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INTERFACE SPECIFICATION DOCUMENT

30 September 2003

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IS TITLE

Navstar GPS Space Segment / User Segment L5 Interfaces

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1. SCOPE

1.1 Scope. This Interface Specification (IS) defines the requirements related to the interface between the Space Segment (SS) of the Global Positioning System (GPS) and the Navigation Users of the GPS for the L5 Navigation Signal.

1.2 IS Approval and Changes. ARINC Engineering Services, LLC has been designated the Interface Control Contractor (ICC), and is responsible for the basic preparation, approval, distribution, and retention of the IS in accordance with SMC/GZ Operating instruction 63-1102. The Navstar GPS Joint Program is the only signatory necessary to make this IS effective. The JPO administers approvals under the auspices of the Configuration Control Board (CCB), which is governed by CZ Operating Instruction 63-1101. Military organizations and contractors are represented by their respective segment member. All civil organizations are represented by the Department of Transportation member (SMC/GPC).

Proposed changes to the approved version of this IS can be initiated by any participating organization. The ICC is responsible for maintaining a distribution list of all reviewing organizations and distributing submitted changes. The ICC is responsible for the preparation of the change paper and change coordination, in accordance with SMC/GZ Operating Instruction 63-1102, and presentation of the change before the NAVSTAR GPS Joint Program Office Configuration Control Board in accordance with CZ OI 63-1101.

Any exception to this IS or its changes shall be administered in the form of comment submitted through the respective Configuration Control Board member. Standard practices mandated by CZ Operating Instruction 63-1101 include compiling all submitted comments and indicating the project officer's proposed resolution. Exceptions of the type stating applicability of this IS to a particular contract shall be submitted through the Procuring Contracting Officer for that contract.

Review cycle for all Proposed Interface Revision Notices (PIRNs) is 45 days after receipt by individual addressees unless a written request for a waiver is submitted to the ICC. Non-responses are interpreted as acceptance.

2. APPLICABLE DOCUMENTS

2.1 Government Documents. The following documents of the issue specified contribute to the definition of the interfaces between the GPS Space Segment (GPS SS) and the GPS Navigation User Segment (GPS US), and form a part of this IS to the extent specified herein.

Specifications

Federal

None

Military

None

Other Government Activity

None

Standards

Federal

None

Military

None

Other Publications

ICD-GPS-200 current issue	Navstar GPS Space Segment / Navigation User Interfaces
SMC/CZ Operating Instruction 63-1102 26 February 2002	Interface Control Working Group (ICWG) Charter for Developmental and Operational Interface Specification

2.2 Non-Government Documents. The following documents of the issue specified contribute to the definition of the interfaces between the GPS SS and the GPS Navigation US and form a part of this IS to the extent specified herein.

Specifications

None

Other Publications

None

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3. REQUIREMENTS

3.1 Interface Definition. The signal interface between the GPS SS and the GPS Navigation US consists of three radio frequency (RF) links: L1, L2 and L5. Figure 3-1 illustrates the interface between the SS and the users. The L5 link is only available on Block IIF and the planned future Block III SVs. Utilizing these links, the space vehicles (SVs) of the SS shall provide continuous earth coverage signals that provide to the users the ranging codes and the system data needed to accomplish the GPS navigation (NAV) mission. These signals shall be available to a suitably equipped user with RF visibility to an SV, including users in terrestrial and near-terrestrial applications as well as users in orbital applications up to geostationary altitude. The civil functions of the L1 and L2 RF links are specified in ICD-GPS-200. Only the L5 link and its relationship with the L1 and L2 links are specified herein.

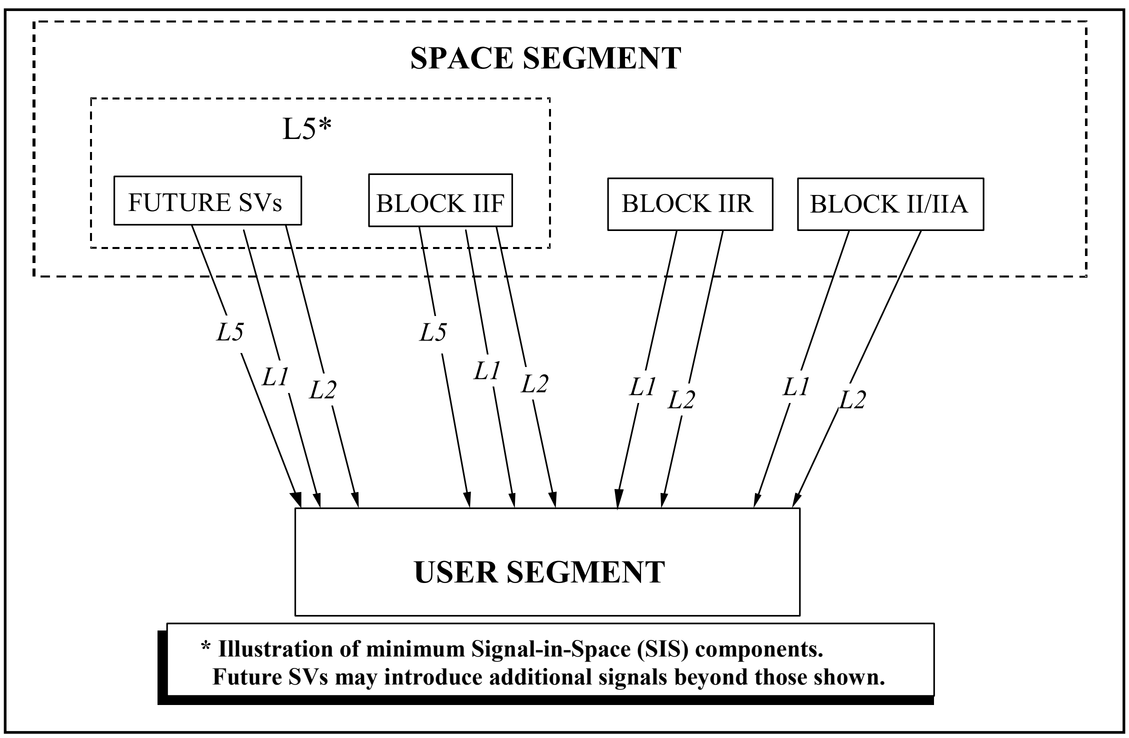


Figure 3-1. GPS Space Segment to User Segment Interfaces

3.2 Interface Identification. The carriers of the L5 L-band link are modulated by two bit trains in phase quadrature. One is a composite bit train generated by the modulo-2 addition of a pseudo-random noise (PRN) ranging code, a synchronization sequence, and the downlink system data (referred to as NAV data), and the second is modulated with a PRN ranging code and synchronization sequence that differ from those used with the NAV data.

3.2.1 Ranging Codes. Two PRN ranging codes are transmitted on L5: the in-phase code (denoted as the I5-code); and the quadraphase code (denoted as the Q5-code). Code-division-multiple-access techniques allow differentiating between the SVs even though they all transmit at the same L5 frequency. The SVs shall transmit intentionally "incorrect" versions of the I5 and the Q5-codes when needed to protect the users from receiving and utilizing anomalous NAV signals. These two "incorrect" codes are termed non-standard I5 (NSI5) and non-standard Q5 (NSQ5) codes.

3.2.1.1 L5-Codes. The PRN ranging codes $I5_i(t)$ and $Q5_i(t)$ for SV ID number i are independent, but time synchronized, 1 millisecond in length, a chipping rate of 10.23 Mbps. For each code, the 1-millisecond sequences are the modulo-2 sum of two sub-sequences referred to as XA and XB_i; their lengths are 8,190 chips and 8,191 chips, respectively that restart to generate the 10,230 chip code. The XB_i sequence is selectively advanced, thereby allowing the basic code generation technique to produce a set of 74 (37 I5 and 37 Q5) different code sequences of 1-millisecond in length. Of these, 32 pairs are designated for use by SVs, while the remaining 5 pairs are reserved. Assignment of these code phase segments by SV-ID number (or other use) is given in Table 3-I. SV-ID numbers and PRN are identical to those for the L1 and L2 signals as specified in ICD-GPS-200.

The 74 codes are a selected subset of over 4,000 possible codes that could be generated using the selective advance. The remaining codes are reserved for other L5 signal applications such as Satellite-Based Augmentation System (SBAS) satellite signals.

3.2.1.2 Non-Standard Codes. The NSI5 and NSQ5 codes, used to protect the user from a malfunction in the SV's reference frequency generation system (reference paragraph 3.2.1), are not for utilization by the user and, therefore, are not defined in this document. The SVs shall also be capable of initiating and terminating the broadcast of NSI5 and/or NSQ5 code(s) independently of each other, in response to Control Segment (CS) command.

3.2.2 NAV Data. The system data, $D_5(t)$, includes SV ephemerides, system time, SV clock behavior data, status messages and time information, etc. The 50 bps data is coded in a rate 1/2 convolutional coder. The resulting 100 symbols per second (sps) symbol stream is modulo-2 added to the I5-code only; the resultant bit-train is used to modulate the L5 in-phase (I) carrier. The content and characteristics of the system data, $D_5(t)$, are given in Appendix II of this document. In general, the data content is based on that modulated on the C/A-codes in the L1 and L2 channels of the SV, with data specific to the L5 signal added, and a different error detection encoding used.

The L5 quadraphase (Q5) carrier has no data.

Table 3-I. Code Phase Assignments (sheet 1 of 2)

GPS PRN Signal No.*	XB Code Advance – Chips**		Initial XB Code State***	
	I5	Q5	I5	Q5
1	266	1701	0101011100100	1001011001100
2	365	323	1100000110101	0100011110110
3	804	5292	0100000001000	1111000100011
4	1138	2020	1011000100110	0011101101010
5	1509	5429	1110111010111	0011110110010
6	1559	7136	0110011111010	0101010101001
7	1756	1041	1010010011111	1111110000001
8	2084	5947	1011110100100	0110101101000
9	2170	4315	1111100101011	1011101000011
10	2303	148	0111111011110	0010010000110
11	2527	535	0000100111010	0001000000101
12	2687	1939	1110011111001	0101011000101
13	2930	5206	0001110011100	0100110100101
14	3471	5910	0100000100111	1010000111111
15	3940	3595	0110101011010	1011110001111
16	4132	5135	0001111001001	1101001011111
17	4332	6082	0100110001111	1110011001000
18	4924	6990	1111000011110	1011011100100
19	5343	3546	1100100011111	0011001011011

* PRN sequences 33 through 37 are reserved for other uses (e.g. ground transmitters).

** XB Code Advance is the number of XB clock cycles beyond an initial state of all 1s.

*** In the binary notation for the first 13 chips of the I5 and Q5 XB codes as shown in these columns. The rightmost bit is the first bit out. Since the initial state of the XA Code is all 1s, these first 13 chips are also the complement of the initial states of the I5 or Q5-codes.

NOTE: The code phase assignments constitute inseparable pairs, each consisting of a specific I5 and a specific Q5-code phase, as shown above.

Table 3-I. Code Phase Assignments (sheet 2 of 2)

GPS PRN Signal No.*	XB Code Advance – Chips**		Initial XB Code State***	
	I5	Q5	I5	Q5
20	5443	1523	0110101101101	1100001110001
21	5641	4548	0010000001000	0110110010000
22	5816	4484	1110111101111	0010110001110
23	5898	1893	1000011111110	1000101111101
24	5918	3961	1100010110100	0110111110011
25	5955	7106	1101001101101	0100010011011
26	6243	5299	1010110010110	0101010111100
27	6345	4660	0101011011110	1000011111010
28	6477	276	0111101010110	1111101000010
29	6518	4389	0101111100001	0101000100100
30	6875	3783	1000010110111	1000001111001
31	7168	1591	0001010011110	0101111100101
32	7187	1601	0000010111001	1001000101010
33	7329	749	1101010000001	1011001000100
34	7577	1387	1101111111001	1111001000100
35	7720	1661	1111011011100	0110010110011
36	7777	3210	1001011001000	0011110101111
37	8057	708	0011010010000	0010011010001

* PRN sequences 33 through 37 are reserved for other uses (e.g. ground transmitters).

** XB Code Advance is the number of XB clock cycles beyond an initial state of all 1s.

*** In the binary notation for the first 13 chips of the I5 and Q5 XB codes as shown in these columns. The rightmost bit is the first bit out. Since the initial state of the XA Code is all 1s, these first 13 chips are also the complement of the initial states of the I5 or Q5-codes.

NOTE: The code phase assignments constitute inseparable pairs, each consisting of a specific I5 and a specific Q5-code phase, as shown above.

3.2.3 L5 Signal Structure. The L5 consists of two carrier components that are in phase quadrature with each other. Each carrier component is bi-phase shift key (BPSK) modulated by a separate bit train. One bit train is the modulo-2 sum of the I5-code, NAV data, and synchronization sequence while the other is the Q5-code with no NAV data, but with another synchronization sequence. For a particular SV, all transmitted signal elements (carriers, codes, synchronization sequences, and data) are coherently derived from the same on-board frequency source.

3.3 Interface Criteria. The criteria specified in the following define the requisite characteristics of the L5 interface.

3.3.1 Composite Signal. The following criteria define the characteristics of the composite L5 signal.

3.3.1.1 Frequency Plan. The L5 signal is contained within a 24 MHz band centered about the L5 nominal frequency. The carrier frequencies for the L1, L2 and L5 signals shall be coherently derived from a common frequency source within the SV. The nominal frequency of this source -- as it appears to an observer on the ground -- is 10.23 MHz. The SV carrier frequency and clock rates -- as they would appear to an observer located in the SV -- are offset to compensate for relativistic effects. The clock rates are offset by $\Delta f/f = -4.4647E-10$, equivalent to a change in the I5 and Q5-code chipping rate of 10.23 MHz offset by a $\Delta f = -4.5674E-3$ Hz. This is equal to 10.22999999543 MHz. The nominal carrier frequency (f_0) -- as it appears to an observer on the ground – shall be 1176.45 MHz, or 115 times 10.23 MHz.

3.3.1.2 Correlation Loss. Correlation loss is defined as the difference between the SV power received in a 24 MHz bandwidth and the signal power recovered in an ideal correlation receiver. The worst case correlation loss occurs when the I5 carrier is modulated by the sum of the I5-code and the NAV data stream. For this case, the correlation loss apportionment shall be as follows:

1. SV modulation and filter imperfections: 0.6 dB
2. Ideal UE receiver waveform distortion (due to 24 MHz filter): 0.4 dB

3.3.1.3 Carrier Phase Noise. The phase noise spectral density of the un-modulated carrier shall be such that a phase locked loop of 10 Hz one-sided noise bandwidth shall be able to track the carrier to an accuracy of 0.1 radians root mean square (RMS). See additional supporting material for phase noise characteristics in section 6.3.2.

3.3.1.4 Spurious Transmissions. In-band spurious transmissions shall be at least 40 dB below the un-modulated L5 carrier over the allocated 24 MHz channel bandwidth.

3.3.1.5 Phase Quadrature. The two L5 carrier components modulated by the two separate bit trains (I5-code plus data and Q5-code with no data) shall be in phase quadrature (within ±100 milliradians) with the Q5 signal carrier lagging the I5 signal by 90 degrees. Referring to the phase of the I5 carrier when $I5_i(t)$ equals zero as the "zero phase angle", the I5 and Q5-code generator output shall control the respective signal phases in the following manner: when $I5_i(t)$ equals one, a 180-degree phase reversal of the I5-carrier occurs; when $Q5_i(t)$ equals one, the Q5 carrier advances 90 degrees; when the $Q5_i(t)$ equals zero, the Q5 carrier shall be retarded 90 degrees (such that when $Q5_i(t)$ changes state, a 180-degree phase reversal of the Q5 carrier occurs). The resultant nominal composite transmitted signal phases as a function of the binary state of the modulating signals are as shown in Table 3-II.

3.3.1.6 Signal Power Levels. The SV shall provide I5 and Q5 navigation signal strength at end-of-life (EOL), worst-case in order to meet the minimum levels specified in Table 3-III. The minimum received power is measured at the output of a 3 dBi linearly polarized user receiving antenna (located near ground) at worst normal orientation, when the SV is above a 5-degree elevation angle. The received signal levels are observed within the in-band allocation defined in paragraph 3.3.1.1. Additional related data is provided as supporting material in paragraph 6.3.1.

Table 3-II. Composite L5 Transmitted Signal Phase**		
Nominal Composite L5 Signal Phase*	Code State	
	I5	Q5
0°	0	0
-90°	1	0
+90°	0	1
180°	1	1

* Relative to 0, 0 code state with positive angles leading and negative angles lagging.

** Based on the composite of two L5 carrier components at the same power.

Table 3-III. Received Minimum RF Signal Strength		
SV Blocks	Signal	
	I5	Q5
IIF	-157.9 dBW	-157.9 dBW

3.3.1.7 Equipment Group Delay. Equipment group delay is defined as the delay between the L-band radiated output of a specific SV (measured at the antenna phase center) and the output of that SV's on-board frequency source; the delay consists of a bias term and an uncertainty. The bias term on L1/L2 P(Y) is of no concern to the users since it is included in the clock correction parameters relayed in the NAV data, and is therefore accounted for by the user computations of system time (reference paragraphs 20.3.3.1.3, 20.3.3.3.2.3 and 20.3.3.3.2.4). The uncertainty (variation) of these delays as well as the group delay differential between the signals of L1, L2, and L5 are defined in the following.

3.3.1.7.1 Group Delay Uncertainty. The effective uncertainty of the group delays shall not exceed 3.0 nanoseconds (two sigma).

3.3.1.7.2 Group Delay Differential. The group delay differential between the radiated L1 and L5 signals (i.e. L1 P(Y) and L5 I5; and L1 P(Y) and L5 Q5) is specified as consisting of random plus bias components. The mean differential is defined as the bias component and will be either positive or negative. For a given navigation payload redundancy configuration, the absolute value of the mean differential delay shall not exceed 30.0 nanoseconds. The random variations about the mean shall not exceed 3.0 nanoseconds (two-sigma). L1 and L2 group delay differential is described in 3.3.1.7.2 of ICD-GPS-200. Corrections for the bias components of the group delay differential are provided to the users in the Nav message using parameters designated as T_{GD} (reference paragraph 20.3.3.3.3.2 of ICD-GPS-200) and Inter-Signal Correction (ISC) (reference paragraph 20.3.3.3.2.4, also in 30.3.3.3.2.3 of ICD-GPS-200).

3.3.1.8 Signal Coherence. L5 transmitted signals for a particular SV shall be coherently derived from the same on-board frequency standard. All PRN signals shall be clocked coherently with the P(Y)-code signal transitions. On the L5 channel the chip transitions of the two modulating signals (i.e., that containing the I5-code and that containing the Q5-code) shall be such that the average time difference between the transitions does not exceed 10.0 nanoseconds (two-sigma).

3.3.1.9 Signal Polarization. The transmitted signal shall be right-hand circularly polarized (RHCP). For the angular range of ±14.3 degrees from boresight, L5 ellipticity shall be no worse than 2.4 dB. Nominal values are listed in section 6.3.3.

3.3.2 PRN Code Characteristics. The characteristics of the I5- and the Q5-codes are defined below in terms of their structure and the basic method used for generating them. Figures 3-2 and 3-3 depict simplified block diagrams of the scheme for generating the 10.23 Mbps $I5_i(t)$ and $Q5_i(t)$ patterns, and for modulo-2 summing the I5 patterns with the NAV bit train, $D_5(t)$, which is rate 1/2 encoded and clocked at 100 sps. In addition, the 100 sps symbols are modulated with a 10-bit Neuman-Hoffman code that is clocked at 1 kHz. The resultant composite bit trains are then used to modulate the L5 in-phase carrier. The Q5-code is modulated with a 20-bit Neuman-Hoffman code that is also clocked at 1 kHz.

3.3.2.1 Code Structure. The $I5_i(t)$ pattern (I5-code) and the $Q5_i(t)$ pattern (Q5-code) are both generated by the modulo-2 summation of two PRN codes, XA(t) and $XBI_i(n_{Ii}, t)$ or $XBQ_i(n_{Qi}, t)$, where n_{Ii} and n_{Qi} are initial states of XBI_i and XBQ_i for satellite i. There are over 4000 unique L5 codes generated using different initial states of which 74 are assigned and identified in Table 3-I using the same basic code generator.

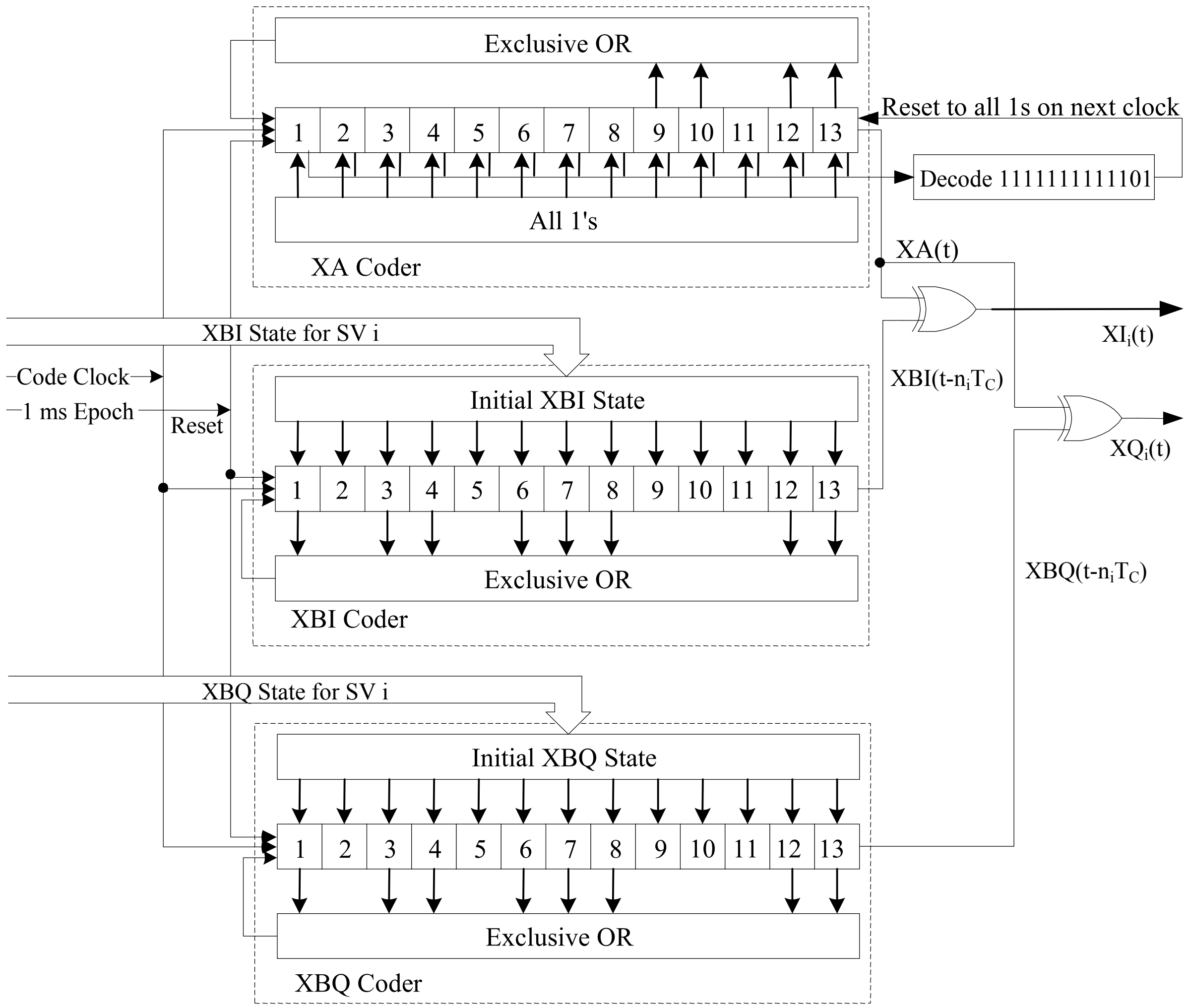


Figure 3-2. Generation of Codes

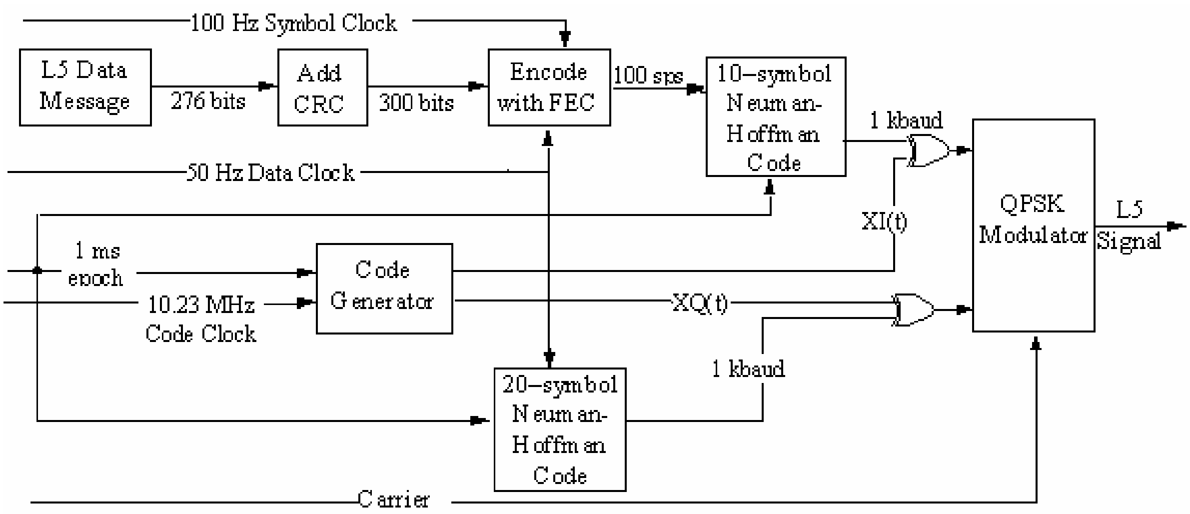


Figure 3-3. Modulation of Signals

3.3.2.2 Code Generation. Each $I5_i(t)$ pattern (I5-code) and $Q5_i(t)$ pattern (Q5-code) are the modulo-2 sum of two extended patterns clocked at 10.23 Mbps (XA and XBI_i or XBQ_i). XA is an 8190 length code, with an initial condition of all 1s, that is short cycled 1-chip before its natural conclusion and restarted to run over a period of 1 millisecond (synchronized with the L1 frequency C/A-code) for a total of 10,230 chips. The XBI_i and XBQ_i, with initial conditions indicated in Table 3-I, are 8191 length codes that are not short cycled. They are restarted at their natural completion and run over a period of 1 millisecond (synchronized with the XA code) for a total of 10,230 chips. The polynomials for XA and XBI_i or XBQ_i codes, as referenced to the shift register input, are:

XA: $1 + x^9 + x^{10} + x^{12} + x^{13}$, and

XBI_i or XBQ_i: $1 + x + x^3 + x^4 + x^6 + x^7 + x^8 + x^{12} + x^{13}$.

Samples of the relationship between shift register taps and the exponents of the corresponding polynomial, referenced to the shift register input, are as shown in Figures 3-4 (XA code) and 3-5 (XB code). In the case of the XB codes, the shift register can either be initialized with all 1s and advanced n_i states as specified in Table 3-I, or initialized with the state indicated in Table 3-I.

The state of each generator can be expressed as a code vector word which specifies the binary sequence constant of each register as follows: (a) the vector consists of the binary state of each stage of the register, (b) the stage 13 value appears at the right followed by the values of the remaining states in order of descending stage numbers, and (c) the shift direction is from lower to higher stage number with stage 13 providing the current output. This code vector convention represents the present output and 12 future outputs in sequence. Using this convention, at each XA epoch (state 8190), the XA shift register is initialized to the code vector 1111111111111, while at each XB epoch (state 8191), the XB shift register is initialized to a code vector peculiar to the PRN number and phase. The XB code vectors are as indicated in Table 3-I. Alternatively, the XB shift register is initialized to the code vector 1111111111111 and advanced n_i states as indicated in Table 3-I.

The natural 8191 chips of the XA sequence is shortened to 8190 chips to cause precession of the second XA sequence with respect to the natural 8191 chip XB sequence, as shown in Figure 3-6. Re-initialization of the XA shift register produces a 10230-chip sequence by omitting the last 6151 chips of the second natural XA sequence, or reinitializing to all 1s at the 1 ms epoch. The XB shift register is simply allowed to run its natural course until the next 1 ms epoch when it is reinitialized at its initial state, B0, based upon PRN number and phase. This results in the phase of the XB sequence leading by one chip during the second XA sequence in the 1-millisecond period. Depending upon the initial state of the XB sequence, a third 8191-chip sequence may be started before the 10230-chip sequence is completed. Two different scenarios that may result are shown in Figure 3-6.

In scenario a, the initial state of the XB sequence, B0, is less than State 6152. Thus, the second natural XB sequence does not run to completion prior to the next 1 ms epoch. In scenario b, the initial state of the XB sequence, B0, is greater than State 6151. Thus, the second natural XB sequence runs to completion and a third natural sequence starts (except when B0 is State 6152) prior to the next 1 ms epoch.

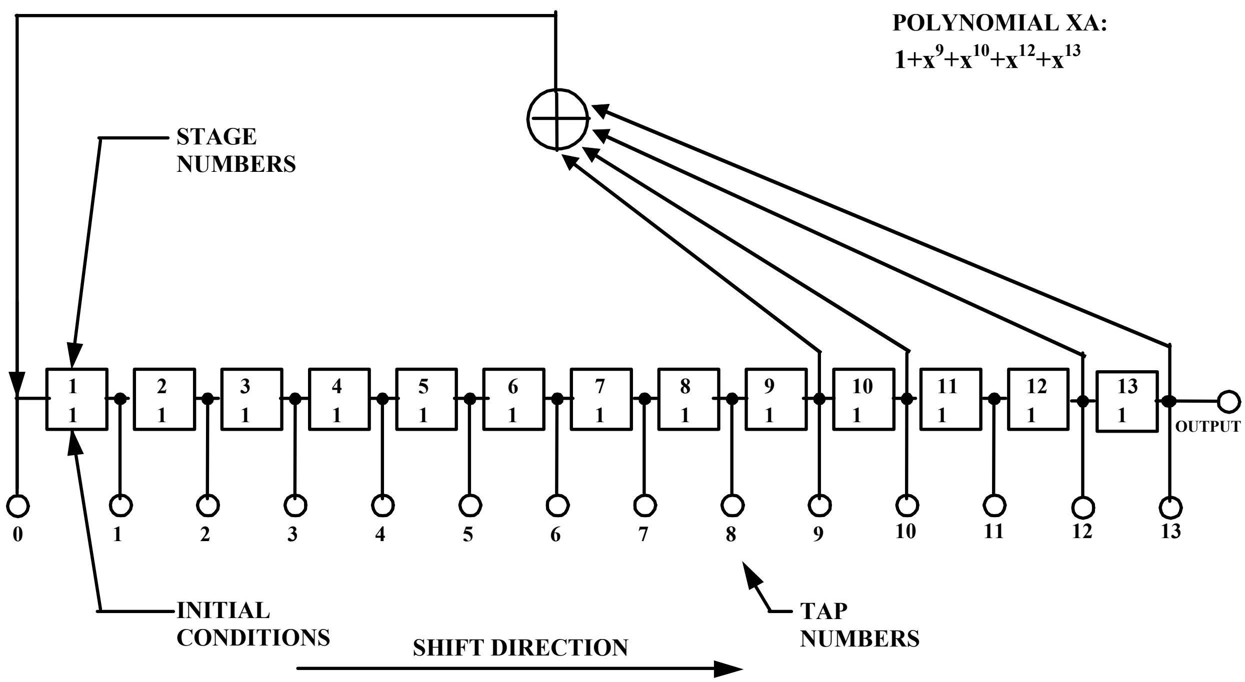


Figure 3-4. XA Shift Register Generator Configuration

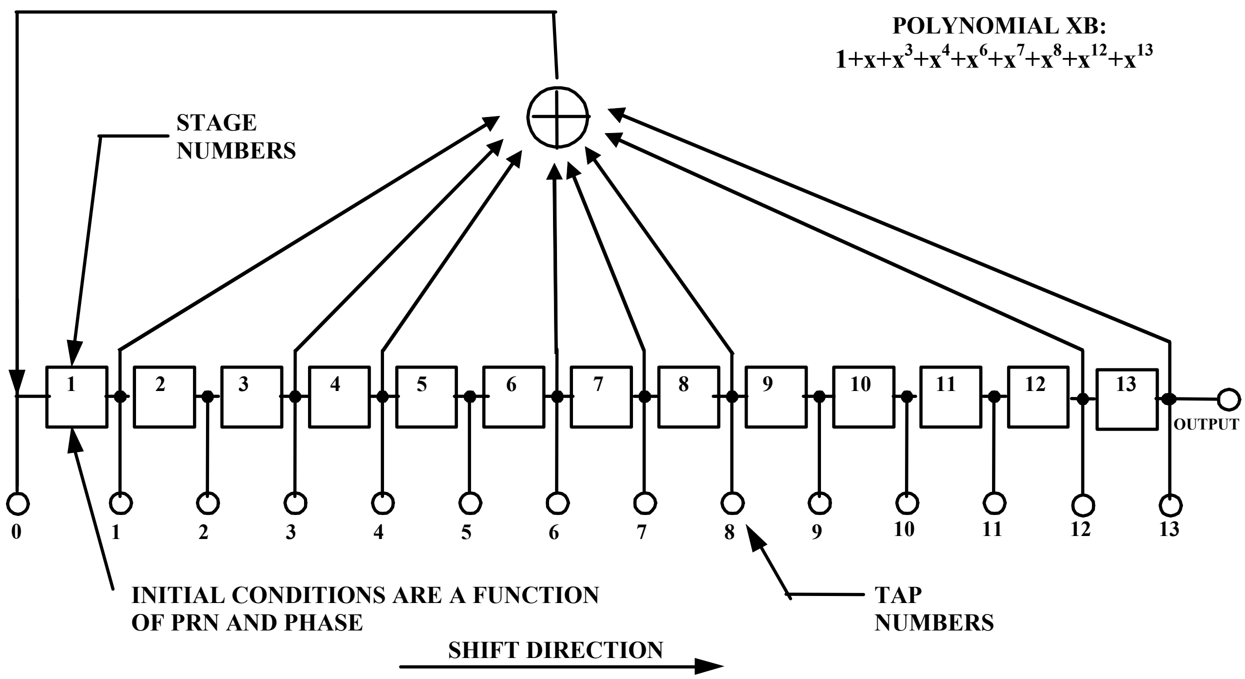
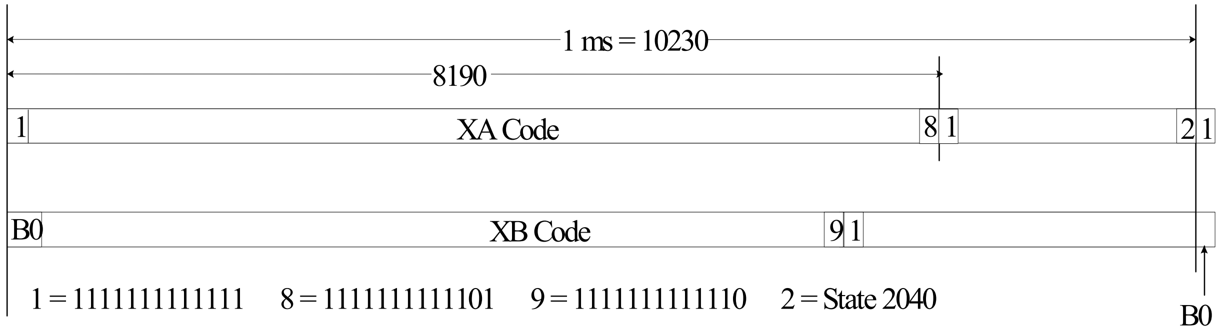
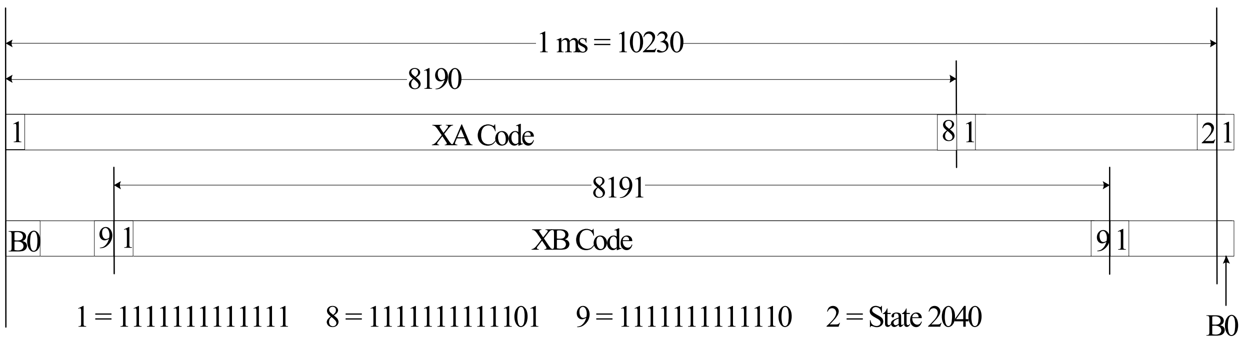


Figure 3-5. XB Shift Register Generator Configuration



a) B0 = Initial State at 1 ms (less than State 6152)



b) B0 = Initial State at 1 ms (greater than State 6151)

Figure 3-6. Relative Phases between the XA and XB Sequences

3.3.2.3 Q5 Synchronization Sequence. Each of the 1 ms Q5-code blocks is further encoded with a 20-bit Neuman-Hoffman code. The 20 bits are modulo-2 added to the Q5 code chips at the PRN code epoch rate of 1 kHz. The code, nh20(t), starting coincident with the 20 ms data epoch on the I5 channel, is as follows:

1^{st} Last

nh20(t) = 0 0 0 0 0 1 0 0 1 1 0 1 0 1 0 0 1 1 1 0

3.3.3 Navigation Data. The content and format of the NAV data, $D_5(t)$, are given in Appendix II of this document.

3.3.3.1 Navigation Data Modulation. The NAV bit train, $D_5(t)$, is rate 1/2 convolutional encoded and, thus, clocked at 100 symbols per second (sps). In addition, the 100 sps symbols are modulated with a 10-bit Neuman-Hoffman code that is clocked at 1 kHz (reference paragraph 3.3.3.1.2). The resultant symbol sequence is then modulo-2 added with I5 PRN code and used to modulate the L5 in-phase carrier.

3.3.3.1.1 Forward Error Correction. The NAV bit train, $D_5(t)$, will always be rate 1/2 convolutional encoded with a Forward Error Correction (FEC) code. Therefore, the symbol rate is 100 sps. The convolutional coding will be constraint length 7, with a convolutional encoder logic arrangement as illustrated in Figure 3-7. The G1 symbol is selected on the output as the first half of a 20-millisecond data bit period coincident with the first bit of the 20-bit Q5 Neuman-Hoffman code.

Six-second navigation messages broadcast by the SV are synchronized with every fourth of the SV's P(Y)-code X1 epochs. Although these epochs are not necessarily accessible to the L5 user, they are used within the SV to define GPS time. However, message synchronization does provide the L5 user an access to the time of every 4^{th} P(Y)-code X1 epoch. The navigation message is FEC encoded in a continuous process independent of message boundaries (i.e. at the beginning of each new message, the encoder registers illustrated in Figure 3-7 contains the last six bits of the previous message). Thus, herein, reference will continue to be made to these X1 epochs. See ICD-GPS-200 for details.

The FEC encoding convolves successive messages. It is necessary to define which transmitted symbol is synchronized to SV time as follows. The beginning of the first symbol that contains any information about the first bit of a message will be synchronized to every fourth X1 epoch (referenced to end/start of week). The users' convolutional decoders will introduce a fixed delay that depends on their respective algorithms (usually 5 constraint lengths, or 35 bits), for which they must compensate to determine system time from the received signal. This convolutional decoding delay and the various relationships with the start of the data block transmission and SV timing are illustrated in Figure 3-8 for the L5 signal.

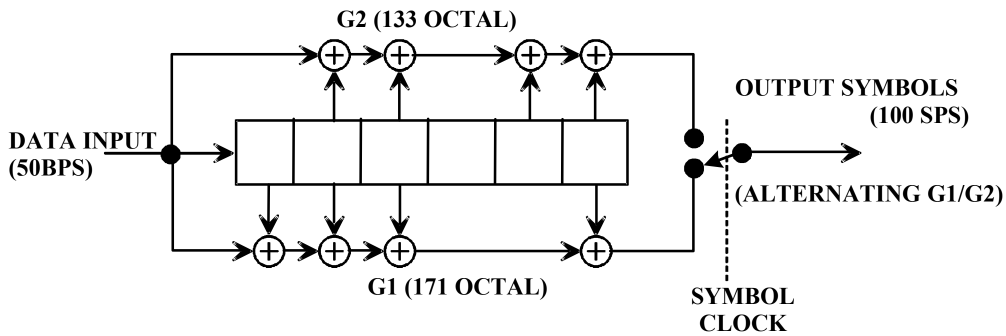


Figure 3-7. Convolution Encoder

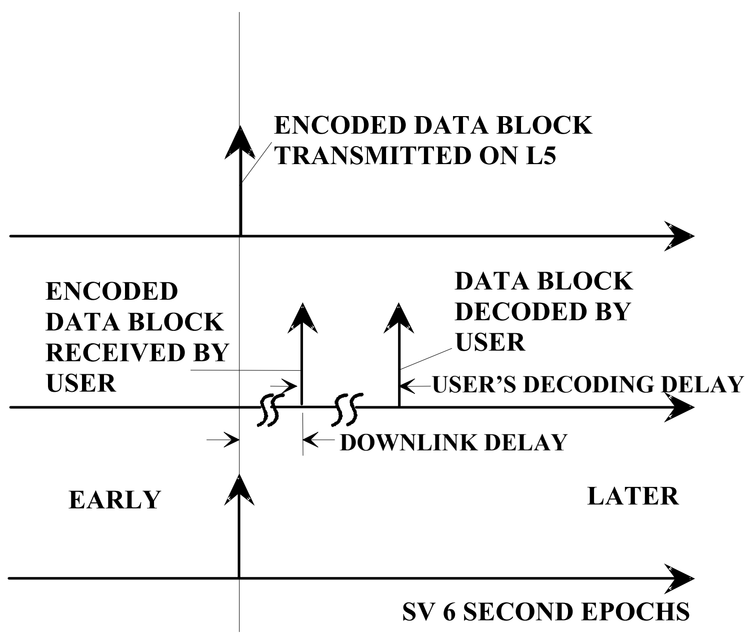


Figure 3-8. Convolutional Transmit/Decoding Timing Relationships

3.3.3.1.2 Neuman-Hoffman Code. Each of the 100 sps symbols are further encoded with a 10-bit Neuman-Hoffman code. The 10-bit Neuman-Hoffman code is defined to be 0000110101. The 10 bits are modulo-2 added to the symbols at the PRN code epoch rate of 1 kHz starting at the 100 sps symbol transitions. The result is that a "1" data symbol is replaced by 1111001010, and a "0" data symbol is replaced by 0000110101.

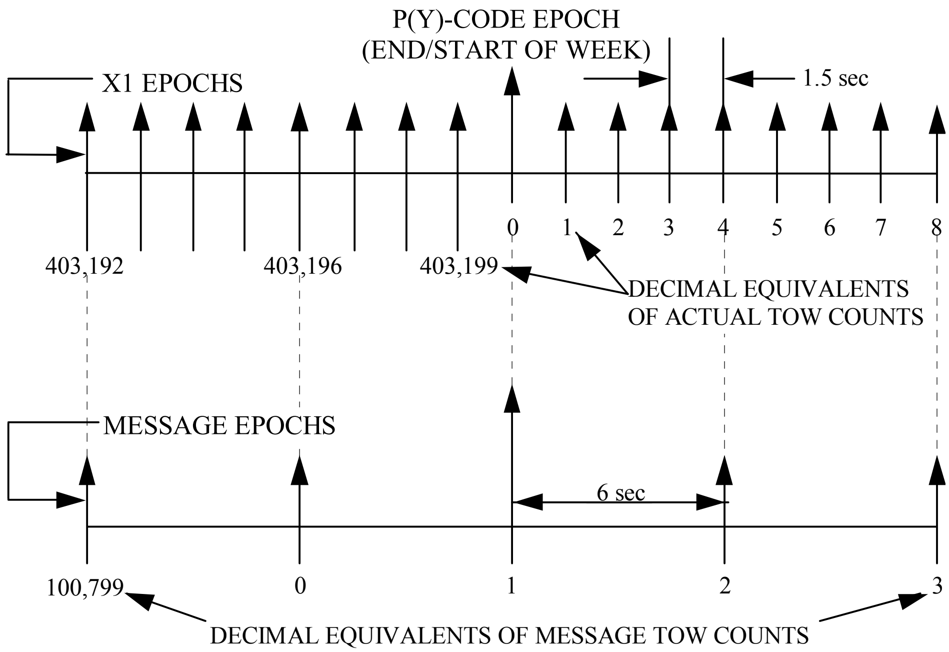
3.3.4 GPS Time and SV Z-Count. GPS time is established by the Operational Control System (OCS) and is referenced to a UTC (as maintained by the U.S. Naval Observatory) zero time-point defined as midnight on the night of January 5, 1980/morning of January 6, 1980. GPS time is the ensemble of corrected composite L1/L2 P(Y) SV times, corrected via the clock corrections in the L1 and L2 NAV data and the relativity correction. The largest unit used in stating GPS time is one week defined as 604,800 seconds, concatenated with the GPS week number. GPS time may differ from UTC because GPS time is a continuous time scale, while UTC is corrected periodically with an integer number of leap seconds. There also is an inherent but bounded drift rate between the UTC and GPS time scales. The OCS controls the GPS time scale to be within one microsecond of UTC (modulo one second).

The L5 NAV data contains the requisite data for relating GPS time to UTC. The accuracy of this data during the transmission interval will be such that it relates GPS time to UTC to within 90.0 nanoseconds (one sigma). This data is generated by the CS (or provided to the CS); therefore, the accuracy of these relationships may degrade if for some reason the CS is unable to upload data to an SV.

In each SV the X1 epochs of the P-code of the L1 and L2 offer a convenient unit for precisely counting and communicating time. Time stated in this manner is referred to as Z-count, which is given as a 29-bit binary number consisting of two parts as follows:

a. The binary number represented by the 19 least significant bits of the Z-count is referred to as the time of week (TOW) count and is defined as being equal to the number of X1 epochs that have occurred since the transition from the previous week. The count is short-cycled such that the range of the TOW-count is from 0 to 403,199 X1 epochs (equaling one week) and is reset to zero at the end of each week. The TOW-count's zero state is defined as that X1 epoch which is coincident with the start of the present week. This epoch occurs at (approximately) midnight Saturday night-Sunday morning, where midnight is defined as 0000 hours on the Universal Time Coordinated (UTC) scale, which is nominally referenced to the Greenwich Meridian. Over the years the occurrence of the "zero state epoch" may differ by a few seconds from 0000 hours on the UTC scale since UTC is periodically corrected with leap seconds while the TOW-count is continuous without such correction. A truncated version of the TOW-count, consisting of its 17 most significant bits, is contained in each of the six-second messages of the L5 downlink data stream; the relationship between the actual TOW-count and its truncated message version is illustrated by Figure 3-9.

b. The ten most significant bits of the Z-count are a modulo-1024 binary representation of the sequential number assigned to the current GPS week (see paragraph 6.2.4). The range of this count is from 0 to 1023 with its zero state being defined as the GPS week number zero and every integer multiple of 1024 weeks, thereafter (i.e. 0, 1024, 2048, etc.).



NOTES:

1. THE TOW COUNT APPEARS IN EACH 6-SECOND MESSAGE.
2. THE 6-SECOND MESSAGE TOW COUNT CONSISTS OF THE 17 MSBs OF THE ACTUAL TOW COUNT AT THE START OF THE NEXT MESSAGE.
3. TO CONVERT FROM THE MESSAGE TOW COUNT TO THE ACTUAL TOW COUNT AT THE START OF THE NEXT MESSAGE, MULTIPLY BY FOUR.

Figure 3-9. Time Line Relationship of a Six-Second Message

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4. NOT APPLICABLE

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5. NOT APPLICABLE

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6. NOTES

6.1 Acronyms

AFMC	-	Air Force Materiel Command
AFSPC	-	Air Force Space Command
ASCII	-	American Standard Code for Information Interchange
A-S	-	Anti-Spoof
bps	-	bits per second
BPSK	-	Bi-Phase Shift Key
C/A	-	Course/Acquisition
CRC	-	Cyclic Redundancy Check
CS	-	Control Segment
dB	-	Decibel
dBW	-	Decibels with respect to 1 Watt
DoD	-	Department of Defense
ECEF	-	Earth-Centered, Earth-Fixed
EOL	-	End of Life
FEC	-	Forward Error Correction
GPS	-	Global Positioning System
Hz	-	Hertz
I5	-	Inphase Code on L5 Signal
ICC	-	Interface Control Contractor
ICD	-	Interface Control Document
ID	-	Identification
IODC	-	Issue of Data, Clock
ISC	-	Inter-Signal Correction
LSB	-	Least Significant Bit
MSB	-	Most Significant Bit
NAV	-	Navigation
NSI5	-	Non-Standard I-Code
NSQ5	-	Non-Standard Q-Code
OCS	-	Operational Control System
PIRN	-	Proposed Interface Revision Notice
PRN	-	Pseudo-Random Noise
P(Y)	-	Precise (Anti-Spoof) Code
Q5	-	Quadraphase code on L5 Signal

RF	-	Radio Frequency
RHCP	-	Right Hand Circular Polarization
RMS	-	Root Mean Square
SBAS	-	Space-Based Augmentation System
sps	-	Symbols per Second.
SIS	-	Signal In Space
SS	-	Space Segment
SV	-	Space Vehicle
TBD	-	To Be Determined
TBS	-	To Be Supplied
TOW	-	Time Of Week
URA	-	User Range Accuracy
US	-	User Segment
UTC	-	Universal Time Coordinated
WN	-	Week Number
WN_e	-	Extended Week Number

6.2 Definitions.

6.2.1 User Range Accuracy. See paragraph 6.2.1 of ICD-GPS-200.

6.2.2 SV Block Definitions. The following block definitions are given to facilitate discussion regarding the capability of the various blocks of GPS satellites to support the SV-to-user interface.

6.2.2.1 Developmental SVs. See paragraph 6.2.2.1 of ICD-GPS-200.

6.2.2.2 Operational SVs. The operational satellites are designated Block II, Block IIA, Block IIR, Block IIRM, Block IIF and Block III SVs. Characteristics of these SVs are provided below. These SVs transmit configuration codes as specified in paragraph 20.3.3.4.1.4. The navigation signal provides no direct indication of the type of the transmitting SV.

6.2.2.2.1 Block II SVs. See paragraph 6.2.2.2.1 of ICD-GPS-200. These satellites do not broadcast the L5 signal.

6.2.2.2.2 Block IIA SVs. See paragraph 6.2.2.2.2 of ICD-GPS-200. These satellites do not broadcast the L5 signal.

6.2.2.2.3 Block IIR SVs. See paragraph 6.2.2.2.3 of ICD-GPS-200. These satellites do not broadcast the L5 signal

6.2.2.2.4 Block IIR-M SVs. See paragraph 6.2.2.2.4 of ICD-GPS-200. These satellites do not broadcast the L5 signal.

6.2.2.2.5 Block IIF SVs. See paragraph 6.2.2.2.5 of ICD-GPS-200. The IIF operational SVs do broadcast the L5 signal.

6.2.2.2.6 Block III SVs. The block of operational planned SVs will be termed "Block III" SVs. The Block III operational SVs will broadcast the L5 signal.

6.2.3 Operational Interval Definitions. See paragraph 6.2.3 of ICD-GPS-200. There is no requirement for extended operations on L5.

6.2.4 GPS Week Number. See paragraph 6.2.4 of ICD-GPS-200 and paragraphs 20.3.3.1.1.1, 20.3.3.3.1.2 and 20.3.3.3.2.1.

6.3 Supporting Material.

6.3.1 L5 Received Signals. The guaranteed minimum user-received signal levels are defined in paragraph 3.3.1.6. Higher received signals levels can be caused by such factors as SV attitude errors, mechanical antenna alignment errors, transmitter power output variations due to temperature variations, voltage variations and power amplifier variations, and due to a variability in link atmospheric path loss. The maximum received signal levels as a result of these factors is not expected to exceed –150.0 dBW.

6.3.2 Integrated Phase Noise Characteristics. As an aid to user equipment receiver designers, a plot is provided (Figure 6-1) of a typical GPS Block IIF carrier phase noise spectral density.

Figure 6-1. Carrier Phase Noise Spectral Density (TBS)

6.3.3 Ellipticity Characteristics. As an aid to user equipment receiver designers, a table is provided (Table 6-I) of a typical GPS Block IIF ellipticity as a function of angular range.

Table 6-I. Typical Ellipticity vs Angular Range

Angle (deg)	±0	±2	±4	±6	±8	±10	±12	±14.3
Ellipticity (dB)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	2.0

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10. APPENDIX I. RESERVED

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20. APPENDIX II. GPS NAVIGATION DATA STRUCTURE FOR NAV DATA, $D_5(t)$

20.1 Scope. This appendix describes the specific GPS navigation (NAV) data structure denoted by, $D_5(t)$.

20.2 Applicable Documents.

20.2.1 Government Documents. In addition to the documents listed in paragraph 2.1, the following documents of the issue specified contribute to the definition of the NAV data related interfaces and form a part of this Appendix to the extent specified herein.

Specifications

None

Standards

None

Other Publications

None

20.2.2 Non-Government Documents. In addition to the documents listed in paragraph 2.2, the following documents of the issue specified contribute to the definition of the NAV data related interfaces and form a part of this Appendix to the extent specified herein.

Specifications

None

Other Publications

none

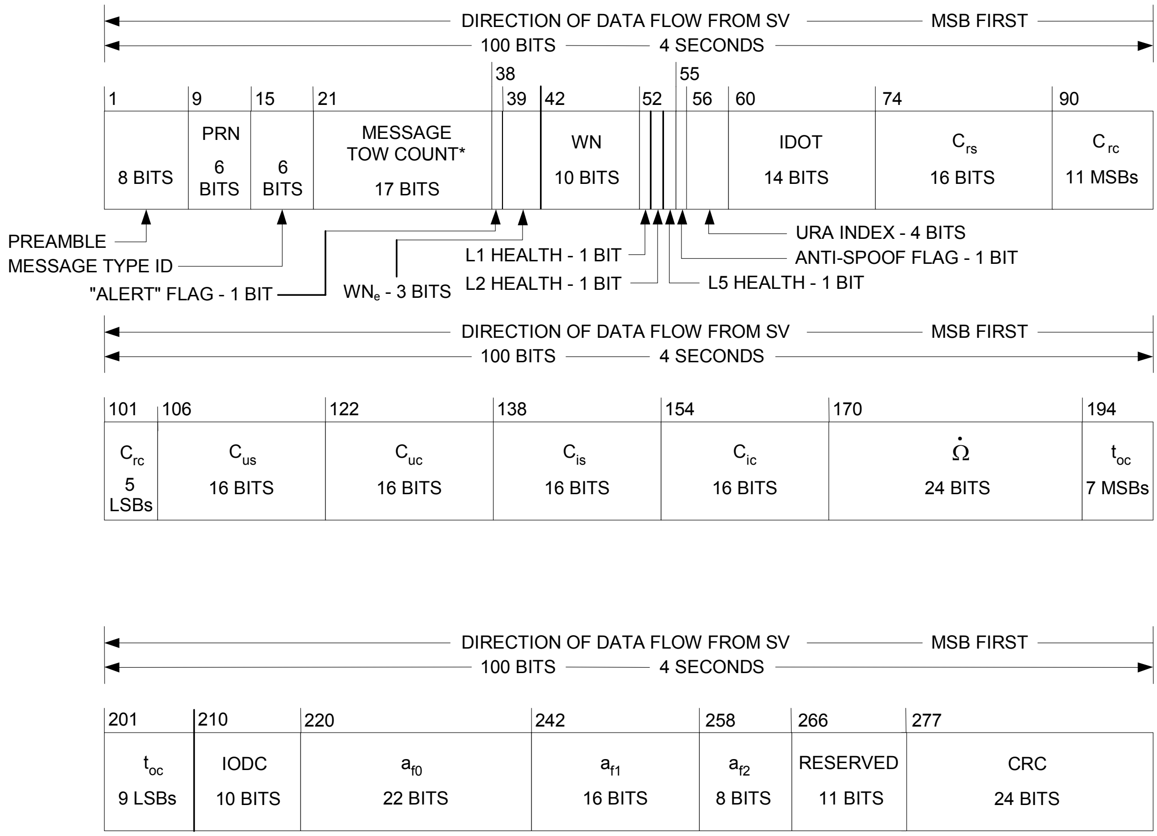
20.3 Requirements.

20.3.1 Data Characteristics. The L5 channel data stream mostly contains the same data as the L1 and L2 channels, but in a different format. The data stream shall be transmitted by the SV on the L5 channel at the rate of 50 bps with rate 1/2 FEC resulting in100sps. Also, the L5 data stream uses a different parity algorithm.

20.3.2 Message Structure. As shown in Figures 20-1 through 20-5, the L5 message structure utilizes a basic format of six-second 300-bit long messages. Each message contains a Cyclic Redundancy Check (CRC) parity block consisting of 24 bits covering the entire six-second message (300 bits) (reference Section 20.3.5). At present, only message types 1-5 are defined. Message types 0 and 6 through 63 are reserved.

In addition, Messages Types 7 through 9 are presently undefined but are reserved to be used in future broadcast of new clock and ephemeris parameters. The new parameters will be different than the parameters of Messages Type 1 and 2 and as such the related algorithms will also be different than the current equations of Table 20-IV of ICD-GPS-200. The initial broadcast of Messages Type 1 and 2 will be for test purposes and, as such, will stop and be replaced by Messages Type 7 through 9 as soon as the latter message types are fully defined and implemented.

20.3.3 Message Content. Each message starts with an 8-bit preamble – 10001011, followed by a 6-bit PRN number of the transmitting SV, a message type ID, with a range of 0 (000000) to 63 (111111), and the 17-bit message TOW count. When the value of the message TOW count is multiplied by 6, it represents SV time in seconds at the start of the next 6-second message. An “alert” flag, when raised (bit 38 = “1”), indicates to the user that the SV User Range Accuracy (URA) may be worse than indicated in Message Type 1, and the SV should be used at the user’s own risk.



* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-1. Message Type 1 Format

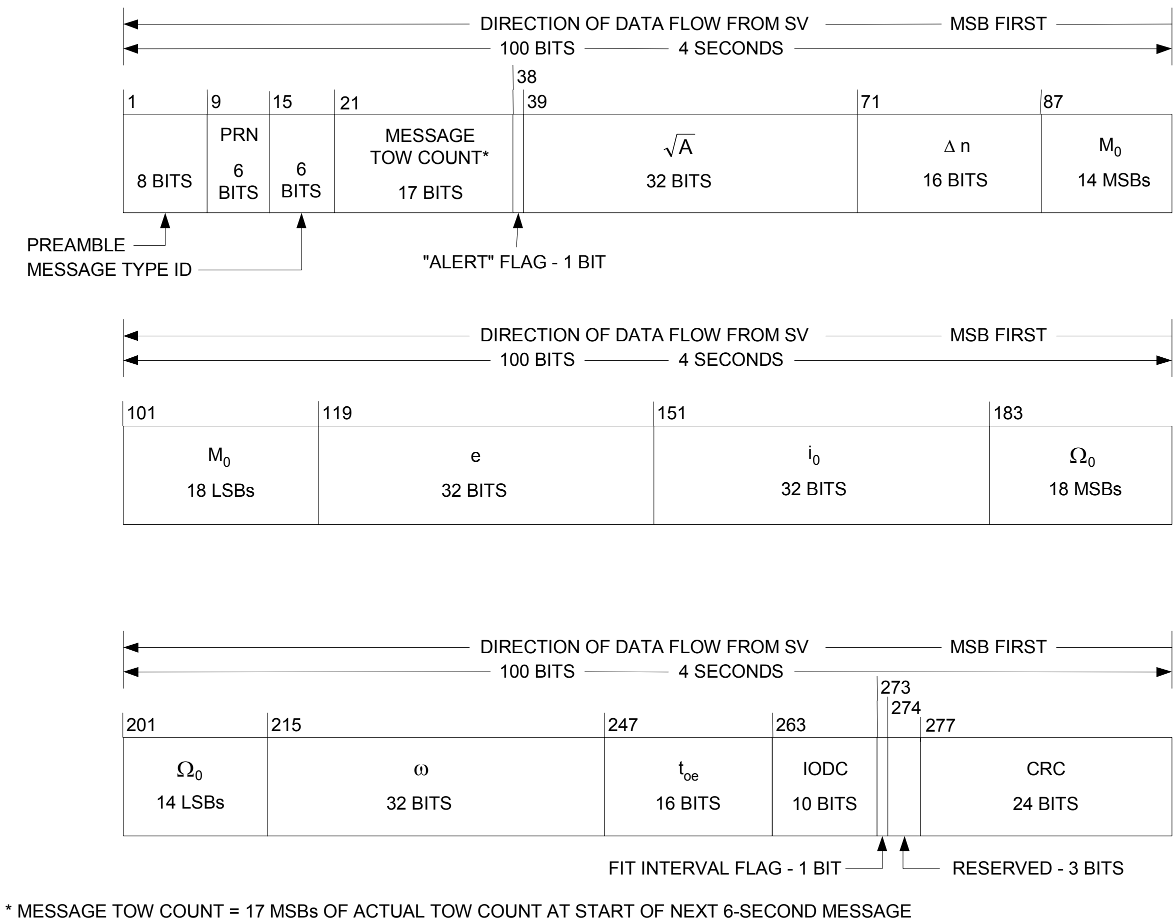
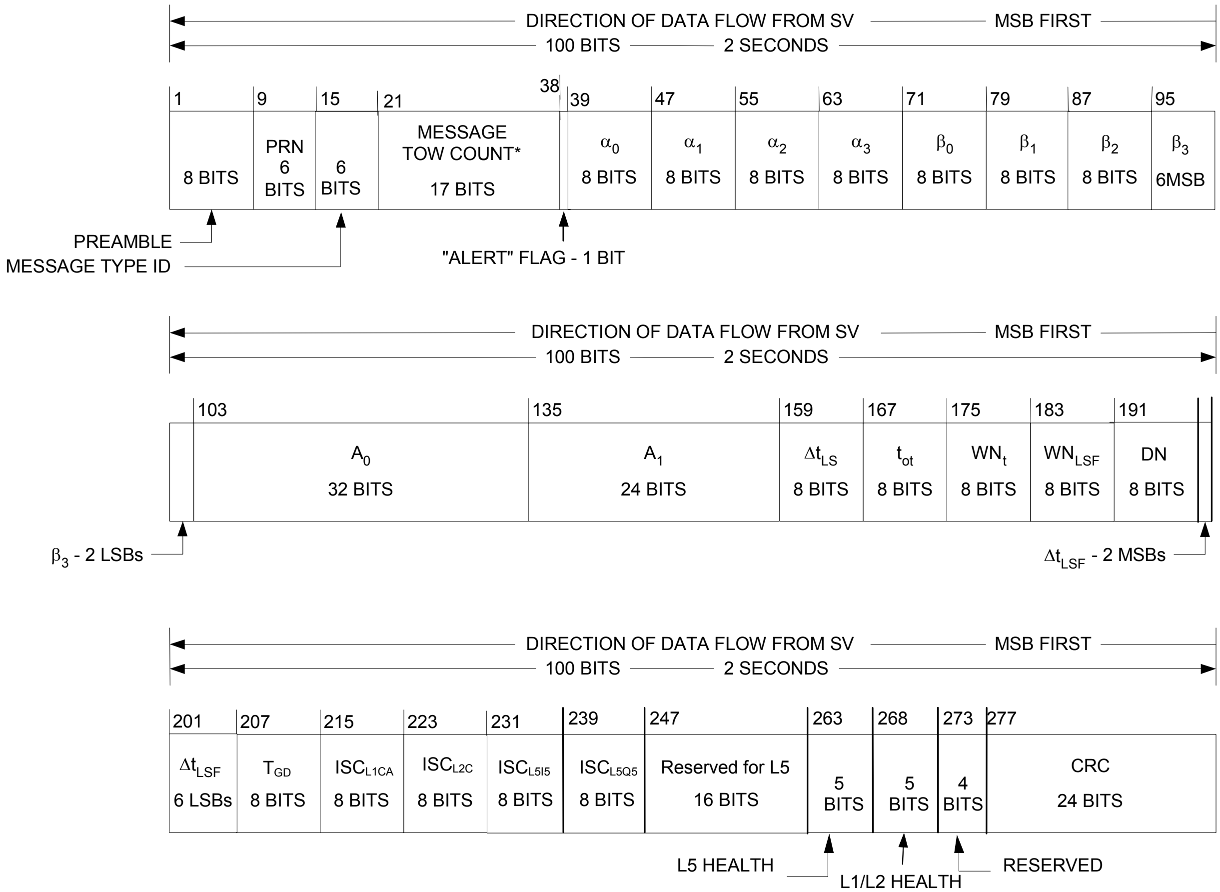
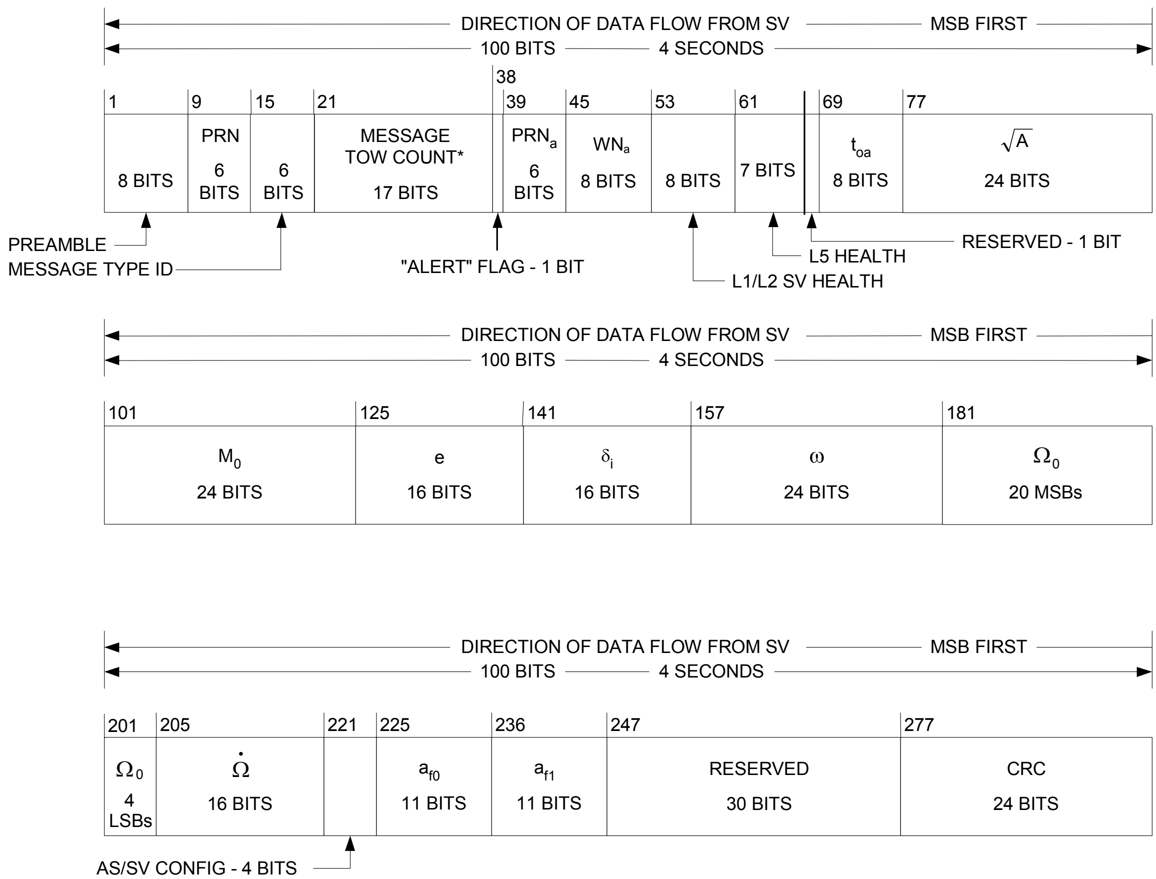


Figure 20-2. Message Type 2 Format



* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-3. Message Type 3 Format



* MESSAGE TOW COUNT = 17 MSBs OF ACTUAL TOW COUNT AT START OF NEXT 6-SECOND MESSAGE

Figure 20-4. Message Type 4 Format

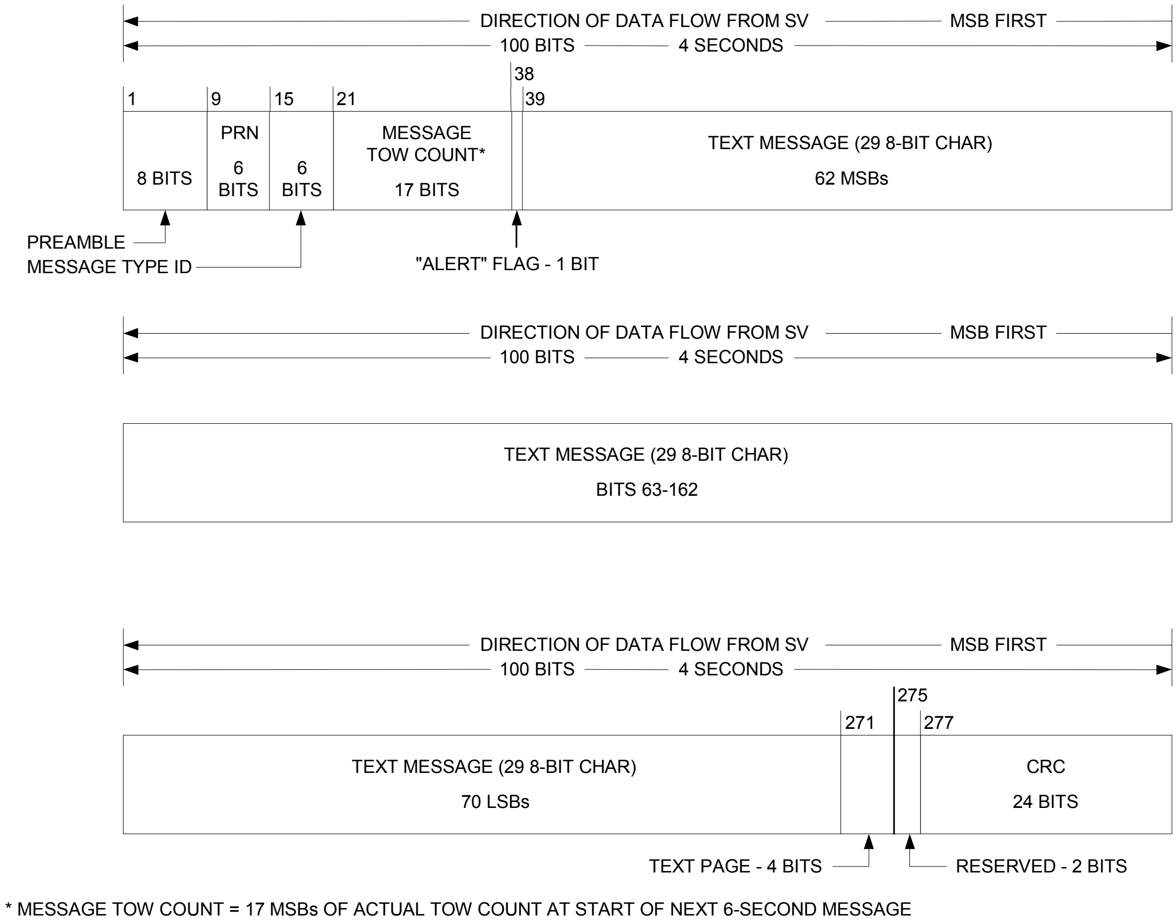


Figure 20-5. Message Type 5 Format

20.3.3.1 Message Type 1 Clock, Health and Accuracy Parameters.

20.3.3.1.1 Message Type 1 Clock, Health and Accuracy Parameter Content. The clock parameters in Message Type 1 describe the SV time scale during the period of validity. The parameters in a data set shall be valid during the interval of time in which they are transmitted and shall remain valid for an additional period of time after transmission of the next data set has started. The timing information for the messages is described in Section 20.3.4.

20.3.3.1.1.1 Transmission Week Number. Bits 39 through 51 shall contain 13 bits which are a modulo-8192 binary representation of the current GPS week number at the start of the data set transmission interval (see paragraph 6.2.4 of ICD-GPS-200). These 13 bits are comprised of 10 LSBs (WN) that represent the 10 MSBs of the 29-bit Z-count as qualified in paragraph 20.3.3.3.1.1 of ICD-GPS-200, and 3 MSBs (WN_e) which are three extra bits to extend the range of transmission week number from 10 bits to 13 bits.

20.3.3.1.1.2 SV Health (L1/L2/L5) . The three, one-bit, health indication in bits 52 through 54 refers to the L1, L2, and L5 signals of the transmitting SV. The health of each signal is indicated by,

0 = Signal OK,
1 = Signal bad or unavailable.

The health indication shall be given relative to the "as designed" capabilities of each SV. Accordingly, any SV that does not have a certain capability will be indicated as "healthy" if the lack of this capability is inherent in its design or if it has been configured into a mode that is normal from a user standpoint and does not require that capability.

The predicted health data will be updated at the time of upload when a new data set has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV.

Additional SV health data are given in Message Types 3 and 4. The data given in Message Type 1 may differ from that shown in other Message Types of the transmitting SV and/or on other SVs since the latter may be updated at a different time.

20.3.3.1.1.3 SV Accuracy. Bits 56 through 59 shall contain the URA index of the SV (reference paragraph 6.2.1) for the unauthorized (non-Precise Positioning Service) user. The URA index (N) is an integer in the range of 0 through 15 and is defined in paragraph 20.3.3.3.1.3 of ICD-GPS-200

20.3.3.1.1.4 Issue of Data, Clock (IODC). Bits 210 through 219 shall contain the IODC. The IODC indicates the issue number of the data set and thereby provides the user with a convenient means of detecting any change in the correction parameters. Constraints on the IODC term are defined in paragraph 20.3.4.4.

20.3.3.1.1.5 SV Clock Correction. Message Type 1 contains the parameters needed by the users for apparent SV clock correction (t_{oc}, a_{f2}, a_{f1}, a_{f0}). The related algorithm is given in paragraph 20.3.3.1.3.

20.3.3.1.2 Message Type 1 Clock, Health and Accuracy Parameter Characteristics. For those parameters whose characteristics are not fully defined in Section 20.3.3.1.1, the number of bits, the scale factor of the LSB (which is the last bit received), the range, and the units shall be as specified in Table 20-I.

20.3.3.1.3 User Algorithms for Message Type 1 Clock Data. The algorithms defined in paragraph 20.3.3.3.3.1 of ICD-GPS-200 allow all users to correct the code phase time received from the SV with respect to both SV code phase offset and relativistic effects. However, since the SV clock corrections of equations in paragraph 20.3.3.3.3.1 of ICD-GPS-200 are estimated by the CS using dual frequency L1 and L2 P(Y) code measurements, the single-frequency L5 user and the dual-frequency L1 and L5, and L2 and L5 users must apply additional terms to the SV clock corrections equations. These terms are described in paragraph 20.3.3.3.2.4. Those dual-frequency L1 C/A and L2 C users shall use the corrections provided in the L1 or L2 NAV messages, described in paragraph 30.3.3.3.1.4 of ICD-GPS-200.

Parameter	No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
Week No.	13	1		weeks
SV accuracy	4			(see text)
Signal health (L1/L2/L5)	3	1		(see text)
IODC	10			(see text)
t_{oc}	16	2^{4}	604,784	seconds
a_{f2}	8*	2^{-55}		sec/sec^2
a_{f1}	16*	2^{-43}		sec/sec
a_{f0}	22*	2^{-31}		seconds

Table 20-I. Message Type 1 Clock, Health and Accuracy Parameters

* Parameters so indicated are two's complement, with the sign bit (+ or -) occupying the MSB;
** See Figure 20-1 for complete bit allocation in Message Type 1;
*** Unless otherwise indicated in this column, effective range is the maximum range attainable with indicated bit allocation and scale factor.

20.3.3.2 Message Type 1 and 2 Ephemeris Parameters.

20.3.3.2.1 Message Type 1 and 2 Ephemeris Parameter Content. The contents of the ephemeris representation parameters in Message Types 1 and 2 are defined below, followed by material pertinent to the use of the data.

The ephemeris parameters describe the orbit of the transmitting SV during the curve fit intervals described in section 20.3.4. Table 20-II of ICD-GPS-200 gives the definition of the orbital parameters using terminology typical of Keplerian orbital parameters; it is noted, however, that the transmitted parameter values are expressed such that they provide the best trajectory fit in earth-centered, earth-fixed (ECEF) coordinates for each specific fit interval. The user shall not interpret intermediate coordinate values as pertaining to any conventional coordinate system.

The issue of data clock (IODC) term provides the user with a convenient means for detecting any change in the ephemeris representation parameters. The IODC is provided in Message Type 1 and 2 for the purpose of comparison of the IODC term between the two message types. Whenever the IODC value in the two message types do not match, a data set cutover has occurred and new data must be collected. The timing and constraints on the IODC are defined in paragraph 20.3.4.4.

Any change in the Message Type 1 and 2 data will be accomplished with a simultaneous change in the IODC word. The CS will assure that the t_{oc} /t_{oe} value, for at least the first data set transmitted by an SV after an upload, is different from that transmitted prior to the cutover.
A "fit interval" flag is provided in Message Type 2 to indicate whether the ephemerides are based on a four-hour fit interval or a fit interval greater than four hours (reference paragraph 20.3.3.2.3.1).

20.3.3.2.2 Message Type 1 and 2 Ephemeris Parameter Characteristics. For each ephemeris parameter contained in Message Types 1 and 2, the number of bits, the scale factor of the LSB (which is the last bit received), the range, and the units are as specified in Table 20-III of ICD-GPS-200. See Figures 20-1 and 20-2 for complete bit allocation in Message Types 1 and 2.

20.3.3.2.3 User Algorithm for Ephemeris Determination. The user shall compute the ECEF coordinates of position for the phase center of the SVs' antennas utilizing a variation of the equations shown in Table 20-IV of ICD-GPS-200. The ephemeris parameters are Keplerian in appearance; the values of these parameters, however, are produced by the CS via a least squares curve fit of the predicted ephemeris of the phase center of the SVs' antennas (time-position quadruples; t, x, y, z expressed in ECEF coordinates). Particulars concerning the periods of the curve fit, the resultant accuracy, and the applicable coordinate system are given in the following subparagraphs and subparagraphs of 20.3.3.4.3.2, 20.3.3.4.3.3, and 20.3.3.4.3.4 of ICD-GPS-200.

20.3.3.2.3.1 Curve Fit Intervals. Bit 273 of Message Type 2 is a "fit interval" flag which indicates the curve-fit interval used by the CS in determining the ephemeris parameters, as follows:

0 = 4 hours,
1 = greater than 4 hours.

Whenever the fit interval flag indicates a fit interval greater than 4 hours, the IODC can be used to determine the actual fit interval of the data set. The relationship of the curve-fit interval to transmission time and the timing of the curve-fit intervals are covered in section 20.3.4.4.

20.3.3.3 Message Type 3 Parameters. The contents of Message Type 3 are defined below, followed by material pertinent to the use of the data.

20.3.3.3.1 Message Type 3 Parameter Content. Message Type 3 contains UTC and ionospheric parameters and other data.

20.3.3.3.1.1 Ionospheric Data. The ionospheric parameters which allow the "L5 only" user to utilize the ionospheric model (reference paragraph 20.3.3.3.2.2) for computation of the ionospheric delay are contained in Message Type 3. The bit lengths, scale factors, ranges, and units of these parameters are given in Table 20-X of ICD-GPS-200. See Figure 20-3 for complete bit allocation in Message Type 3.

The ionospheric data shall be updated by the CS at least once every six days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the ionospheric data transmitted by the SVs may not be accurate.

20.3.3.3.1.2 Coordinated Universal Time (UTC) and GPS Time Parameters. See paragraph 30.3.3.3.1.1 of ICD-GPS-200.

20.3.3.3.1.3 Estimated L1-L2 Group Delay Differential. The group delay differential correction terms, T_{GD}, $ISC_{L1/CA}$, ISC_{L2C} are contained in bits 207 through 230 of message type 3. See paragraph 30.3.3.3.1.4 of ICD-GPS-200. These group delay differential correction terms are also used for the benefit of single frequency L5-I5 and L5-Q5 users and dual frequency L1/L5 and L2/L5 users.

20.3.3.3.1.4 Estimated L5 Group Delay Differential. The group delay differential correction terms, ISC_{L5I5} and ISC_{L5Q5}, for the benefit of single frequency L5-I5 and L5-Q5 users and dual frequency L1/L5 and L2/L5 users are contained in bits 231 to 246 of Message Type 3. The bit length, scale factors, ranges, and units of these parameters are given in Table 20-II. See Figure 20-3 for complete bit allocation in Message Type 3. The bit string of "10000000" shall indicate that the group delay value is not available (see Table 20-II). The related user algorithms are given in paragraphs 20.3.3.3.2.4, 20.3.3.3.2.5, and 20.3.3.3.2.6.

20.3.3.3.1.5 L5 Health. The five-bit, health indication in bits 263 through 267 refers to the transmitting SV for the L5 signal. The MSB shall indicate a summary of the health of the NAV data, where

0 = all NAV data are OK,

1 = some or all NAV data are bad.

The four LSBs shall indicate the health of the L5 signal components in accordance with the codes given in paragraph 20.3.3.4.1.3. The health indication shall be given relative to the "as designed" capabilities of each SV (as designated by the configuration code - see paragraph 20.3.3.4.1.4). Accordingly, any SV that does not have a certain capability will be indicated as "healthy" if the lack of this capability is inherent in its design or if it has been configured into a mode that is normal from a user standpoint and does not require that capability.

The predicted health data will be updated at the time of upload when a new data set has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV.

Additional SV health data are given in Message Types 1 and 4. The data given in Message Type 1 may differ from that shown in the other Message Types of the transmitting SV and/or on other SVs since the latter may be updated at a different time.

20.3.3.3.1.6 L1/L2Health. The five-bit health indication in bits 268 through 272 refers to the L1 and L2 signals of the transmitting SV. The data shall indicate the health of the L1 and L2 signal components in accordance with the codes given in Table 20-VIII of ICD-GPS-200.

The predicted health data will be updated at the time of upload when a new data set has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV.

Additional SV health data are given in Message Type 1 and 4. The data given in Message Type 3 may differ from that shown in the other Message Types of the transmitting SV and/or on other SVs since the latter may be updated at a different time.

Table 20-II. Group Delay Differential Parameters ****				
Parameter	No. of Bits**	Scale Factor (LSB)	Effective Range***	Units
T_{GD}	8*	2^{-31}		seconds
$ISC_{L1C/A}$	8*	2^{-31}		seconds
ISC_{L2C}	8*	2^{-31}		seconds
ISC_{L5I5}	8*	2^{-31}		seconds
ISC_{L5Q5}	8*	2^{-31}		seconds

* Parameters so indicated are two's complement with the sign bit (+ or -) occupying the MSB;
** See Figure 20-3 for complete bit allocation in Message Type 3;
*** Effective range is the maximum range attainable with indicated bit allocation and scale factor;
**** The bit string of "10000000" will indicate that the group delay value is not available.

20.3.3.3.2 Algorithms Related to Message Type 3 Data. The following algorithms shall apply when interpreting UTC, Ionospheric Model data, and Group Delay Differential data in the NAV message.

20.3.3.3.2.1 UTC and GPS Time. See paragraph 30.3.3.3.2.1 of ICD-GPS-200 and 20.3.3.5.2.4 of ICD-GPS-200.

20.3.3.3.2.2 Ionospheric Model. The "two frequency" (L1 and L5 or L2 and L5) user shall correct the time received from the SV for ionospheric effect by utilizing the time delay differential between L1 and L5 (reference paragraph 20.3.3.3.2.4). The "one frequency" user, however, should use the model given in Figure 20-4 of ICD-GPS-200 to make this correction. The calculated value of T_{iono} is referred to the L1 frequency; if the user is operating on the L5 frequency, the correction term must be multiplied by γ_{15} (reference paragraph 20.3.3.3.2.5). It is estimated that the use of this model will provide at least a 50 percent reduction in the single - frequency user's RMS error due to ionospheric propagation effects. During extended operations, if the CS is unable to upload the SVs, the use of this model will yield unpredictable results.

20.3.3.3.2.3 L1/L2 Inter-Signal Group Delay Differential Correction. See paragraph 30.3.3.3.2.3 of ICD-GPS-200.

20.3.3.3.2.4 L1/L5 Inter-Signal Group Delay Differential Correction. The L5 correction terms, ISC_{L5I5} and ISC_{L5Q5}, are initially provided by the CS to account for the effect of SV group delay differential between L1 P(Y)-code and L5 I5-code and between L1 P(Y)-code and Q5-code, respectively. These values are based on measurements made by the SV contractor during SV manufacture. The values of ISC's for each SV may be subsequently updated to reflect the actual on-orbit group delay differential. For maximum accuracy, the single frequency user L5-I5 user must use the correction terms to make further modifications to the code phase offset given by:

$$(\Delta t_{SV})_{L5I5} = \Delta t_{SV} - T_{GD} + ISC_{L5I5}$$

where, T_{GD} (see paragraph 20.3.3.3.3.2 of ICD-GPS-200) and ISC_{L5I5} (described in paragraph 20.3.3.3.1.4) are provided to the user as Message Type 3 data. For maximum accuracy, the single frequency user L5-Q5 user must use the correction terms to make further modifications to the code phase offset given by:

$$(\Delta t_{SV})_{L5Q5} = \Delta t_{SV} - T_{GD} + ISC_{L5Q5}$$

where, ISC_{L5Q5} (described in paragraph 20.3.3.3.1.4) is provided to the user as Message Type 3 data.

The values of ISC_{L5I5} and ISC_{L5Q5} are measured values that represent the mean SV group delay differential between the L1 P(Y) code and the L5-I5 code or L5-Q5 code respectively as follows.

$$ISC_{L5I5} = t_{L1P} - t_{L5I5}$$

$$ISC_{L5Q5} = t_{L1P} - t_{L5Q5}$$

where t_{Lix} is the GPS time the i^{th} frequency x signal is transmitted from the SV.

20.3.3.3.2.5 L1/L5 Ionospheric Correction. The two frequency (L1 C/A and L5 I5) user shall correct for the group delay due to ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5I5} - \gamma_{15} PR_{L1C/A} + c(ISC_{L5I5} - \gamma_{15} ISC_{L1C/A})}{1 - \gamma_{15}} - cT_{GD}$$

The two frequency (L1 C/A and L5 Q5) user shall correct for the group delay due to ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5Q5} - \gamma_{15} PR_{L1C/A} + c(ISC_{L5Q5} - \gamma_{15} ISC_{L1C/A})}{1 - \gamma_{15}} - cT_{GD}$$

where

- PR = pseudorange corrected for ionospheric effects,
- PR_i = pseudorange measured on the L-band channel indicated by the subscript.
- ISC_i = inter-signal correction for the channel indicated by the subscript (see paragraph 20.3.3.3.1.4)
- T_{GD} = see paragraph 20.3.3.3.3.2 of ICD-GPS-200.
- c = speed of light.

and where, denoting the nominal center frequencies of L1 and L5 as f_{L1} and f_{L5} respectively.

$$\gamma_{15} = (f_{L1}/f_{L5})^2 = (1575.42/1176.45)^2 = (154/115)^2.$$

20.3.3.3.2.6 L2/L5 Ionospheric Correction. The two frequency (L2 and L5I5) user shall correct for the group delay due to ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5I5} - \gamma_{25} PR_{L2C} + c(ISC_{L5I5} - \gamma_{25} ISC_{L2C})}{1 - \gamma_{25}} - cT_{GD}$$

The two frequency (L2C and L5 Q5) user shall correct for the group delay due to ionospheric effects by applying the relationship:

$$PR = \frac{PR_{L5Q5} - \gamma_{25} PR_{L2C} + c(ISC_{L5Q5} - \gamma_{25} ISC_{L2C})}{1 - \gamma_{25}} - cT_{GD}$$

where

- PR = pseudorange corrected for ionospheric effects,
- PR_i = pseudorange measured on the L-band channel indicated by the subscript.
- ISC_i = inter-signal correction for the channel indicated by the subscript (see paragraph 20.3.3.3.1.4)
- T_{GD} = see paragraph 20.3.3.3.3.2 of ICD-GPS-200.
- c = speed of light.

and where, denoting the nominal center frequencies of L2 and L5 as f_{L2} and f_{L5} respectively.

$$\gamma_{25} = (f_{L2}/f_{L5})^2 = (1227.6/1176.45)^2 = (24/23)^2$$

20.3.3.3.2.7 Example Application of Correction Parameters. A typical system application of the correction parameters for a user receiver is shown in Figure 20-6. The ionospheric model referred to in Figure 20-6 is discussed in paragraph 20.3.3.3.2.2 in conjunction with the related data contained in Message Type 3.

20.3.3.4 Message Type 4 Almanac Parameters. The contents of Message Type 4 are defined below, followed by material pertinent to the use of the data.

20.3.3.4.1 Message Type 4 Almanac Parameter Content. Message Type 4 contains almanac data.

20.3.3.4.1.1 Almanac Data. Message Type 4 contains the almanac data and SV health words for SVs in the constellation. The almanac data are a reduced-precision subset of the clock and ephemeris parameters. The number of bits, the scale factor (LSB), the range, and the units of the almanac parameters are given in Table 20-VI of ICD-GPS-200. The algorithms and other material related to the use of the almanac data are given in paragraph 20.3.3.4.2.

The almanac parameters shall be updated by the CS at least once every 6 days while the CS is able to upload the SVs. If the CS is unable to upload the SVs, the accuracy of the almanac parameters transmitted by the SVs will degrade over time.

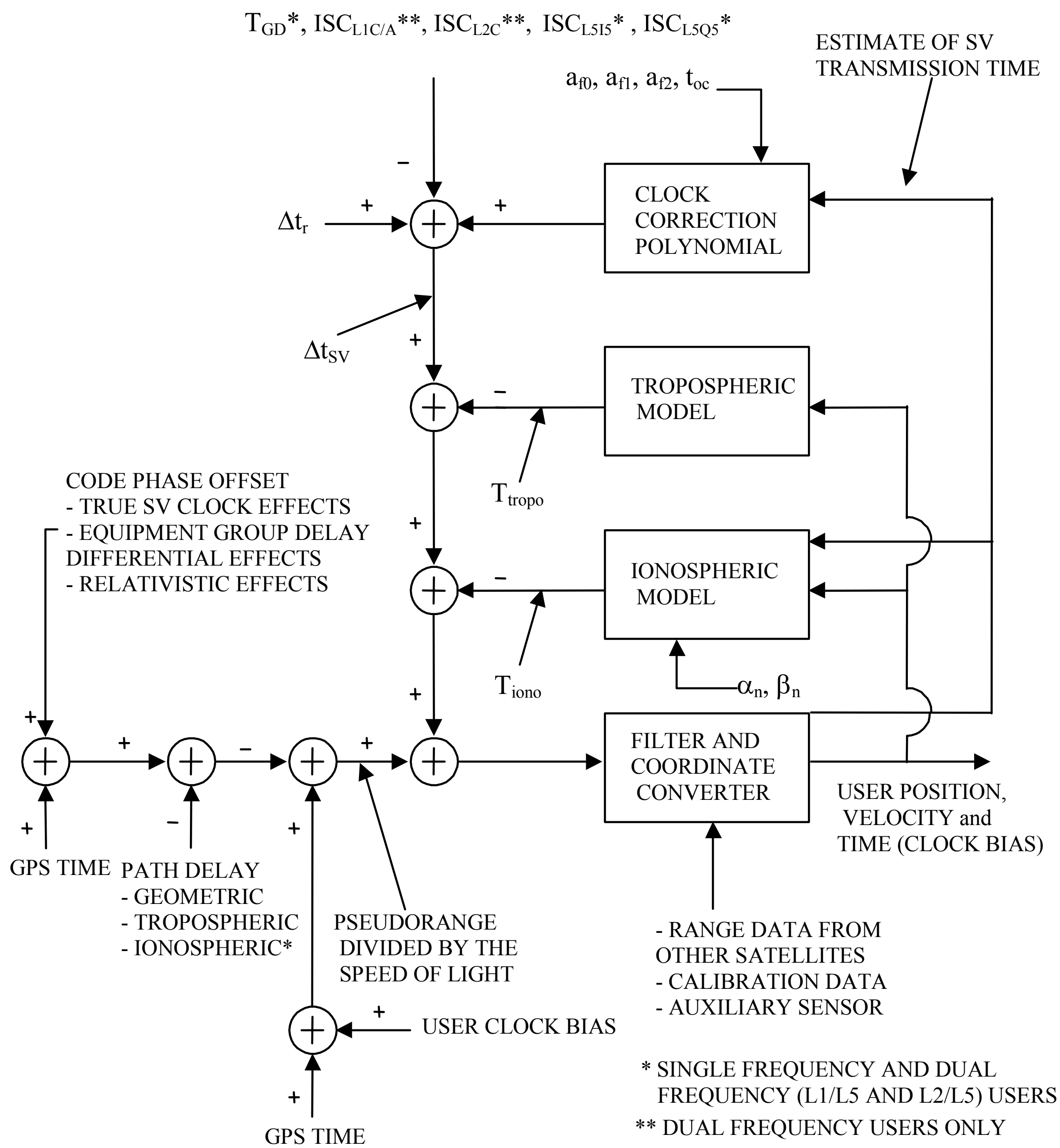


Figure 20-6. Sample Application of Correction Parameters

20.3.3.4.1.2 L1/L2 SV Health. Message Type 4 contains two types of SV health data for the SV indicated with by the PRN_a parameter: (a) L1 and L2 health, and (b) L5 health. The L5 health data is described in paragraph 20.3.3.4.1.3. The eight-bit L1/L2 health words are defined in paragraph 20.3.3.5.1.3, Table 20-VII, and Table 20-VIII of ICD-GPS-200.

The predicted health data will be updated at the time of upload when a new almanac has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV or other SVs in the constellation.

The data given in Message Types 1 and 3 of the other SVs may differ from that shown in Message Type 4 since the latter may be updated at a different time.

20.3.3.4.1.3 L5 Health. The three MSBs of the seven-bit L5 health words in Message Type 4 shall indicate health of the NAV data in accordance with the code given in Table 20-III. The five-bit L5 health words in Message Type 3 provide a one-bit summary of the NAV data's health status in the MSB position in accordance with paragraph 20.3.3.3.1.5. The four LSBs of both the seven-bit and the five-bit words provide the health status of the SV's signal components in accordance with the code given in Table 20-IV.

The predicted health data will be updated at the time of upload when a new almanac has been built by the CS. The transmitted health data may not correspond to the actual health of the transmitting SV or other SVs in the constellation.

The data given in Message Types 1 and 3 of the other SVs may differ from that shown in Message Type 4 since the latter may be updated at a different time.

Table 20-III. L5 NAV Data Health Indications

Bit Position in 7-Bit L5 Health Word			Indication
1	2	3	
0	0	0	ALL DATA OK
0	0	1	PARITY FAILURE -- some or all parity bad
0	1	0	PREAMBLE FORMAT PROBLEM -- any departure from standard format (e.g., preamble misplaced and/or incorrect, etc.), except for incorrect Z-count, as reported in TOW
0	1	1	Z-COUNT BAD -- any problem with Z-count value not reflecting actual code phase
1	0	0	Message Types 1 and 2 -- one or more elements in one or more of the messages are bad
1	0	1	Message Types 3 and 4 -- one or more elements in one or more of the messages are bad
1	1	0	ALL UPLOADED DATA BAD -- one or more of the uploaded elements in any one (or more) of the messages are bad
1	1	1	ALL DATA BAD -- one or more elements in any one (or more) of the messages are bad

Table 20-IV. Codes for Health of SV L5 Signal Components	
MSB LSB	Definition
0 0 0 0	All Signals (I & Q) OK
0 0 0 1	All Signals (I & Q) Weak*
0 0 1 0	All Signals (I & Q) Dead
0 0 1 1	I Signal Has No Data Modulation
0 1 0 0	I Signal Is Weak
0 1 0 1	I Signal Is Dead
0 1 1 0	Q Signal Is Weak
0 1 1 1	Q Signal Is Dead
1 0 0 0	L5 Specific Data Is Bad
1 0 0 1	L5 Parity Is Bad
1 0 1 0	Spare
1 0 1 1	Spare
1 1 0 0	Spare
1 1 0 1	Spare
1 1 1 0	Spare
1 1 1 1	More Than One Combination Would Be Required To Describe Anomalies
* 3 to 6 dB below specified power level due to reduced power output, excess phase noise, SV attitude, etc.	

20.3.3.4.1.4 Anti-Spoof (A-S) Flags and SV Configurations. Bits 221 to 224 of Message Type 4 shall contain a four-bit-long term for each operational SV in the constellation to indicate the A-S status (of the L1 and L2 signals) and the configuration code of each SV. The terms are defined in paragraph 20.3.3.5.1.6 of ICD-GPS-200.

20.3.3.4.1.5 Almanac Reference Week. Bits 45 through 52 of Message Type 4 shall indicate the number of the week (WN_a) to which the almanac reference time (t_{oa}) is referenced (see paragraphs 20.3.3.4.1.1 and 20.3.3.4.2.2). The WN_a term consists of eight bits which shall be a modulo-256 binary representation of the GPS week number (see paragraph 6.2.4) to which the t_{oa} is referenced. Bits 69 through 76 of Message Type 4 shall contain the value of t_{oa}, which is referenced to this WN_a.

20.3.3.4.1.6 SV PRN Number. Bits 39 through 44 of Message Type 4 shall specify PRN number of the SV whose almanac is provided in the message.

20.3.3.4.2 Algorithms Related to Message Type 4 Data. The following algorithms shall apply when interpreting Almanac data in the NAV message.

20.3.3.4.2.1 Almanac. The almanac is a subset of the clock and ephemeris data, with reduced precision. The user algorithm is essentially the same as the user algorithm used for computing the precise ephemeris from the Message Type 1 and 2 parameters (see paragraph 20.3.3.2.3). The almanac content for one SV is given in Table 20-VI of ICD-GPS-200. Important information about the almanac calculation is contained in paragraph 20.3.3.5.2.1 of ICD-GPS-200.

20.3.3.4.2.2 Almanac Reference Time. See the two subparagraphs labeled Normal and Short-term Extended Operations and Long-term Extended Operations of paragraph 20.3.3.5.2.2 of ICD-GPS-200.

20.3.3.4.2.3 Almanac Time Parameters. See paragraph 20.3.3.5.2.3 of ICD-GPS-200.

20.3.3.5 Message Type 5. Message Type 5 is reserved for special messages with the specific contents at the discretion of the Operating Command. It can accommodate the transmission of 29 eight-bit ASCII characters. The requisite 232 bits occupy bits 39 through 270 of Message Type 5. The eight-bit ASCII characters shall be limited to the set described in paragraph 20.3.3.5.1.10 of ICD-GPS-200.

20.3.4 Timing Relationships. The following conventions shall apply.

20.3.4.1 Paging and Cutovers. Paging of messages is completely arbitrary, but sequenced to provide optimum user performance. Message types 1 and 2 shall be broadcast at least once every 24 seconds. All other messages shall be broadcast in-between, not exceeding the maximum update interval in Table 20-V. Message type 5 will be broadcast as needed, but will not reduce the maximum update interval of the other messages. Type 5 messages that are longer than one page will not necessarily be broadcast consecutively.

Table 20-V. Message Content Broadcast Intervals

Message Data	Message Type	Maximum Update Interval (seconds)
Clock/Ephemeris	1	24
Ephemeris	2	24
Ionosphere/UTC	3	96
Almanac	4	48*
Text message	5	as needed

* At least one SV almanac will come within 48 sec. All almanacs for the entire constellation will be broadcast at least every 576 sec.

20.3.4.2 SV Time vs. GPS Time. In controlling the SVs and uploading of data, the CS shall allow for the following timing relationships:

a. Each SV operates on its own SV time;

b. All time-related data (TOW) in the messages shall be in SV-time;

c. All other data in the NAV message shall be relative to GPS time;

d. The acts of transmitting the NAV messages shall be executed by the SV on SV time.

20.3.4.3 Speed of Light. See paragraph 20.3.4.3 of ICD-GPS-200.

20.3.4.4 Data Sets. The IODC is a 10 bit value transmitted in Message Type 1 and 2 that indicates the issue number of the data set provided in the two message types. The transmission of IODC value in different data sets shall be such that the transmitted IODC will be different from any value transmitted by the SV during the preceding seven days. The range of IODC will be as given in Table 20-XII of ICD-GPS-200.

Cutovers to new data sets follow the rules in the second subparagraph of paragraph 20.3.4.4 of ICD-GPS-200.

The start of the transmission interval for each data set corresponds to the beginning of the curve fit interval for the data set. Each data set remains valid for the duration of its curve fit interval.

Normal Operations. Message Type 1 and 2 data sets are transmitted by the SV for periods of two hours. The corresponding curve fit interval is four hours.

Short-term and Long-term Extended Operations. The transmission intervals and curve fit intervals with the applicable IODC ranges are given in Table 20-XII of ICD-GPS-200.

20.3.4.5 Reference Times. See paragraph 20.3.4.5 of ICD-GPS-200.

20.3.5 Message Error Detection. The data signal contains CRC parity coding according to the following conventions.

20.3.5.1 Parity Algorithm. Twenty-four bits of CRC parity will provide protection against burst as well as random errors with a probability of undetected error ≤ $2^{-24} = 5.96 \times 10^{-8}$ for all channel bit error probabilities ≤ 0.5. The CRC word is calculated in the forward direction on a given message using a seed of 0. The sequence of 24 bits ($p_1, p_2, \ldots, p_{24}$) is generated from the sequence of information bits ($m_1, m_2, \ldots, m_{276}$) in a given message. This is done by means of a code that is generated by the polynomial

$$g(X) = \sum_{i=0}^{24} g_i X^i$$

where

$$\begin{aligned} g_i &= 1 \text{ for } i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24 \\ &= 0 \text{ otherwise} \end{aligned}$$

This code is called CRC-24Q. The generator polynomial of this code is in the following form (using binary polynomial algebra):

$$g(X) = (1 + X)p(X)$$

where p(X) is the primitive and irreducible polynomial

$$\begin{aligned} p(X) = X^{23} + X^{17} + X^{13} + X^{12} \\ + X^{11} + X^9 + X^8 + X^7 + X^5 + X^3 + 1 \end{aligned}$$

When, by the application of binary polynomial algebra, the above g(X) is divided into $m(X)X^{24}$, where the information sequence m(X) is expressed as

$$m(X) = m_k + m_{k-1}X + m_{k-2}X^2 + \cdots + m_1X^{k-1}$$

The result is a quotient and a remainder R(X) of degree < 24. The bit sequence formed by this remainder represents the parity check sequence. Parity bit p_i, for any *i* from 1 to 24, is the coefficient of X^{24-i} in R(X).

This code has the following characteristics:

1) It detects all single bit errors per code word.

2) It detects all double bit error combinations in a codeword because the generator polynomial g(X) has a factor of at least three terms.

3) It detects any odd number of errors because g(X) contains a factor 1+X.

4) It detects any burst error for which the length of the burst is ≤ 24 bits.

5) It detects most large error bursts with length greater than the parity length r = 24 bits. The fraction of error bursts of length b > 24 that are undetected is:

a) $2^{-24} = 5.96 \times 10^{-8}$, if b > 25 bits.

b) $2^{-23} = 1.19 \times 10^{-7}$, if b = 25 bits.