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Acquisition and Tracking of NavIC L5 band signals

Manjula T R
Assistant Professor, Department of Electronic and communication engineering,
Jain University, School of Engineering and Technology, Global Campus,
Bangalore, Karnataka, India.
Orcid Id: 0000-0002-6910-1980

Raju Garudachar
Professor, Department of Electronic and communication Engineering,
Jain University, School of Engineering and Technology, Global Campus,
Bangalore, Karnataka, India.

Abstract

NavIC (Navigation with Indian constellation) is Indian regional navigation satellite indigenously developed by India to cater to the needs of public and military in the navigation field with satellites fully operational in orbits since October 2016. To extend NavIC utility in number of applications ranging from navigation to ionosphere studies in India and worldwide, regular evaluation and upgradation of IRNSS system is significant. As a first step in this view, real time NavIC L5 band data is theoretically analysed and processed in Matlab for signal acquisition and tracking and the results of signal acquisition and tracking are presented with analysis. Further the limitations of signal tracking loop under drastic atmospheric conditions are highlighted.

Keywords: carrier tracking, code, navigation, phase discriminator, Costas loop, loop filter

INTRODUCTION

With every country coming up with its own Navigation system exhibiting self reliability in the navigation field, India is one among many, America (GPS), China (Beidou), Russia (GLONASS), Japan (Quasi Zenith), ESA(Galileo) which has developed NavIC navigation system to meet the regional demands in the navigation field

NavIC navigation system constitute a constellation 7 satellites (1A, 1B, 1C, 1D, 1E, 1F & 1G) with 3 in geo synchronous orbits and 3 in geostationary orbits continuously (sec) transmitting navigation signals containing coded almanac and ephemeris data [11]. NavIC receiver on the user side process the received signal and navigation data is extracted. Navigation data is utilized in the position determination algorithm [6] to locate user position. Navigation signals are broadcast from NavIC constellation in L5 (1176.45MHz) and S (2492.028MHz) band. The user equipped with IRNSS receiver operates on the received signal to determine user position. Although signals from 4 satellites suffice to compute user position, 3 more satellites extend global coverage upto 1500km and further to compensate for signal outages caused during unfavourable atmospheric conditions [8]

NavIC SIGNAL CHARACTERISTICS

Navigation information constituting Ephemeris and Almanac data that describes orbital motion and position of satellites in orbits is a 50 Hz navigation data, encrypted by CA (Course acquisition) code which has chipping rate of 1.023MHz. Further it is BPSK modulated by L5 carrier signal. The transmitted L5 signal is given by [5]

$$X_i(t) = A\left[CA_i(t) + D_i(t)\right]Sin(w_{L5}t) \quad \text{................1}$$

where

CA_i course acquisition code of ith satellite

D navigation data of ith satellite

W_{L5} L5 radian frequency (2 *pi*f_{L5})

A Signal magnitude

Each NavIC satellite has unique identification number [1] referred to as CA (course acquisition) code also called as pseudo random code (PRN) code, facilitates multiple access of satellite signals through code division multiple access(CDMA).

Signal Acquisition

Signal acquisition is a 3D process of detecting satellite signal and its corresponding carrier frequency and code phase of the PRN code from the received signal. The navigation signal transmitted from satellite is recorded from the receiver antenna. The signal is down converted into Intermediate frequency (IF) in the front end of the receiver [5]. IF data consists of navigation signals from all NavIC satellites. Further IF data is processed in the receiver to identify the visible satellites. This is accomplished in sequence within a loop by first wiping off the carrier by demodulating with replicated carrier signal and subsequently wiping off PRN code by correlating the received PRN/CA code with replicated PRN (CA) codes of all satellites [7] resulting in In phase(I) and quadrature phase correlator (Q) components

The correlation power (I^2+ Q^2) is measured for more than 1 code period (N) is squared and accumulated. M such correlation are averaged and compared against threshold. If resultant correlation magnitude is greater than threshold, satellite signal is detected; the carrier frequency values and code phase are extracted for the detected satellite. The correlation power [4] is given by

$$R^2(m) = \sum_{k=1}^{M}\left(\left[\sum_{n=1}^{N} x(n).CA[n].\cos(wn)\right]^2 + \left[\sum_{n=1}^{N} x(n).CA[n].Sin(wn)\right]^2\right) \quad \text{............2}$$

IMPLEMENTATION

Signal acquisition is coded as search algorithm for carrier frequency and code phase at the point of synchronization between the received signal and replicated signal. For a sampling rate of 56MHz, one CA code period has 56000 samples, the replicated carrier frequency at IF frequency is shifted in increments of 125Hz over Doppler frequency range of ±10KHz to have 81 frequency search bins and multiplied with received carrier signal. Subsequently, received CA code samples of 1ms (i.e., 56000 samples) is correlated with replicated CA code by circularly shifting which is equivalent to circular convolution. This correlation between received signal and the replicated signal results in correlation peak power larger than the threshold for the detected satellite and the corresponding carrier frequency and code phase at the point of correlation peak is retrieved; acquisition results are tabulated in Results section

DFT/FFT tool is used to effectively implement the circular convolution, as circular convolution is equivalent to multiplication in frequency domain. It is mathematically expressed as

$$R[m] = x[n] \otimes CA[n]$$
$$= F^{-1}\left(F(x[n].F(CA[n])\right) \quad \text{........................3}$$

Signal Tracking

Once satellite signals are detected in signal acquisition stage, continuous tracking of the satellite signal is equally significant for further decoding and extraction of navigation data and is referred to as signal tracking. The need for signal tracking arises from the fact the carrier signal experiences frequency deviation due to Doppler shift. Relative motion between satellite and receiver induces Doppler frequency offset in the carrier frequency and for stationary receiver it is assumed to be ±10KHz. Similarly CA code phase samples also undergo shift.

Signal tracking is about detecting frequency and code shift of the detected satellite signal and synchronize with the replicated signals with the aim of retrieving navigation data. This is accomplished in two stages

1. Carrier tracking loop
2. Code tracking loop

Carrier tracking loop

Carrier tracking loop tracks the frequency and phase of the received signal by detecting the phase error between replicated signal and incoming signal and accordingly replicated signal produced by numerically controlled oscillator (NCO) is adjusted to synchronize with incoming signal in both frequency and phase. For zero phase error detected, navigation data is accurately extracted.

Arctangent discriminator given by atan(Q/I) is used as phase discriminator (PD) to detect phase error angle between I and Q component. Though several phase discriminators [2] are available, Atan PD has linear output over half of the input error range (±90^0) and hence preferable over other types. The PD output is filtered for noise by loop filter and drives the NCO signal frequency towards the incoming carrier signal frequency.

The loop filter parameters [2]: filter order, damping ratio and band width determine PLL's ability to filter out the noise and track high signal dynamics

Code tracking loop

Post the carrier signal synchronization, received CA code samples is synchronized by aligning with replicated CA code samples by shifting right or left. To determine the direction of shift, the I and Q outputs are multiplied with prompt code (PRN code which is phase aligned), early code (prompt PRN code shifted by some samples to the right) and late code (prompt PRN code shifted by some samples to the left) resulting in I_E I_p I_L *and* Q_E Q_p Q_L corresponding to I and Q channel respectively. A code discriminator function is given by equation 4, generates error (ϵ) proportional to the code phase error between the replica and incoming signal. This error is filtered and applied to code generator and output frequency is increased or decreased and accordingly the prompt code is phase shifted to be phase aligned with received one.

A code discriminator is given by

$$\varepsilon = \frac{(I_E^2 + Q_E^2) - (I_L^2 + Q_L^2)}{(I_E^2 + Q_E^2) + (I_L^2 + Q_L^2)} \quad \text{..............................4}$$

The above two loops function in sequence and satellite signal is tracked and navigation data is extracted. The combined carrier and code tracking loop is implemented as a basic

PLL/Costas loop with some modifications in architecture as illustrated in the Figure. 1.

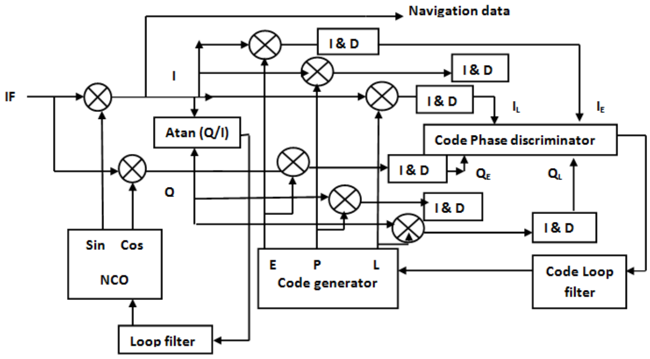

Figure 1: Combined carrier and CA code tracking loop

Matlab implementation of signal tacking

NCO of the Carrier tracking loop and code generator of the code tracking loop is initialised to carrier frequency and code phase shift respectively, acquired from signal acquisition stage. The loop runs updating the NCO and code generator at every Integration time (1ms) based on the discriminator output, remaining phase lock onto the signal, simultaneously retrieving the navigation data [3].

Performance analysis of carrier tracking loop

Performance of carrier tracking loop is measured in terms of ability of the loop to maintain phase lock onto the received signal and capability of tracking high signal dynamics. The carrier tracking loop tries to maintain phase lock of the signal as long as phase errors are within boundary. The dominant source of phase error in Costas PLL based receiver is thermal noise phase jitter and dynamic stress error [9]. In order to maintain phase lock, the total phase error of the carrier tracking loop must not exceed one fourth the phase pull in range of arctangent discriminator of Costas loop.

RESULTS AND DISCUSSION

Real IF data for analysis was collected from IRNSS UR receiver installed at IRNSS laboratory in Jain University Campus. IF data at an intermediate frequency of 16.221MHz is sampled to obtain digitised IF samples which are processed with acquisition and Tracking algorithms implemented in MATALB

Table.1. describes the acquisition results with satellite ID, corresponding acquired frequency, Doppler frequency and C/A code offset. The magnitude of correlation power is plotted against Doppler frequency bin and code samples in Figure.2 For the recorded 2msec of L5, IF data, satellites PRN1, 2, 3, 4, 5, & 6 are detected.

Table 1: Signal Acquisition Results

Satellites (PRN) detected	Acquired Frequency(Hz)	Doppler frequency(Hz)	C/A Code Offset (samples)
3	1.622088e7	-111	36402
2	1.622093e7	-66	52770
4	1.622087e7	-123	52802
1	1.621788e7	-3115	2578
5	1.6220972e7	-28	52818
6	1.6220977e7	35	52834

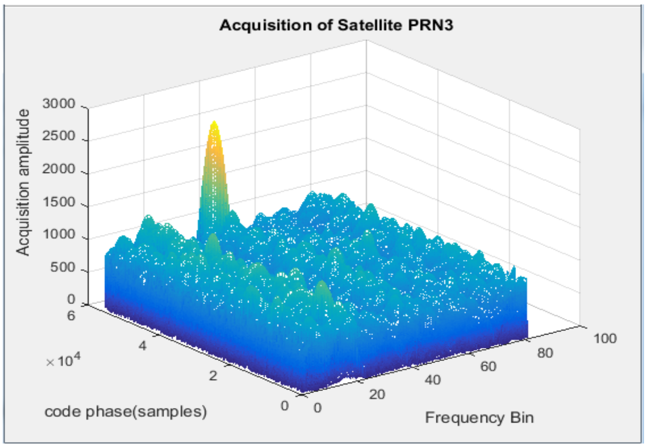

Figure 2: Correlation peak power of PRN3 satellite signal

With respect to Signal tracking, the in-phase (I) and Quadrature phase (Q) correlation power for Early (E) Prompt (P) and Late (L) channel is plotted in the Figure.3 implies the maximum power distribution in the Prompt channel from where navigation data is extracted. The performance of tracking loops is assessed with respect to carrier phase error and code phase error. On an average, the phase residual of PLL is within ±0.06 and code phase error is within ± 0.8 chips as illustrated in Figure.4. & 5. respectively, for an integration period of 1msec. The navigation binary data plot in the Figure. 5 illustrates navigation data was successfully extracted

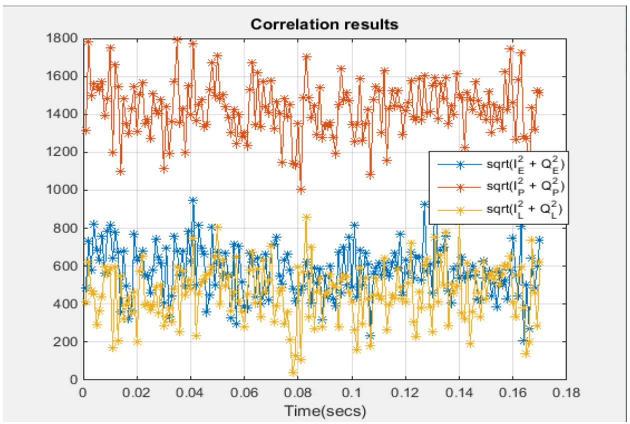

Figure 3: Correlation power plot of I and Q channel

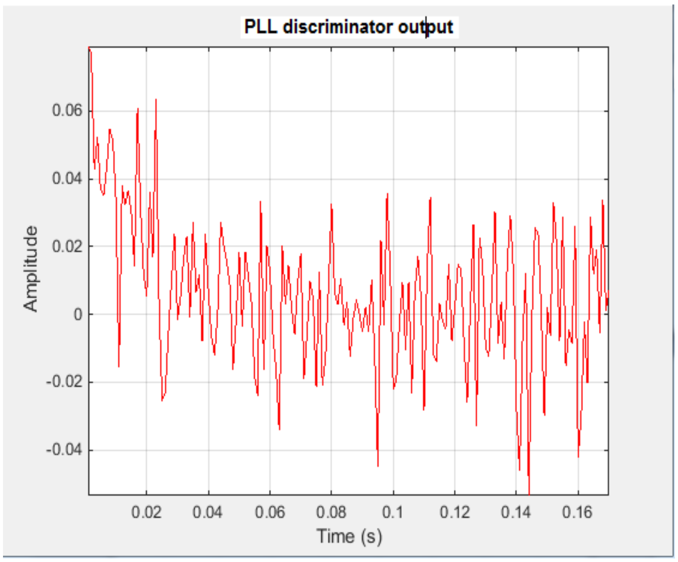

Figure 4:. Phase error plot of carrier tracking loop

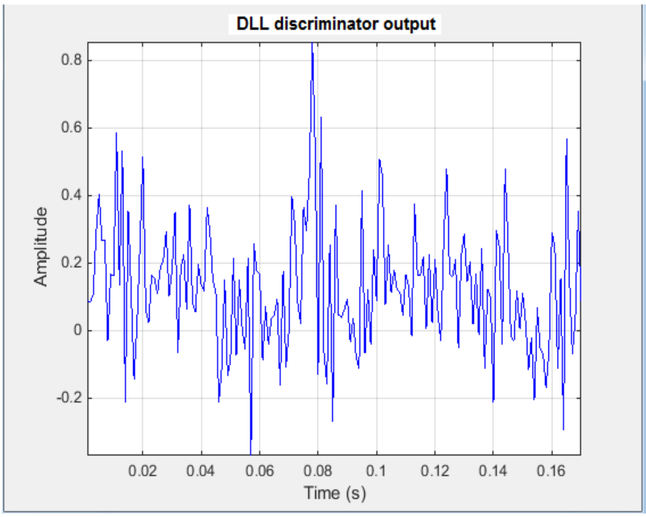

Figure 5:. Phase error plot of code tracking loop

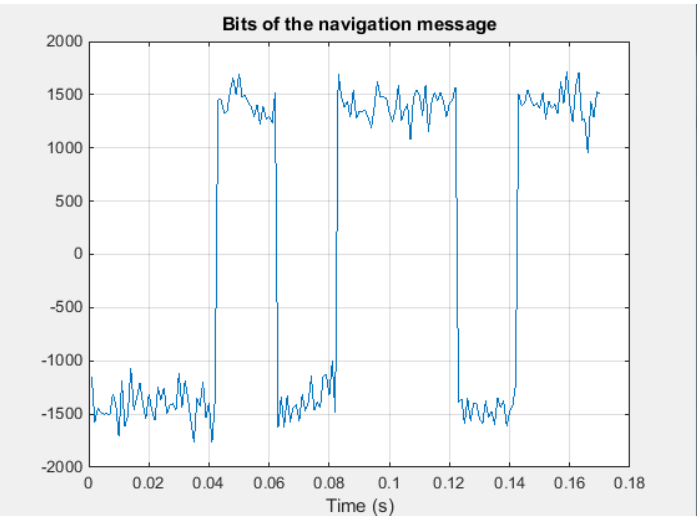

Figure 6:. Extracted Navigation binary data

CONCLUSIONS

NavIC navigation system has set started to be used in wide number of applications. As a performance study, real time NavIC L5 band signals are processed in Matlab for signal acquisition and tracking with successful extraction of the navigation data. Further the work can be extended to compute user position by utilizing the navigation data and analyse the performance of the carrier tracking loop under drastic signal conditions

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