Development of GNSS receiver algorithms for Acquisition of Galileo E1 Signal

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***Abstract*— The Galileo GNSS Software Receiver is founded on the principles of signal processing, navigation algorithms, and software-defined radio, enabling it to receive, process, and make sense of the signals transmitted by Galileo satellites in Earth's orbit. Galileo GNSS Software Receiver serves as a linchpin, offering the requisite accuracy and reliability for a myriad of industries and applications. MATLAB-based processing, and embedded software, the correlator leverages the power of Galileo's constellation to provide users with highly accurate positioning, navigation, and timing data. This paper explores the implementation of the Galileo E1 open service signal's Acquisition algorithms within the GNSS-SDR ecosystem. This paper mainly deals with development of algorithms for acquisition of E1-signal of Galileo GNSS system. Acquisition includes the timing, position, navigation data, etc. The generated spectrum are plotted using MATLAB software.**

Keywords: GNSS-SDR, E1-signal, Acquisition, I/NAV navigation message, BOC modulation, data component, pilot component, Parallel code phase search(PCPS) acquisition.

I. INTRODUCTION

Galileo GNSS system is the European based GNSS system which is network of satellites providing signals from space that transmit positioning and timing information due to GNSS receivers. It is an independent, global, interoperable with GPS and GLONASS. Galileo system provides the services like Open service, Safety-of-life, Commercial service, public regulated service, search & rescue (SAR) service [1]. Galileo system consisting of 30 satellites in circular medium earth orbit planes with an inclination of 56^0.

Galileo E1 signal provides the open service (OS) in E1 sub band broadcasted with a carrier frequency of 1575.42 MHz. E1 OS is generated by E1B and E1C which are data and pilot components respectively [2]. This paper deals with the development of algorithms for Galileo E1 signal tracked by the receiver. Received signal includes timing, positioning, navigation information.

The structure of this essay is as follows. In Section II, the suggested design methodology and principle of operation is presented with frequency bands, Binary Offset Carrier (BOC) modulation [3] applied on incoming data and pilot components with subcarrier signals used by Galileo system. The simulation results are shown in Section III. This section grasps the paper.

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II. LITERATURE REVIEW

K. Borre et. al [2] describes the detailed structure analysis of E1 Galileo open service signal with their carrier frequency and receiver frequencies. This book explains the structure of E1 signal, modulation scheme used for generation, E1 signal waveforms. A. Khine Myint Mon explains the study and analysis of BOC modulation. BOC modulation is the scheme used for navigation signals mainly in GPS, Galileo systems, etc. structure of BOC (1,1), BOC (1,6) schemes and their waveforms are described in [3]. ESA issued various versions of the signal in space interface control document (SIS-ICD) describes about the navigation signal structure along with frame, subframe, pages structure of I/NAV, F/NAV message structure is detailed in [4]. In order to find the position of receiver OSNMA in the page structure of I/NAV message format is described by ESA which is detailed in [5]. This paper describes development of acquisition algorithm of Galileo E1 signal. As acquisition process involves finding the peak spectrum of visible satellite Adrian Florin Paun et. al [6] explains the performance of acquisition algorithm for certain threshold values to acquire the visible satellite. To perform the acquisition process different methods of acquisition are used of them parallel code phase search algorithm is the method used here. Dr. Atar Mon et. al [7] detailed about the acquisition algorithms used in software defined receiver and the Cross Ambiguity Function (CAF) which is a used for evaluation and processing of generated signal. Once the Acquisition and tracking of E1 signal, that signal need to be analysed with real time signal, the procedure to analyse the tracked signal is detailed in [8].

III. E1 SIGNAL STRUCTURE

The principle of operation of Galileo GNSS satellite is triangulation or trilateration principle. It is technique used by the Galileo satellites to determine the position of a receiver on earth's surface by measuring the distance from 3 or more satellites in space. Galileo E1 OS signal consisting of the data, data-free (pilot) components, subcarrier signals are shown in Fig. 1.

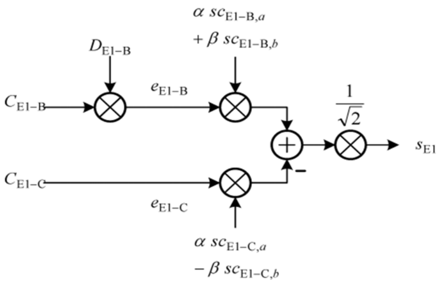


Fig. 1. E1 CBOC signal generation [4]

E1 CBOC i.e., S_{E1} is generated as

- e_{E1-B} is resultant signal of E1-B component obtained by combining ranging code C_{E1-B} and navigation message D_{E1-B} and then modulated with subcarriers $\alpha SC_{E1_B,a}(t) + \beta SC_{E1_B,b}(t)$. These subcarriers are combination of BOC modulated structures with BOC(1,1) and BOC(6,1) are added together and modulated with resultant e_{E1-B} signal.
- e_{E1-C} is pilot component signal which doesn't have any navigation message modulated with subcarriers $\alpha SC_{E1_B,a}(t) - \beta SC_{E1_B,b}(t)$. These subcarrier signal is same combination as above but subtracted form BOC(1,1) and BOC(6,1) combination.
- After generation of above sequences, those signals are subtracted and resultant is multiplied with 0.707 to get Composite BOC (CBOC) signal.

C_{E1-B} & C_{E1-C} are the ranging codes in hexadecimal form, D_{E1-B} is a navigation data message from I/NAV message.

Mathematically, the above can be expressed as

$$e_{E1-B}(t) = \sum_{i=-\infty}^{+\infty} c_{E1-B,|i|_{L_{L1-B}}} D_{E1-B,[i]_{D\,C_{L1-B}}}\, rect_{T_{c,E1-B}}(t - iT_{c,E1-B}) \quad (1)$$

$$e_{E1-C}(t) = \sum_{i=-\infty}^{+\infty} c_{E1-C,|i|_{L_{L1-C}}}\, rect_{T_{c,E1-C}}(t - iT_{c,E1-C}) \quad (2)$$

$rect_{T_{c,E1-B}}(t - iT_{c,E1-B})$ and $rect_{T_{c,E1-B}}(t - iT_{c,E1-C})$ are the subcarrier waveforms of E1-B and E1-C components respectively.

The ranging signals are transmitted with chip rate of 1.023Mcps and has sub-carrier rate of 1.023MHz in both E1B & E1C components. The navigation data D_{E1-B} is transmitted with symbol rate 250 symbols/sec.

Thus, the generated E1 Open Service signal is mathematically expressed as

$$S_{E1} = \frac{1}{\sqrt{2}} * (e_{E1-B}(t) * (\alpha SC_{E1-B,a}(t) + \beta SC_{E1-B,b}(t) - e_{E1-C}(t) * (\alpha SC_{E1-C,a}(t) - \beta SC_{E1-C,b}(t))) \quad (3)$$

$$\text{where, } SC_x(t) = sgn\left(\sin\left(2\pi R_{S,x}(t)\right)\right)$$

$$\alpha = \sqrt{\frac{10}{11}}, \beta = \sqrt{\frac{1}{11}}$$

$\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are chosen such as that the combined power of the $SC_{E1\_B,b}$ and the $SC_{E1\_C,b}$ sub carrier components equals 1/11 of the total power of $(e_{E1\_B} + e_{E1\_C})$ [4]. The CBOC subcarrier is formed by sum and difference of BOC (1,1) & BOC (6,1) and forms CBOC (+) & CBOC (-) waveforms. These waveforms are expressed as

$$S_{CBOC(+)}(t) = \alpha\, S_{BOC(1,1)}(t) + \beta\ S_{BOC(6,1)}(t) \quad (4)$$

$$S_{CBOC(-)}(t) = \alpha\, S_{BOC(1,1)}(t) - \beta\ S_{BOC(6,1)}(t) \quad (5)$$

Equation 4 & 5 shows the subcarrier components which are modulated with E1B and E1C components respectively. The waveform of one period of the sub-carrier $\alpha\, sc_{E1-B,a}$ (t) + $\beta\, sc_{E1-B,b}$ (t) of the E1-B signal component and the sub-carrier $\alpha\, sc_{E1-B,a}$ (t) - $\beta\, sc_{E1-B,b}$ (t) for the E1-C signal component are shown in Fig. 2.

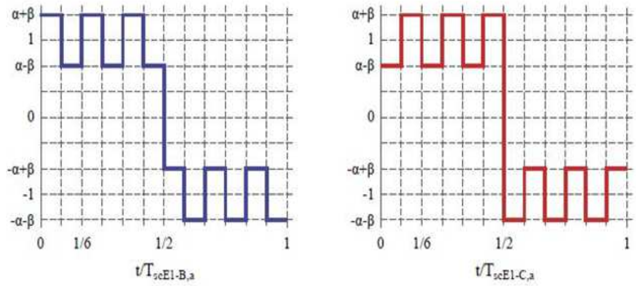


Fig. 2. one period for CBOC subcarrier for E1B component on left side and E1C component on right side [4]

Navigation message D_{E1-B} is combined with C_{E1-B} which includes clock timing, user position. Navigation messages are of 3 types F/Nav, I/Nav, C/Nav of which I/Nav is used by E1 signal for defining navigation message. This message structure includes pages, subframes, frames to indicate all parameters of each satellite as well as receiver information. I/Nav message structure is shown in Fig. 3. Galileo GNSS E1B and E5b signal uses same I/Nav message simultaneously. If E1B component takes even page part of I/Nav message in the same time synchronisation odd part of page is taken by E5b component.

The navigation message has a frame structure with a duration of 720 sec for each frame, it includes Almanac data of every satellite. These almanac data is embedded in the word type 8 and 9 of subframe structure. Each Frame of I/Nav message consists of 24 subframes where each subframe has different SVID information. Each subframe is of duration 30 sec which has information about different data types, OSNMA data, SAR data. Each subframe has 15 pages which may be nominal page or alert page. Nominal page of 128 bits has duration of 2 sec of which 1 sec duration to transmit even data and 1 sec duration to transmit odd data. The major role of navigation message is performed by page structure as it is the basic building block of frame structure. In each page of E1 OS message, 40bit information of OSNMA, 128bit information of datatypes, 22bits of SAR data and by performing cyclic redundancy check (CRC) on them will plays a role in finding the position of user. Every page ends with the tail bits 000000 i.e., six bit of zeros indicates the end of the page structure.

Navigation message starts with synchronization pattern of 10bits 0101100000 and ends with tail of 6 bits of zero padding i.e. 000000.

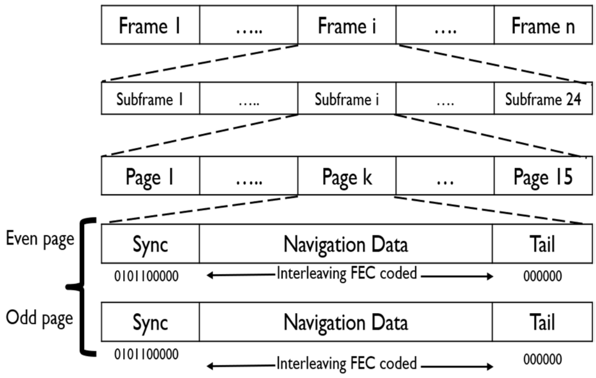


Fig. 3. I/NAV message structure

IV. ACQUISITION ALGORITHM

The process of searching the visible satellites to the receiver is called acquisition. Acquisition process is carried with the ranging codes which is unique for each satellite SVID is taken as the input at carrier frequency for acquiring visible satellites. Algorithm searches for visible SVID and correlates the CDMA code of satellite and receiver. If correlation is successful then satellite with particular SVID code gets detected else not gets detected. This process provides the doppler frequency deviation, delay of the received ranging codes.

Acquisition of Galileo system is carried out with parallel code phase search (PCPS) acquisition method which involves the parallelizing the code phase search. The block diagram of PCPS acquisition method is shown in Fig.4. From Fig.4 the incoming signal is multiplied with local oscillator signal to generate in-phase and quadrature signals. Combination of both signals is called complex signal converted to frequency domain using DFT. Simultaneously, PRN code is also converted into frequency domain using DFT which is a complex conjugate signal and both of these transformed signals are multiplied and converted to time domain using inverse Fourier transform and the absolute value of obtained result is the correlation between the input and PRN code.

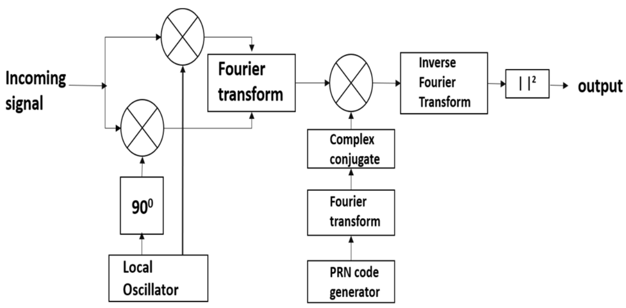


Fig. 4. parallel code phase search acquisition

The output of the acquisition method is plotted as peak spectrum using MATLAB. If peak is detected in the correlation spectrum indicates the satellite is visible and index of the peak marks the PRN code phase of incoming signal. If no peak detected there will be a noisy spectrum gets plotted indicates no satellite visible or satellite is not visible at a particular incoming signal.

A) Steps for Acquisition Algorithm

1. Define the satellite SVID to be visible to the antenna.
2. Perform the algorithm on defined SVIDs without any SNR, doppler frequency, signal delay.
3. Determine the random doppler frequency and signal delay for each satellite.
4. Consider SNR of 0dB initially for each satellite and perform algorithm. Observe and plot waveforms for all SVIDs.
5. Repeat step-4 by varying SNR by keeping doppler frequency, signal delay same as above.
6. Search for signal of satellite in both phase and frequency.
7. Detect the satellite signal and determine each of its phase and frequency.

B) Performance of developed acquisition algorithm using above steps.

Acquisition process starts with defining the SVID to be acquired. In this paper SVIDs of {8,12,19,27} are considered along with doppler deviation frequency of {1030,2080,2130,3190} Hz respectively and with signal delay of {2190,3190,2130,3190}sec respectively for each SVID. Along with that SNR is initially taken as 0dB and further varied from 0dB to -5dB, 10dB, -20dB, 28dB, -30dB.

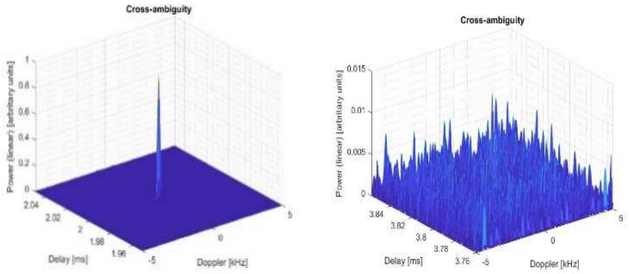
Performed developed algorithm on above SVIDs without any parameters and plotted waveforms in following sections. Then repeat the steps by considering above defined parameters and varying SNR.

By considering these parameters the PRN code of each SVID is correlated with the incoming signal to search the visible satellite. To plot the spectrum of visible satellite peak detection method is used with the threshold value of 2.2 for peak in the plot. The process involve in acquisition is Parallel code phase search (PCPS) method which correlates the Fourier transform of incoming signal with the Fourier transform of PRN signal and performing inverse Fourier transform on obtained signal to plot the spectrum of visible satellites. The whole procedure carried out according to the Fig. 4.

V. SIMULATION RESULTS

On performing the acquisition process, the results obtained are as follows:

Case-(i): Without considering the effect of SNR, signal delay, doppler effect Acquisition algorithm generates the waveforms for visible satellite and invisible satellite for the receiver as plotted in Fig. 5 as

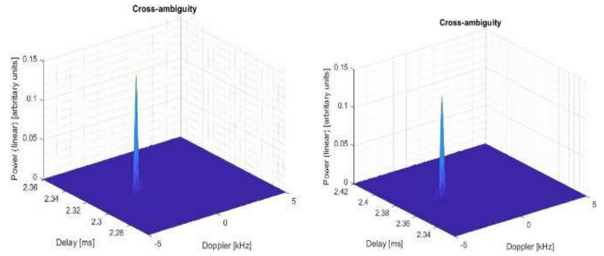


a) Satellite Visible b) Satellite invisible

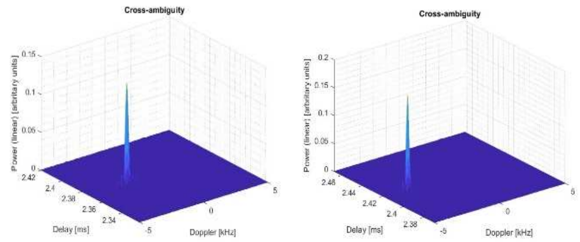
Fig. 5. CAF spectrum for visible and invisible satellite

Case-(ii): By considering the doppler frequency, signal delay parameter same and with varying SNR the Acquisition algorithm plots for defined satellites are as follows:

1. The spectrum of SVID {8,12,19,26} for SNR=0dB is shown in fig.6 a, b, c, d respectively.



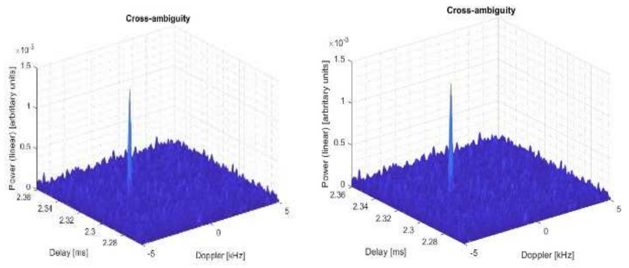
a) SNR=0dB SVID=8 b) SNR=0dB SVID=12



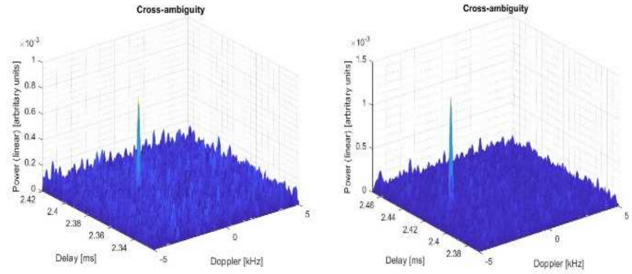
c) SNR=0dB SVID=19 d) SNR=0dB SVID=26

Fig. 6. CAF spectrum for SVID = {8,12,19,26} at SNR=0Db

2. The spectrum of SVID {8,12,19,26} for SNR= -28dB is shown in fig.7 a, b, c, d respectively.



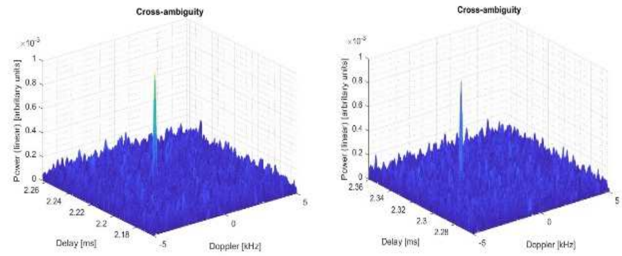
a) SNR=-28dB SVID=8 b) SNR=-28dB SVID=12



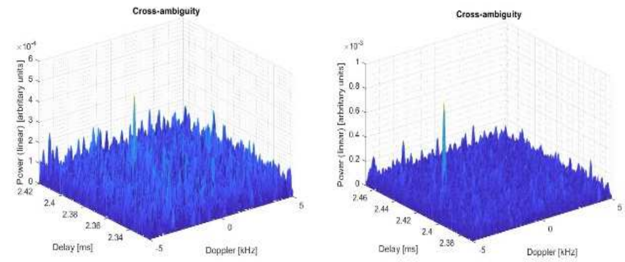
c) SNR=-28dB SVID=19 d) SNR=-28dB SVID=26

Fig. 7. CAF spectrum for SVID = {8,12,19,26}at SNR=-28dB

3. The spectrum of SVID {8,12,19,26} for SNR=30dB is shown in fig.8 a, b, c, d respectively.



a) SNR=-30dB SVID=8 b) SNR=-30dB SVID=12



c) SNR=-30dB SVID=19 d) SNR=-30dB SVID=26

Fig. 8. CAF spectrum for SVID = {8,12,19,26}at SNR=-30dB

Thus, the acquisition process is carried out with various SNR values on four SVIDs with doppler frequencies, signal delays by varying signal-to-noise ratio (SNR) values from 0 dB to -28dB.

With SNR=0dB, Fig.5 shows the CAF spectrum in which a peak is observed at correlated location on spectrum and the base part of spectrum is smooth indicates 0dB SNR.

With SNR=-28dB, Fig.6 shows the CAF spectrum in which a peak is observed at correlated location on spectrum which resembles the location for SNR=0dB but the base part of spectrum is noisy indicates there is certain value of SNR is taken.

With SNR=-300dB, Fig.7 shows the CAF spectrum in which a peak is observed at correlated location on spectrum which resembles the location for SNR=0dB and SNR=-28dB and base part of spectrum is noisy resembles spectrum of SNR=-28dB but at SNR=-30dB SVID=19 from fig. 7c indicates no satellite is visible but according to user define a peak to be detected. Such that SNR= -28dB is final considered limit for this acquisition algorithm.

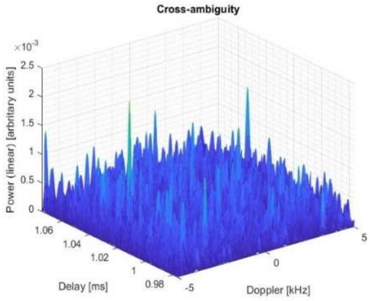


Fig. 9. CAF spectrum for no satellite is visible in acquisition process.

In case if no satellite gets visible to the receiver, then the CAF spectrum will appear as Fig.9. if no satellite is visible CAF spectrum has many peaks below the threshold value which is noisy spectrum indicates no satellite is available during the acquisition process.

VI. CONCLUSION

This paper mainly deals with the acquiring the visible Galileo satellites to the receiver by the method of PCPS which uses the Fourier transform for time domain to frequency domain conversion to perform correlation with the incoming signal. The Acquisition method used for detecting available satellites plots the peaks when satellite available as Fig.5 and Fig.7 else plots noisy structure as Fig.6 and Fig.8. This peak detection is done with the threshold point of 2.2 for SNR=-28dB whereas for SNR=0dB initially considered threshold point as 1.5 but on varying SNR, the threshold point = 2.2 is suitable for SNR ranging from 0dB to -28dB. In future, the tracking of acquired satellites is to be carried out.

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