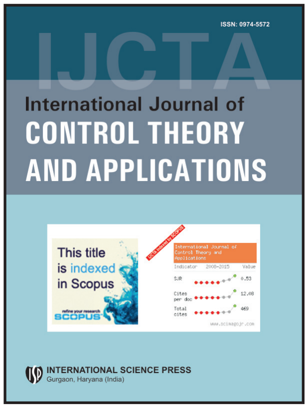

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Generation of Galileo 'E1 Signals' at Ground Station for Acquisition and Tracking

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Abstract: Galileo is the European global navigation satellite systems, providing a highly accurate position service under civilian control. It is inter-operable with Global Positioning systems (GPS) and Global Navigation Satellite Systems (GLONASS), the two other global satellite navigation systems. The design of the Galileo receiver depends on stimulation of Galileo signals. It is preferred to use stimulated signals than real signals to control the properties of Galileo receiver. Three independent satellite signals E5, E6 and E1 are transmitted by Galileo satellites. E1signals supports Open Service and hence, importance is given to generate these E1 signals using Simulink. Generation of E1 signals is necessary for the purpose of Acquisition and Tracking.

Keywords**:** BOC Modulation, E1 Signals, Galileo System, Ranging Codes.

1. INTRODUCTION

Galileo navigation systems consists of 30 satellites (27 operational + 3 spares), positioned in three circular Medium Earth Orbits (MEO) at an nominal average of about 29,601.297 km and at an inclination of about 56 degrees with respect to equatorial plane . The main aim of Galileo navigation systems is to provide a high precision positioning and improved provision for search and rescue services[1]. One of the biggest advantages of Galileo is that any satellite failures can be notified to the users within seconds, making the systems a reliable one. The services offered by Galileo navigation systems are Open Service (OS), Galileo Safety of Life (SoL), Commercial Service (CS), Public Related Service (PRS), Support to Search and Rescue Service (SAR). The European navigation satellite system Galileo is moving ahead. The open service signal L1 OS transmitted from the satellites is described[2]. Compared to GPS some new features are introduced: Binary offset carrier modulation, coherent adaptive sub-carrier modulation, pilot signals, and tiered codes. These features make the GPS and Galileo signals live together on the same frequencies, and they make Galileo signals in general more robust. The irony of BOC modulation is that it comes with two different variants Sine BOC modulation and Cosine BOC modulation. [3]aims to specify the differences between these two variants of BOC modulation by analyzing them over their spectral characteristics for different orders of BOC modulated signals which are traditionally used in the Civil Navigation and are still in use in many navigation systems. All the BOC variants taken are the actual ones used in navigation systems. Techniques for enhancing GNSS signal acquisition and tracking sensitivity and increasing the robustness and availability of position fixes are described in[4]. Specifically, a technique called Staggered Coherent Integration is proposed which enables up to 1 dB improvement in sensitivity compared to conventional techniques. Also discussed are challenges in tracking the weak signals seen in indoor conditions and techniques to improve sustained tracking under these conditions. Closed form expressions for GNSS-R waveform simulation using the composite GPS L1 and L5 and Galileo E1, E5, and E6 signals as function of the receiver bandwidth is given in[5]. Simulation of E1 and E6 signal using Simulink is shown in[6].

Composite Binary Offset Carrier (CBOC) modulation has been selected for the future Galileo signals to be used in mass-market applications. CBOC signals can be processed with a sine BOC (1,1) receiver, with lower bandwidth and sampling frequency needs. [7] Analyzes how much deterioration (if any) in terms of tracking accuracy (i.e., code tracking error variance and robustness to multipath) occurs when we process a CBOC signal with a reference sine BOC (1, 1) receiver (instead of processing it with a CBOC receiver). Software - Defined GPS and Galileo Receiver is provided in[8]. Galileo E5 and E6 signals are used for Commercial Service and Public Related Service whereas Galileo E1 signals used for Open Service and Safety of Life service and so, care is given to generate these E1 signals using Simulink.

2. CHARACTERISTICS OF E1 SIGNALS

In this paper, E1 signals are generated using Simulink. E1 signals is an open access signals E1 signals has unencrypted navigation data and ranging codes accessible to all users and also contains unencrypted integrity messages and encrypted commercial data. The Galileo E1-signal comprises of signal components E1-B and E1-C which is transmitted in the frequency band 1559 - 1610 MHz allocated to Radio Navigation Satellite Service (RNSS) on a worldwide co-primary basis (ITU-R Radio Regulations). The signal components E1-B and E1-C are data channel and pilot channel respectively. Data channel is the result of modulating ranging codes, sub carrier and secondary code along with a navigation data stream. A pilot channel is made of ranging code, sub carrier and secondary code only, but not modulated by a navigation data stream. The attributes of E1 signals are given in Table 1. Within 4ms period the signal to noise ratio (SNR) prevents the downloading of data for signals weaker than 25dB/Hz. The 4ms repetition rate is ideal because there is one symbol per code epoch. E1 signals are transmitted in right hand circular polarization with different ranging codes per signal component, per signal, per frequency and per Galileo satellites.

Table 1: Galileo E1 signal characteristics

Signal Attributes	*[E1-B]*	*[E1-C]*
Carrier Frequency	1575.42 MHz	
Bandwidth	24.552 MHz	
Sub Carrier Frequency	1.024 MHz 6.138 MHz	
Primary code length	4092 chips	
Secondary PRN code length	N/A	25 Chips
Code period	4 ms	100 ms
Symbol rate	250 sps	N/A
Modulation	Binary Offset Carrier (BOC)	

3. E1 SIGNAL GENERATION

A. Block Diagram for Generating E1 Signals

The block diagram of E1 signal generation is shown in Figure 1. The E1 signal is simply the product of carrier, spreading code, BOC and Data Components. Navigation data (i.e) data components are applicable only for E1-B.

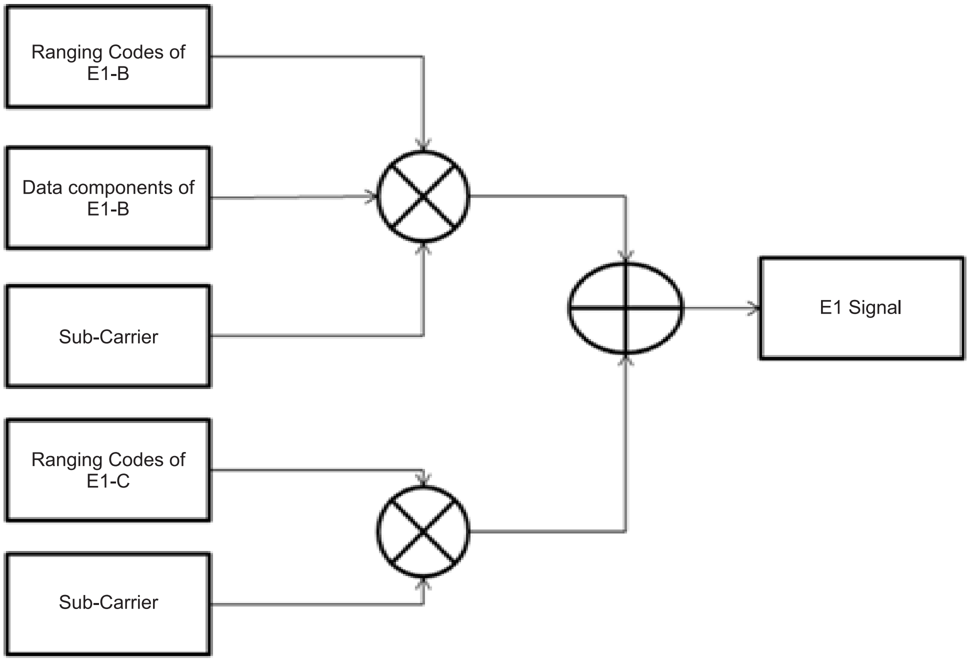
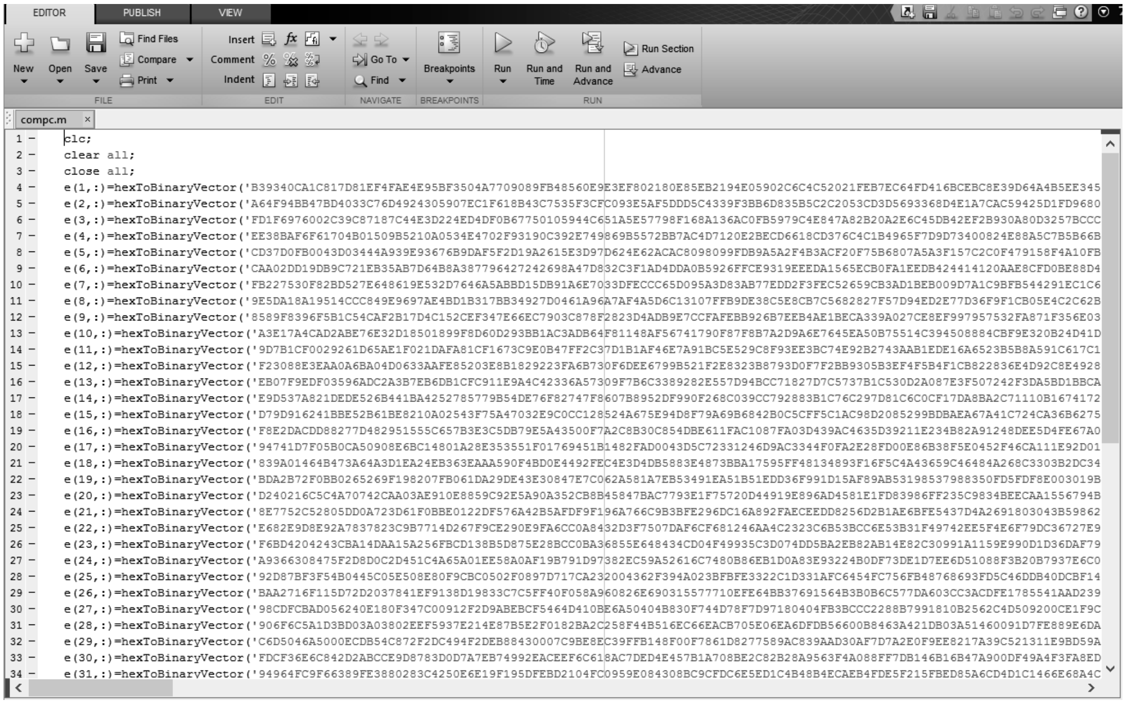


Figure 1: Block diagram of E1 signal generation



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clear all;
close all;
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e(22,:)=hexToBinaryVector('E682E9D8E92A7837823C9B7714D267F9CE290E9FA6CC0A8432D3F7507DAF6CF681246AA4C2323C6B53BCC6E53B31F49742EE5F4E6F79DC36727E9
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e(24,:)=hexToBinaryVector('A9366308475F2D8D0C2D451C4A65A01EE58A0AF19B791D97382EC59A52616C7480B86EB1D0A83E93224B0DF73DE1D7EE6D51088F3B20B7937E6C0
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Figure 2: Conversion of memory codes from hexadecimal to binary form

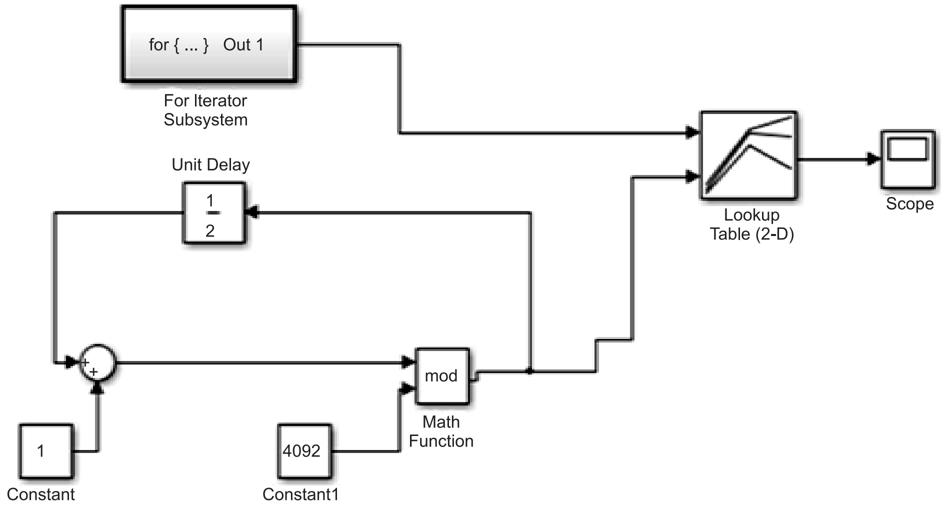

Figure 3: Simulink model for generating ranging codes for E1-B

B. Ranging Codes for E1-B

Ranging codes are used to generate Code division Multiple Access codification for all Galileo signals. Each signal will be assigned to one ranging code with different parameters which depends on their length, chip rate and symbol rate. Ranging codes can be implemented either by 'memory codes' or 'register based codes'. Memory Codes are also called ' pseudo noise sequences ' which are pre-defined codes. These codes are constructed to have very good characteristics on correlation. There are about fifty memory codes in hexadecimal notations. These memory codes are converted in to binary bits using Matlab language. A special function 'hexToBinaryVector' is used to convert these hexadecimal notations in to binary form. Conversion of single memory codes from hexadecimal to binary results in generation of 4092 chips. The converted memory codes are stored in 'look-up' table. 'For loop' is used since fifty codes are needed to be processed. 'Unit delay' is been implemented in order to avoid unwanted noise in the output. Generated ranging codes are visualized using 'scope'. The generated ranging codes of E1-B is shown in Figure 4.

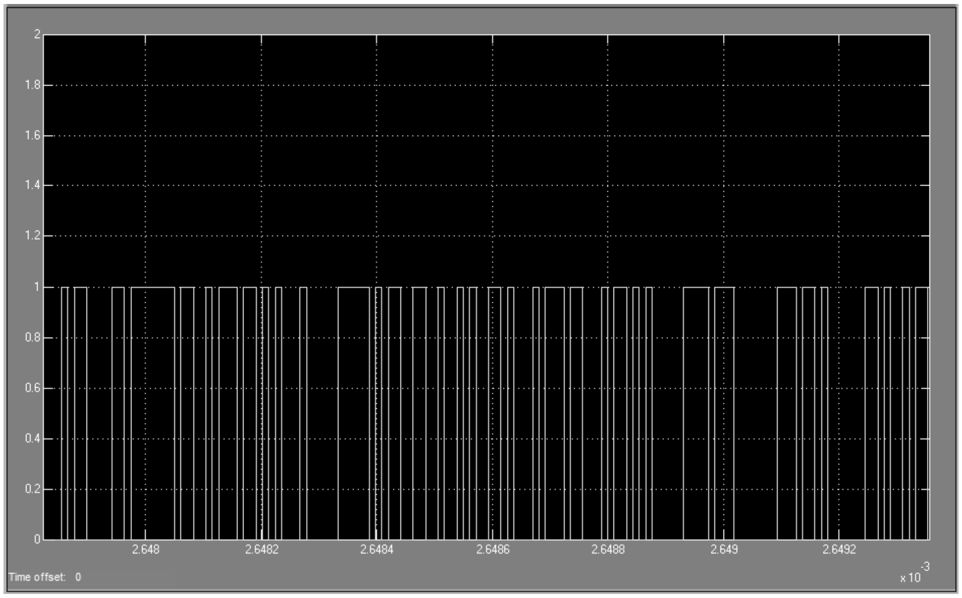

Figure 4: Generated Ranging codes of E1-B

C. Data Components for E1-B

The random values are generated by using "randn" function which is used to generated normally distributed Pseudo random (PN) numbers. 'Sign' conversion block generates output 1 for positive input and output 1 for negative input. Then the bits are converted in to frame using 'frame conversion' block. The converted bits must be over sampled for 368280 times using ' Repeat 'block. Transpose block is introduced to transpose an input vector signals. The generated output is displayed in ' Time vs Amplitude'. The Simulink model of E1-B is shown in Figure 5 and the generated data component is shown in Figure 6.

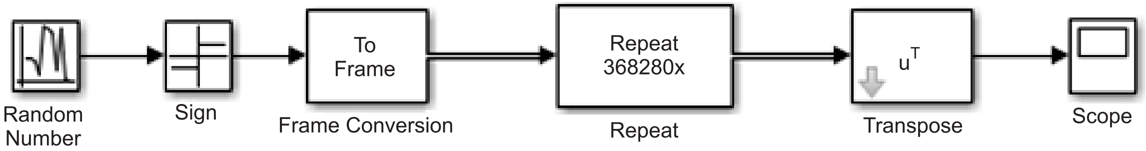

Figure 5: Simulink model for generating data components for E1-B

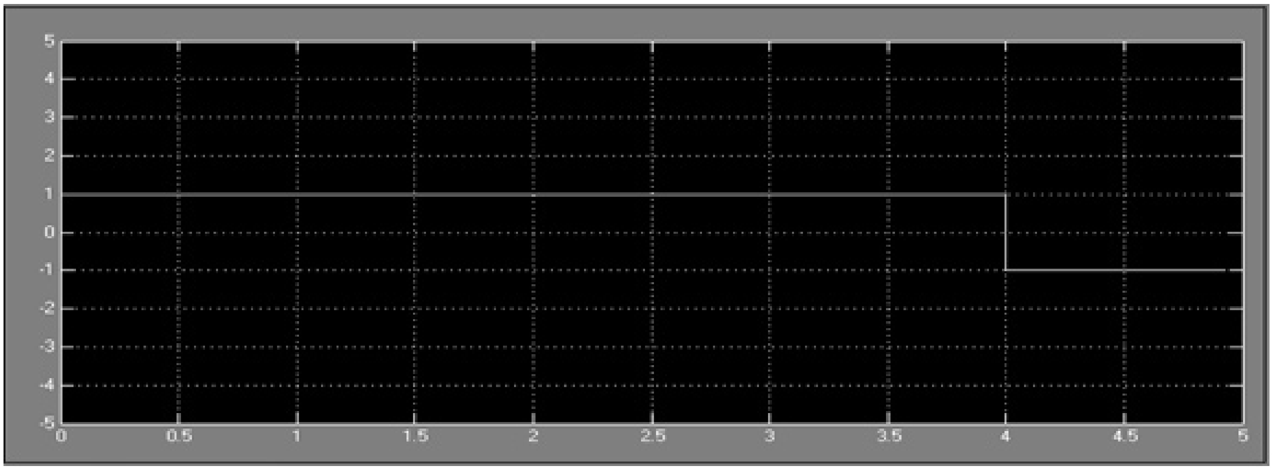

Figure 6: Generated Data components

D. Ranging Codes for E1-C

For E1-C, ranging codes has both primary codes and secondary codes. Both these codes are in hexadecimal notations. Primary codes have 4092 chips with the duration of 4ms and secondary codes have 25 chips with the duration of 100 ms. Thus, generating ranging codes of E1-C is as similar to the code generation of E1-B. Fifty memory codes along with one secondary code are converted in binary using 'hexToBinaryVector' as shown in Figure 2. Converted codes are assigned to a variable and stored in '.mat' format. Thus ranging codes are generated by providing assigned variable as table contents in 'look-up' table. Thus ranging codes of E1-C is visualized as in Figure 7.

E. Sub Carrier Modulation

A sub-carrier is a sideband of radio carrier wave which is modulated to send additional information. BOC modulation is used to modulate Sub-carrier. BOC Modulation is used to add additional signals that have the same carrier frequency in to the radio frequency band without interfering with other signals. BOC Modulation is identified as BOC(m, n). The two independent parameters m and n are used to concentrate the signal power in to specific parts of the system to reduce interference with other signals. The parameter m stands for the ratio of the sub-carrier frequency (f_s) and reference frequency ($f_o = 1.023$ MHz), n stands for ratio of the code rate (f_c) and reference frequency. Thus m and n are identified as:

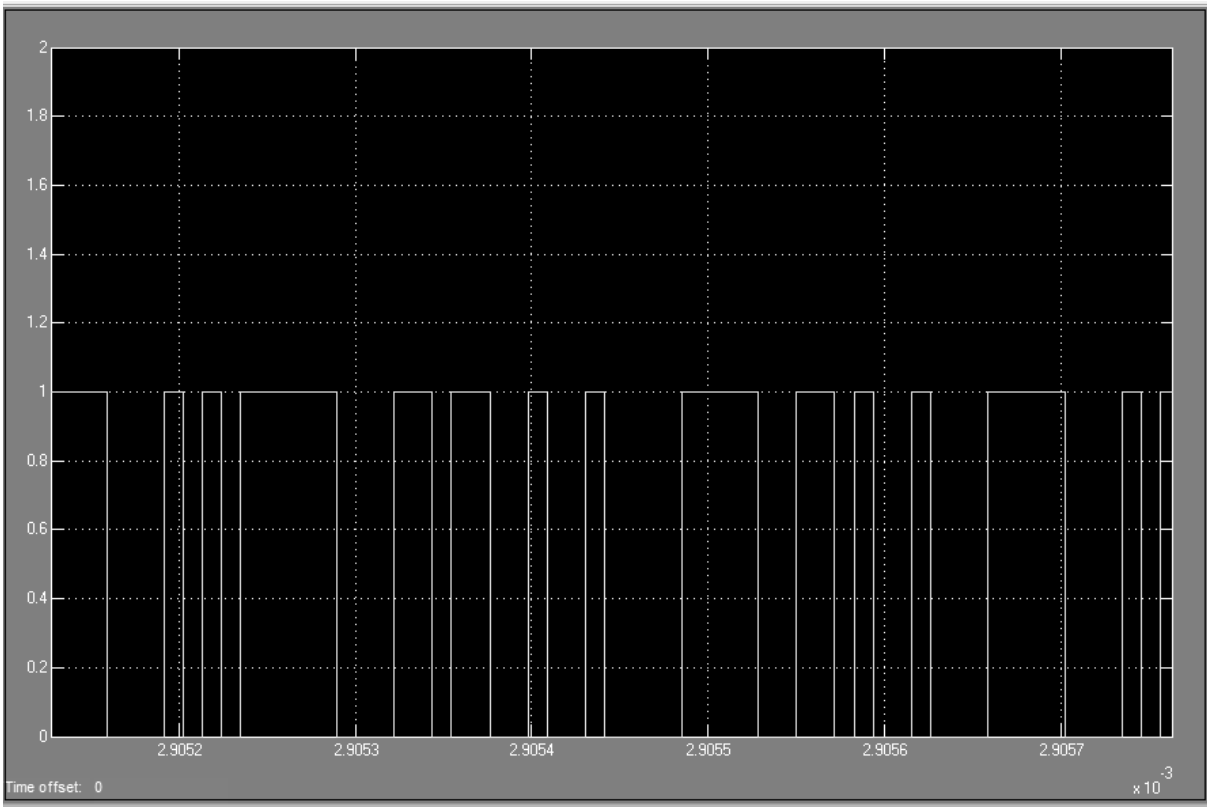

Figure 7: Generated Ranging Codes of E1-C

$$m = \frac{f_s}{f_o}, \quad n = \frac{f_c}{f_o} \tag{1}$$

The Galileo E1 signals has two sub-carrier frequencies which is 1.023 MHz and 6.138 MHz. Thus, BOC(1, 1) has sub-carrier frequency of 1.023 MHz and chipping rate of 1.023 Mcps, and BOC(6, 1) has sub-carrier frequency of 6.138 MHz and chipping rate of 1.023 Mcps.

BOC(1, 1) and BOC(6, 1) is given as

$$\text{BOC sin}(1, 1) = \sin(2 \times pi \times f_{sa} \times t), \tag{2}$$

$$\text{BOC sin}(6, 1) = \sin(2 \times pi \times f_{sb} \times t), \tag{3}$$

where, $f_{sa} = 1.023 \times 10^6$ and $f_{sb} = 6 \times 1.023 \times 10^6$.

The sub carrier parameter is defined as sc_a and sc_b which is given as

$$sc_a = \text{sign(BOC sin(1, 1))}, \tag{4}$$

$$sc_b = \text{sign(BOC sin(6, 1))}, \tag{5}$$

The sub carrier channel for E1-B and E1-C component is defined as

$$sc\text{B} = (\text{alfa} \times sc_a) + (\text{beta} \times sc_b), \tag{6}$$

$$sc\text{C} = (\text{alfa} \times sc_a) - (\text{beta} \times sc_b), \tag{7}$$

where, alfa = $\sqrt{\frac{10}{11}}$ and beta = $\sqrt{\frac{1}{11}}$

From the equation (6) and (7), *sc*B and *sc*C are implemented in Simulink and shown in Figure 8. The Simulink model of the subcarrier components of E1-C is shown in Figure 9 and the generated BOC subcarrier scB and scC is shown in Figure 10 and Figure 11.

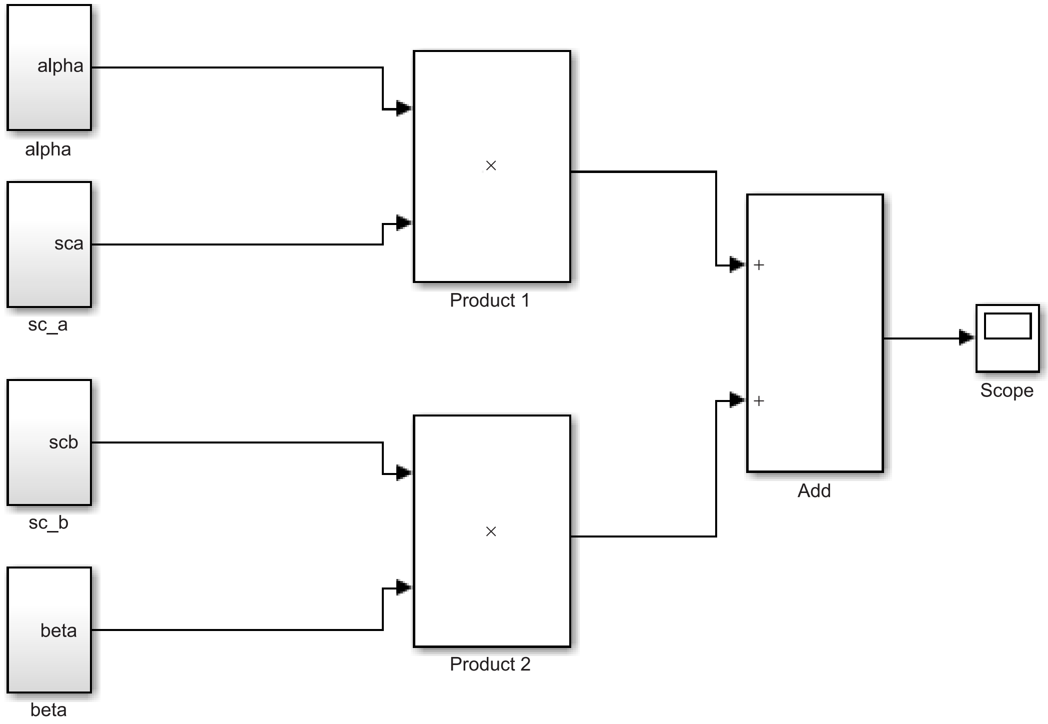

Figure 8: Simulink model for Sub Carrier of Component E1-B

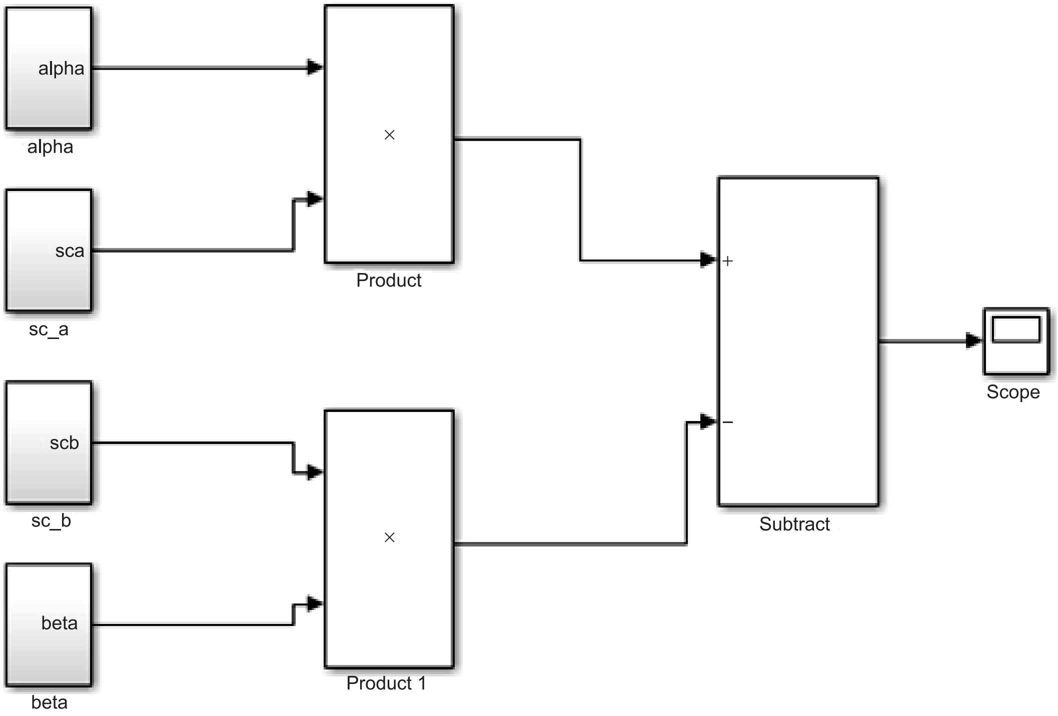

Figure 9: Simulink model for Sub Carrier of component E1-C

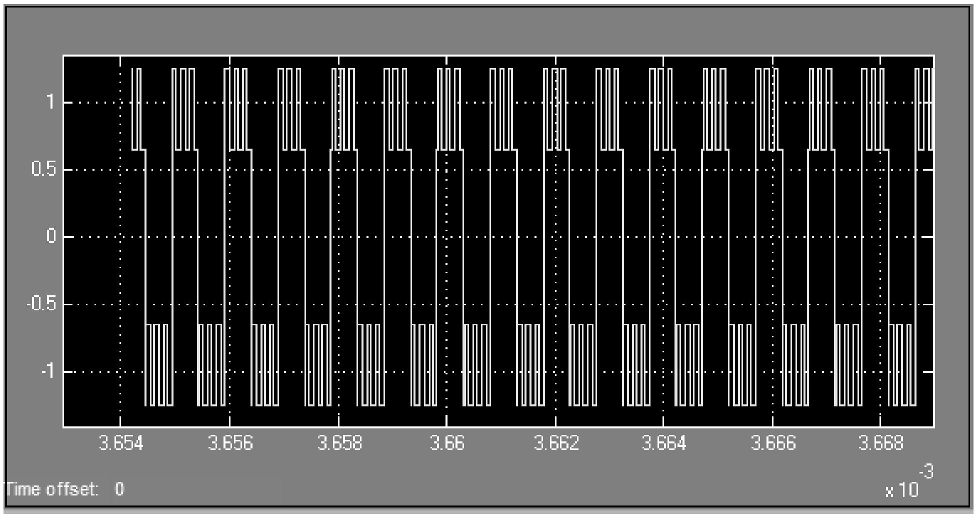

Figure 10: Generated output of Sub-Carrier (scB)

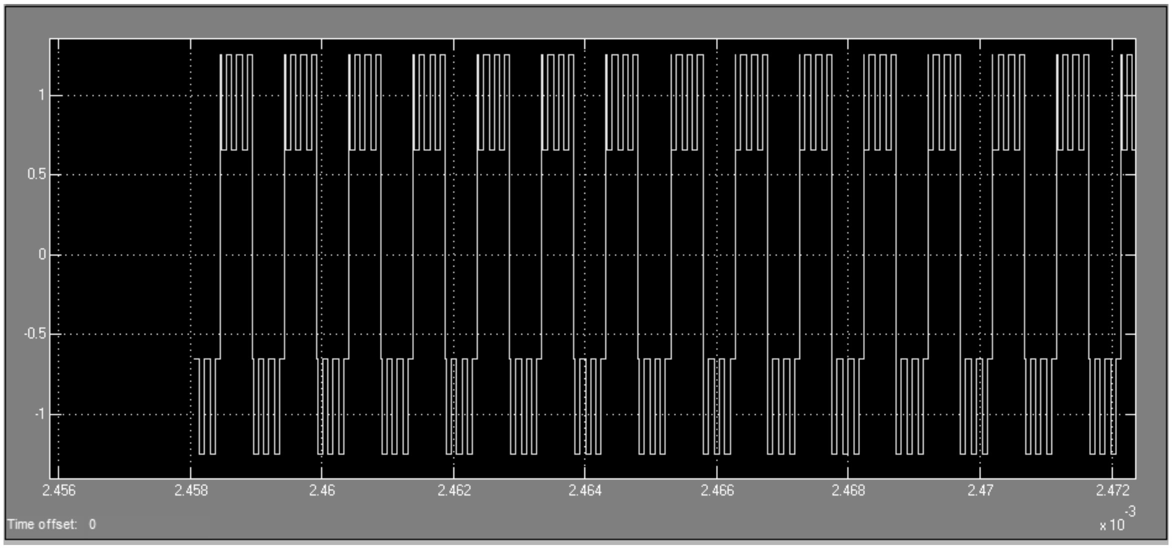

Figure 11: Generated output of Sub-Carrier (scC)

F. Galileo E1 Signal

Ranging codes of E1-B, Data components of E1-B, Sub-carrier modulation and ranging codes of E1-C are processed to generate E1 signals. These locally generated signals are used for the purpose of acquisition and tracking. Ranging codes of E1-B, data components of E1-B are multiplied. The resulting output is been multiplied with Sub Carrier component of E1-B. On the other side, Ranging codes of E1-C and the Sub Carrier of component E1-C are multiplied. These two outputs are subtracted and then multiplied with the constant value of about 0.7071. The resulting output would be E1 signals. The minimum bandwidth is generally twice the chipping rate for simple codes, while for BOC codes it's twice the sum of chipping rate and code rate. Thus the minimum practical bandwidth is 8MHz. Higher chipping rate provide more accuracy. E1 signal is expected to guarantee a horizontal accuracy better than 50 cm/s and a timing accuracy better than 100ns. BOC modulation splits the spectrum in to two main lobes centered at sub carrier frequency around the carrier frequency. Center peaks are located at ±1.023 MHz and the side peaks are located on ±6.138 MHz. The simulink model for the generation of E1 signal is shown in Figure 12 and the generated Galileo E1 signal is shown in Figure 13.

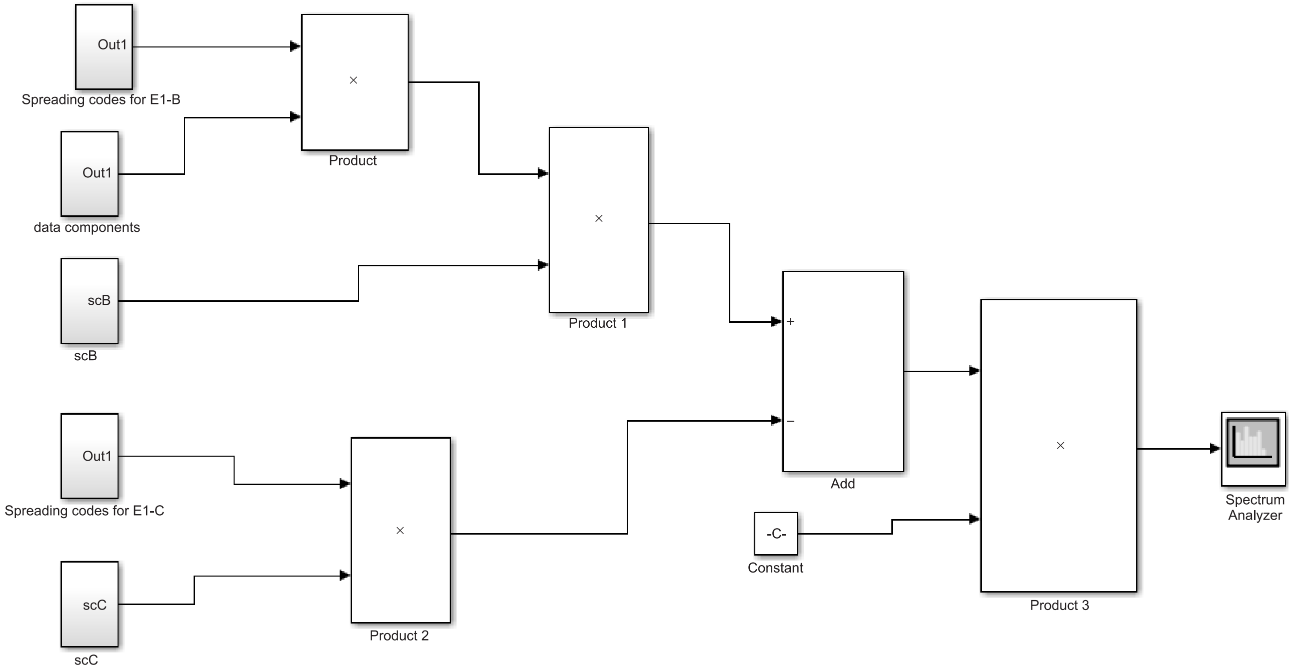

Figure 12: Simulink model for generation of E1 signals

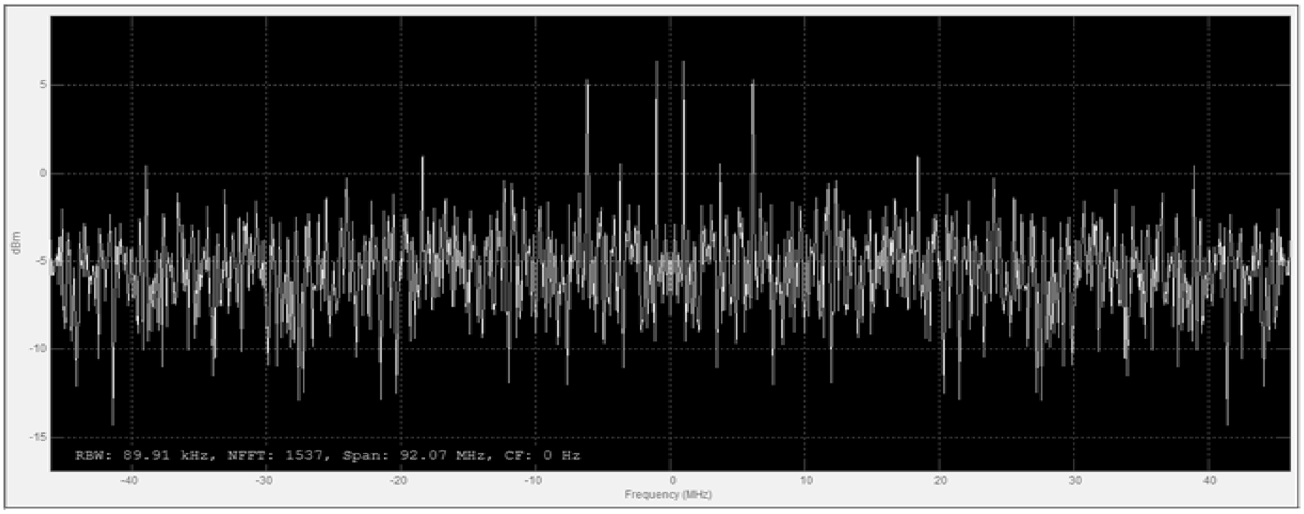

Figure 13: Generated Galileo E1 Signals

4. CONCLUSION

In this paper,

- Ranging code of both E1-B and E1-C are generated by means of memory codes.
- The data components are generated by normally distrubuted Pseudo random (PN) numbers .
- BOC modulation is the result of multiplexing narrowband signals BOC (1, 1) with wide band signals BOC (6, 1).

These process are combined together in order to generate E1 signals for Galileo Navigation systems. The whole process is carried out with the help of Simulink.

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