NAVIC STANDARD SIMULATION

Through Python

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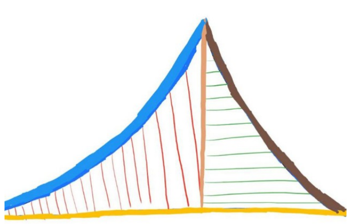

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Chapter 1

Introduction

NavIC (an acronym for 'Navigation with Indian Constellation') is the operational name for Indian Regional Navigation Satellite System (IRNSS), developed independently and indigenously by Indian Space Research Organization (ISRO). The objective of this autonomous regional satellite navigation system is to provide accurate real-time positioning and timing services to users in India and a region extending upto $1,500$ km (930 mi) around it.

NavIC is designed with a constellation of 7 satellites and a network of ground stations operating 24 x 7. Three satellites of the constellation are placed in geostationary orbit and four satellites are placed in inclined geosynchronous orbit. The ground network consists of control centre, precise timing facility, range and integrity monitoring stations, two-way ranging stations, etc.

NavIC provides two levels of service, the "standard positioning service", which is open for civilian use, and a "restricted service" (an encrypted one) for authorised users (including the military). NavIC has a theoritical positional accuracy of 5m - 20m for general users and 0.5m for military purposes.

This book describes the NavIC standards simulation using Python code. << Will add description about the organization of the sections here, after all sections are edited >>

1.1. Scope of simulation

The scope of the simulation is limited to sending baseband signal (without a carrier) thorugh transmitter module, mixing it with channel madelling module and verifying that the same baseband signal is received at the output of the receiver module.

Chapter 2

NavIC System Overview

2.1. The Frequency Bands

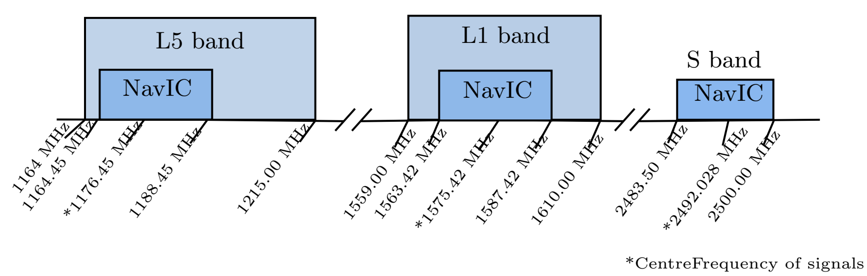

Figure 2.1: Frequency bands of NavIC Signals

Bands	Carrier Frequency	Bandwidth	Usage
L1	1575.42 Mhz	24 Mhz	for low power devices
L5	1176.45 Mhz	24 Mhz	navigation and positioning
S	2492.028 Mhz	16.5 Mhz	SBAS and messaging

Table 2.2: NavIC frequency bands

Satellite communication utilizes multiple frequency bands to accommodate different types of communication services and addresses various technical considerations. Here are some reasons why multiple frequency bands are used in satellite communication:

Spectrum Allocation: The electromagnetic spectrum is divided into various frequency bands to allocate different services and applications. This division ensures that different systems can operate without interfering with each other. By utilizing multiple frequency bands, satellite communication can effectively coexist with other wireless services and minimize interference issues.

Signal Propagation Characteristics: Different frequency bands exhibit unique propagation characteristics. Lower frequency bands, such as L band, have better signal penetration through obstacles and are less affected by atmospheric conditions, making them suitable for applications where signal reliability is crucial. Higher frequency bands, such as Ku band or Ka band, offer larger bandwidths and higher data transmission rates, making them ideal for applications requiring high-speed data transfer.

Bandwidth and Capacity: Different frequency bands offer varying bandwidths, and by utilizing multiple bands, satellite communication systems can increase overall capacity. This allows for the simultaneous transmission of multiple signals, accommodating a wide range of services such as television broadcasting, voice communication, internet access, and data transfer.

Frequency Reuse and Interference Mitigation: Satellite systems employ frequency reuse techniques to maximize the utilization of the available frequency spectrum. By using different frequency bands, satellite operators can reuse frequencies in different geographical areas without causing interference. This allows for efficient utilization of the limited spectrum resources.

Regulation and International Coordination: The allocation and usage of frequency bands are regulated by international bodies and national spectrum management organizations. These regulations help ensure efficient spectrum utilization, prevent interference between different systems, and promote global coordination and compatibility of satellite communication services.

In summary, the use of multiple frequency bands in satellite communication enables efficient spectrum utilization, accommodates different services, and addresses various technical considerations such as signal propagation, bandwidth, capacity, and interference mitigation. By leveraging the advantages offered by different frequency ranges, satellite systems can provide reliable, high-speed communication services to a wide range of applications and users.

The seven satellites in the NavIC constellation so far use two frequencies for providing positioning data — the L5 and S bands. This was because India hadn't received the International Telecommunication Union authorisation for using the L1 and L2 frequency bands, which are widely used worldwide for navigation services. The new satellites NVS-01 onwards, meant to replace these satellites, will also have L1 band. L1 is an interoperable frequency and can be used across all chipsets(of mobile devices), provided they use our signal architecture.

2.1.1. L-band

The L band offers several advantages for wireless communication systems, including a balance between signal propagation characteristics and antenna size. It provides good signal penetration through various atmospheric conditions, vegetation, and even some obstacles. These properties make it suitable for applications such as satellite communication, navigation systems, and mobile networks.

Satellite communication is one of the significant applications of the L band. Satellites in geostationary orbits often utilize this frequency range for broadcasting television signals, as well as for maritime, navigation and aeronautical communications. The L band allows for reliable and efficient transmission over long distances, making it a valuable resource for global connectivity. Because of satellites' increased use, number and size, congestion has become a serious issue in the lower frequency bands.

L1 and L5 are specific frequencies within the L band that are used in Global Navigation Satellite Systems (GNSS), such as GPS (Global Positioning System) and Galileo. These frequencies play a crucial role in providing accurate positioning, navigation, and timing information.

2.1.1.1. L1

L1 refers to the first frequency within the L band used by GNSS. In NavIC, the L1 frequency is centered around 1575.42 MHz. The L1 signal carries the primary navigation message and is used for standard positioning and timing applications. It is widely used in various sectors, including transportation, surveying, and consumer applications like personal navigation devices and smartphones.

2.1.1.2. L5

L5, on the other hand, is an additional frequency introduced in modernized GNSS systems like GPS and Galileo. In NavIC, the L5 frequency is centered around 1176.45 MHz. It was introduced to provide improved accuracy, integrity, and resistance to interference. The L5 signal carries more precise and reliable positioning information, making it particularly useful in critical applications that require high levels of accuracy, such as aviation, surveying, and scientific research. The L1 frequency offers broad coverage and compatibility with legacy systems, while the L5 frequency provides more precise positioning and improved resistance to interference. The combination of these frequencies allows for more reliable and accurate navigation solutions, benefiting a wide range of industries and applications.

2.1.2. S-band

The S band is another frequency range within the electromagnetic spectrum, located between the L band and the C band. It spans a frequency range of approximately 2 to 4 GHz. In NavIC, S band frequency is centred around 2492.028 MHz. The S band finds applications in various fields, including communication, radar systems, satellite broadcasting, and scientific research.

One of the primary uses of the S band is in satellite communication. Satellites in geostationary orbits often utilize S band frequencies for uplink and downlink communication with ground stations. The S band provides a good balance between antenna size and data capacity, making it suitable for broadcasting television signals, voice communication, and data transmission. However, the higher frequency bands typically give access to wider bandwidths, but are also more susceptible to signal degradation due to 'rain fade' (the absorption of radio signals by atmospheric rain, snow or ice).

2.2. NavIC Architecture

The NavIC architecture is as shown in Fig 2.2. It mainly consists of

1. Space segment
2. Ground segment
3. User segment

2.2.1. Space segment

Space segment consists of a constellation of 7 satellites. Three satellites of the constellation are placed in geostationary orbit, at 32.5°E, 83°E and 129.5°E respectively, and four satellites are placed in inclined geosynchronous orbit with equatorial crossing of 55°E and 111.75°E respectively, with inclination of 29° (two satellites in each plane).

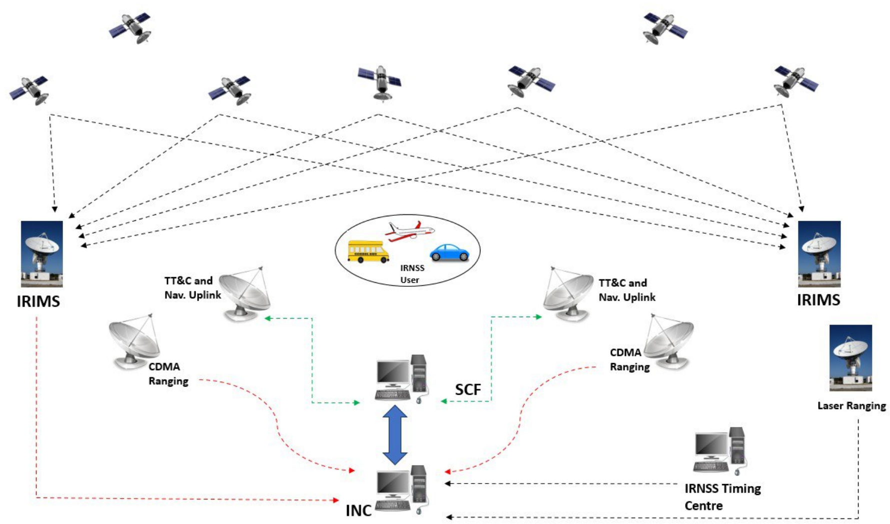

Figure 2.2: NavIC Architecture

2.2.2. Ground segment

Ground segment takes care of operation and maintenance of the constellation. It consists of

1. ISRO Navigation Centre
2. IRNSS Spacecraft Control Facility
3. IRNSS Range and Integrity Monitoring Stations
4. IRNSS Network Timing Centre
5. IRNSS CDMA Ranging Stations
6. Laser Ranging Stations
7. Data Communication Network

2.2.3. User segment

User segment consists of

1. A single frequency receiver having capability to receive SPS signal at either L1, L5 or S band frequency

2. A multi-frequency receiver having capability to receive SPS signal at combination of L1, L5 and S band frequencies

3. A multi-constellation receiver compatible with NavIC and other GNSS signals.

The Figure2.3 above specifies the radio frequency interface between space and user segments.

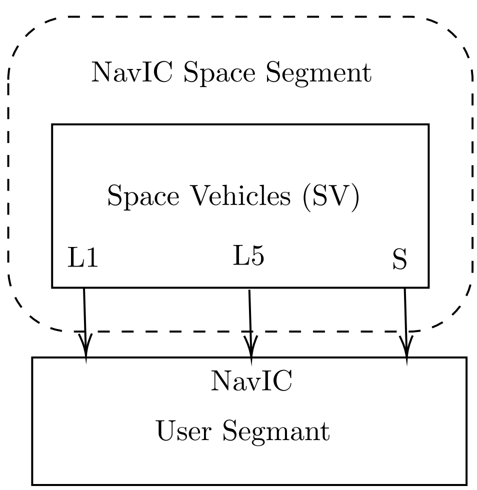

Figure 2.3: the NavIC bands segment blocks

2.3. NavIC Services

The NavIC provides basically two types of services:

1. Standard Positioning Service (SPS)
2. Restricted Service (RS)

Both SPS and RS signals contain ranging codes that allow receivers to compute their travelling time from satellite to receiver, along with navigation data, in order to know the satellite's position at any time.

2.3.1. Standard Positioning Service (SPS)

It is available to all civilian users free of charge and provides positioning, navigation, and timing information with a moderate level of accuracy. The SPS signals in NavIC primarily operate in the L5 and S frequency bands.

2.3.2. Restricted Service (RS)

The RS is intended for authorized users and offers enhanced accuracy, integrity, and availability compared to the SPS signals. The RS signals in NavIC operate in both the L5 and S bands and broadcast through a phased array antenna to keep required coverage and signal strength.

Chapter 3

Transmitter

The NavIC transmitter is simulated to send baseband signal to the channel as shown in Fig 3.1.

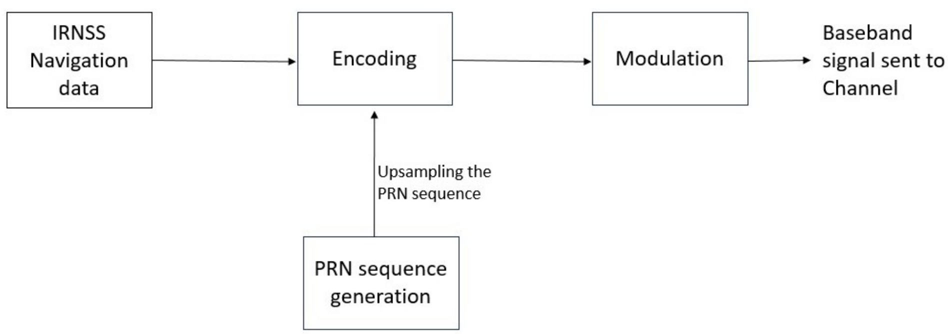

Figure 3.1: Transmitter Block diagram

3.1. IRNSS Navigation data

Navigation data in satellite communication refers to the crucial information transmitted between satellites and ground-based receivers to facilitate accurate positioning and navigation. It includes data related to satellite orbits, precise timing, and other parameters necessary for determining the satellite's position relative to the Earth's surface.

3.2. Frame structure

NavIC master frame consists of 2400 symbols, divided into 4 subframes. Each subframe is 600 symbols long. Each subframe has 16 bit Sync word followed by 584 bits of interleaved data. Subframes 1 and 2 transmit fixed primar navigation parameters. Subframe 3 and 4 transmit secondary navigation parameters in the form of messages. The master frame structure is shown in figure 3.2.

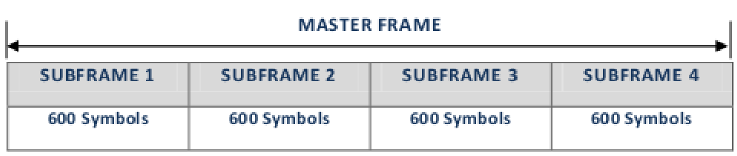

Figure 3.2: Master Frame Structure

Each subframe is 292 bits long without FEC encoding and sync word. It starts with TLM word of 8 bits and ends with 24 bit Cyclic Redundancy Check(CRC) followed by 6 tail bits. In subframes 1 and 2 navigation data is alloted with 232 bits, starting from bit 31. In subframe 3 and 4, 220 bits are alloted starting from bit 37. The typical structure of the subframes are shown in figure 3.3 and figure 3.4 respectively.

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 3.3: Structure of subframe 1 and 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 3.4: Structure of subframe 3 and 4

3.3. Encoding

3.3.1. 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.

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

$$G1 : X^{10} + X^3 + 1 \tag{3.1}$$

$$G2 : X^{10} + X^9 + X^8 + X^6 + X^3 + X^2 + 1 \tag{3.2}$$

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 SPS PRN code generator is shown in figure 3.5.

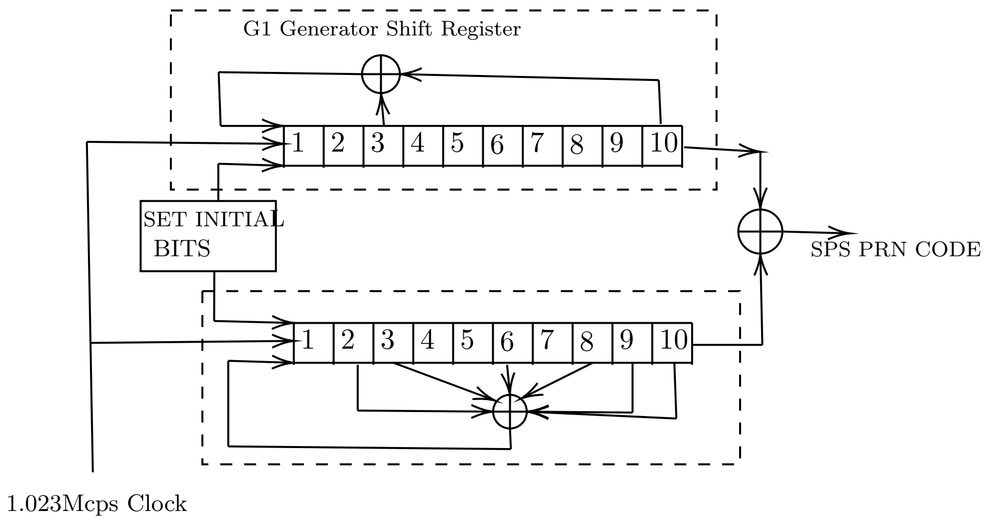

Figure 3.5: SPS PRN Code Generator

The satellites that are used in the current code implementation are with PRN ids - $1, 3, 5$ and 7. The initial condition of G2 register in L5 and S bands for the given PRN ids is given in table 3.2.

3.3.2. FEC Encoding

The Navigation data subframe of 292 bits is convolution encoded with a rate of 1/2 and clocked at 50 symbols per second. The coding scheme is given in figure 3.6. Each subframe of 292 bits, after encoding, results in 584 symbols.

PRN ID	L5-SPS G2 initial condition	S-SPS G2 initial condition
1	1110100111	0011101111
3	1000110100	1000110001
5	1110110000	1010010001
7	0000010100	0010001110

Table 3.2: Code phase assignment for SPS signals

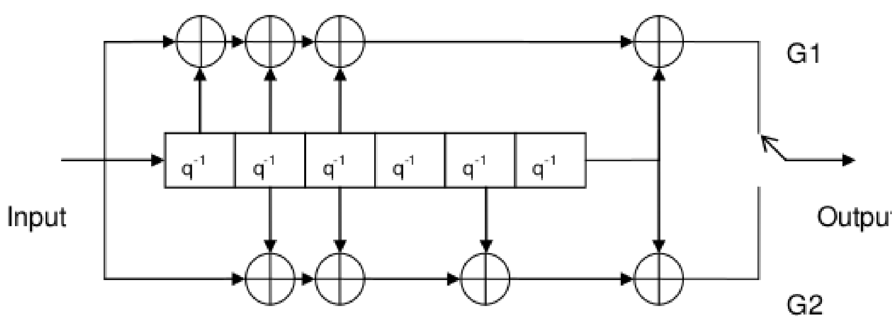

Figure 3.6: FEC Encoding

3.3.3. Interleaving

Any burst errors during the data transmission can be corrected by interleaving. In matrix interleaving, input symbols are filled into a matrix column wise and read at the output row wise. This will spread the burst error, if any, during the transmission. For SPS, data is filled into matrix of size 73 by 8(73 columns, 8 rows).

3.3.4. Sync word and Tail bits

Each subframe has a 16 bit word synchronization pattern which is not encoded. Sync pattern is $EB90$ Hex. Tail bit consists of 6 zero value bits enabling completion of FEC decoding of each subframe in the receiver.

3.3.5. Cyclic Redundancy Check(CRC)

The parity coding of data signal follows 24Q polynomial for each subframe. 24 bits of CRC parity will provide protection against burst as well as random errors with undetected error probability of 2^{-24} for all channel bit error probabilities 0.5.

$$g(X) = \sum_{i=0}^{24} g_i X^i \tag{3.3}$$

$g_i = 1$; for $i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24$

$= 0$ otherwise

3.4. Modulation

3.4.1. 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. The CDMA modulated code is upconverted by the L5 and S carriers at 1176.45 MHz and 2492.028 MHz respectively. However, this simulation does not carry out this upconversion.

3.4.2. Baseband Modulation

The carrier signal is modulated by BPSK(1), Data channel BOC(5,2), and Pilot Channel BOC(5,2). To have a constant envelop when passed through power amplifier, we add additional signal called interplex signal.

3.4.2.1. Mathematical Equations

SPS Data Signal:

$$s_{sps}(t) = \sum_{i=-\infty}^{\infty} c_{sps}(|i|_{L\_sps}).d_{sps}(\,[i]_{CD\_sps}).rect_{T_{c,sps}}(t - iT_{c,sps}) \tag{3.4}$$

RS BOC Pilot Signal:

$$s_{rs\_p}(t) = \sum_{i=-\infty}^{\infty} c_{rs\_p}(|i|_{L\_rs\_p}).rect_{Tc,rs\_p}(t - iT_{c,rs\_p}).sc_{rs\_p}(t,0) \tag{3.5}$$

RS BOC Signal:

$$s_{rs\_d}(t) = \sum_{i=-\infty}^{\infty} c_{rs\_d}(|i|_{L\_rs\_d}).d_{rs\_d}(\,[i]_{CD\_rs\_d}).$$
$$rect_{T_{c,rs\_d}}(t - iT_{c,rs\_d}).sc_{rs_d}(t,0) \tag{3.6}$$

The sub-carrier is defined as:

$$sc_x(t,\phi) = sgn\,[sin(2\pi f_{sc,x}t + \phi)] \tag{3.7}$$

The IRNSS RS data and pilot BOC signals are sinBOC. Hence the subcarrier phase $\phi = 0$. The complex envelope of composite signal with Interplex signal

(I(t)) is:

$$s(t) = \frac{1}{3}\left[\sqrt{2}(s_{sps}(t) + s_{rs\_p}(t)) + j(2.s_{rs\_d}(t) - I(t))\right] \tag{3.8}$$

The Interplex signal $I(t)$ is generated to realize the constant envelope composite signal. The operation $|i|_X$ gives the code chip index for any signal. Similarly $[i]_X$ gives data bit index for any signal. Symbol definitions are given in below table 3.4.

Symbol	**Definition**
A	received signal amplitude
f_c	carrier frequency
f_{sub}	subcarrier frequency
t	time
q	phase offset
s(t)	BPSK signal transmitted data(-1,1)

Table 3.4: Symbol Description

The functions for data generation, SPS-PRN sequence generation and baseband modulation are present in the below code.

```
codes/transmitter/transmitter.py
```