Galileo signal design: State of Art

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BIOGRAPHY

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INTRODUCTION

The Global Positioning System (G.P.S.) has been a revolutionary system that opened new opportunities and enabled innovative services for both governmental and civilian applications.
Rapidly, an efficient and reliable positioning system has become mandatory for public protection and security applications. As consequence Europe has realized the need to develop an independent positioning system (Galileo) with enhanced capabilities, performance and an unconditioned reliability.
Galileo has pursued from the very first moment the goal of having wide band signals in all its assigned frequency bands but it was a particularly difficult task because the band E1 and L1 had already congested.
It will be at the same time compatible and inter operable with American G.P.S. Compatibility refers to the ability of space based positioning, navigation and timing (P.N.T.) services to be used separately or together without interfering with each individual service or signal, and without adversely affecting navigation warfare.
Interoperability refers to the ability of civil space base P.N.T. services to be used together to provide better capabilities at the user level than would be achieved by relying solely on one service or signal.
To achieve this it was necessary planning special signal with particular waveform. An important aspect in designing the modulation scheme is obtain good spectral properties and suitable spectral shaping, low interference with existing G.P.S. signals, good root mean square (R.M.S.) bandwidth, good time resolution (in order to allow the separation between channel paths and to decrease the synchronization errors).
The family of modulations that allowed this was the B.O.C. (Binary Offset Carrier). This paper is concerned with this modulation: it will be described their performance both the transmitter that the receiver point of view. Moreover after a brief description of Galileo signal in which will highlight the differences between the various services to be provided by Galileo itself, will be introduced the AltBOC modulation used on E5. Attention will focused on the signal processing techniques required to process the AltBOC modulation because they are much more challenging than those for traditional BPSK or even for the usual B.O.C. modulation. This stems from the extremely large bandwidth and from the complex interaction of 4 components of spreading code.

GALILEO SERVICES AND SIGNALS

GALILEO will provide four basic services. These services will be provided worldwide and independently from other systems by combining Galileo signals-in-space:

• GALILEO Open Service (OS) - This service results from a combination of open signals, free of user charge, and provides superior position and timing performance compared to other GNSS systems.

• GALILEO Safety of Life (SoL) service - Will be offered and guaranteed to the critical transport community, e.g. aviation, maritime, etc., delivering enhanced performance that includes the provision of the integrity function, i.e. a warning of system malfunction that will reach the user in a given alarm time. This service will be certified against applicable standards and performance, for example the SBAS standards of the International Civil Aviation Organisation (ICAO) in 2009.

• GALILEO Commercial Service (CS) - Provides access to two additional signals, to allow for a higher data throughput rate and to enable users to improve accuracy. The signals are encrypted. A service guarantee is envisaged for this service.

• GALILEO Public Regulated Service (PRS) - provides position and timing to specific users requiring a high continuity of service, with controlled access. Two PRS navigation signals with encrypted ranging codes and data will be available.

In addition, GALILEO support to search and rescue services represents Europe's contribution of to the international COSPAS-SARSAT co-operative effort on humanitarian search and rescue activities. GALILEO is to play an important part of the Medium Earth Orbit Search and Rescue system (MEOSAR)

Each Galileo satellite transmits navigation signals denoted as E1, E6, E5a and E5b signals.

- **E1 signal**: E1 is an open access signal transmitted in the L1 band comprising a data channel E1-B and a pilot (or dataless) channel E1-C. It has unencrypted ranging codes and navigation data, accessible to all users. The E1-B data stream also contains unencrypted integrity messages and encrypted commercial data. The E1-B data rate is 125 bps. The E1 signal supports the OS, CS, and the SoL service
- **E6 signal**: E6 is a commercial access signal transmitted in the E6 band that includes a data channel E6-B and a pilot (or dataless) channel E6-C. Its ranging codes and data are encrypted. A data rate of 500 bps allows the transmission of added-value commercial data. The E6 signal is a dedicated signal for supporting the CS
- **E5a signal**: E5a is an open access signal transmitted in the E5 band that includes a data channel and a pilot (or dataless) channel. The E5a signal has unencrypted ranging codes and navigation data, which are accessible by all users. It transmits the basic data to support navigation and timing functions, using a relatively low 25 bps data rate that enables more robust data demodulation. The E5a signal supports the OS
- **E5b signal:** E5b is an open access signal transmitted in the E5 band that includes a data channel and a pilot (or dataless) channel. It has unencrypted ranging codes and navigation data accessible to all users. The E5b data stream also contains unencrypted integrity messages and encrypted commercial data. The data rate is 125 bps. The E5b signal supports the OS, CS and SoL service

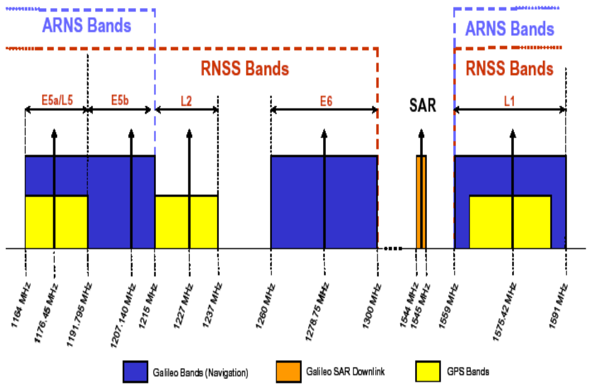
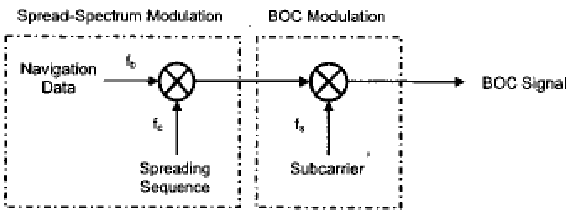


Fig 1: Galileo frequency spectrum

BOC MODULATION

A BOC-modulated signal consists of a sinusoidal carrier, a subcarrier, a pseudorandom noise (PRN) spreading code, and a data sequence. The BOC signal is the product in the time domain of these components. To investigate the appearances of singularities (jumps) in a BOC signal we focus on the product of the subcarrier waveform and the spreading code sequence. Since the sinusoidal carrier is continuous and thus does not contribute to any phase jump in the modulated signal, we do not take the behaviour of this carrier wave into account in the sequel of this paper. Furthermore, the data sequence is not taken into account, since it usually has a far lower frequency than all other components. To introduce BOC signals, we take 2Ts (resp., fs) as the subcarrier period (resp., frequency). For the subcarrier several waveforms are possible. In this paper, we will limit our study to the case of a rectangular sine-phased subcarrier. Besides, we will refer to the spreading symbols (resp., sequence) in the code as pseudo-random noise (PRN) chips (resp.,code). The length (resp. chipping rate or code rate) of such a PRN chip is denoted by Tc (resp., fc). Physically, that means that the code might change (but not necessarily) from −1 to +1 and conversely every 1/ fc second. In addition, we assume that the spreading code is a sequence of independent and identically distributed random variables. As a result, we do not take into account any additional requirements on the correlation function of the spreading code.. The reason for doing this is that in our study we only consider a limited number of code chips, while the mathematical requirements on the code can only be verified when considering the whole code, containing much more code chips. GNSSs satellites have an atomic clock on-board with a nominal reference frequency f_0 from which all components of the generated navigation signals are derived. In case of a BOC signal, besides the carrier frequency also the subcarrier frequency f_s and the code rate fc are multiples of f_0, that is, $f_s = m \cdot f_0$, $f_c = n f_0$. The BOC signal with subcarrier frequency mf0 and code rate n f0 is referred to as BOC(m, n) For the sake of simplicity, m and n are assumed to be positive integers, with $m \geq n$, which is the case in practice.



Signals like BOC(10,5) also appear in literature. Such type of signals is intended for specific services such as the galileo public regulated service (PRS) to be of interest for experts. As we will see in the next section only the division of m by n is of importance for the results in this paper, not the values of m and n themselves.

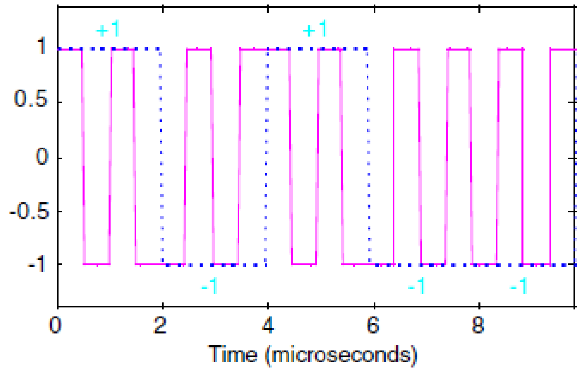


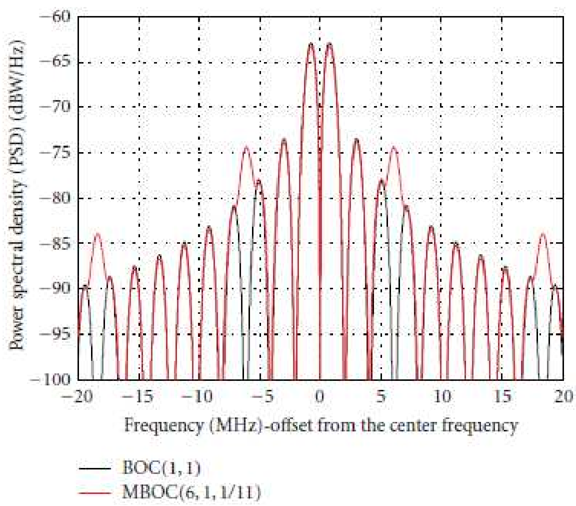
Fig 2: Example Segment of BOC(10,5) Baseband Signal (Solid Line), with Spreading Code Sequence +1, –1, +1, –1, –1 (Dashed Line)

The complex envelope representation of the BOC signal is given by:

$$\sum_j a_j \cdot \mu_{kT_s}(t - jkT_s) \cdot c_{T_s}(t)$$

with

- a_j:the sequence of data-modulated spreading code values,
- μ_{kTs} (t) the spreading symbol of duration Tc = kTs,
- c_{Ts} (t) the subcarrier of period 2Ts and k the number of subcarrier half-periods during which the spreading code value remains unchanged.



The agreement reached in 2004 by United States (US) and European Commission (EC) focused on the Galileo and GPS coexistence clearly stated as central point to the selection of a common signal in

space (SIS) baseline structure that is the BOC(1,1). In addition, the same agreement paved the way for common signal optimization with the goal to provide increased performance as well as considerable flexibility to receiver manufacturers. Therefore, EC and US started to analyze possible innovative modulation strategies in the view of Galileo E1 OS optimization and for the future L1C signals of the new generation GPS satellites. [15].
The MBOC power spectral density (PSD) is a mixture of BOC(1,1) spectrum and BOC(6,1) spectrum; then different time waveforms can be combined to produce the MBOC like spectral density. The contribution of the BOC(6,1) subcarrier brings in an increased amount of power on higher frequencies, which leads to signals with narrower correlation functions and then yielding better performance at the receiver level. The European approach to the MBOC implementation consists in adding in time a BOC(1,1) and a BOC(6,1), defined as composite BOC (CBOC) modulation. At the time of writing, the US is likely to choose a time-multiplexed implementation, named TMBOC

ALTBOC MODULATION

E5 band (1164 -1215 MHz), composed of E5a and E5b bands, is part of the spectrum allocated by ITU for new Radio Navigation Satellite Services in 2000. E5 signal has the wider bandwidth (51.150 MHz) never used in satellite navigation. Galileo E5 signal is composed by two data components and two pilot components broadcasted together by means of the multiplexing scheme AltBOC(15,10). E5a band will be used for Freely/NAV message (Open Service) and the codes of data and pilot components are uncripted, E5b band will be used for Integrity/NAV message for Safety of Life and Open Service. Integrity of signal is probably the most advanced service introduced by Galileo. The sub-carriers are specially chosen waveforms that result in a split spectrum and a constant envelope after the modulation. Four codes are combined with these specially chosen complex sub-carriers to obtain the modulating signal which then phase modulates the E5 carrier. Alternatively, the complete modulation can be seen as an 8-PSK modulation.

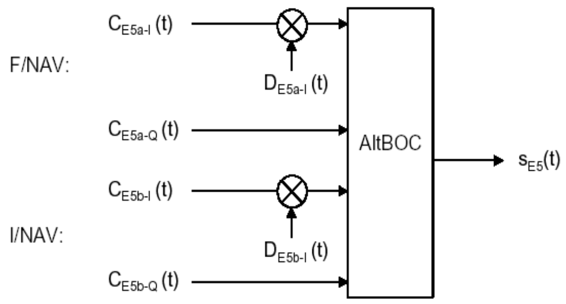


Fig 3: Generation of a AltBOC modulated signal

The generation of combined E5a and E5b signals presents several advantages:

- correlation losses are low
- gain in precision due to the possibility to transmit many side-lobes, in a wide band coherent signal optimization of the use of E5a and E5b: simple/lowcost receivers can use a single band whereas more complex receivers can operate in dual mode single band mode (non-coherent reception of E5a and E5b) or in a coherent dual band mode and thus get advantages in term of performance.
- it allows some flexibility for the service definition, since a service can be dedicated to one band only while the second one could in certain conditions use both.
- the payload baseband generator and the E5 radio frequency channel are simplified and the high power amplifier/output multiplexer subsystem as well.

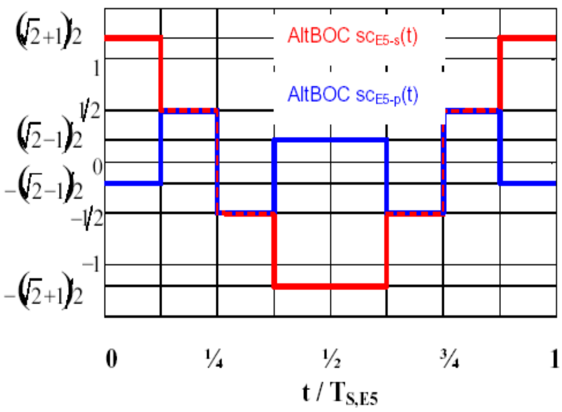


Fig 4: Example Segment of AltBOC(15,10) baseband signal

The spectrum is shown in Figure below. The transmitted signal requires a bandwidth of 51.15MHz to include the two main lobes, giving E5 the largest bandwidth of any GNSS signal.

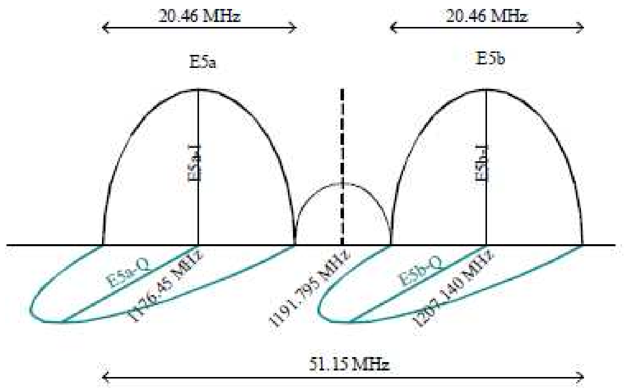


Fig 5: E5 Signal spectrum

A direct method to process the E5 signal at the receiver uses the entire 51.15MHz bandwidth and performs the correlation with the locally generated replica. This results in a correlation waveform as shown. The correlation waveform possesses side peaks along with a sharp main central correlation triangle. The side peaks can result in ambiguous signal acquisition.

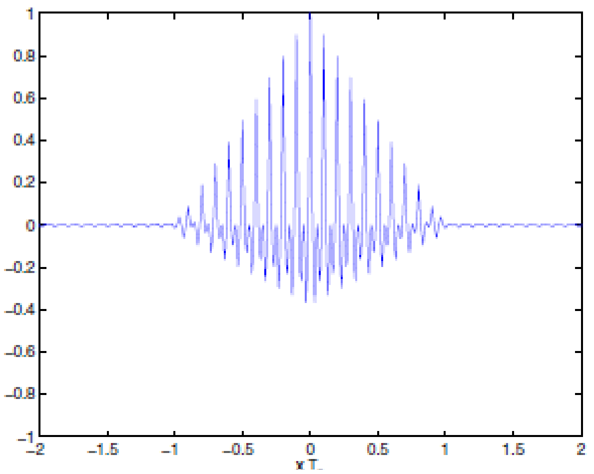


Fig 6: AltBOC(15,10) autocorrelation function

Demodulation technique for AltBOC signals shows the following drawbacks:

- cumbersome signal processing is required, since complex local signals must be generated and combined and, after the correlation operations, further calculations are required to decode the navigation data (look-up table);
- the receiver performance is degraded by correlation losses: this is due to the fact that the subcarriers locally generated are different from those used by the Galileo satellites and this implies a correlation loss

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