# An Innovative Data Demodulation Technique for Galileo AltBOC Receivers

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**Abstract.** This paper describes an innovative solution that can be used to recover the navigation data from Alternative Binary Offset Carrier (AltBOC) modulated signals, a modulation scheme foreseen for the Galileo satellite navigation system to transmit four channels in the E5 band (1164-1215 MHz). In this paper a novel data demodulation approach, called Side-Band Translator (SBT), suitable to coherent dual band AltBOC receiver architectures, is introduced and validated from the analytical point of view. This patented approach is based on the idea to perform a "translation operation": this means that the two separate in-phase components of the AltBOC signal, containing the navigation data, are recovered from the received signal with a proper signal processing, moving the information from the side lobes of the AltBOC spectrum to the baseband. The innovative aspects of this demodulation technique are pointed out in the paper, highlighting the main advantages with respect to already proposed techniques.

**Keywords.** Data demodulation, Side-Band Translator, E5, AltBOC, Galileo.

## 1 Introduction

The future Galileo system, a new Global Navigation Satellite System (GNSS) developed by the European Commission and the European Space Agency (ESA) and foreseen to be operational in 2013, will use the novel *Alternative Binary Offset Carrier (*AltBOC) modulation scheme to transmit four channels in the E5 band (1164-1215 MHz).

Several papers in the literature have addressed the design of acquisition schemes and tracking stages for this modulation, in order to exploit the wideband features of the signals (e.g. in terms of multipath robustness), with an affordable complexity of the receivers architectures as for example in (Dovis et al. 2007).

In spite of the fact that the features of the AltBOC modulated signals and the potential performance of future AltBOC receivers are discussed in several papers in literature, the recovering of the navigation data (demodulation of the two data channels) is not exhaustively examined. Only few patents claim receiver architectures for receiving and processing AltBOC modulated signals: they propose some demodulation strategies that show some drawbacks, in terms of implementation complexity and interference vulnerability.

The paper is organized as follows: in Section 2 a brief review of the AltBOC signal is provided, and in Section 3 current proposals for data demodulation are reviewed. Section 4 will introduce the AltBOC receiver and Section 5 will focus on the proposed Side Band Translator. The impact on the implementation is analyzed in Section 6, and then Section 7 will draw some conclusions.

## 2 Overview of the AltBOC modulation

Four channels ($e_{E5a-I}$, $e_{E5a-Q}$, $e_{E5b-I}$ and $e_{E5b-Q}$) will be transmitted in the E5 band by each Galileo satellite taking advantage of a novel modulation and multiplexing scheme, the AltBOC modulation. Two of four E5 channels are the so-called *data channels* ($e_{E5a-I}$ and $e_{E5b-I}$), since they carry navigation data, whereas the other two ($e_{E5a-Q}$ and $e_{E5b-Q}$) are called *pilot channels* and are not data modulated.

A receiver will be able to distinguish the four channels since four different quasi-orthogonal *Pseudo-Random Noise* (PRN) codes ($c_{E5a-I}$, $c_{E5a-Q}$, $c_{E5b-I}$ and $c_{E5b-Q}$) will be

used for each satellite of the Galileo system. In this way it is possible to recognize the two data channels ($e_{E5a-I}$ and $e_{E5b-I}$) in the received signal and to demodulate their navigation data. It must be noticed that the four codes transmitted by one satellite are synchronous, without relative bias or relative chip-slip. In particular for the data channels the edge of each data symbol coincides with the edge of a code chip: periodic spreading codes start coincides with the start of a data symbol.

A detailed description of the generation of the Galileo AltBOC modulated signal $s_{E5}(t)$ can be found in the *Galileo Open Service Signal In Space Interface Control Document* (GAL OS SIS ICD/D.0, 2006). The analytical expression of the $s_{E5}(t)$ signal is reported here with the notation used in the Galileo OS SIS ICD (baseband complex envelope representation):

$$
\begin{aligned}
s_{E5}(t) = \ & \frac{1}{2\cdot\sqrt{2}}\cdot\left[\mathbf{e_{E5a-I}}(t)+j\cdot e_{E5a-Q}(t)\right]\cdot\left[sc_{E5-S}(t)-j\cdot sc_{E5-S}(t-T_{S,E5}/4)\right]+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[\mathbf{e_{E5b-I}}(t)+j\cdot e_{E5b-Q}(t)\right]\cdot\left[sc_{E5-S}(t)+j\cdot sc_{E5-S}(t-T_{S,E5}/4)\right]+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[\overline{e}_{E5a-I}(t)+j\cdot \overline{e}_{E5a-Q}(t)\right]\cdot\left[sc_{E5-P}(t)-j\cdot sc_{E5-P}(t-T_{S,E5}/4)\right]+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[\overline{e}_{E5b-I}(t)+j\cdot \overline{e}_{E5b-Q}(t)\right]\cdot\left[sc_{E5-P}(t)+j\cdot sc_{E5-P}(t-T_{S,E5}/4)\right]
\end{aligned}
\tag{1}
$$

In Equation (1) the two data channels ( $e_{E5a-I}$ and $e_{E5b-I}$ ) are shown with bold types. They are defined with the following expressions:

$$
\mathbf{e_{E5a-I}}(t) = \sum_{i=-\infty}^{+\infty}\left[c_{E5a-I,|i|_{L_{E5a-I}}}\cdot d_{E5a-I,[i]_{DC_{E5a-I}}}\cdot \mathrm{rect}_{T_{C,E5a-I}}(t-i\cdot T_{C,E5a-I})\right]
\tag{2}
$$

$$
\mathbf{e_{E5b-I}}(t) = \sum_{i=-\infty}^{+\infty}\left[c_{E5b-I,|i|_{L_{E5b-I}}}\cdot d_{E5b-I,[i]_{DC_{E5b-I}}}\cdot \mathrm{rect}_{T_{C,E5b-I}}(t-i\cdot T_{C,E5b-I})\right]
\tag{3}
$$

where $\mathrm{rect}_T(t)$ is the "rectangle" function, which is equal to 1 for $0 < t < T$ and it is equal to 0 elsewhere. In Equation (2) and Equation (3) the two PRN codes codes ( $c_{E5a-I}$ and $c_{E5b-I}$ ) and the two navigation data streams ( $d_{E5a-I}$ and $d_{E5b-I}$ ) are pointed out.

The other two channels ( $e_{E5a-Q}$ and $e_{E5b-Q}$ ), the so-called *pilot channels*, do not carry navigation data, as shown in Equations (4) and (5):

$$
e_{E5a-Q}(t) = \sum_{i=-\infty}^{+\infty}\left[c_{E5a-Q,|i|_{L_{E5a-Q}}}\cdot \mathrm{rect}_{T_{C,E5a-Q}}(t-i\cdot T_{C,E5a-Q})\right]
\tag{4}
$$

$$
e_{E5b-Q}(t) = \sum_{i=-\infty}^{+\infty}\left[c_{E5b-Q,|i|_{L_{E5b-Q}}}\cdot \mathrm{rect}_{T_{C,E5b-Q}}(t-i\cdot T_{C,E5b-Q})\right]
\tag{5}
$$

It must also be noticed that the AltBOC modulation allows to use the E5 band as two separate sidebands, conventionally denoted as E5a (1164-1191.795 MHz) and

E5b (1191.795-1215 MHz). In this way, a single data channel (equivalent to a BPSK signal) and a pilot channel (another BPSK signal) will be transmitted in each sideband. Accordingly, this modulation scheme can be treated as to two separate QPSK modulations, placed respectively around the E5a and the E5b centre frequency.

The demodulation of the navigation data from the received signal is then a cumbersome task that must be carried out by future AltBOC receivers, since the two channels $e_{E5a-I}$ and $e_{E5b-I}$ are transmitted in two adjacent sidebands.

**3 Existing AltBOC Demodulation Techniques**

At time of writing, only few patents (Gerein, 2005 and De Wilde et al 2006) claim receiver architectures for receiving and processing AltBOC modulated signals, considering some different implementations of the complex correlation operations needed for the coherent tracking of the entire E5 band (coherent dual band Galileo AltBOC receiver architecture). In detail only in (Gerein, 2005) a possible solution for the data demodulation is proposed. In (De Wilde et al 2006) the term "demodulation" is improperly used, since in this document the recovering of the navigation data is not discussed, but only some methods and devices for tracking the pilot channels are presented.

The demodulation strategy proposed in (Gerein, 2005) shows some drawbacks, concerning the implementation complexity and interference vulnerability. In this case a not straightforward solution is used to recover the navigation data. First, two replicas of the PRN codes used in the data channels ( $c_{E5a-I}$ and $c_{E5b-I}$ , called respectively $c_2$ and $c_1$ in the patent) and the corresponding square wave subcarriers are locally generated and combined. The obtained local signals are correlated with the received signal, aiming to obtain the real and imaginary components of the sum $(R_1 + R_2)$ and the difference $(R_2 - R_1)$ between the correlation functions of the two codes. Further signal processing is required to recover the navigation data from $(R_1 + R_2)$ and $(R_2 - R_1)$ , using a look-up table approach. More details and the complete demonstration can be found in (Gerein, 2005).

This 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 in (Gerein, 2005) are different from those used by the Galileo satellites and this implies a correlation loss, as stated in (Soellner and Erhard, 2003). In particular in (Gerein, 2005) the Complex-BOC and the Complex-LOC modulations are considered as approximations of the AltBOC received signals. But the true AltBOC modulation that will be used for the Galileo E5 band differs from the Complex-LOC and the Complex-BOC essentially for the presence of additional terms in the modulated signal expression (the so-called *product signals*) and for a different shape of the subcarrier waveforms (GAL OS SIS ICD/D.0, 2006);

- this demodulation technique is vulnerable, since the two data channels are jointly demodulated, taking advantage of $(R_1 + R_2)$ and $(R_2 - R_1)$ correlation results. In this way an error on one data bit (e.g. caused by an interfering signal on a single sidelobe of the E5 band) can affect also the correct demodulation of the other channel;

- it is not possible to temporarily demodulate only one data channel (e.g. in a certain condition where the navigation data of the other channel are not necessary), switching off the demodulation section of the other channel or reusing its dedicated hardware or software resources.

## 4 Proposed Galileo AltBOC Receiver Architecture

A modified architecture for an AltBOC receiver, based on the coherent reception and processing of the entire Galileo E5 band, is depicted in Fig. 1. This receiver is similar to the ones proposed in (Gerein, 2005) and (De Wilde et al 2006), but an innovative despreading and demodulation section, tailored to the AltBOC modulation, is used.

In Fig. 1 a high level block diagram of the receiver is presented: it is only intended to simply explain the functioning of the receiver. The implementation details about the complex correlation and discrimination operations and the possible optimizations that can be performed in the architecture of the receiver (e.g. see Gerein, 2005 and De Wilde et al 2006) are not reported here, due to the fact that are considered background.

After the *Radio Frequency* (RF) front end and the *Intermediate Frequency* (IF) section, the received signal is processed by the PLL, the DLL and the demodulation sections that are the most important functional blocks of the receiver. In fact the main differences between a conventional GPS receiver and the AltBOC receiver can be noticed in the operations performed by these blocks:

- the *Phase Locked Loop* (PLL) is used to coherently track the central carrier of the E5 band (located at 1191.795 MHz), separating the in-phase and the quadrature components of the received signal (*I* and *Q*);

- the *Delay Locked Loop* (DLL) is necessary in order to recover spreading code synchronism and then data symbol synchronism. In fact, as previously noticed, the four E5 channels of each Galileo satellite are coherently transmitted, without relative bias or relative chip-slip. The DLL functioning is based on the tracking of the two *pilot channels* ($e_{E5a-Q}$ and $e_{E5b-Q}$). This is done generating local replicas of the PRN codes used for the pilot channels ($c_{E5a-Q}$ and $c_{E5b-Q}$) and of the subcarrier waveforms ($sc_{E5-S}$ and $sc_{E5-S}(t - T_{S,E5}/4)$). These local signals are used to perform complex correlation operations with the *I* and *Q* received samples, as discussed in (Sleewaegen et al, 2004). It must be pointed out that the tracking operations can be performed taking advantage of different kinds of discriminator: in Fig. 1 the simplest one, the Early-Late discriminator, is used for sake of simplicity;

- the *demodulation section* recovers the navigation data from the two *data channels* ($e_{E5a-I}$ and $e_{E5b-I}$), taking advantage of the synchronism recovered by the DLL. In particular it is necessary to perform the *despreading*, with local replicas of the PRN codes used for the data channels ($c_{E5a-I}$ and $c_{E5b-I}$), and the *data detection*.

It must be noted that the demodulation section in the receiver architecture in Fig. 1 shows remarkable differences with respect to the architecture proposed in (Gerein, 2005). In fact a different demodulation technique, based on an innovative device called **Side-Band Translator**, is used.
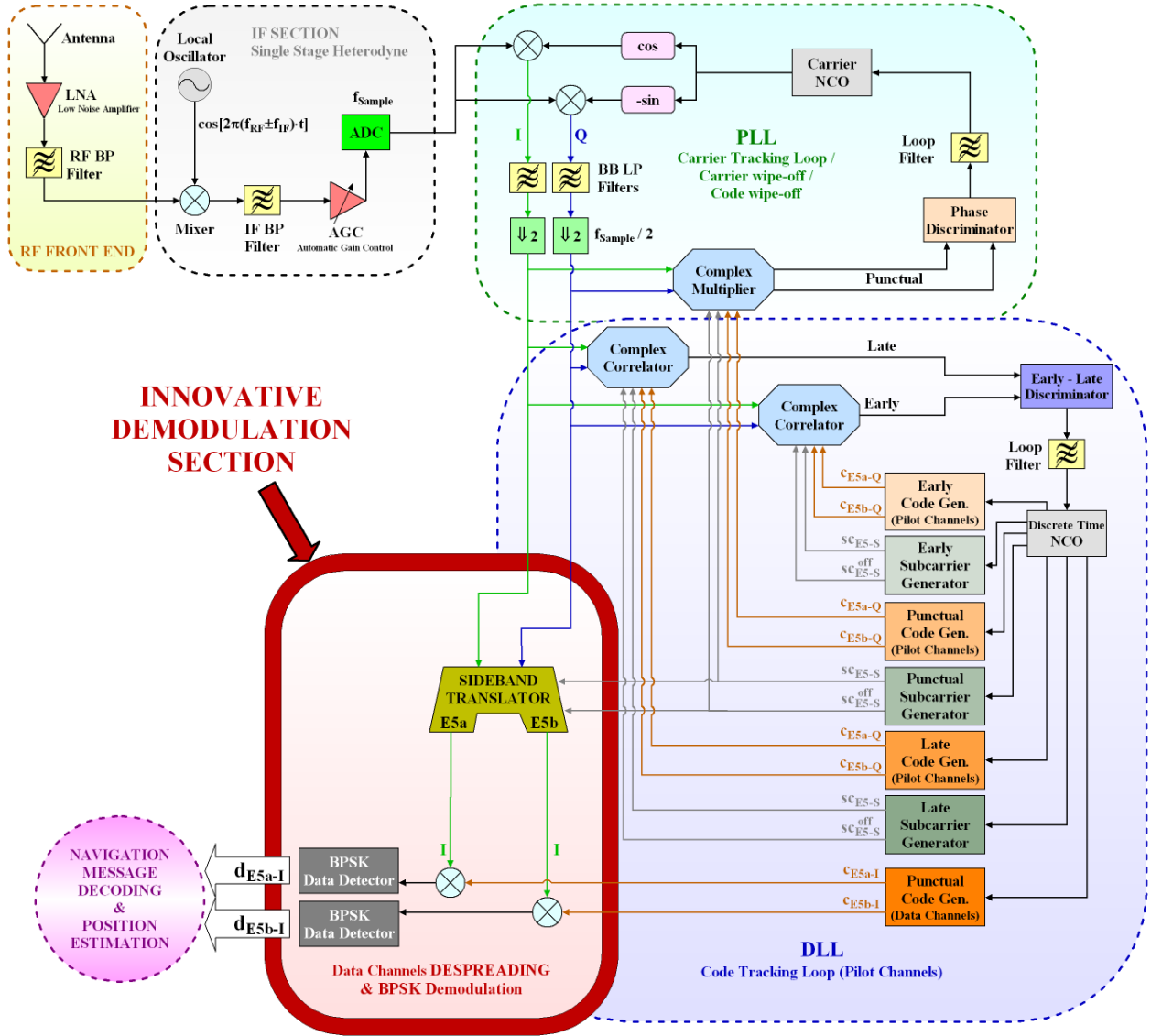
Fig. 1: Block diagram of a modified coherent dual band receiver architecture for Galileo AltBOC signals

## 5. The Side-Band Translator (SBT)

The sideband translator is an innovative subsystem within the AltBOC receiver that can be used to demodulate the navigation data included in the wideband AltBOC signal. This solution has been patented (Margaria, Mulassano and Dovis, 2007), and it is based on the idea to perform a "*translation operation*": this means that the two separate in-phase components, containing the navigation data ( $e_{E5a-I}$ and $e_{E5b-I}$ ), are recovered from the received signal $s_{E5}(t)$, previously described in Equation (1).

To understand the operations performed by the SBT, it is useful to consider a simpler situation, as in the case of a BOC receiver. With a BOC modulation, the signal to be transmitted is multiplied with a rectangular subcarrier: this operation causes a frequency shift that leads to the two typical sidelobes of the BOC spectrum (similar to the spectrum of the E5 AltBOC signal). To demodulate this split-spectrum signal, once the received signal is correctly tracked by the DLL and the PLL of the BOC receiver (the local PRN code is synchronized), a possible approach is to multiply the received BOC signal again with a local replica of the rectangular subcarrier that can be generated with the synchronism recovered by the DLL. This operation

translates the two sidebands of the BOC signal again to the baseband: in this way, the signal becomes again a baseband signal and the information contained in it could be easily recovered with a BPSK data detector, after the despreading with the local PRN code. Accordingly, with a BOC modulation the *sideband translation* operation corresponds to a simple multiplication with a local rectangular subcarrier that re-converts the received signal in a baseband signal.

However, with the AltBOC modulation this operation is more complex, because there are four channels transmitted in the E5 band (instead of only one, as in the previous example) and the frequency shifts of these channels to the two sidebands are performed taking advantage of complex exponentials.

In detail the SBT selects the two in phase data channels $e_{E5a-I}(t)$ and $e_{E5b-I}(t)$ and moves them from the sidebands of the AltBOC spectrum to the baseband, as highlighted by the red arrows in the scheme in Fig. 2.
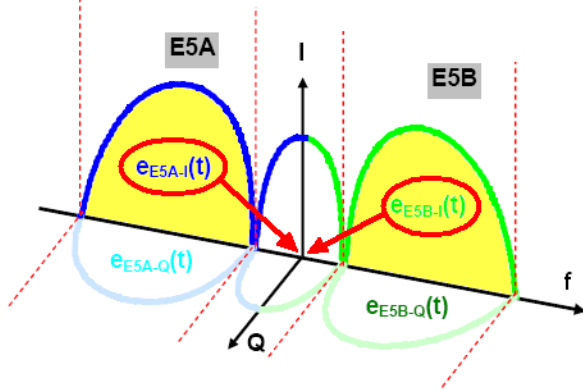


Fig. 2: Illustration of the frequency spectrum of the E5 AltBOC modulated signal and the operations performed by the sideband translator block

Accordingly, the sideband translator block needs to use complex exponential multiplications to move these channels to the baseband, performing two separate frequency shifts, and then it must choose the correct channels (only the in-phase channels, containing the navigation data), selecting only the real part of the obtained signals as shown in Fig. 3.

Finally the SBT provides the two recovered in-phase channels ( $e_{E5a-I}$ and $e_{E5b-I}$ ), that are passed to subsequent despreading and BPSK data detector blocks. In this way the navigation data are recovered by means of a straightforward signal processing operation, simpler than the approach used in (Gerein, 2005).

The operations performed by the sideband translator block can be understood considering the AltBOC

modulated signal expression, reported again here for sake of clarity:

$$
\begin{aligned}
s_{E5}(t) = {} & \frac{1}{2\cdot\sqrt{2}}\cdot\left[\mathbf{e_{E5a-I}}(t)+j\cdot e_{E5a-Q}(t)\right]\cdot\left[sc_{E5-S}(t)-j\cdot sc_{E5-S}(t-T_{S,E5}/4)\right]+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[\mathbf{e_{E5b-I}}(t)+j\cdot e_{E5b-Q}(t)\right]\cdot\left[sc_{E5-S}(t)+j\cdot sc_{E5-S}(t-T_{S,E5}/4)\right]+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[\overline{e}_{E5a-I}(t)+j\cdot \overline{e}_{E5a-Q}(t)\right]\cdot\left[sc_{E5-P}(t)-j\cdot sc_{E5-P}(t-T_{S,E5}/4)\right]+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[\overline{e}_{E5b-I}(t)+j\cdot \overline{e}_{E5b-Q}(t)\right]\cdot\left[sc_{E5-P}(t)+j\cdot sc_{E5-P}(t-T_{S,E5}/4)\right]
\end{aligned}
\tag{6}
$$

The dashed terms contained in the last two lines of Equation (6) can be neglected, because they correspond to the so-called *product signals*: these terms are multiplied by $sc_{E5-P}(t)$ subcarrier waveform, with smaller amplitude than $sc_{E5-S}(t)$, and they do not carry useful information. The product signals are only needed to obtain a constant envelope modulated signal. More details can be found in (GAL OS SIS ICD/D.0, 2006), (Ries L. et al, 2002), (Ries L. et al, 2003) and (Soellner and Erhard, 2003).
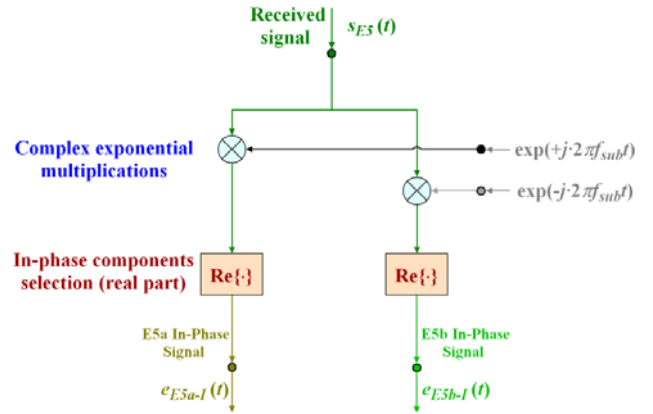


Fig. 3: Theoretical scheme of the sideband translator

It is then possible to decompose the modulated signal $s_{E5}(t)$ in its real and imaginary components, neglecting the product signals:

$$
s_{E5}(t) = s_{E5\mathbf{I}}(t)+j\cdot s_{E5\mathbf{Q}}(t)
\tag{7}
$$

$$
\begin{aligned}
s_{E5\mathbf{I}}(t) \cong {} & \frac{1}{2\cdot\sqrt{2}}\cdot\left[e_{E5a-I}(t)+e_{E5b-I}(t)\right]\cdot sc_{E5-S}(t)+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[e_{E5a-Q}(t)-e_{E5b-Q}(t)\right]\cdot sc_{E5-S}(t-T_{S,E5}/4)
\end{aligned}
\tag{8}
$$

$$
\begin{aligned}
s_{E5\mathbf{Q}}(t) \cong {} & \frac{1}{2\cdot\sqrt{2}}\cdot\left[e_{E5a-Q}(t)+e_{E5b-Q}(t)\right]\cdot sc_{E5-S}(t)+ \\
& \frac{1}{2\cdot\sqrt{2}}\cdot\left[e_{E5b-I}(t)-e_{E5a-I}(t)\right]\cdot sc_{E5-S}(t-T_{S,E5}/4)
\end{aligned}
\tag{9}
$$

The two components $s_{E5\mathbf{I}}(t)$ and $s_{E5\mathbf{Q}}(t)$ can be considered as the ideal received signals in the *I* and *Q*

branch of the receiver in Fig. 1. In fact, assuming the correct synchronization of the receiver (PLL and DLL correctly locked) and neglecting the noise, the distortions and other propagation effects, the received signal $s_{E5}(t)$ is downconverted to the baseband and is partitioned in the $I$ and $Q$ branch of the receiver, separating its real and imaginary parts.

It must be remarked that taking advantage of the E5 AltBOC modulation, the four channels $e_{E5a-I}(t)$, $e_{E5a-Q}(t)$, $e_{E5b-I}(t)$ and $e_{E5b-Q}(t)$ are transmitted in the two sidebands of the E5 band. This is achieved using the subcarrier waveform $sc_{E5-S}(t)$, that resembles a sampled cosine, and its delayed version $sc_{E5-S}(t - T_{S,E5}/4)$, similar to a sampled sine. The two subcarrier waveforms are presented in detail in (GAL OS SIS ICD/D.0, 2006). In the following, for sake of simplicity, the second function is denoted as $sc_{E5-S}^{off}(t)$. In the first two lines of Equation (6) these two waveforms are used like complex exponentials:

- The first subcarrier exponential is obtained with the term $[sc_{E5-S}(t) - j \cdot sc_{E5-S}^{off}(t)]$. It performs a similar operation in the frequency domain than the complex exponential $\exp(-j \cdot 2\pi f_{sub} t)$, where $f_{sub}$ is the subcarrier frequency $f_{sub} = R_{S,E5} = 15.345$ MHz. This exponential operates a downshift for the two E5a channels and in this way $e_{E5a-I}(t)$ and $e_{E5a-Q}(t)$ are shifted from the baseband to the left sidelobe of the AltBOC spectrum (E5a sideband);

- In a similar way, the second subcarrier exponential $[sc_{E5-S}(t) + j \cdot sc_{E5-S}^{off}(t)]$ corresponds to the complex exponential $\exp(+j \cdot 2\pi f_{sub} t)$ and it upshifts the two E5b channels $e_{E5b-I}(t)$ and $e_{E5b-Q}(t)$.

The sideband translator takes advantage of this idea, performing the opposite operation: with a proper use of the two exponentials, the two in-phase channels $e_{E5a-I}(t)$ and $e_{E5b-I}(t)$ can be extracted from the baseband received signal $s_{E5}(t)$.

To obtain the $e_{E5a-I}(t)$ channel it is necessary to operate an upshift of the received signal in the frequency domain, multiplying it for the second exponential. In this way the $e_{E5a-I}(t)$ signal becomes

centered to the baseband and it can be recovered selecting the in-phase (real) component of the result of the multiplication, as shown in the following equations:

$$e_{E5a-I}(t) \cong \mathrm{Re}\left\{ \begin{array}{l} [s_{E5I}(t) + j \cdot s_{E5Q}(t)] \cdot \\ \cdot [sc_{E5-S}(t) + j \cdot sc_{E5-S}^{off}(t)] \end{array} \right\} \quad (10)$$

$$e_{E5a-I}(t) \cong \mathrm{Re}\left\{ \begin{array}{l} [s_{E5I}(t) \cdot sc_{E5-S}(t) - s_{E5Q}(t) \cdot sc_{E5-S}^{off}(t)] + \\ + j \cdot [s_{E5I}(t) \cdot sc_{E5-S}^{off}(t) + s_{E5Q}(t) \cdot sc_{E5-S}(t)] \end{array} \right\} \quad (11)$$

$$e_{E5a-I}(t) \cong s_{E5I}(t) \cdot sc_{E5-S}(t) - s_{E5Q}(t) \cdot sc_{E5-S}^{off}(t) \quad (12)$$

Similarly to that done for the $e_{E5a-I}(t)$ channel, it is possible to recover the $e_{E5b-I}(t)$ signal, downshifting the received signal $s_{E5}(t)$ with the following operations:

$$e_{E5b-I}(t) \cong \mathrm{Re}\left\{ \begin{array}{l} [s_{E5I}(t) + j \cdot s_{E5Q}(t)] \cdot \\ \cdot [sc_{E5-S}(t) - j \cdot sc_{E5-S}^{off}(t)] \end{array} \right\} \quad (13)$$

$$e_{E5b-I}(t) \cong \mathrm{Re}\left\{ \begin{array}{l} [s_{E5I}(t) \cdot sc_{E5-S}(t) + s_{E5Q}(t) \cdot sc_{E5-S}^{off}(t)] + \\ + j \cdot [s_{E5Q}(t) \cdot sc_{E5-S}(t) - s_{E5I}(t) \cdot sc_{E5-S}^{off}(t)] \end{array} \right\} \quad (14)$$

$$e_{E5b-I}(t) \cong s_{E5I}(t) \cdot sc_{E5-S}(t) + s_{E5Q}(t) \cdot sc_{E5-S}^{off}(t) \quad (15)$$

Equations (12) and (15) then define the functioning of the sideband translator and allows to simply recover the two data channels $e_{E5a-I}(t)$ and $e_{E5b-I}(t)$.

## 6 Implementation of the SBT Functional Block

A possible implementation of the sideband translator is presented in Fig. 4. In this functional block the two operations described by Equation (12) and Equation (15) are directly implemented in the discrete time domain, with multiplications and sums between the samples of the received signal and the locally generated subcarrier waveforms.

As shown in the block diagram, the results of the two equations could be filtered, with two baseband low-pass filters, in order to reduce the interference and the cross-correlation caused by the adjacent channels. The shape and the bandwidth of the filters must be optimized, because a narrow band filtering can reduce the performance of the demodulation section, worsening the correlation proprieties of the two data channels, but also a filter too wide could be an issue in presence of noise and interferences.
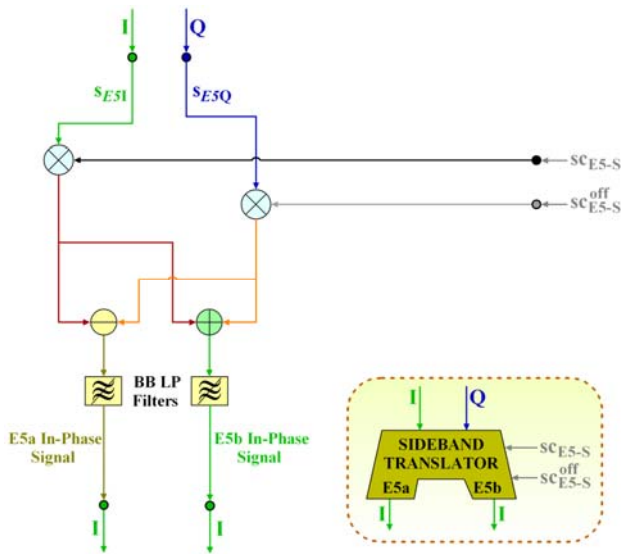
Fig. 4 Block diagram of the sideband translator

In conclusion, the sideband translator functional block provides as two separate outputs the two data channels $e_{E5a-I}(t)$ and $e_{E5b-I}(t)$, extracted from the received signal. In this way it is possible to subsequently recover the navigation data from the two outputs of the SBT, performing two separate despreading operations and two BPSK data detections, as previously represented in Fig. 1.

## 7 Conclusions

In this paper an innovative approach has been presented as a valid solution in order to demodulated the navigation data from an AltBOC modulated signal.

o The two data channels $e_{E5a-I}(t)$ and $e_{E5b-I}(t)$ of the Galileo E5 band are recovered taking advantage of the idea to operate two frequency shifts on the received signal;

o The frequency shifts are performed using real signals, obtained with local replicas of the AltBOC subcarrier waveforms $sc_{E5-S}(t)$ and $sc_{E5-S}^{off}(t)$;

o The two signals recovered with these frequency shifts can be separately filtered, in order to reduce interferences and cross-correlations with adjacent channels;

o Finally, the navigation data are separately recovered as two BPSK signals, performing the despreading and the demodulation operations.

The proposed demodulation approach shows several differences with respect to the solution in (Gerein,

2005), since a different signal processing is used. This leads to the following advantages:

• A **simpler signal processing** that implies a saving in hardware and software resources. In fact the navigation data are directly recovered from the two outputs of the sidebands translator and further calculations to decode the data from their sum and difference, as in (Gerein, 2005), are not necessary;

• A **better receiver performance**, avoiding correlation losses in the demodulation section; in fact in the proposed receiver architecture (see Fig. 1) the correct subcarrier waveforms $sc_{E5-S}(t)$ and $sc_{E5-S}^{off}(t)$ are locally generated and used by the sideband translator to perform the frequency shifts;

• An **improved robustness** of the demodulation section, since an error in a data bit of one channel (e.g. caused by an interfering signal on the E5a sideband) does not affect the correct demodulation of the other data channel; in fact the two data channels are separately downconverted and demodulated, taking advantage of the SBT;

• A **better interference rejection**, because the two low-pass filters in the SBT allow to reduce out-of-band interfering signals and cross-correlations caused by PRN codes of adjacent channels;

• More **flexibility** for the functioning of the demodulation section; in fact it is possible to temporarily demodulate only one data channel (e.g. in a certain condition where the navigation data of the other channel are not necessary), switching off the demodulation of the other channel (power saving) or reusing its dedicated hardware or software resources.

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