THE NAVIC STANDARD

Through Python

G. V. V. Sharma

Contents

Introduction

This book introduces the NAVIC communication standard through Python exercises

Chapter 1

Design Parameters

1.1. The Frequency Bands

The seven satellites in the NavIC constellation so far use two frequencies for providing positioning data — the L5 and S bands. The new satellites NVS-01 onwards, meant to replace these satellites, will also have L1 frequency.

Table 1.1: the navic frequency bands

Signal	Carrier Frequency	Bandwidth	Description
L1	1575.42 Mhz	24 Mhz	widely used band in gnss
L5	1176.45 Mhz	24 Mhz	intended for navigation and positioning services
S	2492.028 Mhz	16.5 Mhz	primarily used for SBAS and messaging services

There will be two kinds of services:

1.1.1. Special 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 frequency band1.1.

1.1.2. 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 bands1.1.

Both services will be carried on L5 (1176.45 MHz) and S band (2492.028 MHz). The navigation signals would be transmitted in the S-band frequency and broadcast through a phased array antenna to keep required coverage and signal strength.

The data structure for SPS and PS takes advantage of the fact that the number of satellites is reduced -7 instead of the 30 used in other constellations- to broadcast ionospheric corrections for a grid of 80 points to provide service to single frequency users. The clock, ephemeris, almanac data of the 7 IRNSS satellites are transmitted with the same accuracy as in legacy GPS, GLONASS and Galileo.

navic operated only in the L5-band and S-band frequencies. 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.

Now that L1 band is available on the NVS-01 satellite(and will be available on subsequent NVS satellites), it is an interoperable frequency and can be used across all chipsets(of mobile devices), provided they use our signal architecture

All NavIC satellites transmit navigation signals in two or more frequency bands as in the table1.1. These 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.

The main signal characteristics are:

Carrier frequency: Radio frequency sinusoidal signal at a given frequency.

Ranging (or spreading) code: A pseudo random sequence of 0s and 1s that allows the receiver to measure the travel time of the signal from satellite to receiver. Often referred to as Pseudo-Random Noise (PRN) codes.

Navigation data: A binary-coded message providing information on the satellite ephemeris, clock parameters, almanac, health status and other complementary information. Some signals, known as "pilot signals", lack this component, thus offering better acquisition and tracking performances.

Chapter 2

Channel Modelling

The phenomena modelled in the satellite communication channel are Doppler shift, delay, power scaling and thermal noise at the receiver.

2.1. Doppler shift

Due to relative motion between the satellites and the receiver, the transmitted signals undergo a frequency shift before arriving at the receiver. This shift in frequency is called Doppler shift and can be computed as

$$f_{shift} = f_d - f_c = \left(\frac{V_{rel}}{c - V_{S,dir}} \right) f_c \tag{2.1}$$

where,

f_{Shift} = Frequency shift due to Doppler

f_d = Frequency observed at receiver

f_c = Carrier frequency at transmitter

V_{rel} = Relative velocity of transmitter and receiver

$V_{S,dir}$ = Velocity of satellite along radial direction

c = Speed of light

V_{rel} is given by

$$V_{rel} = V_{S,dir} - V_{R,dir} \tag{2.2}$$

where,

$V_{R,dir}$ = Velocity of receiver along radial direction

$V_{R,dir}$ and $V_{S,dir}$ are given by

$$V_{R,dir} = \mathbf{V}_R \cdot \hat{\mathbf{dir}} \tag{2.3}$$

$$V_{D,dir} = \mathbf{V}_S \cdot \hat{\mathbf{dir}} \tag{2.4}$$

where,

$\hat{\mathbf{dir}}$ = Unit vector from satellite to receiver i.e. radial direction

$\mathbf{V_S}$ = Velocity of satellite

$\mathbf{V_R}$ = Velocity of receiver

$\hat{\mathbf{dir}}$ is given by

$$\hat{\mathbf{dir}} = \frac{\mathbf{P_S} - \mathbf{P_R}}{\|\mathbf{P_S} - \mathbf{P_R}\|} \tag{2.5}$$

where,

$\mathbf{P_S}$ = Position of satellite

$\mathbf{P_R}$ = Position of receiver

The Doppler shift is introduced by muliplying the satellite signal with a complex exponential,

$$x_{Shift}[n] = x[n]\,e^{-2\pi j\left(f_c + f_{Shift}\right)nt_s} \tag{2.6}$$

where,

$x_{Shift}[n]$ = Doppler shifted signal

$x[n]$ = Satellite signal

t_s = Sampling period

2.2. Delay

Since there is a finite distance between the satellite and the receiver, the signal at the reciever is a delayed version of the transmitted signal. This delay is given by

$$D_s = \frac{d}{c} f_s \tag{2.7}$$

where,

D_s = Total delay in samples

d = Distance between satellite and receiver

c = Speed of light

f_s = Sampling rate

The total delay on the satellite signal is modeled in two steps. First, a static delay is modeled which does not change with time and it is always an integer number of samples. Then, a variable delay is modeled which can be a rational number of samples. While modelling the static delay, the entire delay is not introduced so that variable delay modelling handles the remaining delay.

To introduce the static delay, the samples are read from a queue whose size is the desired static delay length. When samples are read from the queue, an equal number of new samples are updated in the queue. To introduce the variable delay, the signal is passed through an all-pass FIR filter with an almost constant phase response. Its coefficients are calculated using the delay value required.

2.3. Power Scaling

When a transmitting antenna transmits radio waves to a receiving antenna, the radio wave power received is given by,

$$P_r = P_t D_t D_r \left(\frac{1}{4\pi \left(f_c + f_{Shift} \right) D} \right)^2 \tag{2.8}$$

where,

P_r = Received power

P_t = Transmitted power

D_t = Directivity of transmitting antenna

D_r = Directivity of receiving antenna

D = Total delay in seconds

To scale the received signal as per the received power calculated,

$$x_{Scaled}[n] = \frac{\sqrt{P_r}}{\mathrm{rms}\left(x[n] \right)} x[n] \tag{2.9}$$

2.4. Thermal noise

The thermal noise power at the receiver is given by,

$$N_r = kTB \tag{2.10}$$

where,

N_r = Noise power in watts

k = Boltzmann's constant

T = Temperature in Kelvin

B = Bandwidth in Hz

AWGN (Additive White Guassian Noise) samples with zero mean and variance N_r are generated and added to the satellite signal to model thermal noise at receiver.

The functions necessary to model the channel are present in the below code,

```
codes/channelmodel/channelmodel.py
```

Chapter 3

Transmitter

3.1. Frame structure

NavIC master frame consists of 2400 symbols, divided to four subframes. Each subframe is 600 symbols long. Subframes 1 and 2 transmit fixed navigation parameters. Subframe 3 and 4 transmit secondary navigation parameters in the form of messages. Each subframe is 292 bits long without FEC encoding and sync word. It starts with TLM word of 8 bits. Ends with 24 bit Cyclic Redundancy Check(CRC) followed by 6 tail bits. In subframes 1 and 2 navigation data is alloted 232 bits, starting from bit 31. In subframe 3 and 4, 220 bits are alloted starting from bit 37. For detailed structure of subframes, refer to chapter 5.9 in the doc

3.1.1. 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 eroor probability of 2^{-24} for all channel bit error probabilities 0.5

$$g(X) = \sum_{i=0}^{24} g_i X^i \quad g_i = 1 \; for \; i = 0, 1, 3, 4, 5, 6, 7, 10, 11, 14, 17, 18, 23, 24 \tag{3.1}$$

3.2. Encoding

The navigation data subframe of 292 bits is rate 1/2 convolution encoded and clocked at 50 symbols per second. Each subframe of 292 bits after encoding results in 584 bits. For parameters and coding scheme, refer to below doc

3.2.1. 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).

3.2.2. 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. Modulation

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. The CDMA modulated code, modulates the L5 and S carriers at 1176.45 MHz and 2492.028 MHz respectively.

3.3.2. Pseudo Random Noise codes(PRN)

NavIC uses Gold codes fo SPS signal. They are generated using Linear Feedback Shift Registers. For L5 and S band, the code length is 1ms and consists of 1023 chips. The code is chipped at 1.023 Mcps. Two polynomials G1 and G2 are used to generate the gold code sequence. G2's initial state provides unique PRN code for each satellite. All bits of G1 are initialized as 1. G1 and G2 are XOR'ed to generate final 1023 chip long PRN sequence, the time period being 1ms. For more information refer to chapter 4 in the doc.

3.3.3. 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. For detailed mathematical equations, refer to chapter 3.3 in the below document

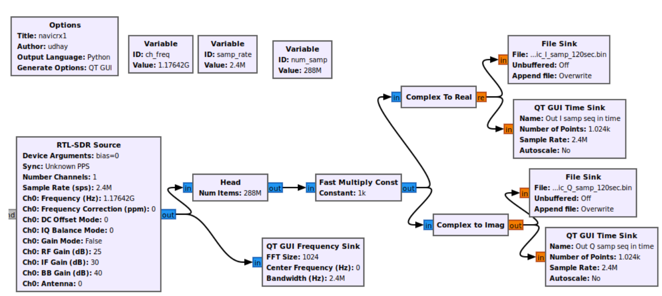
Chapter 4

Receiver

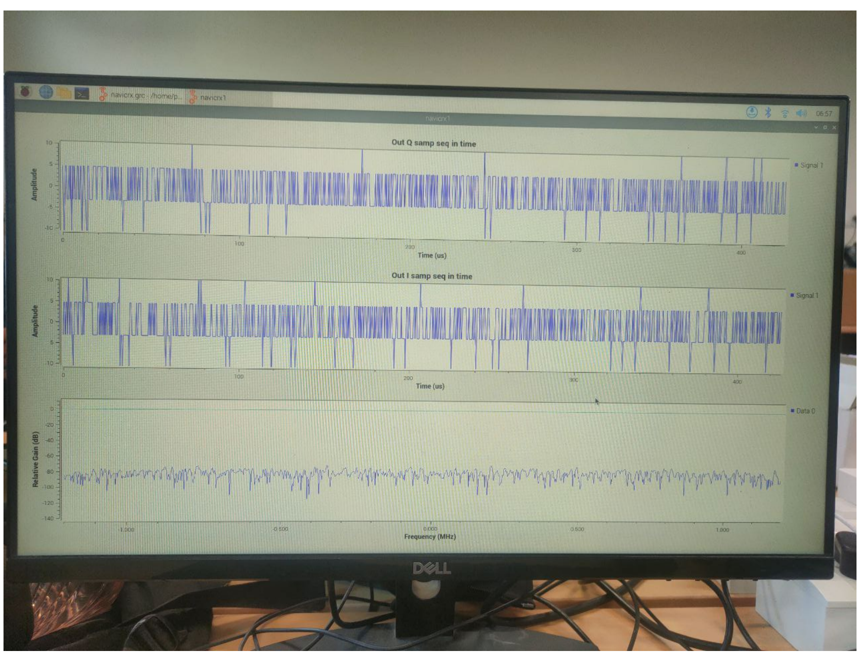
4.1. RTL SDR

Name	**RTL-SDR**(hardware modded R820T2/RTL2838U DVB-T)
Type	Pre-built and pre-modded with custom driver
Frequency range	0.5 – 1766 MHz(mod: RTL2832U Q-branch pins soldered to antenna port)
Max. Bandwidth	Matches sampling rate, but with filter roll-off
Receiver ADC bits	8
Tx. DAC bits	-
TX. Capable	No
Sampling Rate	2.4 MHz (can go up to 3.2 MHz but drops samples)
Frequency accuracy ppm	1
Host interface	USB
FPGA	-
Frequency accuracy ppm	1

4.1.1. Radio block diagram for L5 band signal receiver



4.1.2. Results

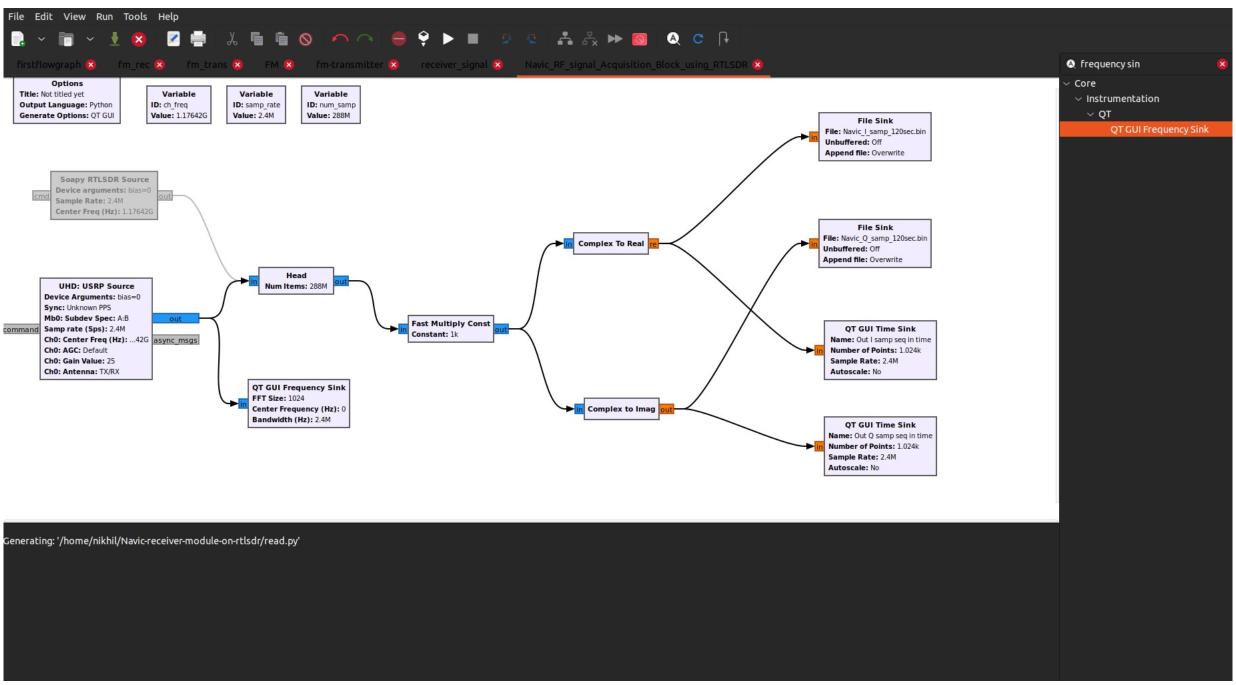


4.2. USRP SDR

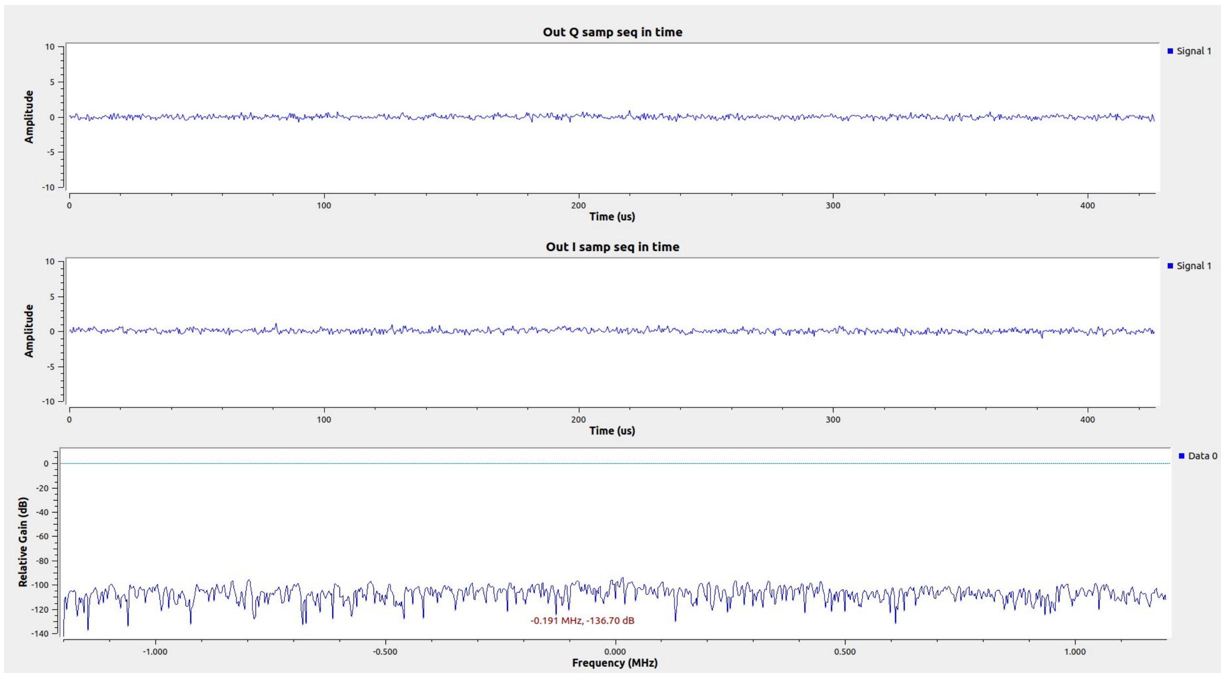
4.2.1. SDR specification

Name	USRP B210
Type	Pre-built
Frequency range	70 MHz – 6 GHz
Max. Bandwidth	56MHz
Receiver ADC bits	12
Tx. DAC bits	12
TX. Capable	Yes
Sampling Rate	56 Msps
Frequency accuracy ppm	-
Host interface	USB 3.0
FPGA	Xilinx Spartan 6 XC6SLX150

4.2.2. Radio block diagram for L5 band signal receiver



4.2.3. Results



Out Q samp seq in time
Amplitude
Time (us)
Signal 1
Out I samp seq in time
Amplitude
Time (us)
Signal 1
Relative Gain (dB)
Frequency (MHz)
Data 0
-0.191 MHz, -136.70 dB