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Acquisition and Tracking of S-Band Signals of Navigation with Indian Constellation (NavIC)

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Abstract: ***The IRNSS satellite network covers a large area of the India with 7 satellites, 3 geostationary and 4 that are geosynchronous. IRNSS signals are transmitted in the L5 and S-Bands. The L5 band frequencies range from 1164.45-1188.45 MHz and the S band frequencies range from 2483.5-2500 MHz.NavIC is the IRNSS satellite constellation network that can be employed to a variety of applications. In order to achieve this signal must be acquired and tracked. IRNSS signals have PRN sequences unique for each satellite. These sequences are used to scramble and encrypt the signal, in order for a receiver to acquire the signal, it needs to have the same PRN sequence as that of the sending satellite, this is achieved in acquisition using an efficient search method. Once the PRN sequence is generated at the receiver it has to be tracked continuously to ensure that there is no loss of signal at a later point, which is achieved in the tracking phase. Several factors can lead to noise generation in the satellite signal; this can lead to either a Doppler shift in carrier or shift in PRN both leading to loss of signal, thus a correctional loop is also implemented in the tracking phase to correct the effect of noise.***

Keywords: NavIC, Early Code, Late Code, Prompt Code, In-Phase, Quadrature phase.

I. INTRODUCTION

A. NavIC (Navigation with Indian Constellations)

IRNSS (Indian Regional Navigation Satellite System) also called by the name of Navigation with Indian Constellation (NavIC) is a territorial satellite route framework that gives precise ongoing situating and timing administrations. It covers India and a locale expanding one thousand five hundred kilometers (930 mi) around it. The framework at the moment comprises of 7 satellites. There are 2 satellites on the ground kept as stand by that are ready to be deployed in case of any misfunction of the 7 satellites that are currently working. In the 7 satellites, 3 satellites are thirty-six thousand kilometers above the earth surface and are geostationary in nature. The 4 remaining satellites are geosynchronous in nature. Frameworks that are constructed for the purpose of navigation are designed keeping in mind the triangulation method. Triangulation method is used to locate the client by making use of the data that is communicated from the satellites present in the orbit. Each satellite transmitter emits coded signals at specific delay values. The signal that is transmitted by the satellite is collected by the ground receiver where the signal is decoded to get position, speed, and time. This data that consists of position speed and time variables are made use of to pinpoint the exact location from where the satellite receiver is and the distance between it and the recipient. The transmission delay plays a major role in determining the distance between the satellite and the recipient. IRNSS signals are comprised of two components. The first component is Standard Positioning Service (SPS) and the second component is Precision Service (PS). The two components of the IRNSS signals are carried on two frequency bands L5 frequency band the S frequency band. The L5 band is 1176.45 megahertz and the S band is 2492.028 megahertz. The standard positioning service signal is modulated using Binary Phase Shift Keying (BPSK) technique by a one-megahertz signal. Navigation data is transmitted via the S band that ranges from 2 to 4 gigahertz and to make sure the values are of sufficient amplitude these signals are broadcast through a phased array antenna. Once IRNSS is completely operational will be able to provide accurate position data of up to 10 meters along the Indian subcontinent and an accuracy of up to 20 meters in the Indian ocean. IRNSS will also provide position data in the region of one thousand five hundred kilometers around India. Comparing it with the Global Positioning System (GPS) which has an accuracy of two to three meters, IRNSS is more accurate. The Global Position System (GPS) has only L-band to transmit data where as IRNSS makes use of two frequency bands (S and L bands) that gives IRNSS an edge over Global Positioning System (GPS).

B. PRN Sequence

We make use of the IRNSS signals which are transmitted using PRN (Pseudo Random Noise) sequences that are uniquely generated for each satellite.

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The use of PRN sequence is because of their special correlation and auto-correlation properties. The block diagram showing the PRN sequence generator for IRNSS satellites is shown in Figure 1.

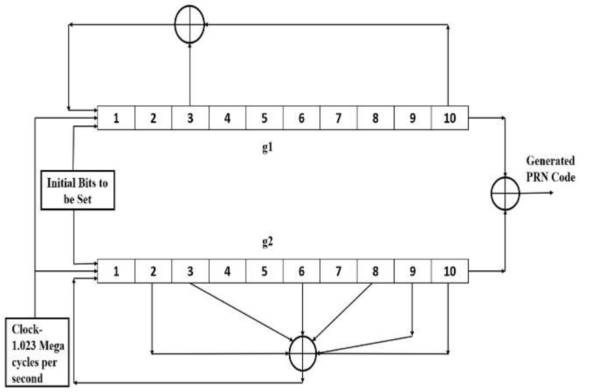

Figure 1. Linear shift registers to generate PRN code.

The block diagram in Figure 1 shows two generator blocks g1 and g2, each block consisting of ten linear shift registers with a feedback mechanism. The generator blocks individually generate the PRN sequence of length 2^{10} -1=1023 bits each. The initial values of the linear shift registers of the first generator block will always be set to zeros. The initial values of the second generator block are determined from Table 1 sourced from ISRO. The generators will have feedback from the selective shift registers and this is represented in the block diagram shown in Figure 1.

Table 1. Initial values of g2 block for S band frequency for all 7 satellites.

PRN Satellite ID	S Band -SPS	
	Initial values for g2 block	Initial ten bits generated in OCTAL format
1	0011101111	1420
2	0101111101	1202
3	1000110001	0716
4	0010101011	1524
5	1010010001	0556
6	0100101100	1323
7	0010001110	1561

The final satellite PRN sequence unique to each satellite is generated by taking the exclusive OR of both the first g1 and second g2 generator outputs.

II. ACQUISITION OF S BAND SIGNALS

For acquisition of IF samples, the data collected is converted to signed two-bit format. The sampling frequency is chosen based on getting the best acquisition and tracking performance. The PRN code is generated based on the satellite number, thus, for S-band SPS for the first satellite, the PRN code is generated as a 10-bit number. The code is up sampled to accommodate the preset number of samples; the digital IF is generated by mixing the direct and indirect signals. FFT search is implemented by generating the In-Phase and Quadrature carrier signals and multiplying with the samples to generate two mixed signals with a phase difference of $\pi/2$. A low pass Parks-McClellan filter is constructed to filter out noise. The low-pass filter signals are convoluted with the coefficients of the filter to produce two filtered signals with the same phase difference as before. The FFT of the up-sampled PRN code is also taken. The autocorrelation function as described for FFT is, $R[m] = x[n] \times CA[-n]$ which is circular convolution of the two signals, since circular convolution is multiplication in the frequency domain, the two signals, FFT of PRN code and the filtered signals are multiplied to obtain the autocorrelated signal. The magnitude of the IFFT of this signal and averaged for K such correlations. This average correlation power is taken and plotted with respect to frequency and code phase (chips), the correlation peak is obtained at the point where the correlation power crosses the preset threshold, confirming that the signal has been acquired and tracking can begin. Figure 2 shows the FFT search block diagram.

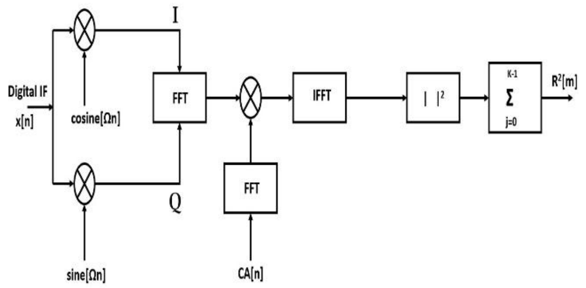

Figure 2. Block Diagram showing FFT search.

III. TRACKING OF S BAND SIGNALS

The PRN code in the received signal, once acquired must be tracked i.e. the PRN code of the sender and receiver must be the same to prevent loss of signal from satellite. The receiver faces 2 problems here, one, is the Doppler frequency shift of the satellite as it moves across the sky, leading to a maximum deviation of ±10 kHz. The other is to continue to keep the phase of the PRN code aligned. The PRN code is up sampled 4 times, so each chip has 4 taps. If the PRN code's phase is completely aligned with that of the receiver, then it has maximum correlation, but a displacement of a few taps means that the correlation is not maximum, just considerable. Thus, the phase of the code may not be aligned perfectly at acquisition, sometimes due to Doppler shifts, leading to phase differences of 200ms or more. To fix the issues of frequency and phase shifts and allow us to track the signal, we implement two loops, the carrier and code tracking loops are implemented. The first is the code tracking loop used to compensate the phase difference in the PRN code that might have occurred due to any disturbances. If the code loses phase of one of the taps, correlation will drop but this alone cannot be enough to determine the phase shift, as the direction is still unknown, whether to shift left or right. To solve this, two codes are generated, called the early and late codes, respectively shifted to the right and left by a selected number of samples. The actual non shifted code is called prompt code. Now, if the received PRN code shifts, it causes all three codes to shift in a particular direction. Since, the early and late codes are shifted by a known number of samples, by correlating the new and old code we can get the direction of shift. A discriminator algorithm is used to give the phase error, its output, ϵ is given by equation (1),

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$$\epsilon = \frac{Early}{Late} \ldots(1)$$

If ϵ=1, then the alignment is perfect, else, if ϵ>1, the code must be shifted to the right and if ϵ<1, the code is shifted to the left.

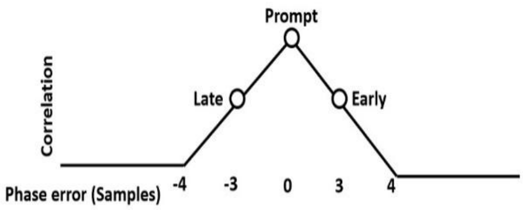

Figure 3. Early Prompt and Late code without error.

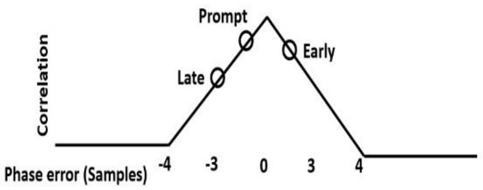

Figure 4. Early Prompt and Late code with error.

The correlation will fall from maximum to zero if the phase error is one full chip, which is of 4 samples, a phase error of a full chip supposedly shifts the code which makes it acts as white noise as it is not in sync. If a shift does happen, it can occur either as a left or right shift. To determine the direction of the shift, we introduce two new codes which are the early and late codes. The CA code is taken as the prompt code which needs to be phase aligned. The early code is the prompt code shifted to the left by 3 samples and the late code is the prompt code shifted to the right by 3 samples, which gives us Figure 3. IF the incoming PRN code now shifts, it causes a shift in the early and late codes which tells us the direction in which the shift needs to be made to correct the phase error shown in Figure 4. The IF signal is down converted to the baseband signal then converted to its In-phase and Quadrature components, these components are multiplied by the early, prompt and late codes to get the values to be correlated, several of these values (at least 20) are generated and averaged for both early and late. The average values are then fed to the discriminator algorithm whose output ϵ shows if phase shift is required. The Code Loop block diagram is shown in Figure 5. The Carrier frequency is tracked to ensure that don't lose the satellite, thus, any change in frequency, Doppler shift or otherwise, can lead to loss of signal. Acquisition gives the frequency but with an error of $\pm 500\ Hz$. Therefore, a carrier loop is constructed. The loop can keep track of the signal i.e. phase lock as long as the frequency shift is within a limit. To track the carrier,and lock into it using a Phase Lock Loop (PLL) shown in Figure 6.

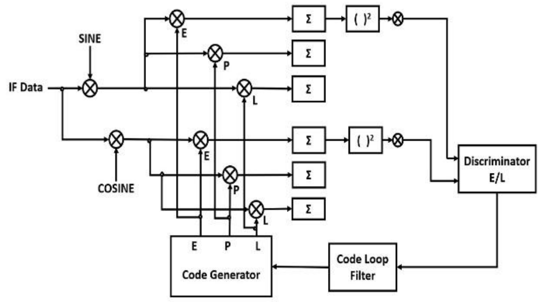

Figure 5. Code loop Tracking.

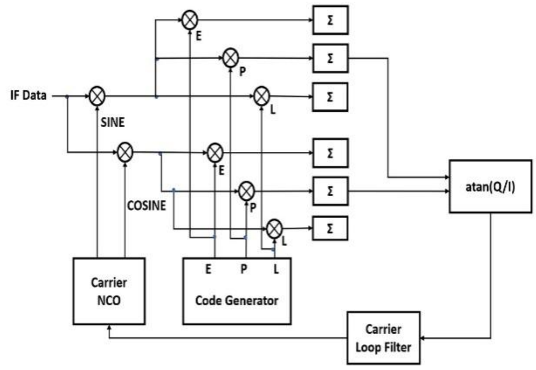

Figure 6. Carrier loop Tracking.

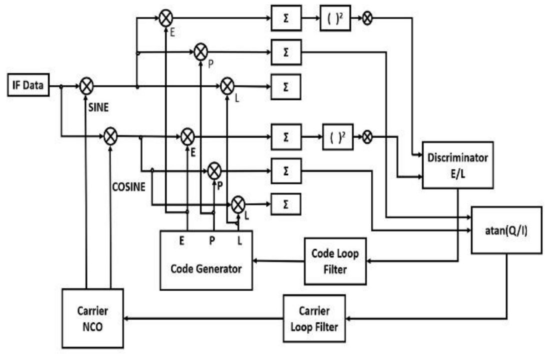

Figure 7. Combined Code and loop tracking.

Similar to the code tracking loop, the IF signal is down converted to the baseband signal then converted to its In-phase and Quadrature components using carrier frequency f_c, which is to be corrected. The In-phase and Quadrature components are multiplied with the prompt code and each summed over one code period and fed to the discriminator algorithm, whose output, here, is the angle in radians between the I and Q components, given by equation (2),

$$atan = \left(\frac{Q}{I}\right) \qquad \ldots (2)$$

The In-phase component should be large as possible while the Quadrature one should be as small as possible. The carrier frequency f_c is corrected by a carrier loop filter which uses the output value of the discriminator to correct the frequency shift through the carrier NCO. Figure 7 shows the overall tracking block diagram.

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IV. RESULTS AND DISCUSSION

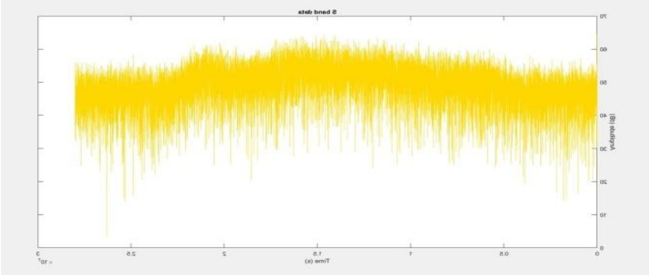

Figure 8. Amplitude of S Band data plotted in dB vs time.

The S band data that we have collected from the satellite has been plotted in the Figure 8. The data has been plotted as a function of time. The amplitude has been taken in Decibels.

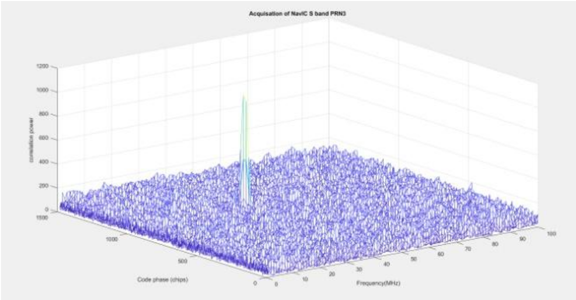

Figure 9. Acquisition of NavIC S band for PRN3.

The acquisition of S-band signals from satellite 3 of IRNSS is successfully implemented and its plot is shown in Figure 9. The graph shows a peak when the threshold amplitude is crossed showing the frequency bin and the number of chips at which the signal is acquired.

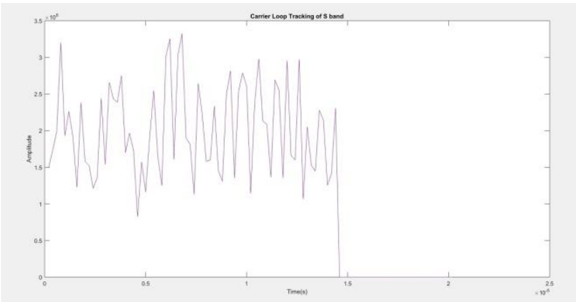

Figure 10. Carrier Loop Tracking of S band PRN3.

The tracking of S-band signals from satellite 3 of IRNSS is successfully implemented and the plot of the phase error of carrier phase loop, plotted as amplitude vs. time is shown in Figure 10.

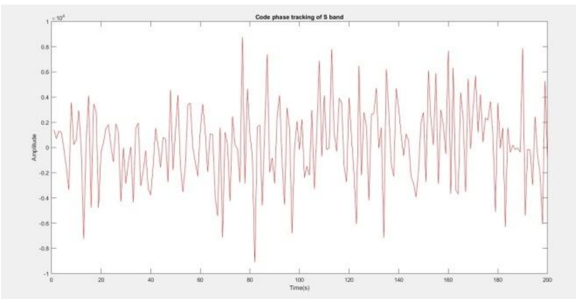

Figure 11. Code Phase Tracking of S band PRN3.

The tracking of S-band signals from satellite 3 of IRNSS is successfully implemented and the plot of the phase error of code phase loop for PRN code, plotted as amplitude vs. time is shown in Figure 11.

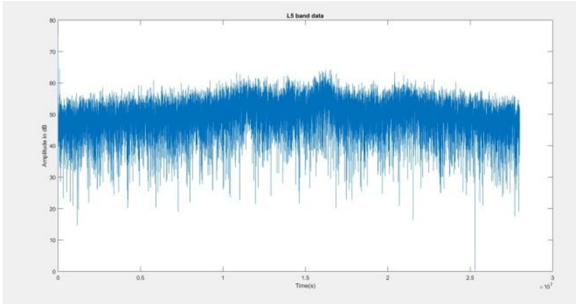

Figure 12. Amplitude of L5 Band data plotted in dB vs time.

The L5 band data that we have collected from the satellite has been plotted in the figure 12. The data has been plotted as a function of time. The amplitude has been taken in decibels.

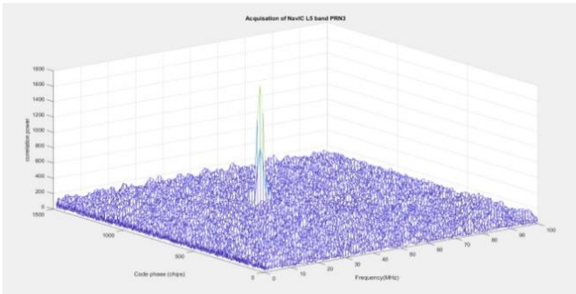

Figure 13. Acquisition of NavIC L5 Band PRN 3.

The acquisition of L5-band signals from satellite 3 of IRNSS is successfully implemented and its plot is shown in Figure 13. The graph shows a peak when the threshold amplitude is crossed showing the frequency bin and the number of chips at which the signal is acquired.

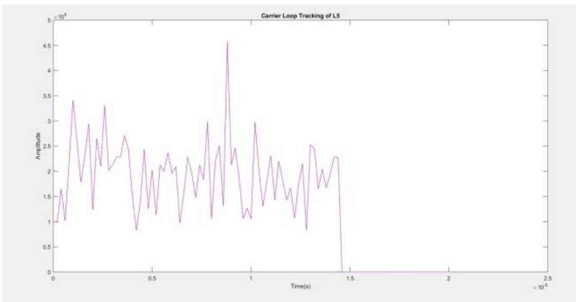

Figure 14. Carrier Loop Tracking of L5 Band PRN3

The tracking of L5-band signals from satellite 3 of IRNSS is implemented and the plot of the phase error of carrier phase loop, plotted as amplitude vs. time is shown in Figure 14.

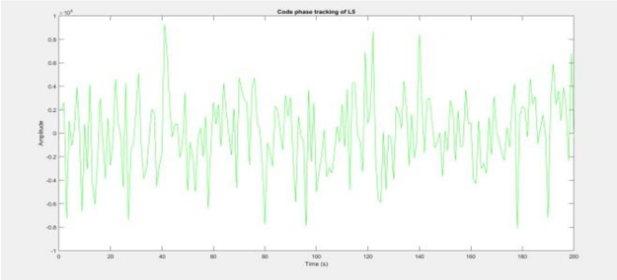

Figure 15. Code Phase tracking of L5 band PRN3.

The tracking of L5-band signals from satellite 3 of IRNSS is successfully implemented and the plot of the phase error of code phase loop for PRN code, plotted as amplitude vs. time is shown in Figure 15. It is observed that the correlation peak when it comes to the L5 band is higher compared to the S band. From this we can ascertain that the L5 band is more favorable when used to calculate soil moisture.Coming to the code tracking loop, we observe the graph tending to shift to the left for the L5 band and for S band the graph tends to be more uniform suggesting the code shifts to not be very drastic.Observations regarding the carrier tracking of both the bands suggest that the amplitude in case of L5 band is larger compared to the S band. Hence more of the in-phase component is retained suggesting lesser phase shifts.

V. CONCLUSION

The acquisition and tracking of S-band and L5-band signals from satellite 3 of IRNSS has been successfully implemented and the plots of the data, its acquisition, the phase error of code phase and carrier phase loops have been plotted separately for both the L5 and S band data. From the plots, it can be observed that while the acquisition may vary in frequency for both the L5 and S bands, the tracking is relatively the same. Therefore, it can be summarized that both L5 and S bands are viable as any phase errors caused by noise can be eliminated in the tracking phase regardless of frequency. This is acquisition of NavIC signals can be further used to estimate the soil moisture using GNSS-R.

VI. ACKNOWLEDGEMENT

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