INDIAN REGIONAL NAVIGATION SATELLITE SYSTEM

SIGNAL IN SPACE ICD
FOR
STANDARD POSITIONING SERVICE

VERSION 1.1

AUGUST 2017

SATELLITE NAVIGATION PROGRAMME

ISRO SATELLITE CENTRE
INDIAN SPACE RESEARCH ORGANIZATION
BANGALORE

IRNSS SIS ICD FOR
STANDARD POSITIONING SERVICE

VERSION 1.1

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REVIEWED BY

_____

L. MRUTHYUNJAYA
GROUP HEAD, NAVIGATION
PROGRAMME MANAGEMENT GROUP

APPROVED BY

_____

RAMASUBRAMANIAN R
PROGRAMME DIRECTOR
SATELLITE NAVIGATION PROGRAMME

ISRO SATELLITE CENTRE
INDIAN SPACE RESEARCH ORGANIZATION
BANGALORE

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Preface

This document provides the Signal and the Data Structure for Standard Positioning Service (SPS) of the Indian Regional Navigational Satellite System (IRNSS). The document addresses the signal modulations, the frequency bands, the received power levels, the data structures and their interpretations, user algorithms etc.

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1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

The Signal In Space (SIS) Interface Control Document (ICD) for Standard Positioning Service specifies the interface between the IRNSS space segment and the IRNSS user segment for SPS service.

1.2 DOCUMENT OVERVIEW

The document is organized as follows:

- Chapter 1 contains the scope of the document.

- Chapter 2 contains the IRNSS system overview.

- Chapter 3 contains the signal characteristics such as frequency bands, modulation, PRN codes and frame structure.

- Chapter 4 provides the characteristics of the spreading codes.

- Chapter 5 provides the features of IRNSS data structure.

- Chapter 6 provides the formats and the contents of the sub-frames.

2   IRNSS SYSTEM OVERVIEW

Indian Regional Navigation Satellite System (IRNSS) is an independent, indigenously developed satellite navigation system fully planned, established and controlled by the Indian Space Research Organization (ISRO).

2.1 IRNSS ARCHITECTURE

The IRNSS architecture mainly consists of:

➢   Space Segment

➢   Ground Segment

➢   User Segment

Figure 1 depicts the IRNSS architecture
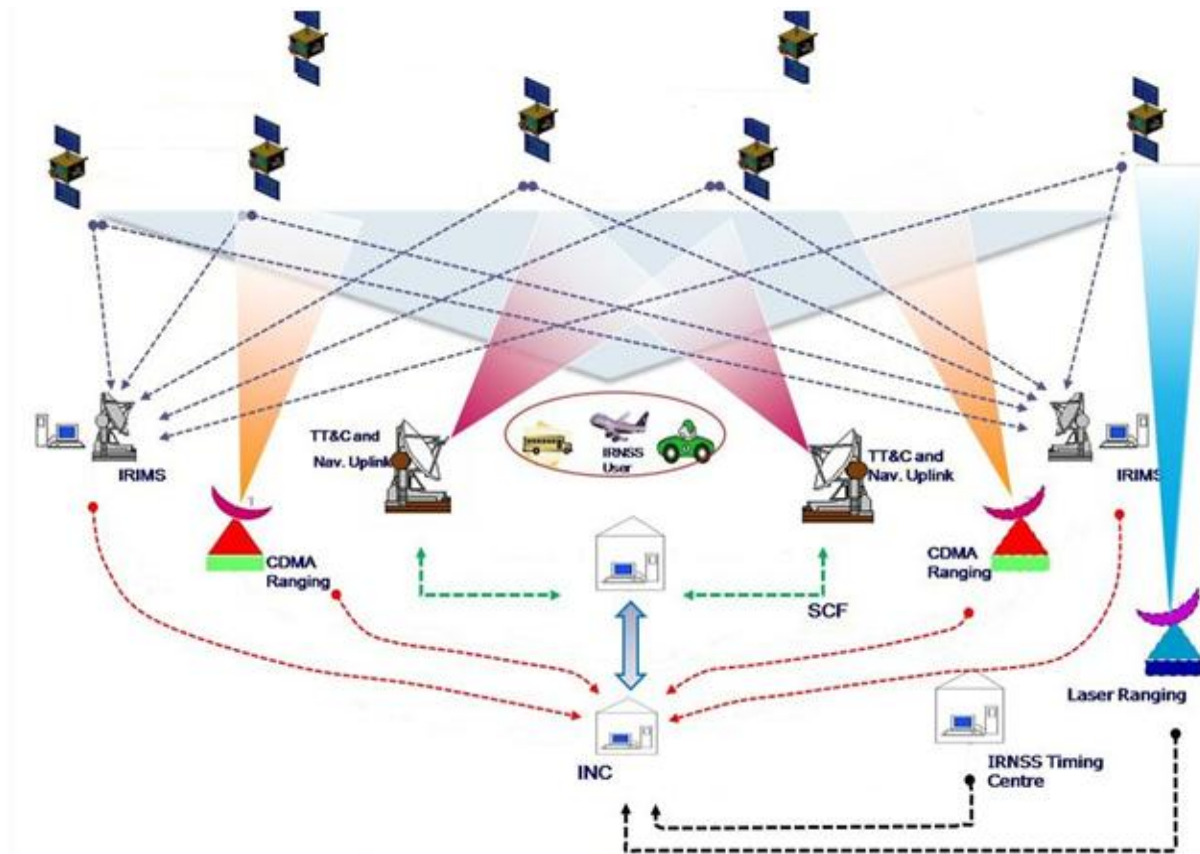
Figure 1: IRNSS Architecture

2.2 IRNSS SPACE SEGMENT

Based on various considerations the IRNSS constellation is worked out to be a combination of GSO and IGSO satellites.

2.3 IRNSS GROUND SEGMENT

Ground Segment is responsible for the maintenance and operation of the IRNSS constellation. The Ground segment comprises of:

> ISRO Navigation Centre
> IRNSS Spacecraft Control Facility
> IRNSS Range and Integrity Monitoring Stations
> IRNSS Network Timing Centre
> IRNSS CDMA Ranging Stations
> Laser Ranging Stations
> Data Communication Network

2.4 USER SEGMENT

The User segment mainly consists of:

> Single frequency IRNSS receiver capable of receiving SPS signal at L5 or S band frequency.

> A dual frequency IRNSS receiver capable of receiving both L5 and S band frequencies.

> A receiver compatible to IRNSS and other GNSS signals.

Figure 2 specifies the radio frequency interface between space and user segments. Each IRNSS satellite provides SPS signals in L5 and S bands.
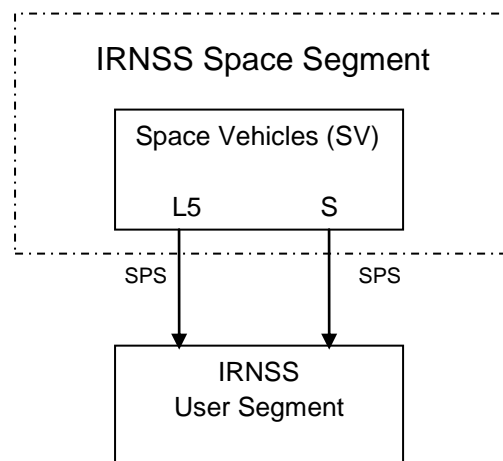
Figure 2: IRNSS Space Segment Interface with User Segment

2.5 IRNSS SERVICES

Standard Position Services (SPS), an open service without encryption and Restricted Service (RS), an authorized with encryption are the basic services offered by IRNSS.

3   IRNSS SIGNAL CHARACTERISITCS

3.1 IRNSS FREQUENCY BANDS

The IRNSS SPS service is transmitted on L5 (1164.45 – 1188.45 MHz) and S (2483.5-2500 MHz) bands. The frequency in L5 band has been selected in the allocated spectrum of Radio Navigation Satellite Services as indicated in Figure 3 and S band as indicated in Figure 4.
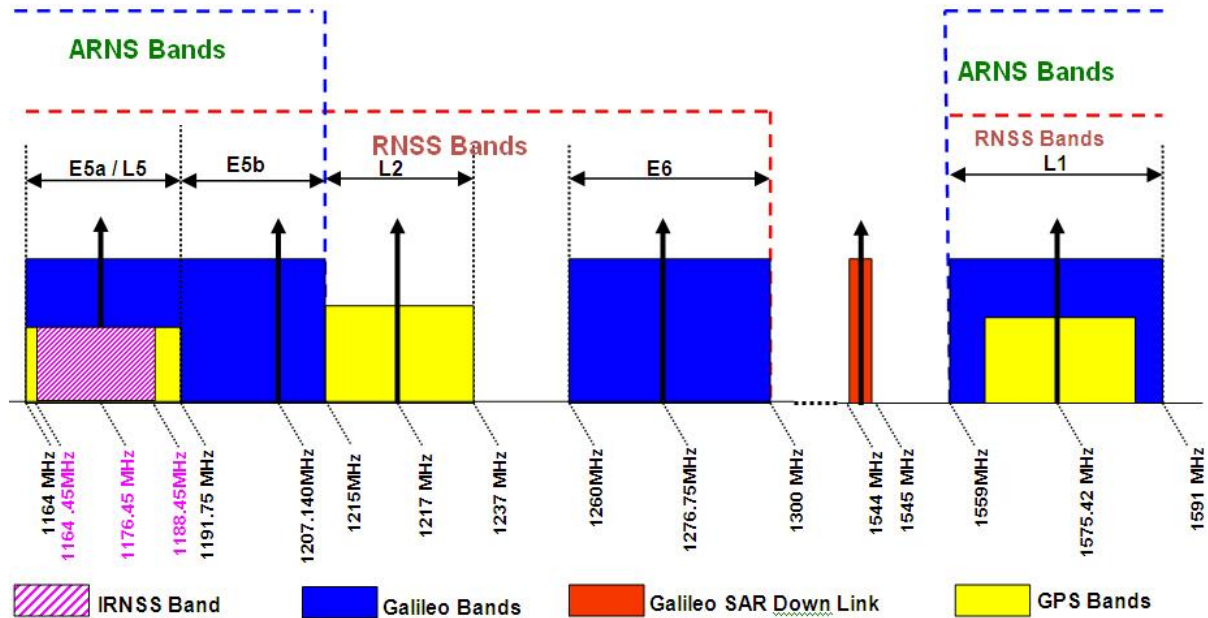
Figure 3: Spectrum for Radio Navigation Satellite Services in L Band
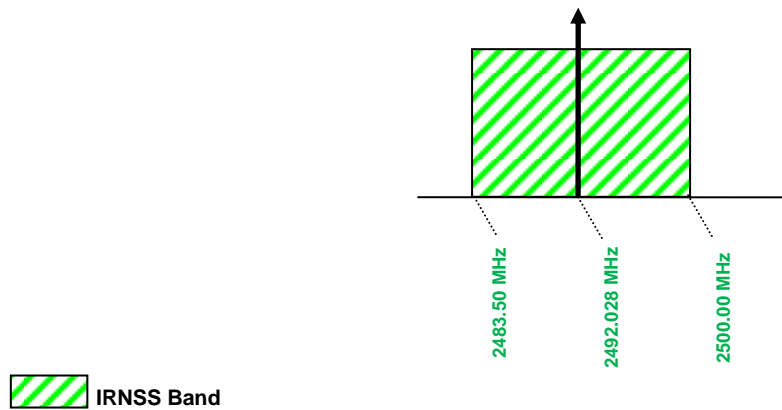
Figure 4: Spectrum for IRNSS Signal in S Band

3.2 IRNSS CARRIER FREQUENCIES

The IRNSS carrier frequencies and the bandwidths of transmission for the SPS service is shown in Table 1.

Table 1: Carrier Frequencies and bandwidths

Signal	Carrier Frequency	Bandwidth
SPS – L5	1176.45 MHz	24 MHz (1164.45 -1188.45 MHz)
SPS – S	2492.028 MHz	16.5MHz (2483.50 – 2500.00MHz)

3.3 MODULATION SCHEME

3.3.1 Standard Positioning Service

The SPS signal is BPSK(1) modulated on L5 and S bands. The navigation data at data rate of 50 sps (1/2 rate FEC encoded) is modulo 2 added to PRN code chipped at 1.023 Mcps identified for SPS service. The CDMA modulated code, modulates the L5 and S carriers at 1176.45MHz and 2492.028 MHz respectively.

3.3.2 Interplex Modulation

Figure 5 depicts the modulation scheme adopted in IRNSS. Each carrier is modulated by three signals namely, BPSK (1), Data channel BOC (5, 2) and Pilot channel BOC (5, 2). These signals when passed through power amplifier or TWTA operated at saturation will produce a non constant envelope. Hence additional fourth signal namely, interplex signal is added in order to have a constant envelope at the output of TWTA RF spectrum.

3.3.2.1 Mathematical Description

The mathematical description for baseband navigation signals, using symbol definitions given above is as follows:

SPS Data Signal

$$s_{sps}(t) = \sum_{i=-\infty}^{\infty} c_{sps}(|i|_{L\_sps}) \cdot d_{sps}([i]_{CD\_sps}) \cdot rect_{Tc,sps}(t-iT_{c,sps}) \dots\dots\dots\dots\dots\dots\dots\dots\dots(1)$$

RS BOC Pilot Signal

$$s_{rs\_p}(t) = \sum_{i=-\infty}^{\infty} c_{rs\_p}(|i|_{L\_rs\_p}) \cdot rect_{Tc,rs\_p}(t-iT_{c,rs\_p}) \cdot sc_{rs\_p}(t,0)\dots\dots\dots\dots\dots\dots\dots\dots\dots(2)$$

RS BOC Signal

$$s_{rs\_d}(t) = \sum_{i=-\infty}^{\infty} c_{rs\_d}(|i|_{L\_rs\_d}) \cdot d_{rs\_d}([i]_{CD\_rs\_d}) \cdot rect_{Tc,rs\_d}(t-iT_{c,rs\_d}) \cdot sc_{rs\_d}(t,0)\dots\dots\dots\dots\dots(3)$$

The sub-carrier is defined as :

$$sc_x(t,\varphi) = sgn[sin(2\pi f_{sc,x}t + \varphi)]\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(4)$$

The IRNSS RS data and pilot BOC signals are sinBOC.

Hence the subcarrier phase φ=0.

The complex envelope of composite signal with Interplex signal (I(t)) is:

$$s(t) = \frac{1}{3} [\sqrt{2} \, (s_{sps}(t) + s_{rs\_p}(t)) + j(2. \, s_{rs\_d}(t) - I(t))] \dots\dots\dots\dots\dots \dots\dots\dots\dots\dots\dots(5)$$

The Interplex signal I(t) is generated to realize the constant envelope composite signal.

Symbol definitions are given in Table 2.

Table 2: Symbol Definitions

Symbol	Description
$c_x(i)$	'i'th chip of spreading code
$d_x(i)$	'i'th bit of navigation message
$sc_x(t)$	Binary NRZ subcarrier
$/i/_X$	'i' modulo 'X'
$[i]_X$	Integer part of (i/X)
CD_x	No. of chips per navigation data bit
L_x	Length of spreading code in chips
$rect_x(t)$	Rectangular pulse function with duration 'x'
$T_{c,x}$	Spreading code chip duration
f_{sc}	Subcarrier frequency
φ	Subcarrier phase

The operation $/i/_X$ gives the code chip index for any signal. Similarly $[i]_X$ gives data bit index for any signal. Table 3 gives data, code and subcarrier rates for composite signal generation.
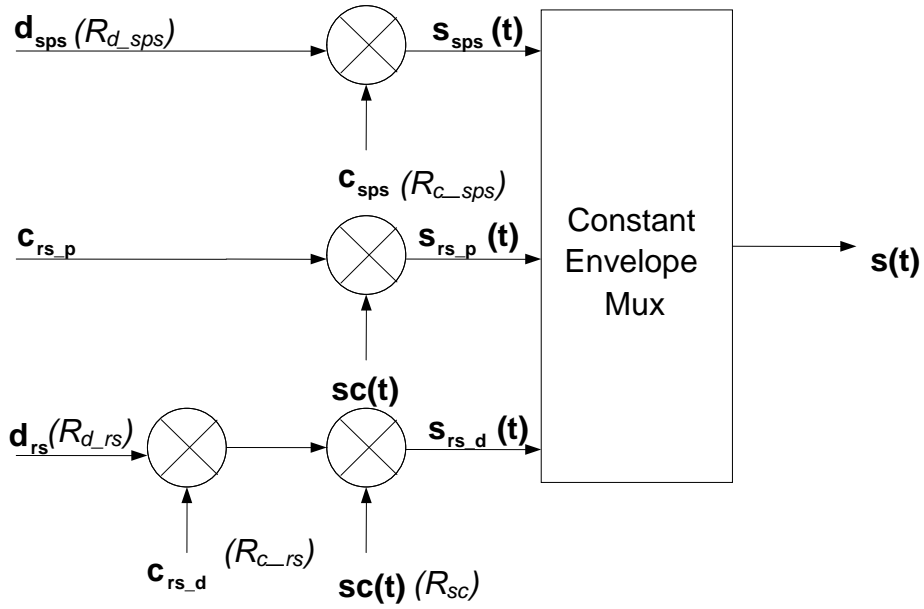
Figure 5: Composites Signal Generation

Below table shows parameter description for composite signal generation.

Table 3: Parameters for Composite Signal Generation

Parameter	Description
R_{d_sps}	SPS data rate
R_{c_sps}	SPS code chip rate
R_{d_rs}	RS data rate
R_{c_rs}	RS code chip rate
R_{sc}	Sub-carrier frequency

3.4 TRANSMITTED SIGNAL PHASE NOISE

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

3.5 CORRELATION LOSS

Correlation loss is defined as the difference between the transmitted power received in the specified signal bandwidth and the signal power recovered in the ideal receiver of the same bandwidth, which perfectly correlates using an exact replica of the waveform within an ideal band-pass filter with linear phase. For all IRNSS signals, the correlation loss that occurs in the navigation payload shall not exceed 0.6 dB.

3.6 TRANSMITTED SIGNALS CODE/DATA COHERENCY

The raising/ leading edge of each data symbol coincides with the starting edge of the PRN code chip. The starting edge of each secondary code chip coincides with the starting edge of primary code chip.

3.7 SPURIOUS CHARACTERISTICS

For all IRNSS signals, in-band spurious transmission shall be at least -50 dB with respect to power level of un-modulated carrier wave.

3.8 RECIEVED POWER LEVELS ON GROUND

3.8.1 Minimum Levels

Table 4 indicates the assured minimum power levels of the IRNSS signals received by a user receiver on ground. The minimum received power on ground is measured at the output of an ideally matched RHCP 0 dBi user receiving antenna when the spacecraft elevation angle is higher than 5°.

Table 4: Minimum received power of IRNSS signals

Signal	Signal Component	Minimum Received Power (dBW)
L5	SPS BPSK(1)	-159.0
S	SPS BPSK (1)	-162.3

3.8.2 Maximum Levels

Table 5 indicates the Maximum power levels of the IRNSS signals received by a user receiver on ground. The maximum received power on ground is measured at the output of an ideally matched RHCP 0 dBi user receiving antenna when the spacecraft elevation angle is higher than 5°.

Table 5: Maximum received power of IRNSS signals

Signal	Signal Component	Maximum Received Power (dBW)
L5	SPS BPSK(1)	-154.0
S	SPS BPSK (1)	-157.3

3.9 POLARIZATION CHARACTERISTICS

All the IRNSS signals are Right Hand Circularly Polarized. The antenna axial ratio does not exceed 2.0 dB.

3.10 CHANNEL GROUP DELAY

Channel group delay is defined as a time difference between transmitted RF signal (measured at phase center of transmitting antenna) and signal at the output of the onboard frequency source.

There are three different delay parameters: Fixed/Bias group delay, Differential group delay and Group delay uncertainty in bias and differential value.

The Fixed delay or Hardware group delay is a bias term. It is included in the clock correction parameters transmitted in the navigation data, and is therefore accounted for by the user computations of system time.

The group delay uncertainty shows the variability in the path delay due to operational environment uncertainty and other factors. The effective uncertainty of the group delay will be in the range of 3nsec (2σ).

Differential group delay is the delay difference between two navigation signals. It consists 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 30nsec. The random variations about the mean will be in the range of 3nsec (two sigma). To correct the bias component of the group delay, T_{GD} parameter is provided to the user in the navigation message.

4   IRNSS PRN CODES

IRNSS utilizes Gold codes for the SPS signal. The codes are selected based on the auto-correlation and cross-correlation properties. The codes are generated using Linear Feedback Shift Registers.

 The code lengths for each signal component are listed in Table 6.

Table 6: Code lengths of IRNSS signals

Channel	Code Length (ms)	Primary (chips)
L5 - SPS	1 ms	1023
S - SPS	1ms	1023

4.1 PRN CODES FOR SPS

PRN Codes selected for Standard Positioning System are similar to GPS C/A Gold codes. The length of each code is 1023 chips. The code is chipped at 1.023 Mcps.

4.1.1 SPS Code Generation

For SPS code generation, the two polynomials G1 and G2 are as defined below:

G1: $X^{10} + X^3 + 1$ and G2: $X^{10} + X^9 + X^8 + X^6 + X^3 + X^2 + 1$

Polynomial G1 and G2 are similar to the ones used by GPS C/A signal. The G1 and G2 generators are realized by using 10 bits Maximum Length Feedback Shift Registers (MLFSR). The initial state of G2 provides the chip delay. The G1 register is initialized with all bits as 1. G1 and G2 are XOR'ed for the generation of the final 1023 chip long PRN sequence. The time period of the PRN sequence is 1 millisecond.

Table 7 shows the identified SPS codes for various SVs for the SPS service.

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Table 7: Code Phase assignment for SPS signals

PRN ID	L5 –SPS		S-SPS	
	Initial Condition for G2 Register	First 10 Chips in Octal2	Initial Condition for G2 Register	First 10 Chips in Octal2
1	1110100111	0130	0011101111	1420
2	0000100110	1731	0101111101	1202
3	1000110100	0713	1000110001	0716
4	0101110010	1215	0010101011	1524
5	1110110000	0117	1010010001	0556
6	0001101011	1624	0100101100	1323
7	0000010100	1753	0010001110	1561
8	0100110000	1317	0100100110	1331
9	0010011000	1547	1100001110	0361
10	1101100100	0233	1010111110	0501
11	0001001100	1663	1110010001	0156
12	1101111100	0203	1101101001	0226
13	1011010010	0455	0101000101	1272
14	0111101010	1025	0100001101	1362

The Figure 6 shows the generation of SPS code. Figure 7 depicts the timing diagram of IRNSS code generations
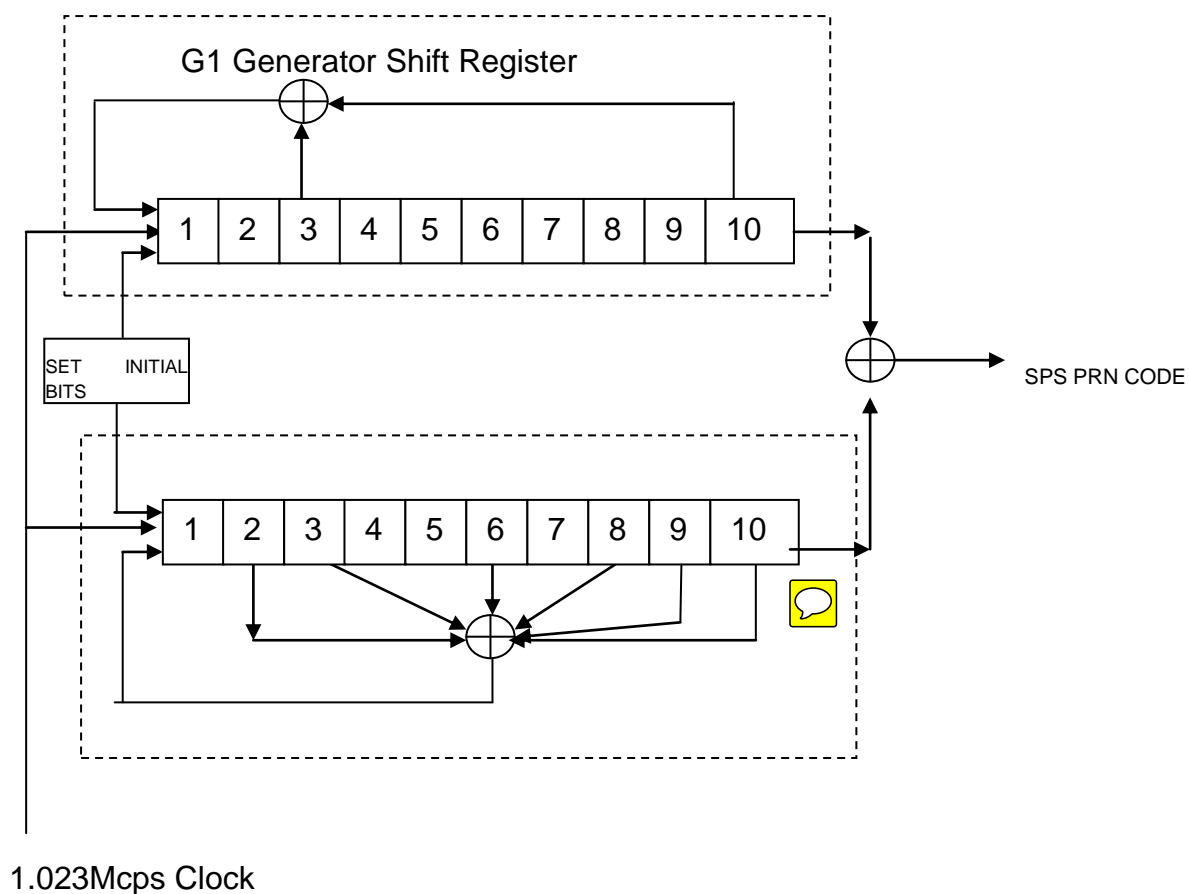
Figure 6: SPS code generator
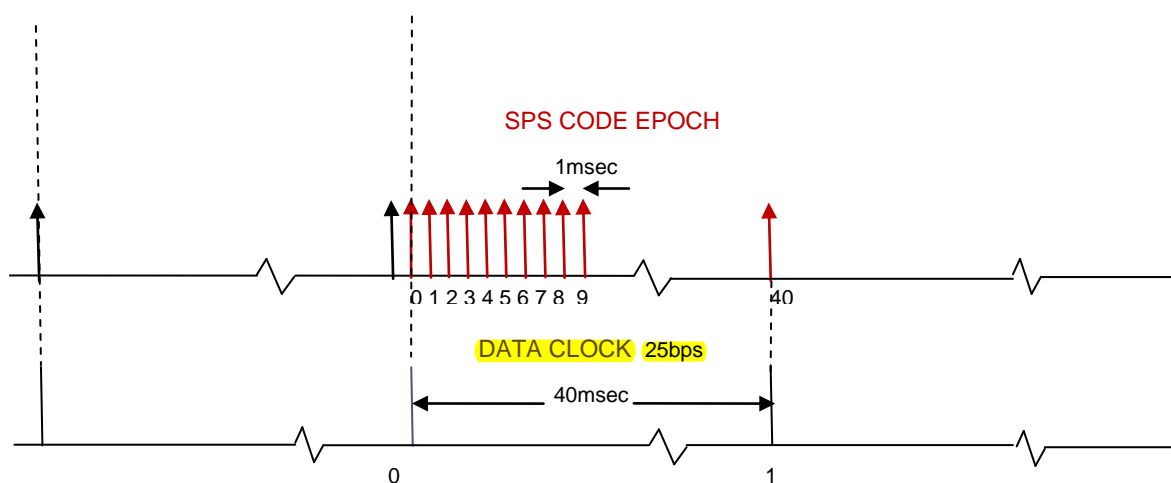
Figure 7 : IRNSS Code Timing Diagram

5   IRNSS DATA STRUCTURE

IRNSS Signal In Space transmits Navigation message contents on SPS service, in L5 and S bands. The IRNSS Master frame comprises of four Sub Frames. Each Subframe is 600 symbols transmitted at 50 sps. Each subframe has 16 bit Sync word followed by 584 bits of interleaved data. The subframe format is shown in Figure 8.

600 symbols	
Sync code	Subframe
16 bits	584 symbols
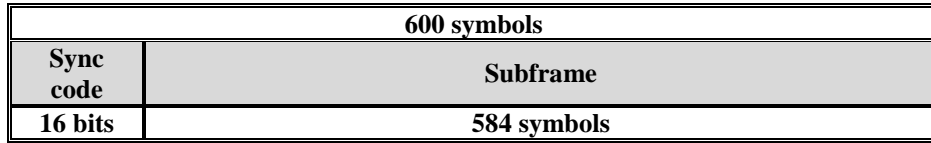
Figure 8 : IRNSS Subframe Structure

The 584 symbols of interleaved data is obtained from FEC encoding 292 subframe bits.

5.1 BIT AND BYTE ORDERING CRITERIA

The following bit and byte ordering criteria will be used while formatting the IRNSS navigation data:

- The most significant bit/byte is numbered as bit/byte 1

- The most significant bit/byte is transmitted first

5.2 FEC ENCODING

The Navigation data subframe of 292 bits is rate 1/2 convolution encoded and clocked at 50 symbols per second. Figure 9 depicts the convolution coding scheme in IRNSS
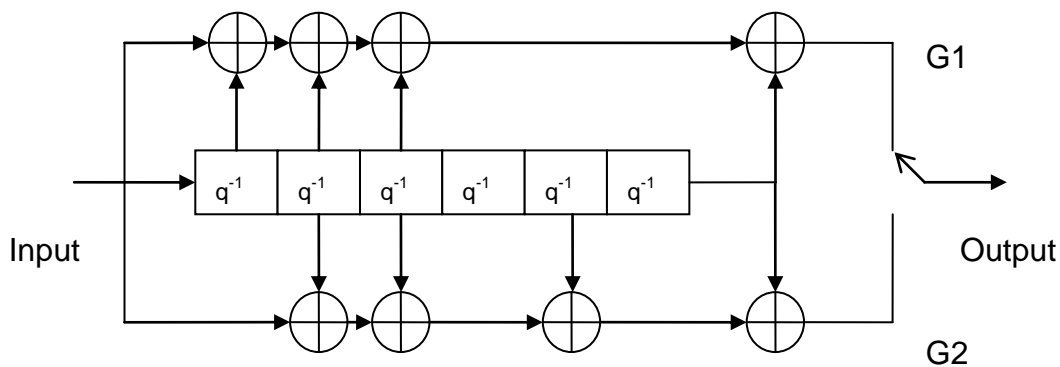
Figure 9: FEC Encoding

The convolution encoding for the navigation data is performed as per the parameters given in Table 8.

<div align="center">**Table 8: FEC encoding parameters**</div>

Parameter	Value
Coding Rate	½
Coding Scheme	Convolution
Constraint Length	7
Generator Polynomial	G1 = (171)o G2 = (133)o
Encoding Sequence	G1 then G2

Each subframe of 292 bits, after encoding, results in 584 symbols.

5.3 INTERLEAVING

The 584 symbols of FEC encoded navigation data is interleaved using a block interleaver with n columns and k rows. Data is written in columns and then, read in rows. Table 9 indicates the interleaving parameters.

<div align="center">**Table 9: Interleaving parameters**</div>

Parameter	Arrangement
Block Interleaver size	584
Block Interleaver Dimensions (*n* columns x *k* rows)	73 x 8

5.4 SYNC WORD

The Synchronization pattern for each of the subframe is 16 bit word. The Synchronization word is not encoded. The synchronization pattern allows the receiver to achieve synchronization to the subframe. The Sync pattern is EB90 Hex.

5.5 TAIL BITS

The tail bit field consists of 6 zero value bits enabling completion of the FEC decoding of each subframe in the user receiver.

5.6 CYCLIC REDUNDANCY CHECK (CRC)

The data signal contains parity coding according to the following conventions. CRC – 24Q polynomial shall be used for each Sub frame. Twenty-four bits of CRC parity will provide protection against burst as well as random errors with a probability of undetected error $\leq 2^{-24}$ = 5.96x10^{-8} for all channel bit error probabilities ≤ 0.5

The generator polynomial is given as $$g(X) = \sum_{i=0}^{24} g_i X^i$$

g_i=1 for i equal to 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24…….…………(6)

= 0 otherwise

5.7 IRNSS SYSTEM TIME

The IRNSS system time is given as 27-bit binary number composed of two parameters as follows:

The Week Number is an integer counter that gives the sequential week number from the origin of the IRNSS time. This parameter is coded on 10 bits appearing in the first subframe, which covers 1024 weeks (about 19 years).

The Time of Week Count (TOWC) indicates the number of 12 second counts at which the next subframe will begin. It is represented in 17 bits. The TOW count value ranges from 1 to 50400 to cover one entire week. The Time Of Week (TOW) in seconds is obtained by multiplying TOWC with 12. The TOWC will have a value of 1 at 00:00:00 Sunday (Changeover from Saturday to Sunday).

The IRNSS System Time start epoch shall be 00:00 UT on Sunday August 22nd 1999 (midnight between August 21st and 22nd). At the start epoch, IRNSS System Time shall be ahead of UTC by 13 leap seconds. (i.e. IRNSS time, August 22nd 1999, 00:00:00 corresponds to UTC time August 21st 1999, 23:59:47)

The epoch denoted in the navigation messages by TOWC and WN will be measured relative to the leading edge of the first chip of the first code sequence of the first subframe symbol. The transmission timing of the navigation message provided through the TOWC is synchronized to IRNSS System Time.

5.8 COORDINATE SYSTEM

IRNSS navigation system uses WGS 84 coordinate system for the computation of user position.

5.9 FRAME STRUCTURE

The IRNSS Master Frame is of 2400 symbols long made of four sub frames. Each sub frame is 600 symbols long. Sub frames 1 and 2 transmit fixed primary navigation parameters. Sub frames 3 and 4 transmit secondary navigation parameters in the form of messages. The master frame structure is shown in Figure 10. All subframes transmit TLM, TOWC, Alert, Autonav, Subframe ID, Spare bit, Navigation data, CRC and Tail bits. Subframe 3 and 4 in addition transmit Message ID and PRN ID.

MASTER FRAME

SUBFRAME 1	SUBFRAME 2	SUBFRAME 3	SUBFRAME 4
600 Symbols	600 Symbols	600 Symbols	600 Symbols
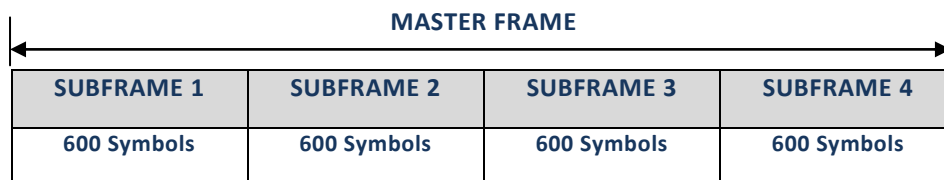
Figure 10: Master Frame Structure

5.9.1 Sub Frame Structure

Each Subframe is 292 bits long (without FEC encoding and Sync Word). The start of each subframe is with TLM word of 8 bits. Each subframe ends with 24 bit CRC followed by 6 tail bits.

In subframes 1 and 2 the Navigation data is allotted 232 bits starting from bit number 31. In subframes 3 and 4 the Navigation data is allotted 220 bits starting from bit number 37. The structure of a typical subframe 1 & 2 is shown in Figure 11. The structure of a typical subframe 3 & 4 is shown in Figure 12.

1	9	26	27	28	30	31	263	287
TLM	TOWC	ALERT	AUTONAV	SUBFRAME ID	SPARE	DATA	CRC	Tail
8 BITS	17BITS	1 BIT	1 BIT	2 BIT	1 BIT	232 BITS	24BITS	6BITS

Figure 11: Structure of Subframe 1 & 2

1	9	26	27	28	30	31	37	257	263	287
TLM	TOWC	ALERT	AUTONAV	SUBFRAME ID	SPARE	MESSAGE ID	DATA	PRN ID	CRC	Tail
8 BITS	17BITS	1 BIT	1 BIT	2 BIT	1 BIT	6 BITS	220 BITS	6	24 BITS	6 BITS

Figure 12: Structure of Subframe 3 & 4

5.9.1.1 TLM

The 8 bits of TLM word are reserved for future.

5.9.1.2 Time of Week Count (TOWC)

Following the TLM word is 17 bits of Time Of Week Count (TOWC). The value of TOWC is multiplied with 12 to obtain the time in seconds corresponding to the start of the next subframe.

5.9.1.3 Alert Flag

Bit 26 is allotted to the Alert Flag. The Alert flag signifies to users that the utilization of navigation data from that particular satellite shall be at the users' own risk.

5.9.1.4 AutoNav

Bit 27 is allotted to the Autonav. Satellites store 7 days ephemeris and clock parameter sets as AutoNav data sets. Satellite can support broadcast of primary navigation parameters from AutoNav data sets with no uplink from ground for maximum of 7 days. During AutoNav mode, the AutoNav flag is set to 1.

5.9.1.5 Subframe ID

Each subframe in the master frame can be identified by the 2 bit subframe ID allotted in bit number 28 and 29. The mapping between 2-bit subframe identifier and subframe number is provided in Table 10.

Table 10:Subframe ID to Subframe Mapping

Subframe ID	Subframe
00	1
01	2
10	3
11	4

5.9.1.6 Spare Bit

Bit 30 is identified as spare bit for future use.

5.9.1.7 Message ID

Each message in the subframe 3 and 4 has a 6 bit message identifier that uniquely identifies the message type in the subframe. The lists of messages are defined in section 6.1.3. The bits allocated for the message identifier are Bit 31 to Bit 36.

5.9.1.8 PRN ID

Each message in the subframe 3 and 4 has a 6 bit PRN identifier that uniquely identifies the spacecraft transmitting the corresponding message. The PRN IDs for IRNSS spacecrafts are defined in Table 7. The PRN ID is allocated Bit 257 - Bit 262 of subframe 3 & subframe 4.

5.10 IRNSS NAVIGATION DATA

The navigation data (NAV data) includes IRNSS satellite ephemeris, IRNSS time, satellite clock correction parameters, status messages and other secondary information etc. Navigation data modulated on top of the ranging codes can be identified as primary and secondary navigation parameters

5.10.1 Primary Navigation Parameters
- Satellite Ephemeris
- Satellite clock correction parameters
- Satellite & signal health status
- User Range Accuracy
- Total group delay

5.10.2 Secondary Navigation Parameters

- Satellite almanac
- Ionospheric grid delays and confidence
- IRNSS Time Offsets with respect to to UTC & GNSS
- Ionospheric delay correction coefficients
- Text messages
- Differential corrections
- Earth orientation parameters

5.10.3 Idle Pattern

Under certain conditions Idle Pattern containing alternating zeroes and ones is transmitted in the data part of the navigation sub-frames of IRNSS. Idle pattern shall begin from bit 41 in Sub-frame 1, bit 31 in sub-frame 2, and bit 37 in sub-frame 3&4, the first bit being a zero.

An idle pattern in Sub-frame 1 or 2 is accompanied by an Alert flag and a valid CRC for the sub-frame. When idle pattern is transmitted in Sub-frame 3 or 4 the Alert flag is not set, but the CRC will be corrupted for the corresponding sub-frame.

6 SUBFRAME STRUCTURE

The primary navigation parameters are transmitted in Subframe 1 and 2. Subframe 3 and 4 cater to the transmission of secondary navigation parameters viz. ionosphere grid corrections, almanac, IRNSS time offsets with respect to UTC and other GNSS, ionosphere correction coefficients, Earth orientation parameters, differential corrections, and text messages. The secondary navigation parameters are transmitted in the form of messages.

6.1 SUBFRAME DATA FORMAT

6.1.1 Subframe 1 Data Format

Table 11 below specifies the contents of data section of subframe 1. The bit layout of subframe 1 is provided in Figure 13.

Table 11: Subframe 1 format

Parameter	Notation	Scale factor (LSB)	Size (bits)	Units
Week Number	WN	1	10	week
Clock bias	a_{fo}	2^{-31}	22*	sec
Clock drift	a_{f1}	2^{-43}	16*	sec/sec
Clock drift rate	a_{f2}	2^{-55}	8*	sec/sec^2
SV Accuracy	URA	1	4	
Time of clock	t_{oc}	16	16	sec
Total Group Delay	T_{GD}	2^{-31}	8*	sec
Mean Motion Difference	Δn	2^{-41}	22*	semi-circles/sec
Issue of Data Ephemeris & Clock	IODEC	1	8	-
Reserved	-	1	10	-
L5 Flag		1	1	-
S Flag		1	1	-
Amplitude of the Cosine Harmonic Correction Term to the Argument of Latitude	C$_{uc}$	2^{-28}	15*	radians
Amplitude of the Sine Harmonic Correction Term to the Argument of Latitude	C$_{us}$	2^{-28}	15*	radians
Amplitude of the Cosine Harmonic Correction Term to the Angle of Inclination	C$_{ic}$	2^{-28}	15*	radians
Amplitude of the Sine Harmonic Correction Term to the Angle of Inclination	C$_{is}$	2^{-28}	15*	radians
Amplitude of the Cosine Harmonic Correction Term to the Orbit Radius	C$_{rc}$	2^{-4}	15*	meters
Amplitude of the Sine Harmonic Correction Term to the Orbit Radius	C$_{rs}$	2^{-4}	15*	meters
Rate of Inclination angle	IDOT	2^{-43}	14*	semi-circles/sec
Spare			2	-

* Parameters indicated are 2's complement

Bit Index	31-40	41-62	63-78	79-86	87-90	91-106	107-114	115-136	137-144	145-154	155	156	157-171	172-186	187-201	202-216	217-231	232-246	247-260	261-262
Notation	WN	a_{f0}	a_{f1}	a_{f2}	URA	t_{oc}	T_{GD}	Δn	IODEC	Reserved	L5 Flag	S Flag	C_{uc}	C_{us}	C_{ic}	C_{is}	C_{rc}	C_{rs}	IDOT	Spare
Size (bits)	10	22*	16*	8*	4	16	8*	22*	8	10	1	1	15*	15*	15*	15*	15*	15*	14*	2

Figure 13: Subframe 1 Data Layout

6.1.2 Subframe 2 Data Format

Table 12 provides the data contents of Subframe 2 and their notation and Figure 14 provides the data layout. The subframe 2 contains remaining Satellite ephemeris parameters.

Table 12:Subframe 2 format

Parameter	Notation	Scale factor (LSB)	Size (bits)	Units
Mean Anomaly	M_o	2^{-31}	32*	semi-circles
Time of ephemeris	t_{oe}	16	16	sec
Eccentricity	e	2^{-33}	32	dimensionless
Square root of Semi major axis	$\sqrt{A}$	2^{-19}	32	$\sqrt{metres}$
Long of Ascending Node	Ω_o	2^{-31}	32 *	semi-circles
Argument of perigee	ω	2^{-31}	32*	semi-circles
Rate of RAAN	$\dot{\Omega}$	2^{-41}	22*	semi-circles/sec
Inclination	i_0	2^{-31}	32*	semi-circles
Spare			2	

* Parameters indicated are 2's complement

Bit Index	31-62	63-78	79-110	111-142	143-174	175-206	207-228	229-260	261-262
Notation	M_0	t_{oe}	e	$\sqrt{A}$	Ω_0	ω	$\dot{\Omega}$	i_0	Spare
Size (bits)	32*	16	32	32	32 *	32*	22*	32*	2

Figure 14: Subframe 2 Data Layout

Note: Time of Clock t_{oc} (broadcasted in subframe 1) and t_{oe} in (broadcasted in subframe 2) to be matched for data integrity.

6.1.3 Subframe 3 & 4 Data Format (IRNSS Message Structure)

Subframe 3 and Subframe 4 transmit IRNSS navigation parameters as Messages. The Table 13 identifies the message types that the IRNSS satellites will transmit. Provision exists to define new message for future requirements in IRNSS. Each message is identified by a unique message identifier. Each message transmits 220 bits of Navigation data.

Table 13: IRNSS Message Types

PARAMETER	MSG ID
Ionospheric grid parameters for 15 grid points (1 of 6 regions)	5
Almanac parameters	7
UTC and Time Sync Parameters with respect to GPS	9
EOP and Ionosphere coefficients	11
Differential corrections for one satellite	14
Text message	18
UTC and Time Sync Parameters with respect to GNSS	26
Null Message	0
Reserved for future	1-4, 6, 8, 10, 12, 13, 15-17, 19-25, 27-63

The PRN ID of the transmitting SV is indicated after the data portion of the IRNSS messages in six bits binary format.

6.1.3.1 Message Type 5 Data Format

Message Type 5 transmits the ionospheric grid corrections in the form of GIVEI and GIVD for one region. Thus, 6 messages of message type 5 (one for each region with 15 IGPs) together provide the complete set of ionospheric grid based parameters for Indian region. Table 14 defines the parameters and the notations used in Message Type 5. The bit-layout for data contents of Message-type 5 is provided in Figure 15.

Table 14: Message Type 5 format

Parameter	Scale Factor	Size (bits)	Units
Regions Masked		10	
Region Id		4	
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters

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GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
GIVEI		4	
GIVD	0.125	9	meters
IODI	`	3	
Spare		8	
PRN ID	PRN ID	6	

Bit Index	37-46	47-50	51-54	55-63	64-67	68-76	77-80	81-89	90-93	94-102	103-106	107-115	116-119	120-128	129-132	133-141	142-145	146-154
Notation	Regions Masked	Region Id	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD
Size (bits)	10	4	4	9	4	9	4	9	4	9	4	9	4	9	4	9	4	9

Contd..

Bit Index	155-158	159-167	168-171	172-180	181-184	185-193	194-197	198-206	207-210	211-219	220-223	224-232	233-236	237-245	246-248	249-256	257-262
Notation	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	GIVEI	GIVD	IODI	SPARE	PRN ID
Size (bits)	4	9	4	9	4	9	4	9	4	9	4	9	4	9	3	8	6

Figure 15: Message Type 5 Data Layout

6.1.3.2 Message Type 7 Data Format

Each message type 7 contains the almanac of one IRNSS spacecraft. Thus, a set of seven messages of type 7(one for each IRNSS spacecraft) together provide the almanac for complete IRNSS constellation. Table 15 below defines the parameters and the notations used in Message Type 7. The bit-layout for data contents of message type 7 is given in Figure 16.

Table 15: Message Type 7 format

Parameter	Notation	Scale Factor	Size (bits)	Units
Week number for almanac	WN_a		10	
Eccentricity	e	2^{-21}	16	Dimensionless
Time of almanac	t_{oa}	2^4	16	sec
Inclination	i_0	2^{-23}	24*	semi-circles
Rate ofRAAN	$\dot{\Omega}$	2^{-38}	16*	semi-circles/sec
SQRT A	$\sqrt{A}$	2^{-11}	24	$\sqrt{meters}$
Longitude of ascending node(LAN)	Ω_0	2^{-23}	24*	semi-circles
Argument of perigee	ω	2^{-23}	24*	semi-circles
Mean anomaly	M_0	2^{-23}	24*	semi-circles
Clock bias A0	a_{fo}	2^{-20}	11*	sec
Clock drift A1	a_{f1}	2^{-38}	11*	sec/sec
PRN ID for Almanac	PRN ID AL		6	
Inter Signal Correction		2^{-31}	8*	sec
Spare			6	
PRN ID	PRN ID		6	

* Parameters indicated are 2's complement

Bit Index	37-46	47-62	63-78	79-102	103-118	119-142	143-166	167-190	191-214	215-225	226-236	237-242	243-250	251--256	257-262
Notation	WN_a	e	t_{oa}	i_0	$\dot{\Omega}$	$\sqrt{A}$	Ω_0	ω	M_0	a_{f0}	a_{f1}	PRN ID AL	Inter Signal Correction	Spare	PRN ID
Size (bits)	10	16	16	24*	16*	24	24*	24*	24*	11*	11*	6	8*	6	6

Figure 16: Message Type 7 Data Layout

6.1.3.3 Message Type 9 Data Format

Message type 9 provides the IRNSS time offset with respect to UTC and GPS. The Table 16 below defines the parameters and the notations used in Message Type 9 and Figure 17 provides the data layout.

(Note:- The message type 9 shall be a sub-set of message type 26, that shall transmit IRNSS time offset with respect to UTC (NPLI) and other GNSS.)

Table 16: Message Type 9 format

Parameter	Notation	Scale Factor	Size (bits)	Units
IRNSS – UTC PARAMETERS				
Bias coefficient of IRNSS time scale relative to UTC time scale	A_{0utc}	2^{-35}	16*	sec
Drift coefficient of IRNSS time scale relative to UTC time scale	A_{1utc}	2^{-51}	13*	sec/sec
Drift rate coefficient of IRNSS time scale relative to UTC time scale	A_{2utc}	2^{-68}	7*	sec/sec^2
Current or past leap second count	Δt_{LS}	1	8*	sec
Time data reference time of week	t_{outc}	2^4	16	sec
Time data reference week number	WN_{outc}	1	10	week
Leap second reference week number	WN_{LSF}	1	10	week
Leap second reference day number	DN	1	4	days
Current or future leap second count	Δt_{LSF}	1	8*	sec
IRNSS – GPS PARAMETERS				
Bias coefficient of IRNSS time scale relative to GPS time scale	A_0	2^{-35}	16*	sec
Drift coefficient of IRNSS time scale relative to GPS time scale	A_1	2^{-51}	13*	sec/sec
Drift rate correction coefficient of IRNSS time scale relative of GPS time scale	A_2	2^{-68}	7*	sec/sec^2
Time data reference time of week	t_{ot}	2^4	16	sec
Time data reference week number	WN_{ot}	1	10	week
GNSS type id for GPS	GNSSID		3	
Spare			63	
PRN ID	PRN ID		6	

* Parameters indicated are 2's complement

Bit Index	37-52	53-65	66-72	73-80	81-96	97-106	107-116	117-120	121-128	129-144	145-157	158-164	165-180	181-190	191-193	194-256	257-262
Notation	A_{0utc}	A_{1utc}	A_{2utc}	Δt_{LS}	t_{outc}	WN_{outc}	WN_{LSF}	DN	Δt_{LSF}	A_0	A_1	A_2	t_{ot}	WN_{ot}	GNSS ID	Spare	PRN ID
Size (bits)	16*	13*	7*	8*	16	10	10	4	8*	16*	13*	7*	16	10	3	63	6

Figure 17: Message Type 9 data layout

6.1.3.4 Message Type 11 Data Format

Message type 11 contains the ionospheric coefficients and Earth orientation parameters. The Table 17 below defines the parameters and the notations used in Message Type 11 and Figure 18 provides the data layout.

Table 17: Message type 11 format

Parameter	Notation	Scale Factor	Size (bits)	Units
EARTH ORIENTATION PARAMETERS				
EOP Data Reference Time	t_{EOP}	2^4	16	sec
X-Axis Polar Motion Value at Reference Time.	PM_X	2^{-20}	21*	arc-sec
X-Axis Polar Motion Drift at Reference Time.	PM_$\dot{X}$	2^{-21}	15*	arc-sec/day
Y-Axis Polar Motion Value at Reference Time.	PM_Y	2^{-20}	21*	arc-sec
Y-Axis Polar Motion Drift at Reference Time.	PM_$\dot{Y}$	2^{-21}	15*	arc-sec/day
UT1-UTC Difference at Reference Time.	ΔUT1	2^{-24}	31*	sec
Rate of UT1-UTC Difference at Reference Time.	ΔU$\dot{T}$1	2^{-25}	19*	sec/day
IONOSPHERE COEFFICIENTS*				
Alpha 0	α_0	2^{-30}	8*	sec
Alpha 1	α_1	2^{-27}	8*	sec/semi-circle
Alpha 2	α_2	2^{-24}	8*	sec/(semi-circle)^2
Alpha 3	α_3	2^{-24}	8*	sec/(semi-circle)^3
Beta 0	β_0	2^{11}	8*	sec
Beta 1	β_1	2^{14}	8*	sec/semi-circle
Beta 2	β_2	2^{16}	8*	sec/(semi-circle)^2
Beta 3	β_3	2^{16}	8*	sec/(semi-circle)^3
Spare			18	
PRN ID	PRN ID		6	

* Parameters indicated are 2's complement

Bit Index	37-52	53-73	74-88	89-109	110-124	125-155	156-174	175-182	183-190	191-198	199-206	207-214	215-222	223-230	231-238	239-256	257-262
Notation	t_{EOP}	PM_X	PM_$\dot{X}$	PM_Y	PM_$\dot{Y}$	ΔUT1	ΔU$\dot{T}$1	α_0	α_1	α_2	α_3	β_0	β_1	β_2	β_3	Spare	PRN ID
Size (bits)	16	21*	15*	21*	15*	31*	19*	8*	8*	8*	8*	8*	8*	8*	8*	18	6

Figure 18: Message Type 11 data layout

6.1.3.5 *Message Type 14 Data Format*

The Table 18 below defines the parameters and the notations used in Message Type 14 and Figure 19 provides the data layout.

Table 18: Message Type 14 format

Parameter	Notation	Scale Factor	Size (bits)	Units
Reserved			1	
PRN ID of spacecraft for applying differential corrections	PRN ID DC		6	
SV clock bias correction	δa_{f0}	2^{-35}	13*	sec
SV clock drift correction	δa_{f1}	2^{-51}	8*	sec/sec
User Differential Range Accuracy Index	UDRA		5*	
Alpha correction to ephemeris parameters	$\Delta\alpha$	2^{-34}	14*	Dimension-less
Beta correction to ephemeris parameters	$\Delta\beta$	2^{-34}	14*	Dimension-less
Gamma correction to ephemeris parameters	$\Delta\gamma$	2^{-32}	15*	semi-circles
Angle of inclination correction	Δi	2^{-32}	12*	semi-circles
Angle of right ascension correction	$\Delta\Omega$	2^{-32}	12*	semi-circles
Semi-major correction	ΔA	2^{-9}	12*	meters
Change rate of User Differential Range Accuracy Index	$UD\dot{R}A$		5*	
Issue of Data Ephemeris & Clock	IODEC**		8	
Reserved			10	
Time of Differential Correction	t_{od}	16	16	sec
Spare			69	
PRN ID	PRN ID		6	

* Parameters indicated are 2's complement

**The IODEC parameters are used to map the differential corrections to the ephemeris & clock set being broadcast in the autonav mode of the satellite.

Bit Index	37	38-43	44-56	57-64	65-69	70-83	84-97	98-112	113-124	125-136	137-148	149-153	154-161	162-171	172-187	188-256	257-262
Notation	Reserved	PRN ID DC	δa_{f0}	δa_{f1}	UDRA	$\Delta\alpha$	$\Delta\beta$	$\Delta\gamma$	Δi	$\Delta\Omega$	ΔA	$\dot{UDRA}$	IODEC	Reserved	t_{od}	Spare	PRN ID
Size (bits)	1	6	13*	8*	5*	14*	14*	15*	12*	12*	12*	5*	8	10	16	69	6

Figure 19: Message Type 14 Data Layout

6.1.3.6 *Message Type 18 Data Format*

The Table 19 below defines the parameters and the notations used in Message Type18 and Figure 20 provides the data layout.

Table 19: Message Type 18 format

Parameter	Size (bits)
Text ID	4
Block count	8
Block ID	8
Text data (25 chars of 8 bits each)	200
PRN ID	6

Bit Index	37–40	41–48	49–56	57–256	257–262
Parameter	Text ID	Block count	Block ID	Text data (25 chars of 8 bits each)	PRN ID
Size (bits)	4	8	8	200	6

Figure 20: Message Type 18 data layout

6.1.3.7 *Message Type 26 Data Format*

Message type 26 provides the IRNSS time offset with respect to UTC, UTC (NPLI) and other GNSS like GPS, GALILEO, GLONASS etc. The Table 20 below defines the parameters and the notations used in Message Type 26 and Figure 21 provides the data layout.

Table 20: Message Type 26 format

Parameter	Notation	Scale Factor	Size (bits)	Units
IRNSS – UTC PARAMETERS				
Bias coefficient of IRNSS time scale relative to UTC time scale	A_{0utc}	2^{-35}	16*	sec
Drift coefficient of IRNSS time scale relative to UTC time scale	A_{1utc}	2^{-51}	13*	sec/sec
Drift rate coefficient of IRNSS time scale relative to UTC time scale	A_{2utc}	2^{-68}	7*	sec/sec^2
Current or past leap second count	Δt_{LS}	1	8*	sec
Time data reference time of week	t_{outc}	2^4	16	sec
Time data reference week number	WN_{outc}	1	10	week
Leap second reference week number	WN_{LSF}	1	10	week
Leap second reference day number	DN	1	4	days
Current or future leap second count	Δt_{LSF}	1	8*	sec
IRNSS – UTC (NPLI) / OTHER GNSS PARAMETERS				

Bias coefficient of IRNSS time scale relative to GNSS time scale	A_0	2^{-35}	16*	sec
Drift coefficient of IRNSS time scale relative to GNSS time scale	A_1	2^{-51}	13*	sec/sec
Drift rate correction coefficient of IRNSS time scale relative of GNSS time scale	A_2	2^{-68}	7*	sec/sec^2
Time data reference time of week	t_{ot}	2^4	16	sec
Time data reference week number	WN_{ot}	1	10	week
GNSS type id	GNSSID		3	
Spare			63	
PRN ID	PRN ID		6	

* Parameters indicated are 2's complement

Bit Index	Notation	Size (bits)
37-52	A_{0utc}	16*
53-65	A_{1utc}	13*
66-72	A_{2utc}	7*
73-80	Δt_{LS}	8*
81-96	t_{outc}	16
97-106	WN_{outc}	10
107-116	WN_{LSF}	10
117-120	DN	4
121-128	Δt_{LSF}	8*
129-144	A_0	16*
145-157	A_1	13*
158-164	A_2	7*
165-180	t_{ot}	16
181-190	WN_{ot}	10
191-193	GNSS ID	3
194-256	Spare	63
257-262	PRN ID	6

Figure 21: Message Type 26 data layout

6.1.3.8 Message Type 0 (Null Message) Data Format

The Table 21 below defines the parameters and the notations used in Message Type 0 and Figure 22 provides the data layout.

Table 21: Message Type 0 format

S. No	Parameter	Size (bits)
1	0	1
2	1	1
3	0	1
⋮		
255	0	1
256	1	1
257	PRN ID	6

Bit Index	37	38	39	40	...	255	256	257-262
Parameter	0	1	0	1	...	0	1	PRN ID
Size (bits)	1	1	1	1		1	1	6

Figure 22: Message Type 0 data layout

6.2 DATA CONTENTS

6.2.1 Subframe 1 & Subframe 2

6.2.1.1 Week Number (WN)

The Week Number is an integer counter that gives the sequential week number from the origin of the IRNSS time. IRNSS Time is the reference time generated by IRNWT located at INC. This parameter is coded in 10 bits which covers 1024 weeks (about 19 years).

6.2.1.2 Clock Parameters

The clock coefficients (a_{f0}, a_{f1} and a_{f2}) transmitted as part of subframe 1 are used for IRNSS time and clock corrections. These estimated corrections account for the deterministic Satellite clock error having characteristics of bias, drift and aging. Bias is the difference between a measured on-time pulse (signal) and a reference on-time pulse (signal) of IRNSS System Time. Drift is the linear component of a systematic change in frequency of an oscillator over a period of time. It is caused by aging, by environmental changes and by other internal factors of the oscillator. Drift rate is the rate of change of drift. Time of clock, t_{oc} is the clock data reference time in seconds.   The above parameters are discussed in Appendix A

6.2.1.3 Issue of Data Ephemeris & Clock (IODEC)

For IRNSS satellites, the IODEC is a 8-bit number which indicates the issue number of the data set and thereby provides the user with a convenient means of detecting any change in the ephemeris and clock parameters. Each time the user equipment is powered on, it must ensure that it is using up-to-date ephemeris and clock data for the satellites involved in its position computation. The IODEC range assigned are defined in Table 22.

Table 22: Issue of Data Ephemeris & Clock (IODEC) and its Applicability

Period	IODEC range	Update rate	Remarks
Broadcast period	0 to 11	2 hours	Nominal sets
Broadcast period	12 to 23	2 hours	Update to nominal set
Broadcast period	24 to 29	4 hours	-
Autonav period	76 to 159	2 hours	Future 7 Days upload
Broadcast Period	160 to 255	< 30 mins	Frequent update

The interpretation of above table is as follows:

- Current day broadcast ephemeris and clock parameters are uplinked in advance as nominal sets with IODEC values in the range 0 to 11(12 sets).

- IODEC values for update to nominal sets is in the range of 12 to 23.

- For the ephemeris and clock parameters with update rate greater than 2 hours, IODEC values are in the range 24 to 29.

- For the ephemeris and clock parameters with update rate lesser than 30 minutes, IODEC values are in the range from 160 to 255.

- During AutoNav mode of operation, IODEC values are in the range 76 to 159.

- The IODEC values in the range 30 to 75 are reserved for future.

6.2.1.4 User Range Accuracy (URA)

URA is a statistical indicator of the ranging accuracies obtainable with a specific SV. URA is a one-sigma estimate of the user range errors in the navigation data for the transmitting satellite and its index value ranges from 0-15. The details on mapping between URA Index (URAI) and URA are provided in Table 23.

Table 23: URA Index to URA Mapping

URA	INDEX URA (meters)
0	$0.00 < URA \leq 2.40$
1	$2.40 < URA \leq 3.40$
2	$3.40 < URA \leq 4.85$
3	$4.85 < URA \leq 6.85$
4	$6.85 < URA \leq 9.65$
5	$9.65 < URA \leq 13.65$
6	$13.65 < URA \leq 24.00$
7	$24.00 < URA \leq 48.00$
8	$48.00 < URA \leq 96.00$
9	$96.00 < URA \leq 192.00$
10	$192.00 < URA \leq 384.00$
11	$384.00 < URA \leq 768.00$
12	$768.00 < URA \leq 1536.00$
13	$1536.00 < URA \leq 3072.00$
14	$3072.00 < URA \leq 6144.00$
15	$6144.00 < URA$ (or no accuracy prediction is available - authorized users are advised to use the SV at their own risk.)

For each URA index (N), users may compute a nominal URA value (X) as given by:

- If the value of N is 6 or less, $X = 2^{(1 + N/2)}$.
- If the value of N is 6 or more, but less than 15, $X = 2^{(N - 2)}$,
- If N = 15 shall indicate the absence of an accuracy prediction and shall advise the user not to use that SV.
- If $4 > N \geq 14$ shall indicate very high ranging error and advise user to use the SV at their own risk

For N = 1, 3, and 5, X should be rounded to 2.8, 5.7, and 11.3 meters, respectively.

6.2.1.5 *Total Group Delay (T$_{GD}$)*

Total group delay (T$_{GD}$), is broadcasted to account for the effect of SV group delay differential between L5-SPS and S-SPS based on measurements made by the SV manufacturer. The value of T$_{GD}$ for each SV may be subsequently updated to reflect the actual on-orbit group delay differential.

This correction term is only for the benefit of "single-frequency" S or L5 frequency SPS users; it is necessitated by the fact that the SV clock offset estimates reflected in the a$_{f0}$ clock correction coefficient are based on the effective PRN code phase as apparent with two frequency (S and L5) ionospheric corrections. Thus, the user who utilizes the S signal only shall modify the code phase offset in accordance with the equation:

$(\Delta t_{SV})_{S,SPS} = \Delta t_{SV} - T_{GD}$

For the user who utilizes L5 only, the code phase modification is given by

$(\Delta t_{SV})_{L5,SPS} = \Delta t_{SV} - \gamma T_{GD}$

Where $\gamma = (f_S/f_{L5})^2$ and f_S and f_{L5} denote the nominal center frequencies of S and L5 respectively.

6.2.1.6 *Signal Health Flags*

The one-bit health flags: L5 flag and S flag indicate the health of NAV data on L5 and S signals as follows.

Table 24: Signal Health Flags

Flag	Value	Description
L5 flag	0	All navigation data on L5 SPS signal are OK
L5 flag	1	Some or all navigation data on L5 SPS signal are bad
S flag	0	All navigation data on S SPS signal are OK
S flag	1	Some or all navigation data on S SPS signal are bad

6.2.1.7 *Other Parameters*

The parameters Cuc, Cus, Cic, Cis, Crc, Crs and IDOT form part of ephemeris parameters and discussed in Table 25 under section 6.2.1.8.

6.2.1.8 *Ephemeris Parameters*

The coordinates of the IRNSS satellite's antenna phase center position in ECEF reference frame shall be computed by the user utilizing the Ephemeris parameters in subframes 1 and 2. The user algorithm to find Ephemeris parameters is discussed in Appendix B. The ephemeris parameters are provided for satellite's antenna phase center. The ephemeris parameters definitions are provided in Table 25.

Table 25: Ephemeris Parameters

Parameters	Definitions
Δn	Mean Motion difference from computed value
C_{uc}	Amplitude of the Cosine Harmonic Correction term to the Argument of Latitude
C_{us}	Amplitude of the Sine Harmonic Correction term to the Argument of Latitude
C_{ic}	Amplitude of the Cosine Harmonic Correction term to the Angle of Inclination
C_{is}	Amplitude of the Sine Harmonic Correction term to the Angle of Inclination
C_{rc}	Amplitude of the Cosine Harmonic Correction term to the Orbit Radius
C_{rs}	Amplitude of the Sine Harmonic Correction term to the Orbit Radius
IDOT	Rate of Inclination Angle
M_o	Mean Anomaly at Reference Time
t_{oe}	Ephemeris Reference time
e	Eccentricity
$\sqrt{A}$	Square Root of the Semi-Major Axis
Ω_o	Longitude of Ascending Node of Orbit Plane at Weekly Epoch
ω	Argument of Perigee
$\dot{\Omega}$	Rate of Right Ascension
i_0	Inclination Angle at Reference Time
IODEC	Issue of Data for Ephemeris and Clock

6.2.2 Message Type 5 Data Contents

Message type 5 contains the ionosphere grid corrections for grid points over Indian region. The ionospheric delay corrections are broadcasted as vertical delay estimates at specified ionospheric grid points (IGPs), applicable to a signal on L5 for the single frequency users over the Indian land mass. This includes 90 IGPs at 350 km above the Earth surface. The 90 IGPs identified for grid based servicing is shown in Figure 23. Since the total IGPs cannot be broadcasted in a single message, these 90 IGPS are divided into 6 regions. Each message contains the corrections for 1 region, containing 15 IGPs (with grid size of 5^ox5^o). The grid based corrections for the single frequency users (L5) over the Indian region include:

- Region ID
- Grid Ionosphere Vertical Delay (GIVD)
- Grid Ionosphere Vertical Error Indicator (GIVEI)
- Regions Masked (10 bits)
- Issue of Data Ionosphere (IODI)

The corrections: Grid Ionosphere Vertical Delay on L5 (GIVD) & their 99.9 % accuracy, called the Grid Ionosphere Vertical Error Indicator (GIVEI) are provided at each IGP. The region masked indicates the total number of regions for which the corrections are provided. For the current service area of IRNSS, regions masked are 6. IODI is used to indicate a change in region masked. It ranges from 0 to 7. It is incremented by 1 with a change in regions masked and is reset to 0 after reaching maximum of 7. The description of the region id and index with respect to the IGP location is provided in Table 26. The IGP locations must be stored permanently by the user along with the region id for each IGP within the region.

For the broadcast region id, the user in-turn will derive the IGP latitude and longitude from the stored values.
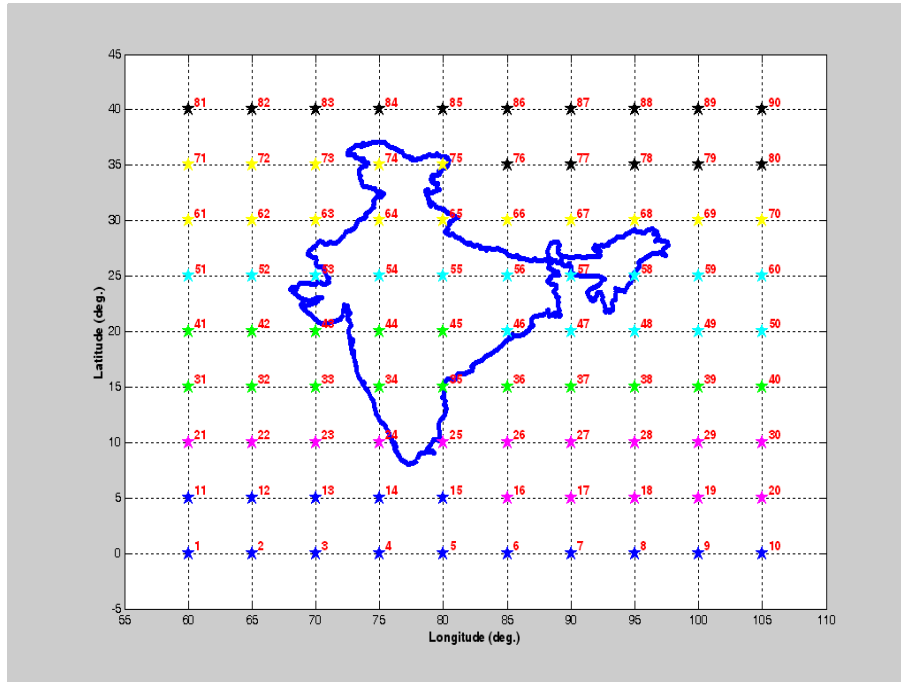
Figure 23: Identified IGPs for Grid Based Corrections over Indian Region

Table 26: Region Id and index for identified IGP locations

S.N	Lon (deg)	Lat (deg)	Region ID	Index
1	60	0	0	0
2	65	0	0	1
3	70	0	0	2
4	75	0	0	3
5	80	0	0	4
6	85	0	0	5
7	90	0	0	6
8	95	0	0	7
9	100	0	0	8
10	105	0	0	9
11	60	5	0	10
12	65	5	0	11
13	70	5	0	12
14	75	5	0	13
15	80	5	0	14
16	85	5	1	0
17	90	5	1	1
18	95	5	1	2
19	100	5	1	3
20	105	5	1	4
21	60	10	1	5
22	65	10	1	6
23	70	10	1	7
24	75	10	1	8
25	80	10	1	9

S.N	Lon (deg)	Lat (deg)	Region ID	Index
26	85	10	1	10
27	90	10	1	11
28	95	10	1	12
29	100	10	1	13
30	105	10	1	14
31	60	15	2	0
32	65	15	2	1
33	70	15	2	2
34	75	15	2	3
35	80	15	2	4
36	85	15	2	5
37	90	15	2	6
38	95	15	2	7
39	100	15	2	8
40	105	15	2	9
41	60	20	2	10
42	65	20	2	11
43	70	20	2	12
44	75	20	2	13
45	80	20	2	14
46	85	20	3	0
47	90	20	3	1
48	95	20	3	2
49	100	20	3	3
50	105	20	3	4
51	60	25	3	5
52	65	25	3	6
53	70	25	3	7
54	75	25	3	8
55	80	25	3	9
56	85	25	3	10
57	90	25	3	11
58	95	25	3	12
59	100	25	3	13
60	105	25	3	14
61	60	30	4	0
62	65	30	4	1
63	70	30	4	2
64	75	30	4	3
65	80	30	4	4
66	85	30	4	5
67	90	30	4	6
68	95	30	4	7
69	100	30	4	8
70	105	30	4	9
71	60	35	4	10
72	65	35	4	11
73	70	35	4	12

S.N	Lon (deg)	Lat (deg)	Region ID	Index
74	75	35	4	13
75	80	35	4	14
76	85	35	5	0
77	90	35	5	1
78	95	35	5	2
79	100	35	5	3
80	105	35	5	4
81	60	40	5	5
82	65	40	5	6
83	70	40	5	7
84	75	40	5	8
85	80	40	5	9
86	85	40	5	10
87	90	40	5	11
88	95	40	5	12
89	100	40	5	13
90	105	40	5	14

The 9-bit IGP vertical delays have a 0.125 meter resolution, for 0 to 63.750 meter valid range. The GIVEI is a 4-bit GIVE indicator and it ranges from 0 to 15. The corresponding GIVE value for each of the indicator is provided in the following Table 27.

Table 27: Evaluation of GIVEI

$GIVEI_i$	$GIVE_i$ Meters	σ^2_i, GIVE Meters^2
0	0.3	0.0084
1	0.6	0.0333
2	0.9	0.0749
3	1.20	0.1331
4	1.5	0.2079
5	1.8	0.2994
6	2.1	0.4075
7	2.4	0.5322
8	2.7	0.6735
9	3.0	0.8315
10	3.6	1.1974
11	4.5	1.8709
12	6.0	3.3260
13	15.0	20.7870
14	45.0	187.0826
15	Not Monitored	Not Monitored

A vertical delay of 63.875 meters (111111111) will indicate Don't Use which means there are no IGP vertical delays greater than 63.750 meters. If that range exceeds, a Don't Use indication will be given and the user will not use the IGP for interpolation technique used in the computation of ionospheric error along his line-of-sight. The user algorithm for computing the delay and associated confidence for the user Line of Sight (LOS) from GIVD and GIVE, is described in detail in Appendix D.

6.2.3 Message Type 7 Data Contents

Message Type 7 contains satellite almanac data. 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 subframe 1 and 2 parameters and is given in Appendix B. The almanac content for one SV is given in Table 28 which holds good for other IRNSS satellites as well.

Table 28: Almanac Parameters Definitions

Parameters	Definitions
M_o	Mean Anomaly at Reference Time
t_{oa}	Almanac Reference time
e	Eccentricity
$\sqrt{A}$	Square Root of the Semi-Major Axis
Ω_o	Longitude of Ascending Node of Orbit Plane at Weekly Epoch
ω	Argument of Perigee
$\dot{\Omega}$	Rate of Right Ascension
i_0	Inclination Angle
a_{fo}	Clock Bias Term
a_{f1}	Clock Drift Term

6.2.4 Message Type 9 Data Contents

Message type 9 contains the parameters required to relate the IRNSS time to UTC and GPS.

IRNSS time offset with respect to UTC is provided by the following parameters:

1. Bias coefficient of IRNSS time scale relative to UTC time scale (A_{0utc})
2. Drift coefficient of IRNSS time scale relative to UTC time scale (A_{1utc})
3. Drift rate correction coefficient of IRNSS time scale relative to UTC time scale(A_{2utc})
4. Current or past leap second count (Δt_{LS})
5. Time data reference time of week (t_{outc})
6. Time data reference week number (WN_{outc})
7. Leap second reference week number (WN_{LSF})
8. Leap second reference day number (DN)
9. Current or future leap second count (Δt_{LSF})

These parameters relate the IRNSS time to UTC and provide information to the user regarding the scheduled future or recent past (relative to the current broadcast time offset parameters) value of delta time due to leap seconds (Δt_{LSF}) together with the week number (WN_{LSF}) and the day number (DN) at the end of which the leap second becomes effective. Day one is the first day relative to the end/start of week and WN_{LSF} is the leap second reference week number to which the DN is referenced.

The user algorithm to derive the UTC time (t_{utc}) from the parameters is given in Appendix F.

IRNSS time can be related to GPS using the IRNSS time offsets with respect to following GPS parameters:

1. Bias coefficient of IRNSS time scale relative to GPS time scale (A_0)

2. Drift coefficient of IRNSS time scale relative to GPS time scale (A_1)

3. Drift rate correction coefficient of IRNSS time scale relative of GPS time scale (A_2)

4. Time data reference time of week (t_{ot})

5. Time data reference week number (WN_{ot})

6. GNSS ID for GPS is 0.

The algorithm to derive GPS time as GNSS time is provided in Appendix F.

6.2.5 Message Type 11 Data Contents

6.2.5.1 Earth Orientation Parameters

The Earth Orientation Parameters message provides the users with parameters to construct the ECEF and ECI coordinate transformation. The parameters are

a) UT1- UTC Difference at reference time

b) X-Axis Polar motion value at reference time and

c) Y-Axis Polar motion value at reference time.

The time difference between the UT1 and UTC time scale is designated as $\Delta UT1$ and the parameter is represented with two parameters. $\Delta UT1$ and $\Delta \dot{U}T1$.   The first parameter indicates the time difference between UT1 and UTC at the reference time t_{EOP} and the second parameter represents the rate of change of the time difference.

The X Axis Polar motion value at reference time is represented with two parameters, PM_X and $P\dot{M}\_X$. The first parameter indicates the predicted angular displacement of instantaneous Celestial Intermediate Pole with respect to semi-minor axis of the reference ellipsoid along Greenwich meridian. The second parameter represents the rate of change of the X Axis polar motion.

The Y Axis Polar motion value at reference time is represented with two parameters, PM_Y and $P\dot{M}\_Y$. The first parameter indicates the predicted angular displacement of instantaneous Celestial Intermediate Pole with respect to semi-minor axis of the reference ellipsoid along a line directed 90˚W of Greenwich meridian. The second parameter represents the rate of change of the Y Axis polar motion.

For information regarding the usage of the Earth Orientation Parameters,refer to Appendix G.

6.2.5.2 Ionosphere Correction Coefficients

Ionospheric error correction for single frequency (L5) users of the IRNSS will be provided through a set of eight coefficients.

The correction coefficients are:

- 4 Alpha Coefficients (α_n; n=0,1,2,3)
  These are the coefficients of the cubic polynomial representing the Amplitude of the positive cosine curve in the cosine model approximation of ionospheric delay.

- 4 Beta Coefficients (β_n; n=0,1,2,3)
  These are the coefficients of the cubic polynomial representing the Period of the positive cosine curve in the cosine model approximation of ionospheric delay.

This ionospheric error along the user's line-of-sight is computed using the algorithm described in Appendix H.

6.2.6 Message Type 14 Data Contents

The differential correction (DC) parameters are provided in message type 14. These parameters provide users with sets of correction terms that apply to the clock and ephemeris data transmitted by other satellites in AutoNav mode.

Each DC data packet contains two types of corrections: ephemeris differential corrections (EDC) and satellite clock differential corrections (CDC). The correction parameters are applied to ephemeris and clock coefficients broadcasted by satellite in AutoNav mode. The CDC parameters contain corrections to satellite clock polynomial coefficients, i.e. correction to satellite clock bias coefficient (δa_{f0}) and satellite clock drift coefficient (δa_{f1}).

The EDC parameters contain correction to six keplerian elements, i.e., Alpha correction to Ephemeris parameters ($\Delta\alpha$), Beta correction to Ephemeris parameters ($\Delta\beta$), Gamma correction to Ephemeris parameters ($\Delta\gamma$), Angle of inclination correction (Δi), Angle of Right Ascension correction ($\Delta\Omega$) and Semi-major correction (ΔA).

The User Differential Range Accuracy (UDRA) enable users to estimate the accuracy obtained after differential corrections are applied. UDRA is mapped to UDRA Index as defined in the following Table 29.

Table 29: UDRA to UDRAI Mapping

Index Value	UDRA(meters)	UD$\dot{R}$A (10^{-6} meter/sec)
15	6144.00 < UDRA 6144.00	≈
14	3072.00 < UDRA≤ 6144.00	3072
13	1536.00 < UDRA≤ 3072.00	1536
12	768.00 < UDRA≤ 1536.00	768
11	384.00 < UDRA≤ 768.00	384
10	192.00 < UDRA≤ 384.00	192
9	96.00 < UDRA≤ 192.00	96
8	48.00 < UDRA≤ 96.00	48
7	24.00 < UDRA≤ 48.00	24
6	13.65 < UDRA≤ 24.00	13.65

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Index Value	UDRA(meters)	UD $\dot{R}$ A (10^{-6} meter/sec)
5	$9.65 < \text{UDRA} \leq 13.65$	9.65
4	$6.85 < \text{UDRA} \leq 9.65$	6.85
3	$4.85 < \text{UDRA} \leq 6.85$	4.85
2	$3.40 < \text{UDRA} \leq 4.85$	3.4
1	$2.40 < \text{UDRA} \leq 3.40$	2.4
0	$1.70 < \text{UDRA} \leq 2.40$	1.7
-1	$1.20 < \text{UDRA} \leq 1.70$	1.2
-2	$0.85 < \text{UDRA} \leq 1.20$	0.85
-3	$0.60 < \text{UDRA} \leq 0.85$	0.6
-4	$0.43 < \text{UDRA} \leq 0.60$	0.43
-5	$0.30 < \text{UDRA} \leq 0.43$	0.3
-6	$0.21 < \text{UDRA} \leq 0.30$	0.21
-7	$0.15 < \text{UDRA} \leq 0.21$	0.15
-8	$0.11 < \text{UDRA} \leq 0.15$	0.11
-9	$0.08 < \text{UDRA} \leq 0.11$	0.08
-10	$0.06 < \text{UDRA} \leq 0.08$	0.06
-11	$0.04 < \text{UDRA} \leq 0.06$	0.04
-12	$0.03 < \text{UDRA} \leq 0.04$	0.03
-13	$0.02 < \text{UDRA} \leq 0.03$	0.02
-14	$0.01 < \text{UDRA} \leq 0.02$	0.01
-15	$\text{UDRA} \leq 0.01$	0.005
-16	No accuracy prediction available—use at own risk	

For any time, t_k, other than t_{od}, UDRA is found by,

$$\text{UDRA} = \text{UDRA} + \text{UD}\dot{R}\text{A} \, (t_k - t_{od})$$

The algorithm for computing the satellite position after applying differential corrections is described in detail in Appendix I .

6.2.7 Message Type 18 Data Contents

Message type 18 provides the text data. Text ID represents a unique identifier for the text being transmitted. The block count represents the number of messages of type 18 the user receiver needs to receive with the same text id to form meaningful text information. The block id represents the position of the text information in the complete text message with the cascaded messages of type 18. With this, a text data of maximum 25 characters can be transmitted in a block.

6.2.8 Message Type 26 Data Contents

Message type 26 contains the parameters required to relate the IRNSS time to UTC, UTC(NPLI) and other GNSS viz. GPS, GALILEO and GLONASS. IRNSS time offset with respect to UTC is provided by the following parameters:

1. Bias coefficient of IRNSS time scale relative to UTC time scale (A_{0utc})
2. Drift coefficient of IRNSS time scale relative to UTC time scale (A_{1utc})
3. Drift rate correction coefficient of IRNSS time scale relative to UTC time scale(A_{2utc})
4. Current or past leap second count (Δt_{LS})
5. Time data reference time of week (t_{outc})
6. Time data reference week number (WN_{outc})
7. Leap second reference week number (WN_{LSF})
8. Leap second reference day number (DN)
9. Current or future leap second count (Δt_{LSF})

These parameters relate the IRNSS time to UTC and provide information to the user regarding the scheduled future or recent past (relative to the current broadcast time offset parameters) value of delta time due to leap seconds (Δt_{LSF}) together with the week number (WN_{LSF}) and the day number (DN) at the end of which the leap second becomes effective. Day one is the first day relative to the end/start of week and WN_{LSF} is the leap second reference week number to which the DN is referenced.

IRNSS time can be related to GPS, GLONASS, GALILEO and UTC (NPLI) using the following parameters:

1. Bias coefficient of IRNSS time scale relative to UTC (NPLI)/GNSS time scale (A_0)
2. Drift coefficient of IRNSS time scale relative to UTC (NPLI)/GNSS time scale (A_1)
3. Drift rate correction coefficient of IRNSS time scale relative of UTC (NPLI)/GNSS timescale (A_2)
4. Time data reference time of week (t_{ot})
5. Time data reference week number (WN_{ot})
6. Timescale id (Timescale ID)

Timescale ID identifies the Timescale for which the time offsets with respect to IRNSS are provided in the message type 26. The mapping between Timescale ID and the corresponding Timescale is provided below.

Table 30: Timescale ID to Timescale Mapping

Timescale ID	Timescale
0	GPS
1	GALILEO
2	GLONASS
7	UTC(NPLI)
3-6	Reserved

The algorithm to derive UTC time (t_{UTC}), UTC (NPLI) time ($t_{UTC(NPLI)}$) and GNSS time (t_{GNSS}) are provided in Appendix F.

6.2.9 Message Type 0 Data Contents

Message type 0 is transmitted in the event of no other message waiting for broadcast. The DATA contents of message type 0 shall be alternating 0s and 1s.

6.3 BROADCAST INTERVALS

Broadcast of subframes and messages is sequenced to provide optimum user performance as defined in Table 31. Subframes 1 & 2 shall be broadcast at least once every 48 seconds. All other messages shall be broadcast in-between as part of subframe 3/4, not exceeding the maximum broadcast interval. Message type 0 is transmitted when there are no messages that have reached their maximum broadcast interval and no messages waiting for broadcast. Flexibility exists in IRNSS for broadcast of messages as distributed across IRNSS spacecrafts for better service. In addition, messages with multiple segments can be broadcasted such that different IRNSS spacecrafts broadcast different segments for the same message. The receiver is expected to collect the segments across spacecrafts for navigation service. Message broadcast sequence need not be synchronized across all IRNSS spacecrafts.

Table 31: Subframe/Message Broadcast Interval

Subframe/Message data	Subframe Id/Message id	Maximum Broadcast Intervals (@ 50sps)
Ephemeris	SF 1 & SF 2	48 sec
Clock	SF 1	48 sec
Ionosphere grid parameters	MT 5	5 min
Almanac	MT 7	60 min
IRNSS time offset with respect to UTC & GPS	MT 9	20 min
Ionosphere coefficients & EOP	MT 11	10 min
Differential corrections	MT 14	as needed
Text	MT 18	as needed
IRNSS time offset with respect to UTC & other GNSS	MT 26	20 min
Null Message	MT 0	as needed

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APPENDICES

Appendix A.   Algorithm for satellite time correction

The clock coefficients transmitted as part of subframe 1 are used for IRNSS time and clock correction. The coefficients transmitted in subframe 1 describe the offset apparent to the user for the interval of time in which the parameters are transmitted. This estimated correction accounts for the deterministic satellite clock error characteristics of bias, drift and aging. The user equipment shall determine the requisite relativistic correction. Accordingly, the offset given below includes a term to perform this function.

The user shall correct the time received from the Satellite with the equation (in seconds):

$t = t_{sv} - \Delta t_{sv}$ where,

t = IRNSS system time (seconds) at message transmission time

t_{sv} = effective satellite PRN code phase time at message transmission time (seconds),

Δt_{sv} = satellite PRN code phase time offset (seconds).

The Satellite PRN code phase offset is given by:

$\Delta t_{sv} = a_{f0} + a_{f1}(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_r$ where,

a_{f0}, a_{f1} and a_{f2} are the polynomial coefficients given in subframe 1, t_{oc} is the clock data reference time in seconds, and Δt_r is the relativistic correction term (seconds) which is given by:

$\Delta t_r = Fe\sqrt{A} \sin(E_k)$

The orbit parameters (e, A, E_k) used here are defined in Appendix B,

While F is a constant given by

$$F = \frac{-2\sqrt{\mu}}{c^2} = -4.442807633 \times 10^{-10} \ sec/\sqrt{meter}$$

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Appendix B.   Algorithm for ephemeris computation

The user shall compute the ECEF coordinates of position for the phase center of the IRNSS Satellite antennas utilizing the equations shown below. Subframes 1 and 2 parameters are Keplerian in appearance;

$\mu = 3.986005 \times 10^{14}$ meters^3/sec^2 -WGS 84 value of the Earth's gravitational constant for IRNSS user

$\dot{\Omega}_e = 7.2921151467 \times 10^{-5}$ rad/sec   -WGS 84 value of the Earth's rotation rate

$a = (\sqrt{A})^2$ -Semi-major axis in meters

$n_0 = \sqrt{(\mu/a)}/a$ -Computed mean motion (rad/sec)

Time from ephemeris reference epoch:

$t_k = t - t_{oe}$

> t is IRNSS system time at time of transmission, i.e., IRNSS time corrected for transit time (range/speed of light)
> t_{oe} Time of ephemeris in seconds
> If $t_k \geq 302400$ subtract 604800 from t_k
> If $t_k \leq -302400$ add 604800 to t_k

Corrected mean motion:

$n = n_0 + \Delta n$

Mean anomaly:

$M_k = M_0 + n t_k$

Kepler's Equation for Eccentric Anomaly, E_k (may be solved by iteration):

$M_k = E_k - e \sin E_k$

True Anomaly:

$$v_k = \tan^{-1}\left\{ \frac{\sin v_k}{\cos v_k} \right\}$$

where

$$\sin v_k = \sqrt{1-e^2}\, \sin E_k \,/(1-e\cos E_k)$$
$$\cos v_k = (\cos E_k - e)\,/\,(1 - e \cos E_k)$$

Argument of Latitude:

$$\Phi_k = v_k + \omega$$

Second Harmonic Perturbations:

$$\delta u_k = c_{us} \sin 2\Phi_k + c_{uc} \cos 2\Phi_k$$
$$\delta r_k = c_{rs} \sin 2\Phi_k + c_{rc} \cos 2\Phi_k$$
$$\delta i_k = c_{is} \sin 2\Phi_k + c_{ic} \cos 2\Phi_k$$

Corrected Argument of Latitude:

$$u_k = \Phi_k + \delta u_k$$

Corrected Radius:

$$r_k = a(1 - e \cos E_k) + \delta r_k$$

Corrected Inclination:

$$i_k = i_o + \delta i_k + (IDOT)t_k$$

Position in orbital Plane:

$$\left. \begin{array}{l} x_k^{'} = r_k \cos u_k \\ y_k^{'} = r_k \sin u_k \end{array} \right\}$$

Corrected longitude of ascending node:

$$\Omega_k = \Omega_o + (\dot{\Omega} - \dot{\Omega}_e)t_k - \dot{\Omega}_e \, t_{oe}$$

Earth-fixed coordinates:

$$\left. \begin{array}{l} x_k = x_k^{'} \cos \Omega_k - y_k^{'} \cos i_k \sin \Omega_k \\ y_k = x_k^{'} \sin \Omega_k + y_k^{'} \cos i_k \cos \Omega_k \\ z_k = y_k^{'} \sin i_k \end{array} \right\}$$

Appendix C. Algorithm for 1st order ionosphere free range for dual frequency user

The two frequencies L5 and S user shall correct for the group delay due to 1st order ionospheric effects by applying the relationship:

$$\rho = (\rho_{L5} - \gamma \, \rho_S) / (1 - \gamma)$$

where, denoting the nominal center frequencies of L5 and S respectively,

$\gamma \qquad = (f_S^2 / f_{L5}^2)$

$\rho \qquad$ = pseudorange corrected for 1st order ionospheric effects.

ρ_{L5}, ρ_S = pseudorange measured on the channel indicated by the subscript.

Appendix C. Algorithm for 1st order ionosphere free range for dual frequency user

Appendix D.   Algorithm for ionosphere delay corrections for single frequency user using ionosphere grid corrections

The corrections are provided at 5°x5° grids at 350 km altitude. The user first computes the point where its LOS cuts the 350 km altitude. This point is termed as the "Ionosphere Pierce Point" (IPP) of the user. Further, using an interpolation scheme, the users takes the information (GIVD, GIVE) from the surrounding grid points to its IPP to compute the vertical delay and the confidence at the IPP. The vertical delay is then converted to slant (along the LOS) using a mapping function.

Pierce Point Location Determination:

Considering the satellite and user locations, the user must first determine the location of the ionospheric pierce point of the signal path from the satellite. The following equations provide the latitude and longitude of that pierce point. First, the latitude is computed as:

$$\phi_{pp} = \sin^{-1}(\sin(\phi_u).\cos(\psi_{pp}) + \cos(\phi_u).\sin(\psi_{pp}).\cos(Az))\ radians$$

where, as illustrated in Figure 24, ψ_{pp} is the Earth's central angle between the user position and the Earth projection of the pierce point and is computed as:

$$\psi_{pp} = \pi/2 - El - \sin^{-1}((R_e/(R_e+h))*\cos(El))\ radians$$

Az and *El* are the azimuth and elevation angles of the satellite from the user's location (ϕ_u,λ_u), measured with respect to the local-tangent-plane, R_e is the approximate radius of the Earth's ellipsoid (taken to be 6378.137 km), and *h* is the height of the maximum electron density (assumed to be equal to 350 km). The longitude of the pierce point is then:

$$\lambda_{pp} = \lambda_u + \sin^{-1}(\ \sin(\psi_{pp})\sin(Az)/\cos(\phi_{pp}))\ radians$$

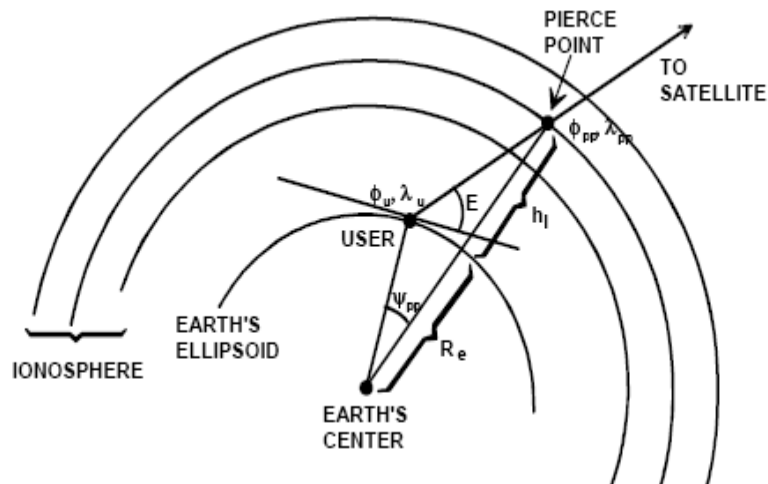**Figure 24: Ionospheric Pierce Point Geometry**

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Selection of Ionospheric Grid Points (IGPs):

After determining the location of the user ionospheric pierce point, the user must select the IGPs to be used to interpolate the ionospheric corrections. This selection is done without regard to whether or not the selected IGPs are monitored, not monitored, or with don't use status.

The selection of IGPs is accomplished as follows.
- Select the four IGPs that define a 5° x 5° cell around the IPP are selected if all the IGPs are Monitored (i.e., the GIVEI <=14). Else,
- Select the three IGPs that define a 5° x 5° triangle that circumscribes the IPP are selected
- If one of the IGPs out of the three selected have GIVEI>14, then no ionospheric corrections are available for that LOS

Ionospheric Pierce Point Vertical Delay & Model Variance Interpolation:

Given three or four nodes of a cell of the IGP grid described above that surround the user's ionospheric pierce point to a satellite, the user can interpolate from those nodes to his pierce point using the algorithm described below.

The IGPs as selected must be used for interpolation, with one exception. If four IGPs were selected, and one of the four is identified as "not monitored", then the three-point interpolation should be used if the user's pierce point is within the triangular region covered by the three corrections that are provided. If one of the four is identified as "don't use", the entire square must not be used.
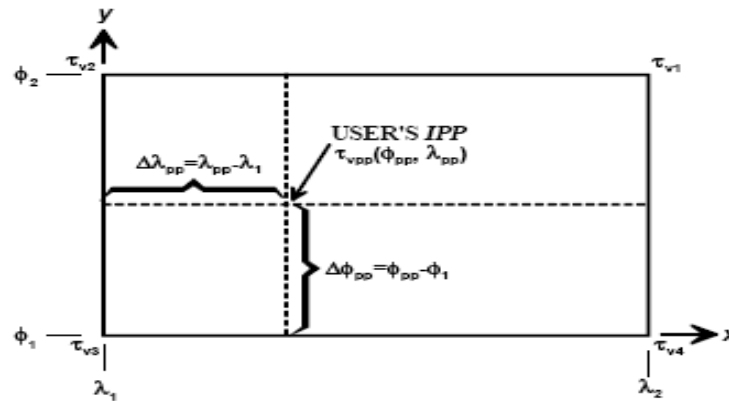
Four Point Interpolation:

Figure 25: Four Point Interpolation Algorithm

Definition:

For four-point interpolation, the mathematical formulation for interpolated vertical ionospheric pierce point delay $\tau_{vpp}(\phi_{pp},\lambda_{pp})$ as a function of ionospheric pierce point latitude ϕ_{pp} and longitude λ_{pp} is:

$$\tau_{vpp}(\phi_{pp}, \lambda_{pp}) = \Sigma W_i(x_{pp},y_{pp})\tau_{\upsilon i}, \; i = 1 \; to \; 4$$

Where the general equation for the weighting function is:

$$f(x,y) = xy$$

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$\tau_{\upsilon i}$ are the broadcast pierce point vertical delay values at four or three corners of the IGP grid, as shown in Figure 25 and Figure 26. τ_{vpp} is the output value at desired pierce point pp, whose geographical coordinates are $(\phi_{pp}, \lambda_{pp})$

$$W_1(x, y) = f(x, y)$$

$$W_2(x, y) = f(1 - x, y)$$

$$W_3(x, y) = f(1 - x, 1 - y)$$

$$W_4(x, y) = f(x, 1 - y)$$

$$\Delta\lambda_{pp} = \lambda_{pp} - \lambda_1$$

$$\Delta\phi_{pp} = \phi_{pp} - \phi_1,$$

where,

$$x_{pp} = \Delta\lambda_{pp}/(\lambda_2 - \lambda_1); \quad y_{pp} = \Delta\phi_{pp}/(\phi_2 - \phi_1);$$
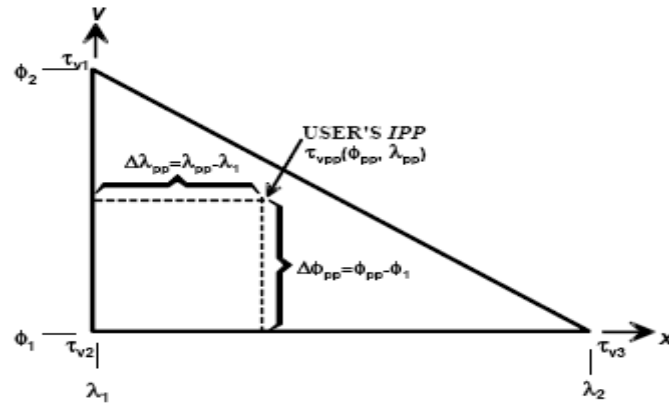
Three Point Interpolation:

Figure 26: Three Point Interpolation Algorithm

Definition:

The algorithm for three point interpolation is similar to the 4 point interpolation, except for the weighting functions as given below:

$$\tau_{vpp}(\phi_{pp}, \lambda_{pp}) = \Sigma W_i(x_{pp}, y_{pp})\tau_{\upsilon i}, \; i = 1 \; to \; 3$$

$$W_1(x, y) = f(1, y)$$

$$W_2(x, y) = f(1, 1 - x - y)$$

$$W_3(x, y) = f(x, 1)$$

IGPs are numbered as shown in Figure 26, so that grid point #2 is always the vertex opposite the hypotenuse and the distance-ratios (x, y) are always determined relative

to the distance to grid point #2. It should be noted that there are an additional three orientations of the triangle shown in Figure 26.

The σ_{UIVE} will be interpolated by the users from the GIVEs defined at the IGPs to the IPP (using four point or three point interpolations) as follows:

$$\sigma_{UIVE} = \sum_{n=1}^{4} W_n\left(x_{pp}, y_{pp}\right) \cdot \sigma_{GIVE_n}$$

or

$$\sigma_{UIVE} = \sum_{n=1}^{3} W_n\left(x_{pp}, y_{pp}\right) \cdot \sigma_{GIVE_n}$$

Computing Slant Ionospheric Delay and Ionospheric Model Variance:

Once the user establishes the vertical delay at the pierce point, the user can then multiply that vertical delay by the obliquity factor F_{pp} to obtain the ionospheric correction *(IC)* to be added to the pseudorange measurement:

$$IC = -\tau_{spp}(\phi_{pp}, \lambda_{pp}) = -F_{pp} \cdot \tau_{vpp}(\phi_{pp}, \lambda_{pp})$$

where τ_{vpp} is the interpolated vertical delay at the user-to-satellite ionospheric pierce point derived as described above, and

$$F_{pp} = (1 - (R_e \cdot cos(El)/(R_e + h))^2)^{-1/2}$$

The σ^2_{UIRE} is computed as:

$$\sigma^2_{UIRE} = F_{pp}^2 \cdot \sigma^2_{UIVE}$$

where,

σ^2_{UIVE} is the variance of the UIVE.

The ionospheric correction (IC) is computed for L5 frequency. If the user is operating on the S frequency, the correction term must be multiplied by scale factor (f_{L5}^2/f_S^2).

Appendix E.   Algorithm for satellite position computation using 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 sub frames 1 and 2.

All other parameters appearing in the equations of Ephemeris Determination, but not included in the content of the almanac, are set to zero for satellite position determination. In these respects, the application of the equation differs between the almanac and the ephemeris computations.

The almanac time parameters shall consist of an 11-bit constant term (a_{f0}) and an 11-bit first order term (a_{f1}). The applicable first order polynomial, which shall provide time to within few microseconds of IRNSS time (t) during the interval of applicability, is given by

$t = t_{sv} - \Delta t_{sv}$ where,

t = IRNSS system time (seconds),

t_{sv} = effective SV PRN code phase time at message transmission time (seconds),

Δt_{sv} = SV PRN code phase time offset (seconds)

The SV PRN code phase offset is given by

$\Delta tsv = a_{f0} + a_{f1} t_k$

$t_k = t - t_{oa}$, Time from Almanac reference epoch. User has to take care of week change over

➢ t is IRNSS system time at time of transmission, i.e., IRNSS time corrected for transit time (range/speed of light)
➢ t_{oa} Time of Almanac in second

and the polynomial coefficients a_{f0} and a_{f1} are given in the almanac. Since the periodic relativistic effect is less than 25 meters, it need not be included in the time scale used for almanac evaluation.

$\mu = 3.986005 \times 10^{14}$ meters^3/sec^2 -WGS 84 value of the earth's gravitational constant for IRNSS user

$\dot{\Omega}_e = 7.2921151467 \times 10^{-5}$ rad/sec   -WGS 84 value of the earth's rotation rate

$a = (\sqrt{A})^2$ -Semi-major axis in meters

$n_0 = \sqrt{(\mu/a)/a}$ -Computed mean motion (rad/sec)

Time from Almanac reference epoch:

$t_k = t - t_{oa}$

➢ t is IRNSS system time at time of transmission, i.e., IRNSS time corrected for transit time (range/speed of light)
➢ t_{oa} Time of Almanac in second

Corrected mean motion:

n = n$_0$

Mean anomaly:

M$_k$ = M$_0$ + nt$_k$

Kepler's Equation for Eccentric Anomaly (may be solved by iteration) (radians):

M$_k$ = E$_k$ - e sin E$_k$

True Anomaly:

$$v_k = \tan^{-1}\left\{\frac{\sin v_k}{\cos v_k}\right\}$$

where

$$\sin v_k = \sqrt{1-e^2}\,\sin E_k\,/(1-e\cos E_k)$$

$$\cos v_k = (\cos E_k - e)/(1-e\cos E_k)$$

Eccentric Anomaly:

$$E_k = \cos^{-1}\left\{\frac{e+\cos v_k}{1+e\cos v_k}\right\}$$

Argument of Latitude:

$$\Phi_k = v_k + \omega$$

$$u_k = \Phi_k$$

Radius:

$$r_k = a(1-e\cos E_k)$$

Inclination:

$$i_k = i_0$$

Position in orbital Plane:

$$\left.\begin{array}{l} x_k' = r_k\cos u_k \\ y_k' = r_k\sin u_k \end{array}\right\}$$

Corrected longitude of ascending node:

$$\Omega_k = \Omega_0 + (\dot{\Omega} - \dot{\Omega}_e)t_k - \dot{\Omega}_e\,t_{oa}$$

Earth Fixed Coordinates:

$$\left. \begin{array}{l} x_k = x_k^{'} \cos\Omega_k - y_k^{'} \cos i_k \sin\Omega_k \\ y_k = x_k^{'} \sin\Omega_k + y_k^{'} \cos i_k \cos\Omega_k \\ z_k = y_k^{'} \sin i_k \end{array} \right\}$$

Appendix F.   Algorithm for IRNSS time offsets computation with respect to UTC, UTC(NPLI) and other GNSS

F.1. User Algorithm For UTC correlation with IRNSS Time

Based on the effectivity time of the parameters in message type 9 and message type 26, UTC time can be derived as follows.

a. Whenever the effectivity time indicated by the WN_{LSF} and the DN values 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 at six hours prior to the effectivity time and ends at six hours after the effectivity time, the UTC time (t_{UTC}) can be derived as:

$t_{UTC} = (t_E - \Delta t_{UTC})$ [modulo 86400 seconds] seconds

and Δt_{UTC} is derived as

$$\Delta t_{UTC} = \Delta t_{LS} + A_{0utc} + A_{1utc} (t_E - t_{outc} + 604800(WN - WN_{outc})) +$$
$$A_{2utc}(t_E - t_{outc} + 604800(WN - WN_{outc}))^2 \text{ seconds}$$

where,

t_E = IRNSS time in seconds as estimated by the user after correcting t_{SV} as given in Appendix A.

WN = current week number (derived from subframe 1)

b. Whenever the user's current time falls within the time span of six hours prior to the effectivity time to six hours after the effectivity time, proper accommodation of the leap second event with a possible week number transition, the UTC time (t_{UTC}) can be derived as:

$$t_{UTC} = W[\text{modulo } (86400 + \Delta t_{LSF} - \Delta t_{LS})] \text{ seconds}$$

where,

$W = (t_E - \Delta t_{UTC} - 43200)$[modulo 86400] + 43200 seconds

and the definition of Δt_{UTC} applies as above throughout the transition period. Whenever a leap second event is encountered, the user equipment must consistently implement carries or borrows into any year/week/day counts.

c. Whenever the effectivity time of the leap second event, as indicated by the WN_{LSF} and DN values, is in the "past" (relative to the user's current time), and the user's current time does not fall in the time span as given in (b), the relationship previously given for t_{UTC} in (a) above is valid except that the value of Δt_{LSF} is substituted for Δt_{LS}.

The user must account for the truncation of WN, WN_{outc} and WN_{LSF} due to rollover of full week number.

F.2 Algorithm For GNSS time correlation with IRNSS time

The GNSS time t_{GNSS} is derived using the following relationship:

$t_{GNSS} = t_E - (A_0 + A_1 (t_E - t_{ot} + 604800 (WN - WN_{ot})) + A_2 (t_E - t_{ot} + 604800 (WN - WN_{ot}))^2)$ seconds where,

t_E = IRNSS time in seconds as estimated by the user after correcting t_{SV} as given in Appendix A.

WN = current week number (derived from subframe 1)

F.3. Algorithm For UTC(NPLI) correlation with IRNSS Time

a. Whenever the effectivity time indicated by the WN_{LSF} and the DN values 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 at six hours prior to the effectivity time and ends at six hours after the effectivity time, the UTC(NPLI) is derived as:

$$t_{UTC(NPLI)} = (t_E - \Delta t_{UTC(NPLI)}) \text{ [modulo 86400 seconds] seconds}$$

and $\Delta t_{UTC(NPLI)}$ is derived as:

$$\Delta t_{UTC(NPLI)} = \Delta t_{LS} + A_0 + A_1 (t_E - t_{ot} + 604800(WN - WN_{ot})) +$$
$$A_2(t_E - t_{ot} + 604800(WN - WN_{ot}))^2 \text{ seconds}$$

where,

t_E = IRNSS time in seconds as estimated by the user after correcting t_{SV} as given in Appendix A.

WN = current week number (derived from subframe 1)

b. Whenever the user's current time falls within the time span of six hours prior to the effectivity time to six hours after the effectivity time, proper accommodation of the leap second event with a possible week number transition, the UTC(NPLI) is derived as:

$t_{UTC(NPLI)} = W[\text{modulo } (86400 + \Delta t_{LSF} - \Delta t_{LS})]$ seconds where ,

$W = (t_E - \Delta t_{UTC(NPLI)} - 43200)[\text{modulo 86400}] + 43200$ seconds

and the definition of $\Delta t_{UTC(NPLI)}$ applies as above throughout the transition period. Whenever a leap second event is encountered, the user equipment must consistently implement carries or borrows into any year/week/day counts.

c. Whenever the effectivity time of the leap second event, as indicated by the WN_{LSF} and DN values, is in the "past" (relative to the user's current time), and the user's current time does not fall in the time span as given in (b), the relationship previously given for $t_{UTC(NPLI)}$ in (a) above is valid except that the value of Δt_{LSF} is substituted for Δt_{LS}.

The user must account for the truncation of WN, WN_{ot} and WN_{LSF} due to rollover of full week number.

Appendix G.   Algorithm for application of EOP

The EOP fields in IRNSS message type 11 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the Space Vehicle antenna phase center using the equations given in Appendix B. The full coordinate transformation for translating to the corresponding ECI Space Vehicle antenna phase center position may be accomplished in accordance with the procedures described in Chapter 5 of International Earth Reference System (IERS) Technical Note 36 and the equations (G-1) and (G-2) provided subsequently in this Appendix

The IERS Technical Note 36 describes multiple methods to obtain the transformation matrix. The choice of method is left to the users discretion.

Note that the message type 11 EOP parameters already account for the tidal variations in the Earth's rotation. The description of the effects is provided in Chapter 8 of IERS Technical Note 36. The tidal variations include the a) effect of tidal deformation (zonal tides) on Earth's rotation and b) Diurnal, Semi-diurnal variations due to ocean tides. These effects should not be further applied by the user.

An ECI position R_{eci} is related to an ECEF position R_{ecef} , by a series of rotation matrices as follows:

$R_{ecef} = [A][B][C][D]\ R_{eci}$

where the rotation matrices A,B,C and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 11 specifies the EOP parameters used in the construction of the Polar Motion A, and Earth Rotation B, matrices.

The user shall compute the Inertial-to-Geodetic rotation matrix in accordance to IERS Technical Note 36 and the equations for UT1, x_p and y_p are mentioned in (G-1) and (G-2).

Compute Universal Time at time t*

$$UT1 = UTC + \Delta UT1 + \Delta \dot{U}T1(t - t_{EOP})\qquad\qquad\text{(G-1)}$$

Compute Polar Motion at time t

$$x_p = PM\_X + P\dot{M}\_X(t - t_{EOP})$$

$$y_p = PM\_Y + P\dot{M}\_Y(t - t_{EOP})\qquad\qquad\text{(G-2)}$$

* t is IRNSS time at time of transmission

Appendix H. Algorithm for ionosphere delay computation using coefficients

The Main terms used in computation of ionospheric delay are as follows:

• Satellite Transmitted Terms

α_n - the coefficients of a cubic equation representing the amplitude of the vertical delay (4 coefficients)

β_n - the coefficients of a cubic equation representing the period of the model

(4 coefficients)

The Ionospheric correction model is given by

$$T_{iono} = \begin{cases} F * \left[5.0 * 10^{-9} + (AMP)\left(1 - \frac{x^2}{2!} + \frac{x^4}{4!}\right) \right], & |x| < 1.57 \\ F * (5.0 * 10^{-9}) & , |x| \geq 1.57 \end{cases} \text{(sec)}$$

where

T_{iono} is referred to the L5 frequency; if the user is operating on the S frequency, the correction term must be multiplied by Correction factor ($\gamma = f_{L5}^2 / f_S^2$).

$$AMP = \begin{cases} \sum_{n=0}^{3} \alpha_n \, \phi_m^n, & AMP \geq 0 \\ \text{if } AMP < 0, & AMP = 0 \end{cases} \text{(sec)}$$

$$x = \frac{2\pi(t - 50400)}{PER} \text{ (radians)}$$

$$PER = \begin{cases} \sum_{n=0}^{3} \beta_n \, \phi_m^n, & PER \geq 72{,}000 \\ \text{if } PER < 72{,}000 & PER = 72{,}000 \end{cases} \text{(sec)}$$

$$F = 1.0 + 16.0[0.53 - El]^3$$

α_n and β_n are the satellite transmitted data words with n=0, 1, 2, and 3.

Other equations that must be solved are:

$$\phi_m = \phi_i + 0.064 \cos(\lambda_i - 1.617)$$

$$\lambda_i = \lambda_u + \frac{\psi \, sinAz}{\cos \phi_i} \quad \text{(semi - circles)}$$

$$\phi_i = \begin{cases} \phi_u + \psi \, cosAz & |\phi_i| \leq 0.416 \\ \text{if } \phi_i > +0.416, then \, \phi_i = +0.416 \\ \text{if } \phi_i < -0.416, then \, \phi_i = -0.416 \end{cases}$$

$$\psi = \frac{0.0137}{El + 0.11} - 0.022$$

$$t = 4.32 \times (10^4)\lambda_i + \text{IRNSS time (sec)}$$

where,

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$0 \leq t < 86400$; therefore if $t \geq 86400$ seconds, subtract 86400 seconds

if t<0 seconds, add 86400 seconds

Note:

All the parameters used in trigonometric functions are converted to radians before applying the specific operation.

The terms used in computation of ionospheric delay are as follows:

a. Receiver Generated Terms

El - Elevation angle between the user and satellite (semi-circles)

Az - Azimuth angle between the user and satellite, measured clockwise positive from the true North (semi-circles)

φ_u - user geodetic latitude (semi-circles) WGS-84

λ_u - user geodetic longitude (semi-circles) WGS-84

IRNSS time - receiver computed system time (sec)

b. Computed Terms

X - Phase (radians)

F - Obliquity factor (dimensionless)

t - Local time (sec)

φ_m - geomagnetic latitude of the Earth projection of the ionospheric intersection

point (mean ionospheric height assumed 350 km) (semi-circles)

λ_i - geodetic longitude of the Earth projection of the ionospheric intersection point (semi-circles)

φ_i - geodetic latitude of the Earth projection of the ionospheric intersection point (semi-circles)

ψ - Earth's central angle between the user position and the Earth projection of

ionospheric intersection point (semi-circles)

Appendix I.   Algorithm for satellite position and clock offset computation using differential corrections

Differential Correction (DC) parameters are provided in message type 14. These parameters provide users with sets of correction terms that apply to the clock and ephemeris data transmitted by other SVs.

1. Application of Clock Related DC Data

The SV PRN code phase offset, uncorrected by clock correction coefficient updates, is given by in Appendix A. If the matched pair of DC data for the subject SV is available, the user may apply clock correction coefficient update values by;

$$\Delta t_{sv} = (a_{f0} + \delta a_{f0}) + (a_{f1} + \delta a_{f1})(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_r$$

2. Application of Ephemeris Related DC Data

The DC data packet includes corrections to parameters that correct the state estimates for ephemeris parameters transmitted in the subframes 1 & 2 (broadcast by the SV to which the DC data packet applies). The user will update the ephemeris parameters utilizing a variation of the algorithm expressed in the following equations. The user will then incorporate the updated quasi-Keplerian element set in all further calculations of SV position, as represented by the equations in Appendix B.

The user will construct a set of initial (uncorrected) elements by:

$$A_i = (\sqrt{A})^2$$

$$e_i = e$$

$$i_i = i_0$$

$$\Omega_i = \Omega_0$$

$$\alpha_i = e \cos(\omega)$$

$$\beta_i = e \sin(\omega)$$

$$\gamma_i = M_0 + \omega$$

where,

$\sqrt{A}$, e, i_0, Ω_0, ω and M_0 are obtained from the applicable SV's sub frame 1 and 2.

The terms α_i, β_i, and γ_i form a subset of stabilized ephemeris elements which are subsequently corrected by $\Delta\alpha$, $\Delta\beta$ and $\Delta\gamma$ the values of which are supplied in the message type 14 — as follows:

$$\alpha_c = \alpha_i + \Delta\alpha$$

$$\beta_c = \beta_i + \Delta\beta$$

$$\gamma_c = \gamma_i + \Delta\gamma$$

The quasi-Keplerian elements are then corrected by:

$A_c = A_i + \Delta A$

$e_c = (\alpha_c^2 + \beta_c^2)^{1/2}$

$i_c = i_i + \Delta i$

$\Omega_c = \Omega_i + \Delta \Omega$

$\omega_c = \tan^{-1}(\beta_c/\alpha_c)$

$M_{0\text{-}c} = \gamma_c - \omega_c + \Delta M_0$

where ΔA, Δi and $\Delta \Omega$ are provided in the message type 14 and ΔM_0 is obtained from:

$$\Delta M_0 = -3\frac{\sqrt{\mu}}{A_c^2}\left[(t_{oe}) - (t_{od})\right]$$

where

t_{oe} is Time of Ephemeris and t_{od} is Time of Differential Correction

The corrected quasi-Keplerian elements above are applied to the user algorithm provided in Appendix B for determination of antenna phase center position.

ACRONYMS

ARNS	**Aeronautical Radio Navigation Service**
BOC	**Binary Offset Carrier**
BPSK	**Binary Phase Shift Keying**
CDMA	**Code Division Multiple Access**
CRC	**Cyclic Redundancy Check**
EOP	**Earth Observation Parameter**
FEC	**Forward Error Correction**
GIVD	**Grid Ionospheric Vertical Delay**
GIVE	**Grid Ionospheric Vertical Error**
GLONASS	**Russia's Global Navigation Satellite System**
GNSS	**Global Navigation Satellite System**
GPS	**Global Positioning System**
GSO	**Geo- synchronous Orbit**
ICD	**Interface Control Document**
IGP	**Ionospheric Grid Point**
IGSO	**Inclined Geo-synchronous Orbit**
INC	**ISRO Navigation Centre**
IODEC	**Issue Of Data Ephemeris & Clock**
IODI	**Issue of Data, Ionosphere**
IRNSS	**Indian Regional Navigation Satellite System**
ISRO	**Indian Space Research Organization**
NPLI	**National Physics Laboratory, India**
NSGU	**Navigation Signal Generation Unit**
NRZ	**Non Return to Zero**
PRN	**Pseudo-Random Noise**
RAAN	**Right Ascension of Ascending Node**
RHCP	**Right Handed Circular Polarization**
RS	**Restricted Service**
SIS	**Signal-In-Space**
SPS	**Standard Positioning Service**
SV	**Space Vehicle**

SYNC	**Synchronization**
TLM	**Telemetry**
TOW	**Time Of Week**
TOWC	**Time Of Week Count**
TTC	**Telemetry, Tracking and Command**
TWTA	**Traveling Wave Tube Amplifier**
UDRA	**User Differential Range Accuracy Index**
UDŘA	**Change rate of User Differential Range Accuracy Index**
UIRE	**User Ionospheric Range Error**
UIVE	**User Ionospheric Vertical Error**
URA	**User Range Accuracy**
UTC	**Coordinated Universal Time**
UTC (NPLI)	**Coordinated Universal Time (NPL India)**
WGS	**World Geodetic Standard**