Simulation and Analysis of Binary Offset Carrier Modulation for Modernized Global Navigation Satellite Systems

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ABSTRACT

Global Navigation Satellite System (GNSS) is a specific term for any satellite navigation system that provides autonomous geo-spatial positioning with global coverage. At present, United states Global Positioning System (GPS) is the only fully functional and available global navigation system. The advent of GPS has revolutionized the field of navigation particularly the field of civil aviation sector. The GPS is a reliable, all weather satellite based radio navigation system that provides accurate three dimensional (3D) navigation solution i.e., position, velocity and timing information, up to 10^{-6} seconds anywhere on or above the earth's surface .Due to increased demand in the field of navigation, several countries started to develop or modernize their own navigational systems. For instance, European Union is developing GAGILEO, the Russian GLONASS is under maintenance phase and China is developing COMPASS to meet its navigational requirements. To provide interoperability with GPS and globally available navigational systems, new modulation schemes are introduced. One such modulation technique is Binary Offset Carrier (BOC) modulation which provides better accuracy than the existing BPSK modulation techniques GPS. This paper presents the generation of BOC signal and comparison of the BOC modulated signals with BPSK modulated signal in the context of GPS.

Keywords: Auto correlation, Pseudo Random Number (PRN) code, Spread Spectrum

I. INTRODUCTION

Global Positioning System is a satellite based navigation system developed by US Department of Defense (DoD) to provide user with his position, velocity and time. It consists of Space segment, Control segment and User segment. GPS Space segment constellation consists of minimum of 24 satellites (Parkinson 1996) that provides users with users with continuous, worldwide positioning capability using the data transmitted in the GPS navigation message.GPS Provides service to unlimited number of users since the user receivers operate passively. The system utilizes the concept of one-way time of arrival (TOA) ranging. The satellites broadcast ranging codes and navigation data on two frequencies c using Code Division Multiple Access (CDMA),that is ,there are only two frequencies in use by the system, called L1(1575.42MHz) and L2(1227.6MHz). Each Satellite transmits on these two frequencies, but with different ranging codes than those employed by other satellites. The PRN codes are selected in such a way that they have low cross-correlation properties with respect to each one another. Each satellite generates a short code called as Coarse/Aquision or C/A code which has a bit rate of 1.023 Mbps and a long code denoted as Precision or P code with a bit rate of 10.23Mbps. The navigation data provides the means for the receiver to determine the location of the satellite at the time of signal transmission and the ranging codes enable the receiver to determine the transit time. Based on the satellite position and the transit time, Receiver location can be computed at any instant of Time.

II. GPS C/A CODE SIGNAL GENERATION

GPS is a spread spectrum system, where the spread signal occupies a bandwidth, much greater than the rate of the data being transmitted [Spiklar 1988]. This redundancy of bandwidth serves to suppress detrimental effects of interfering signals and reduces the peak transmitted signal power levels to effectively hide the signal in background noise. The spreading technique denoted, Direct Sequence-Spread Spectrum (DS-SS), refers to technique where a carrier wave is modulated by a data signal overlaid with a high frequency Pseudo-Random Noise (PRN) spreading signal [1].

The novelty of the GPS is the usage of PRN code sequence as a ranging signal. In combination with data signal this recovers the path difference from transmitter to receiver. The GPS satellite signals share the same carrier frequency and are separable at receiver end only because each respective satellite transmission employs a unique PRN spreading code. Each bit of the PRN code sequence is called a 'chip'. The navigational or ranging signal is effectively a sequence of periodic pulses, with a periodicity equal to the code length and pulse width of one chip, despite the fact that GPS is a code modulation of a continuous wave (CW) carrier. The range to each differently located GPS satellite is measured by the timing of these pulses and comparing the relative time delay of the pulses enables three-dimensional navigation[[2].

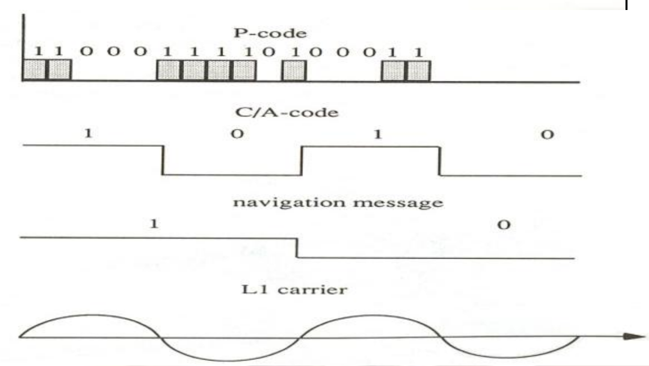


Fig. 1 Schematic of GPS signal components on L1 Carrier frequency

GPS uses Binary Phase Shift Keyed (BPSK) modulation [3], where the carrier phase changes instantaneously by 180°, depending on the data modulated spreading sequence.
The schematic of GPS signal components transmitted on L1 carrier frequency are shown in Fig.1

Signal analysis is paramount importance in GPS to study the two important properties of the signal that are Auto correlation and power spectral density. In this paper presents the generation of C/A GPS Signal on L1 frequency using BPSK modulation .The signal characteristics of the generated C/A GPS signal are also Analyzed.

The GPS C/A code is a Gold code with a sequence length of 1023 chips. As the chipping rate of the C/A code is 1,023MHz, the repetition period PRN sequence is 1ms.This C/A code is modulo -2 added with the navigation data of 50Hz frequency. The resultant signal is BPSK modulated using the L1 carrier frequency (1575.42MHz) to generate the C/A GPS signal. The C/A GPS signal generation architecture is shown in Fig. 2.

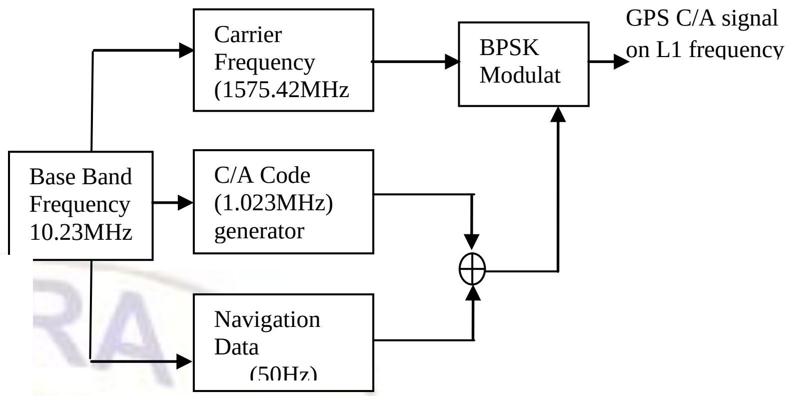


Fig. 2 Block diagram of GPS C/A signal generator

The BPSK modulated C/A signal transmitted by each GPS satellite *k* at an epoch *t on* L1 frequency is represented as:

$$S^k = Ac(C(t) \oplus D(t))\cos(2\pi f_1 t + \phi) \qquad (1)$$

Where S^k is the k^{th} GPS satellite transmitted signal

Ac is the amplitude of the C/A code

$C(t)$ is ±1 indicates the phase of the C/A code

$D(t)$ is ±1 indicates the phase of the data signal

f_1 is L1 frequency(1575.42Mhz)

ϕ is the initial phase

The schematic of GPS signal components transmitted on L1 frequency are shown in Fig. 2

The Spreading modulation for the legacy civil signal at 1575.42MHz, the GPS C/A Code is based on binary phase shift Keyed signal with rectangular pulse shape and spreading code chip rate of 1.023MHz,denoted as BPSK. Although very good performance can be obtained with the C/A code signal , it has been recognized that better performance can be obtained using spreading modulation that provide more power at the higher frequencies away from the centre frequency. Binary Offset Carrier (BOC) spreading modulation is one such technique to accomplish more power at higher frequencies away from center . As high powers are available in BOC modulation scheme, modernization of the GPS which requires the interoperability recommends new modulation techniques such as Binary Offset Carrier (BOC) modulation schemes[4]. Hence in this paper, Power spectral density and autocorrelation of different BOC modulation schemes are analyzed and compared with the BPSK .

III. BINARY OFFSET CARRIER (BOC) MODULATION

Binary Offset Carrier (BOC) describes a class of spread-spectrum modulations recently introduced for the next generation of Global Navigation Satellite Systems (GNSS). Indeed, modernized GPS and the European Galileo system will use BOC (or BOC-based) signals on different carriers and with different parameters, to enable ranging. The main reasons for creating BOC signals were on one hand, the need to improve traditional GNSS signals properties for better resistance to multipath, interferences of all kinds and receiver noise, and on the other hand, the need for improved spectral sharing of the allocated bandwidth with existing signals or future signals of the same class[5].

A BOC-modulated signal consists of a sinusoidal carrier, a sub-carrier, a pseudo-random noise (PRN) spreading code and a data sequence. The BOC signal is the product in the time domain of these components. The BOC signal is actually an extension of the Binary Phase Shift Keying (BPSK) modulation where all BOC components are present except for the sub-carrier[6]. Both sub-carrier and spreading code are binary-valued, which corresponds to the most simple option for the spreading sequence.

Hence the two independent design parameters of BOC modulation are:

- Subcarrier frequency (f_s)
- Spreading code rate or PRN code (f_c).

These two components provide freedom to concentrate signal power within specific parts of the allocated band to reduce interference with the reception of other signals.

GNSS satellites have an atomic clock on-board with a nominal reference frequency f_0 i.e.1.023MHz, from which all components of the generated navigation signals are derived. In the case of the BOC signal, the carrier frequency, the sub-carrier frequency f_s and the PRN code rate f_c are chosen as multiples of f_0.

$$f_s = m.f_0,$$
$$f_c = n.f_0. \quad (2)$$

Hence it is called as BOC (m, n) modulation and for the sake of simplicity m and n are always considered as natural integers.

As the BOC modulation is a square subcarrier modulation where a signal s*(t)* is multiplied by a rectangular subcarrier of frequency *fsc*, which splits the spectrum of the signal into two parts[7]. Formally, the BOC-modulated signal $s_{BOC}(t)$ can be written as

$$s_{boc}(t) = s(t) * sign(\sin(2\pi f_{sc} t)) \quad (3)$$

In BOC modulation the number BOC samples per chip are represented by N_{BOC} factor which is defined as

$$N_{BOC} = 2\frac{f_s}{f_c} \quad (4)$$

Fig. 3 shows the method of generating the BOC(10,5) modulated GPS Signal. The BOC (10,5) modulated signal is generated using the subcarrier frequency of 10.11MHz and the PRN code of 5.11Mbps. Both the subcarrier frequency and C/A code are generated using the GPS fundamental frequency of 1,023MHz

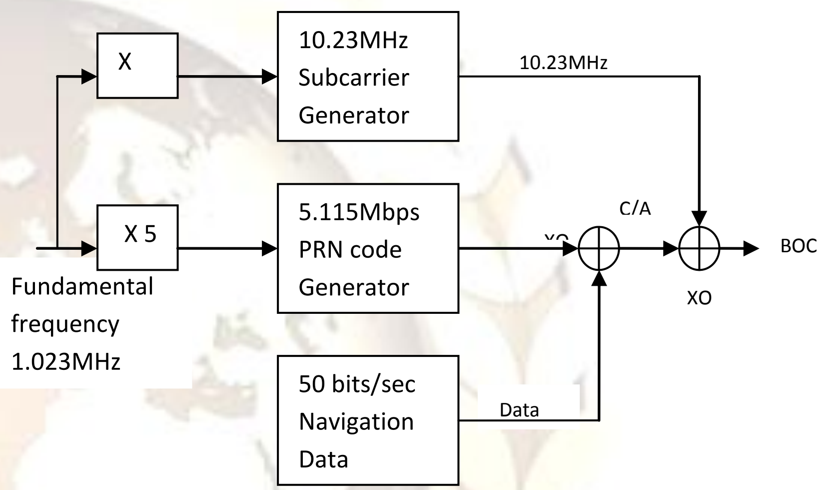


Fig. 3 Block diagram of GPS C/A signal generator using BOC Modulation

In order to carry out the analysis, GPS transmitter and GPS receiver are simulated using the matlab. Signals of five satellites are generated using the Transmitter setup shown in Fig. 4 and their properties at the receiver end are studied using the setup shown in Fig. 5

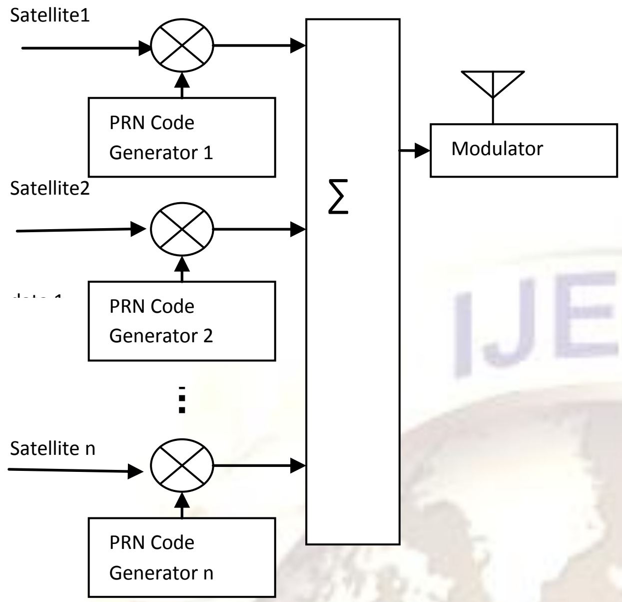


Figure 4 Simulation setup of GPS Transmitter

To generate the GPS signal of each satellite, PRN code of each satellite is generated to generate C/A code signal of the satellite and P-code of the satellite. All the satellite signals are multiplexed and then modulated.

PRN code of five satellites are generated using the matlab code. These PRN codes are modulated using 50 bit navigation data and the carrier frequency i.e.1575.42MHz .The generated GPS signals of five satellites are multiplexed and transmitted.

At the receiver side considering the ideal conditions, after demodulating the signal, each of the satellites signal is reconstructed using the matched filter and the corresponding PRN code of the satellite.

Using the reconstructed satellite signal, the signal properties such as power spectral density and autocorrelation can be analyzed

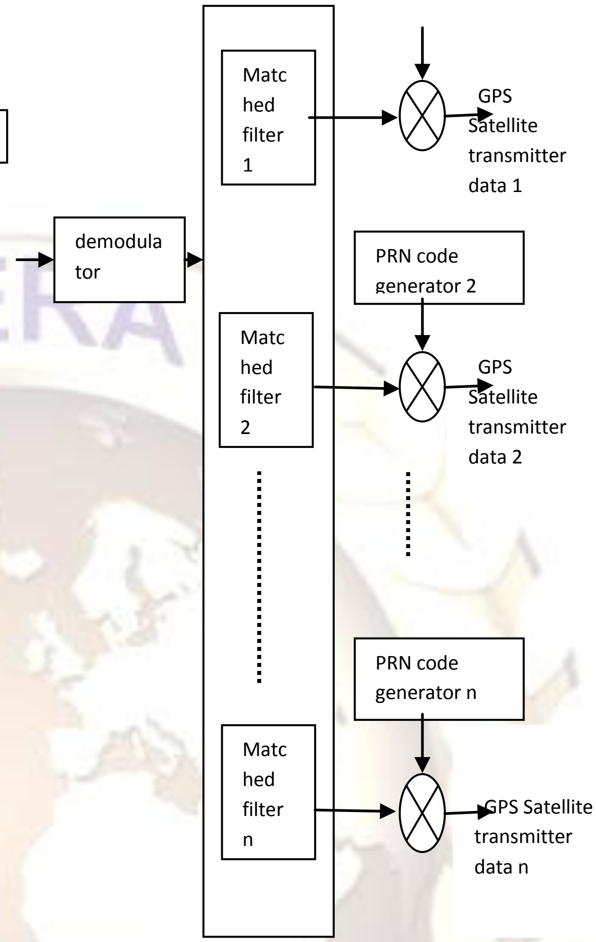


Figure 5 Simulation setup of GPS Receiver

IV. RESULTS

In this paper, GPS C/A code signal is generated using BPSK Modulation technique and BOC modulation. Correlation properties i.e. auto correlation and power spectral density, of the signal are analyzed for both modulation techniques. The results are presented separately for BPSK modulated C/A GPS signal and BOC modulated C/A GPS signal.

Generation of Legacy C/A GPS signal

To generate the C/A GPS signal on L1 carrier frequency, 1023 bit length C/A code which is a 1.023MHz PRN code, 50 Hz navigation data are generated along with the 1575.42MHz sine wave carrier. The length of the C/A code is 1023 bits and is generated by using the Gold codes.

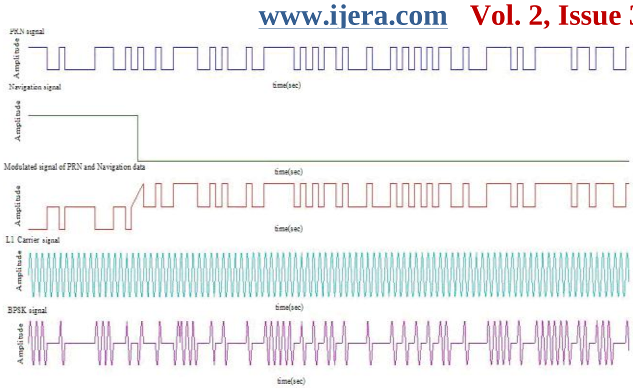


Figure 6 GPS C/A signal generated by the BPSK modulation

To generate 1023-bit C/A Code, two 10-bit feedback shift registers G1, G2 with unique polynomials are used. The Polynomial used for G1 shift register is $x^{\wedge}10 + x^{\wedge}3 + 1$ and for G2 register the polynomial used is $: x^{\wedge}10 + x^{\wedge}9 + x^{\wedge}8 + x^{\wedge}6 + x^{\wedge}3 + x^{\wedge}2 + 1$. By combining the bits of these two registers in parallel 1023 bit length C/A code is generated.

This C/A code is modulo-2 added with 50 Hz navigation data and the resultant data is given as one of the input to the BPSK Modulator. The other input of the BPSK modulator is 1575.42MHz carrier frequency. The required C/A GPS signal is obtained from the output of the BPSK modulator. Fig. 6 represents the GPS C/A signal generated by the BPSK modulation using MATLAB.

Generation of C/A GPS signal using BOC modulation: In order to generate the C/A GPS signal with BOC modulation, along with the carrier, navigation data and 1.023MHz PRN code , a sub carrier frequency is required .Selection of the sub carrier frequency is based on the type of BOC modulation Technique and the PRN code frequency. In this paper, as the BOC (1,1) modulation scheme is used, the subcarrier frequency used is 1.023MHz .The PRN code or spreading code is modulo-2 added with navigation data, the resultant data is in turn modulo-2 added with 1.023MHz sub-carrier frequency. The resultant signal is the Binary Offset Carrier modulated C/A GPS signal.

Power spectral Density: Power spectral densities of the legacy GPS C/A signal and different BOC modulation schemes are analyzed and compared.
Fig. 8 shows the representation of Power spectral density of BOC(1,1) modulated GPS Signal and Legacy GPS signal

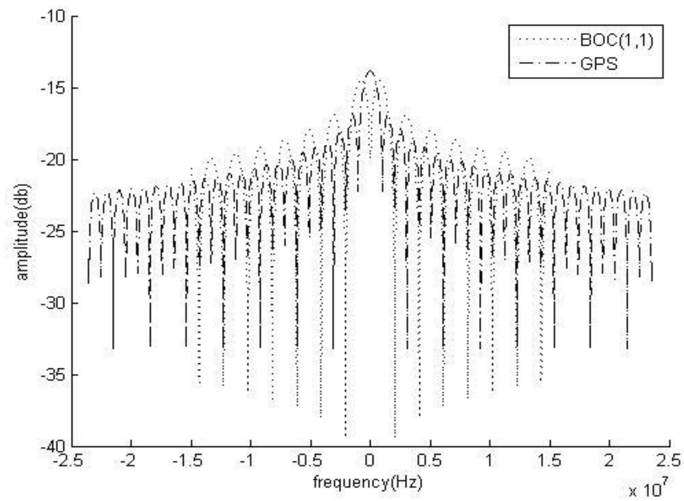


Figure 7 BOC modulated C/A GPS Signal

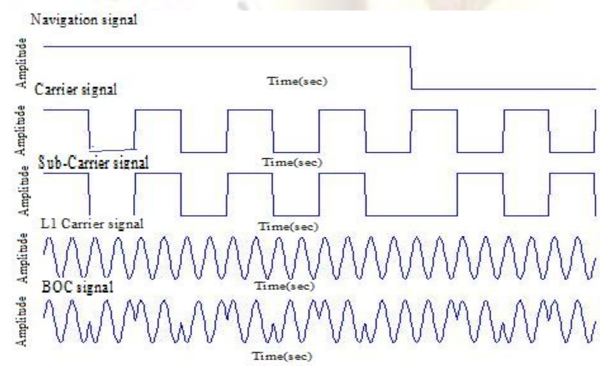


Figure 8 Power spectral density of BOC modulated GPS Signal and Legacy GPS signal

It is clear from the Fig.8 that BOC modulation provides better power at higher frequencies away from the center frequency. The maximum power of legacy GPS signal away from center is -18db and for BOC modulation ,maximum power is -15db which is obtained due to split at the center frequency.

In the similar way BOC (10,5) modulated GPS signal and BOC(15,2.5) modulated GPS signal are also generated and their power spectral densities are also analysed. Fig.9 represents the Power spectral densities of BOC(10,5) and legacy GPS signal. The maximum power of legacy GPS signal away from center is -18db and for BOC modulation , maximum power is -14db which is obtained 10MHz away from the center frequency.

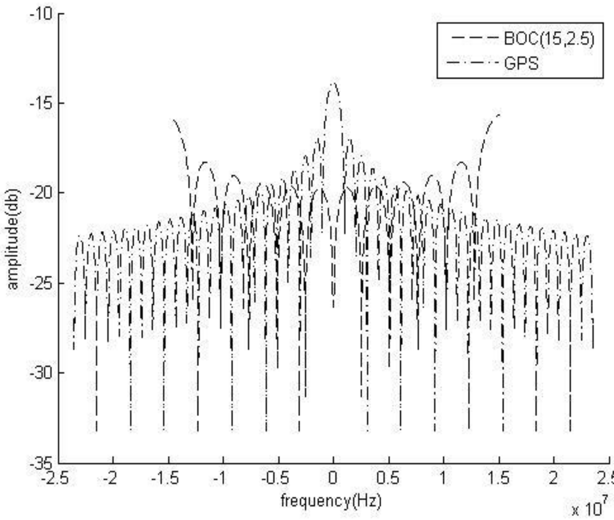
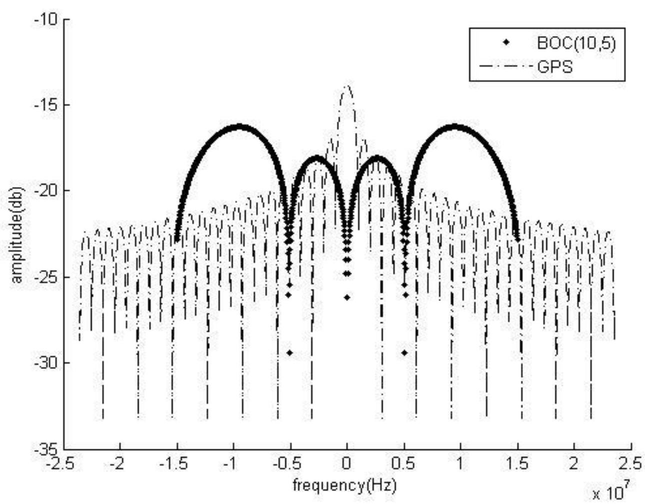


Figure 9 Power spectral density of BOC(10,5)



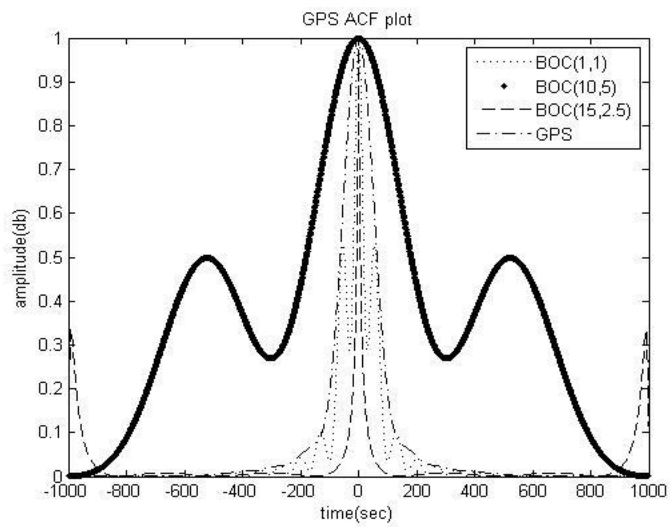
modulated GPS Signal and Legacy GPS signal

Figure 10 Power spectral density of BOC(15,2.5) modulated GPS Signal and Legacy GPS signal

Fig.10 represents the Power spectral densities of BOC(15,2.5) and legacy GPS signal. The maximum power of legacy GPS signal away from center is -18db and for BOC modulation, maximum power is approximately -15db which is obtained 15MHz away from the center frequency.

From this comparison, it is evident that BOC Modulation provides better powers at higher frequencies than the Legacy GPS signal and hence implementation of BOC modulation provides better interoperability for various GNSS systems.

Auto Correlation: Autocorrelation of the legacy GPS C/A signal and different BOC modulation schemes are analyzed and compared. In this BOC(15,2.5) provides



better autocorrelation properties than other BOC(1,1),BOC(10,5) and Legacy GPS signal. Figure

Figure 11 Autocorrelation of BOC modulation schemes and Legacy GPS signal

V. CONCLUSION

The present day Global Navigation Satellite System aims at interoperatability among the existing Satellite Navigation systems i.e. GPS, GLONASS and GALILEO. This interoperatability requires new modulation schemes such as Binary Offset Carrier Modulation. In this paper, Legacy GPS signal properties are analyzed and compared with the GPS signal generated using different BOC modulation schemes such as BOC(1,1),BOC(10,5) and BOC(15,2.5).By analyzing the spectral characteristics, it is found that high powers are achieved at higher frequencies away from the center frequency using the BOC modulated GPS signals . These high powers obtained are due to the splitting of the peak at the center frequency . It is also observed that spectral properties and autocorrelation of the BOC(15,2.5) are superior to that of BOC(1,1),BOC(10,5) and Legacy GPS signal . Hence due to the superior spectral characteristics, BOC(15,2.5) modulation can be used for GPS signal generation, so that the required interoperatability can be achieved in modernized Global Navigation Satellite System.

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