n_m$ and initialize them to all "1" vectors. The updating rules for the first $0 \leq k_R < 8 + 2n_m$ values of the flag vectors $\mathbf{T}$ and $\overline{\mathbf{T}}$ are defined by the following equations:

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

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

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

$$\mathbf{Us}_{i,l} = (Rs_i[w] \oplus Rs_{l,i}[0])_{n_m}$$

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

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

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

otherwise, the value range of w is

$$\{w \mid \overline{T}[w] = 1\} \bigcap \{\{w = 0\} \bigcup \{1 < w \le 4\} \bigcup \{8 \le w < 10\} \bigcup \{10 < w < 14\} \bigcup \{w \ge 11 + n_m\}\}$$ In the case of $1 \le l < 4$, if $l = \theta$, the value range of w is

$$\{w \mid \overline{T}[w] = 1\} \bigcap \{\{0 \le w \le 7\} \bigcup \{10 \le w < 14\} \bigcup \{w \ge 11 + n_m\}\} \bigcap \{\{w \ne l + 1\} \bigcap \{w \ne 4 + l\} \bigcap \{w \ne 10 + l\}\}$$ otherwise, the value range of w is

$$\{w \mid T[w] = 1\} \bigcap \{\{0 \le w \le 7\} \bigcup \{10 \le w < 11 + n_m\}\} \bigcap \{\{w \ne l + 1\} \bigcap \{w \ne 4 + l\} \bigcap \{w \ne 10 + l\}\} \qquad Us_{i,l}[z]$$

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

The order of the four reliability vectors $\left(\mathbf{Us_{i,l}}, \mathbf{U_{i,l}} \right)$ is aligned with the four sorted input vectors $\left(\mathbf{Rs_{l,i}}, \mathbf{R_{l,i}} \right)$. Each input vector $\left(\mathbf{Rs_{l,i}}, \mathbf{R_{l,i}} \right)$ corresponds to a $V2C_{j \to i}$ vector. Each reliability vector $C2V_{i \to j} = (\mathbf{Us_{i,l}}, \mathbf{U_{i,l}})$, ($j \in N_i$) is updated and output according to the sequence order between $\left(\mathbf{Rs_{l,i}}, \mathbf{R_{l,i}} \right)$ and $V2C_{j \to i}$.