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EFFECT OF WHITE NOISE ON GNSS GALILEO SIGNAL E5

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Abstract. This article contains an analysis to white noise interference. To conduct the research, models for both the E5 signal and white noise were developed and combined using an additive mixture. Using available data, spectral structures were established for the interference and then integrated into the E5 signal using the Matlab program. The objective of the study was to examine how white noise impacts the spectral power density of the E5 signal. The findings of this research can be utilized in the development of resilient receivers and signal architectures capable of withstanding this kind of disruption.

Keywords: Galileo, Signal E5, white noise

1. INTRODUCTION

The Galileo project is a major undertaking of the European Union with the ultimate goal of creating the most advanced global satellite positioning system. This autonomous system aims to offer guaranteed global positioning services with high accuracy and reliability, while also ensuring interoperable compatibility with other significant global positioning systems, such as GPS and GLONASS. The system will comprise a constellation of up to 30 satellites in orbit, a network of ground-based control stations, and a range of user receivers. One of the key signals transmitted by the Galileo constellation is the E5 signal, which is designed to provide higher accuracy and better resistance to interference than previous Galileo signals. The E5 signal operates in two frequency bands, E5a and E5b, and is compatible with other global positioning systems, making it a valuable component in multi-constellation receiver designs. It has applications in various fields, including aviation, land surveying, and maritime navigation. This study focuses on analyzing the E5 signal transmitted by the Galileo constellation. First, we created the structure of the E5 signal according to the available information. Subsequently, we created interference - white noise. After creating both structures of these signals, we created an additive mixture of the E5 signal and interference to determine the effect of interference on the original signal. The entire research is carried out using simulation in the Matlab program environment.The findings of this study can be used to develop more robust receivers and signal structures that can withstand the challenges of white noise interference, thereby enhancing the reliability and accuracy of the Galileo global satellite positioning system.

Several studies and researches have already been devoted to the E5 signal. The article [1] discusses the opportunities and challenges associated with processing the Galileo E5 signal, which is a wideband signal transmitted by the Galileo satellite system. The authors highlight the benefits of the Galileo E5 signal. The article also examines the challenges associated with processing the Galileo E5 signal, such as the need for advanced signal processing techniques and hardware to handle the signal's wide bandwidth. The authors propose several solutions to address these challenges, such as developing advanced algorithms for signal processing and utilizing high-performance hardware. Authors of article [2] provides an overview of the AltBOC modulation scheme and describes the design and implementation of a Galileo AltBOC receiver developed by Septentrio, a manufacturer of high-precision GNSS receivers. The article also includes experimental results that demonstrate the performance of the Septentrio Galileo AltBOC receiver. The publication [3] discusses the use of GNSS signals in the E5 band to estimate ionospheric delays and its importance in critical aerospace applications such as satellite-based navigation and communications. It provides an explanation of the ionosphere, the effects on GNSS signals, and practical examples of delay estimation using ionospheric models and algorithms. The impact of GNSS signal interference on navigation and positioning systems during flight operations is explored in the article [4]. The study found that accuracy is significantly affected by narrowband interference, which is more challenging to filter out than broadband interference. The need for further research and the development of robust GNSS systems is emphasized to reduce the risks of signal interference during flight operations. An analysis of Galileo clock and ephemeris broadcasts is carried out in the document [5], utilizing 43 months of data from January 1, 2017, to July 31, 2020, using the Galileo Receiver Independent Exchange (RINEX) consolidated navigation files. Evaluating the Galileo signal in space and estimating the probability of satellite failure is done based on the observation results obtained. In the work [6], the author focuses on conducting an experimental analysis of positioning in a challenging environment. Parameters for horizontal and vertical position and speed were calculated as part of this analysis. The findings of the study reveal that GPS is unable to transmit continuous signals in a degraded environment. On the other hand, the Galileo system has been shown to improve the availability of signals in such an environment. The authors of the study [7] conducted an investigation into the positioning performance of GPS L1/L2/L5 and Galileo E1/E5a/E5b/E6 in both conventional PPP mode and single epoch mode. Uncombined coding and phase distortion products produced at The National Center for Space Studies in France (CNES) were utilized during the study. The study's findings suggest that modeling multi-frequency code and phase measurements in undifferentiated and uncombined form using CNES distortion products can enable the estimation of the tilted ionosphere. Furthermore, Galileo is currently developing new services that provide enhanced security and resistance to attacks, such as the Open Navigation Message Authentication Service (OS-NMA) and the Commercial Authentication Service (CAS). In the literature [8], a comprehensive explanation of the Galileo system structure and signal models was presented during its early stages of development. The author described the frequency plan and signal structure in great detail, highlighting the key features of the system that set it apart from other GNSS systems. The article provided an overview of the Galileo system, including its design and architecture, the number of satellites and orbital parameters, and the features of the signals transmitted by the satellites. The article also discussed the various Galileo signal components, such as the navigation message, the ranging codes, and the pilot signals, and provided a thorough description of the signal modulation schemes used by Galileo.

2. Galileo E5 signal

The Galileo E5 signal, which is transmitted at 1191.795 MHz, is a broadband signal, modulated via AltBOC modulation. It is a modified form of Binary Offset Carrier (BOC) with a code rate of 10.23 MHz and a partial carrier frequency of 15.345 MHz. This signal is split into E5a and E5b signals, which are transmitted over four frequency bands, providing a wide bandwidth for the transmission of the Galileo signal. These frequency bands are selected from the Radionavigation Satellite Services (RNSS) allocated spectrum. In addition, the E5a, E5b and E1 bands are included in the Aeronautical Radio Navigation Services (ARNS) allocated spectrum used by civil aviation users for safety-critical applications [9].

The adoption of international standards by the International Civil Aviation Organization (ICAO) for Galileo and other Satellite Based Augmentation Systems is a significant achievement in the aviation industry. This will allow us to fully utilize the potential of satellite navigation services developed in Europe, in conjunction with GPS. The Galileo system, which is the European Union's global navigation satellite system, will provide the aviation sector with advanced navigation capabilities that will significantly enhance the reliability and availability of services. By offering a more precise and secure signal for positioning and timing, the possibility of signal loss or interference will be considerably reduced. Furthermore, the use of numerous frequency bands will increase signal resilience, making the system more durable and dependable [10].

The following Figure 1 shows the modulation of the E5 signal, which is modulated using the AltBOC modulation scheme [9]:

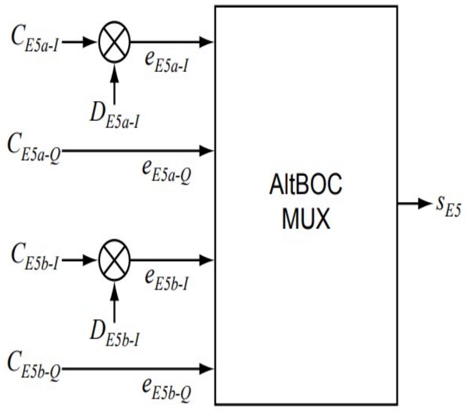

Figure 1 Modulation scheme of signal E5 [11]

The whole transmitted signal E5 consists of the following components:
eE5a - I from the F / NAV navigation data stream DE5a – I modulated with the unencrypted measurement code CE5a - I.
eE5a - Q (pilot component) from unencrypted measurement code CE5a - Q
eE5b – I \ from the I / NAV navigation data stream DE5b – I modulated by the unencrypted measurement code CE5b - I .
eE5b – Q (pilot component) from unencrypted measurement code CE5b – Q [9].

2.1. Structure of signal E5

The equation that modulates the E5 signal in this case is :

$$sE5 = 1/sqrt(2) * (sca + scb + scc) .* cos(2*pi*(fc-subfreq)*t); \quad (1)$$

where:
sE5 - is the signal E5
sca = C1.*x1; scb = C2.*x2; scc = C3.*x3; are the spreading codes to each sub-carrier signal, creating three modulated sub-carrier signals.
x1 = sin(2*pi*subfreq*t);
x2 = sin(2*pi*(subfreq+codefreq)*t);
x3 = sin(2*pi*(subfreq+2*codefreq)*t);
And
C1 = ones(1, length(x1));
C2 = ones(1, length(x2));
C3 = ones(1, length(x3)); Are spreading codes for each sub-carrier signal. The spreading codes are generated by applying the AltBOC(15,10) modulation sequence to each sub-carrier signal. The spreading codes are used to spread the sub-carrier signals before they are combined to form the E5 signal.
fc = 1191.795 - middle frequency
subfreq = 15.345e6 - the subcarrier frequency
t = 0:1/fs:T - time vector for the E5 signal, with a time step of 1/fs seconds, starting at time 0 and ending at time T.

The signal is created by multiplying the sum of the modulated subcarrier signals with a cosine wave to the frequency of the center frequency minus the frequency of the subcarrier. A factor of 1/sqrt(2) is included to normalize the signal. This equation combines the three sub-carrier signals with the distribution codes and then modulates them to the carrier frequency to produce the E5 signal. Based on the equation, a signal was created in the Matlab program interface (Figure 2).

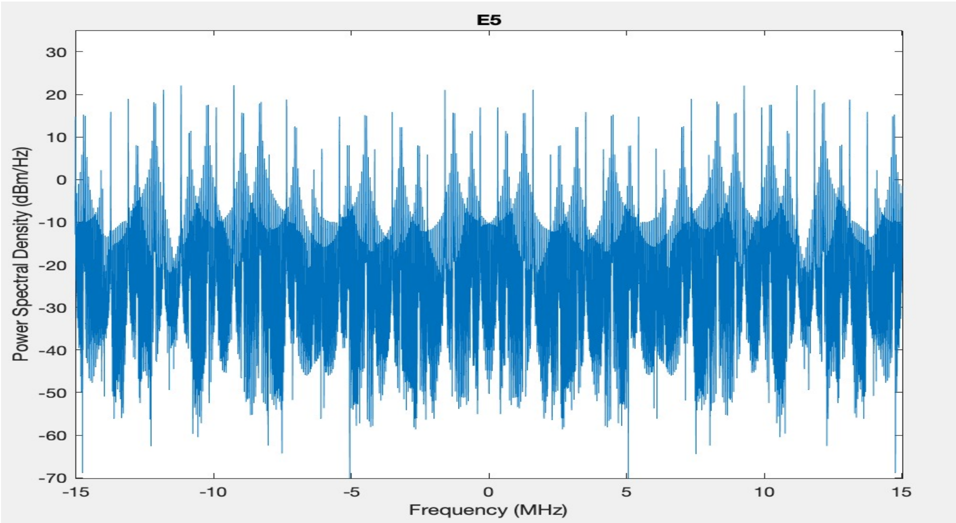

Figure 2 Structure of signal E5

The figure 2 represents the power spectral density (PSD) of the E5 signal. The E5 signal is generated by combining three sub-carrier signals with different distribution codes, which are modulated using AltBOC(15,10) modulation. AltBOC is a composite modulation that combines binary carrier shift (BOC) modulation with subcarrier modulation. The subcarrier used in the Galileo E5 signal has a frequency of 15.345 MHz and is modulated by the BOC(15,10) signal. The resulting composite signal has a code bandwidth of 10 MHz and is transmitted in the E5 frequency band centered at 1191.795 MHz. AltBOC modulation is implemented using a "modulation" vector that contains the binary data to be transmitted. The code generates three subcarriers at 15.345 MHz, 25.575 MHz (15.345 MHz + 10.23 MHz), and 35.805 MHz (15.345 MHz + 2*10.23 MHz) and then applies the appropriate distribution codes to each subcarrier to produce an AltBOC signal. Finally, the three modulated subcarriers are combined to form the Galileo E5 signal.

The PSD graph has a distinctive shape with several peaks and valleys. The carrier signal is placed at the middle frequency. This peak is the strongest component of the signal and carries navigation information. The carrier signal is surrounded by several sidebands that contain additional information about the signal. The sidebands are located in integer multiples of the subcarrier frequency and the code frequency. The valleys in the PSD correspond to the zeros of the E5 signal. These nulls occur at certain frequencies due to the modulation scheme and signal processing used in the Galileo system. Null values can be used for signal processing and analysis, such as carrier frequency estimation or signal interference detection.

3. Structure of interference

White noise is a type of noise that has a constant power spectral density across all frequencies. Gaussian noise, on the other hand, has a bell-shaped PSD with more power concentrated around the center frequency.

In this case, the noise is generated through the equation:

$$\text{noise} = \text{randn}(1, N).*\ \text{noise\_level}; \quad (2)$$

The randn function generates a vector of Gaussian white noise samples with a mean of zero and a standard deviation of one. Row noise = randn(1, N) .* noiselevel; multiplies the generated white noise samples by the noise level vector to produce a Gaussian noise signal with the specified noise level. The higher the values in the noise level vector, the higher the amplitude of the generated noise signal.

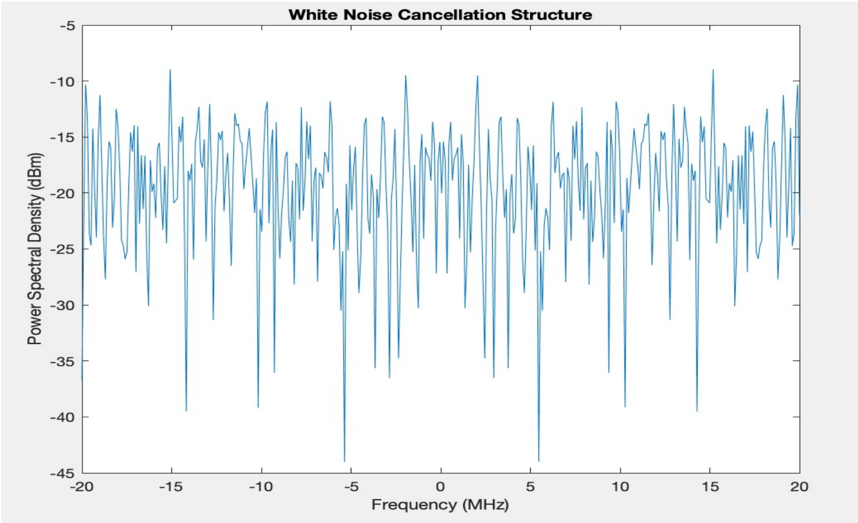

Figure 3 White noise structure

The figure 3 shows a plot of the power spectral density (PSD) of Gaussian noise, where the PSD is calculated using the fast Fourier transform (FFT). The frequency range is specified using the variable 'f', which is a linear vector with a range of -20 MHz to 20 MHz. The time range is specified using the variable 'x', which is a linspace vector with a range of -5ms to 5ms. The sampling frequency is 40 kHz, which is specified using the "fs" variable. The number of samples used to calculate the FFT is specified by the 'N' variable, which is set to 400. The curve is bell-shaped and symmetrical around zero frequency, which is characteristic of white noise. The maximum PSD occurs at zero frequency and decreases as the frequency moves away from zero. PSD is also affected by noise level, with higher noise level leading to higher PSD values. The graph provides valuable information for the design of noise suppression systems because it shows the frequency range and noise level that needs to be suppressed. Using the PSD, it is possible to estimate the power of noise in a given frequency band and to design a filter that attenuates the noise in this band.

3.1. Additive mixture of white noise and signal E5

The noise is added to the E5 signal using the + operator in the following line of code:

sE5_noisy = sE5 + noise; (3)

Here, sE5 is the original E5 signal, and noise is the generated Gaussian noise. The + operator adds the noise to the E5 signal element-wise, resulting in a noisy E5 signal sE5_noisy.

The result of the simulation of adding white noise to the original E5 signal in the Matlab program can be seen in figure no. 4:

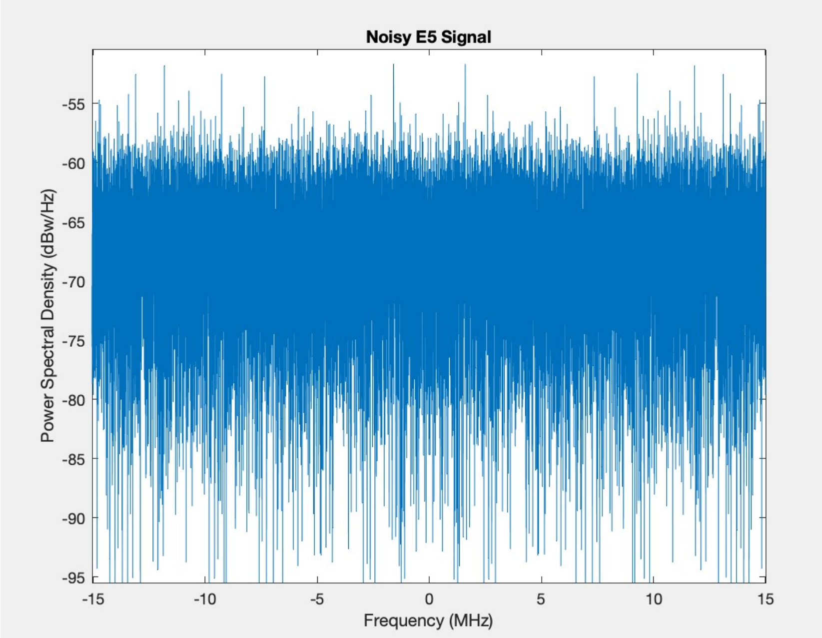

Figure 4 Additive mixure of white noise and signal E5

The noise added to the signal is modeled as white Gaussian noise with varying noise level. The noise level is specified using a linearly spaced field ranging from -1 to 6, where a value of 0 corresponds to no noise and higher values correspond to higher noise levels. Noise is added to the Galileo E5 signal, resulting in a noisy version of the signal.

The PSD of the noisy signal is calculated using a fast Fourier transform (FFT) with a frequency resolution of 1 MHz. PSD represents the distribution of signal power over different frequency components. The x-axis in the figure shows the frequency range from -15 MHz to 15 MHz, while the y-axis shows the PSD in dBW/Hz. The effect of white noise on the PSD of the signal can be observed from the figure. As the noise level increases, the PSD of the signal increases uniformly at all frequencies. This is because white noise has a constant power spectral density across all frequencies. As a result, the added noise increases the overall signal power, resulting in a higher PSD.

In addition, as the noise level increases, the signal-to-noise ratio (SNR) of the signal decreases, which may have a detrimental effect on the performance of PNT applications that rely on the Galileo E5 signal. A higher level of noise can lead to errors in positioning and navigation calculations, reducing the accuracy of the PNT solution.

4. CONCLUSION

The main focus of this article was the creation of mathematical models for the Galileo satellite navigation system's E5 measurement signal. The models were based on available information, and the process involved determining individual signal frequencies and visualizing their structure, as well as providing a block diagram of signal generation. The Galileo signal models' results can be used to assess the system's immunity to interference, and the images provided allow for a better understanding of E5 signal structures and interference. Future research can utilize these models to simulate intentional jamming, atmospheric influences on signal propagation, and monitor signal distortion when received by navigation receivers. Another key finding of the study is that adding artificial noise to the original signal significantly affects the signal structure, which may aid in designing new receivers capable of ignoring or removing this type of interference.

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