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# Analysis and Design of an Ultra-Wideband Non-coherent Transceiver for UWB Pulse Radio Communications in the Terahertz Band

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Interest in terahertz (THz) technology is related to various applications such as object detection, spectroscopy, security, and telecommunications. However, one of the challenges of THz technology is the implementation of effective communication between the transmitter and the receiver. Modulation technique like orthogonal frequency division multiplexing (OFDM) is already used in the THz band. However, the most widely used transmission method, on-off keying (OOK) scheme, presents several problems in high-rate data detection. In fact, the purpose of this work is to design in Matlab Simulink a transmission chain based on the energy detector, frequently used for transmitting radio pulses, since applications focused on the ultra-wide band are much less complex to implement and consume little power. In this regard, we present a delay-modified energy detector that will allow the sample to optimally select the maximum energy levels corresponding to the sending of logical bit 1 and logic bit 0. And we have chosen an energy detector with OOK modulation in the additive white Gaussian noise (AWGN) channel. The proposed system has a low cost, high performance and low power consumption, so it can be effectively used for a THz system.

**Keywords:** Non-coherent receiver, Energy detector, OOK, Additive white Gaussian noise (AWGN).

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## 1. INTRODUCTION

The interest in terahertz waves stems from their unique properties allowing to anticipate many applications in various fields [1-3]. THz waves have also been used for imaging since 1975. One of the interesting properties of THz is that several materials opaque to visible light are semi-transparent to THz waves. So, one can see through most non-metallic and non-polar materials. THz are also non-ionizing, i.e. their energy is too low to cause damage to the molecules that make up the human body (unlike, for example, X-rays). In the field of security, THz can therefore be used for the detection of weapons and explosives concealed on humans [4, 5]. It is also possible to combine imaging with THz spectroscopy, which then makes it possible to identify several hazardous materials having a unique THz signature. However, the applications of terahertz in imaging are limited by their high-water absorption [6-8]. The depth of penetration of THz into biological tissues, composed mainly of water, is therefore very low.

On the other hand, the absorption capacity of THz waves by water has other applications, such as the detection of cancerous tissues having a greater water content than healthy tissues. It is noted that THz communication in free space over long distances requires strong THz fields since the air always contains a certain level of humidity, which quickly attenuates the THz. As mentioned earlier, a high THz field is also necessary for the analysis of samples with a high-water content and for non-linear spectroscopy [9].

However, the most common method of THz detection, electro-optical sampling, is not suitable for high THz fields. In order to remedy this situation, other detection methods are needed [10-12].

Much research carried out in literature to present the interest of THz technology. Authors [13] have proposed a channel model for THz bands. They focused on the multipath effect produced in the THz propagation channel in [14] a data transmission technique for THz system is presented. Serghini et al. in [15] have propose a multiband OOK scheme to enhance transmission over THz bands. In [16], the authors propose a multiband OOK with noncoherent receiver for THz application.

## 2. SYSTEM MODEL

Ultra-wide band terahertz technology is a promising candidate for short range wireless communications in recent years [17, 18]. Terahertz band technology has attracted the attention of researchers because of its huge bandwidth which offers a very high resolution and a bit rate that can reach some gigabits per second since the channel capacity increases with the signal bandwidth according to the Shannon-Hartley theorem. Moreover, the spectrum of the ultra-wideband signal is below the noise floor of narrowband signals (Fig. 1), this characteristic allows ultra-wideband communications not to interfere with narrowband communications. So lately, academics are working on wireless communication systems at the terahertz (THz) frequency. However, the THz channel is a difficult environment for signal transmission.

Thus, the implementation of a THz communication system requires the study of modulation schemes in order to build a strong system that can support high data rate with low Bit Error Rate (BER).

For this reason, we proposed the architecture of the RI-UWB transceiver based on a non-coherent OOK modulation scheme, which consists of a UWB pulse generator that generates very short duration Gaussian pulses, a multiplier, a delay, an integrator and a squar-

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ing block and a sampler. Fig. 9 presents the proposed architecture under simulink of the Non coherent transceiver modified with a retarder which will allow the sampler to take in an optimal way the levels of maximum energies which correspond to the sending of the logical bit 1 and the logical bit 0. The analysis of the BER according to the proposed architecture is carried out in this paper. Also, we presented the results simulated with the software simulink (matlab) which shows the performance of the bit error rate, in a channel with additive white Gaussian noise.

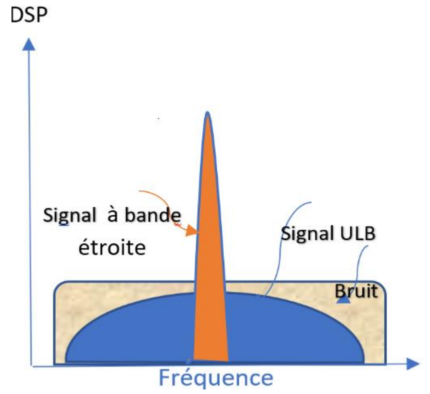



**Fig. 1** – Power spectral density

## 3. ULB SIGNAL AND TRANSMISSION CHANNEL

The waveform used is a Gaussian $A \cdot e^{-a \cdot t^2}$ multiplied by a signal $\cos(2\pi Ft)$ which transposes it to the frequency of $F = 300$ GHz, the signal of the Gaussian pulse in the time domain is defined by equation (1), and its representation in the time domain is illustrated by Fig. 2 and Fig. 3 represents its power spectral density or the constant a depends on the bandwidth $B$ of the signal for an attenuation of $X\_dB$ (equation 3).

$$p(t) = A \cdot \cos(2\pi Ft) e^{-at^2}, \quad (1)$$

$$P(f) = A\sqrt{\frac{\pi}{a}} \cdot e^{\frac{-(2\pi(f-F))^2}{4a}}, \quad (2)$$

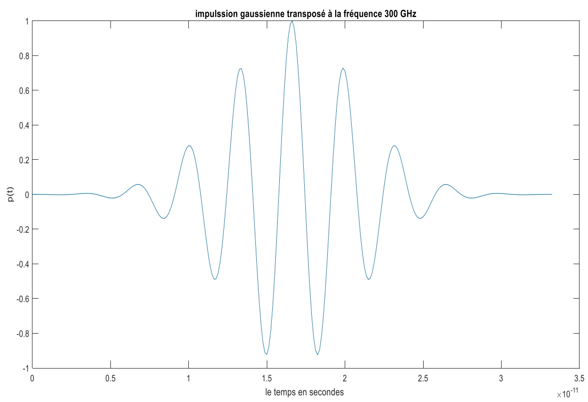



**Fig. 2** – Temporal representation of the pulse

$$a = \frac{\pi^2 B^2 \big|_{-X_{dB}}}{2\ln\left(10^{\frac{X_{dB}}{10}}\right)}. \quad (3)$$

We chose an additive white Gaussian noise channel to validate our simulation results.

Fig. 4 shows the effect of noise on the transmitted signal.

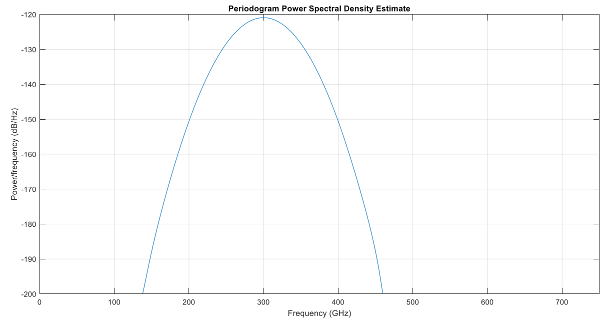



**Fig. 3** – Power spectral density of the Gaussian transposed in frequency

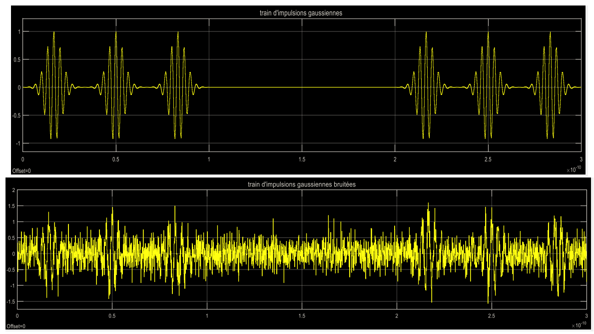



**Fig. 4** – Effect of the additive white Gaussian noise channel (SNR = 10dB) on a wave train

## 4. NON-COHERENT OOK TRANSMISSION SYSTEM

The type of modulation chosen in this work is the OOK modulation, in which the transmission of a pulse corresponds to the transmission of a logical 1 and the absence of a pulse corresponds to a logical 0. This type of modulation is best suited to the energy detection receiver, since it contains information on its amplitude rather than its phase, which offers a simple chain to realize and consumes little energy.

The non-coherent receiver is based on energy detection with a squared elevation block, followed by an integrator which has for role to integrate the square signal during the duration of a bit $T_b$ (Fig. 5), this detection represents an advantage compared to the coherent receiver. It is the absence of the synchronization signal which reduces the power consumption.

For the proposed OOK modulation, a bit 1 is encoded by the emission of three frequency-transposed Gaussian pulses of 300 GHz. At the output of the integrator, a scalar observation is available which corresponds to two assumptions:

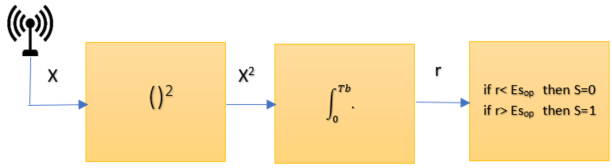



**Fig. 5** – Energy detector

$$\begin{aligned} H_0 &: r = \int_0^{Tb} n(t)\,dt \qquad bit\,0, \\ H_1 &: r = \int_0^{Tb} \left[x_d(t) + n(t)\right]^2 \quad bit\,1, \end{aligned} \tag{4}$$

where $x_d(t)$ and $n(t)$ represent the desired signal and noise, respectively.

The decision rule is to compare the observation r to a threshold energy $Es_{op}$. If the energy of the received signal is less than $Es_{op}$, the decision maker decides that the transmitted bit is the logical 0. If the energy of the received signal is greater than the threshold energy $Es_{op}$, the detector decides that the transmitted bit is the logical 1. However, there are several decision criteria between the two assumptions $H_0$ and $H_1$ that minimize the error probability to calculate the optimal threshold energy value.

The optimal threshold value $Es_{op}$ is obtained using the maximum likelihood (MV) criterion. The (MV) criterion is based on the probability density functions of the hypotheses. The hypotheses $H_0$ and $H_1$ have probability density functions (PDF), $P_0(r)$ and $P_1(r)$ respectively. The Gaussian approximation method was used to solve for the system error probability using OOK signals. Based on the central limit theorem, the PDFs of $P_0(r)$ and $P_1(r)$ are approximated by a Gaussian distribution [6] (Fig. 6). The threshold value approximation $Es_{op}$ can be calculated by solving the following equation:

$$\frac{1}{\sqrt{2\pi\sigma_0^2}} e^{-\frac{\left(Es_{op}-\mu_0\right)^2}{2\sigma_0^2}} = \frac{1}{\sqrt{2\pi\sigma_1^2}} e^{-\frac{\left(Es_{op}-\mu_1\right)^2}{2\sigma_1^2}} . \tag{5}$$

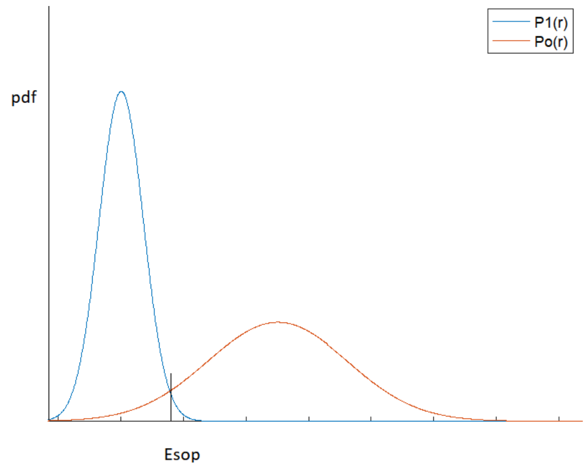


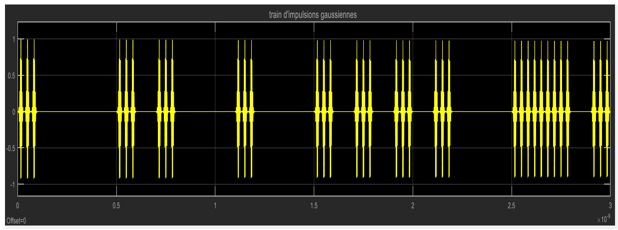

**Fig. 6 –** Probability density of the observation under the $H_i$ hypothesis, $i \in \{0, 1\}$

Such that $\left(\sigma_0^2, \mu_0\right)$ and $\left(\sigma_1^2, \mu_1\right)$ are the variance and mean value of $H_0$ and $H_1$ hypotheses respectively.

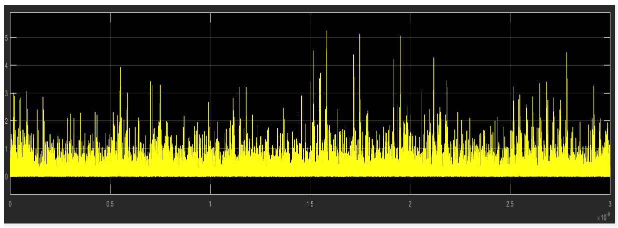
## 5. PROPOSED SYSTEM

The proposed architecture (Fig. 9) of the non-coherent energy detector is composed of a squaring block of ultra-wide band pulse modulated signal $x(t)$. Fig. 8 gives different steps to generate the signal for non-coherent receiver. Fig. 8 shows the simulated signal on each step which allows us to have a clear idea about the signal transformation for different steps. It can be observed from this figure that the signal is affected by Gaussian noise.

Then a delay of the integrated signal of a duration of $T_r = T_b/100$, and a sampler blocker which is going to play the role of a detector of envelope as shown in the Fig. 8c, and a decision organ.



a



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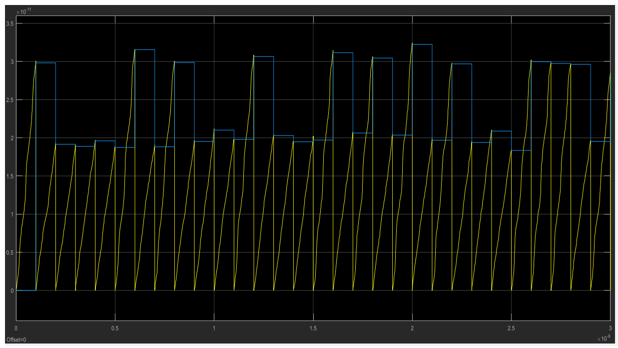

c

**Fig. 8** – UWB signals in the transmission and reception chain: (a) ULB signal without noise; (b) the output of the squaring block; (c) the output of sampler blocker

## 6. RESULTS AND SIMULATIONS

To validate the performance of the proposed circuit we first sent a test signal to estimate the statistical values of the variance and mean of the random variable $r$ under the two assumptions $H_0$ and $H_1$ for each value of SNR. Using equation (5) the optimal threshold energy $Es_{op}$ was determined. Fig. 10 shows the performance of the circuit in terms of the bit error rate, it can be seen that the optimal threshold $Es_{op}$ can significantly optimize the performance of communication system by

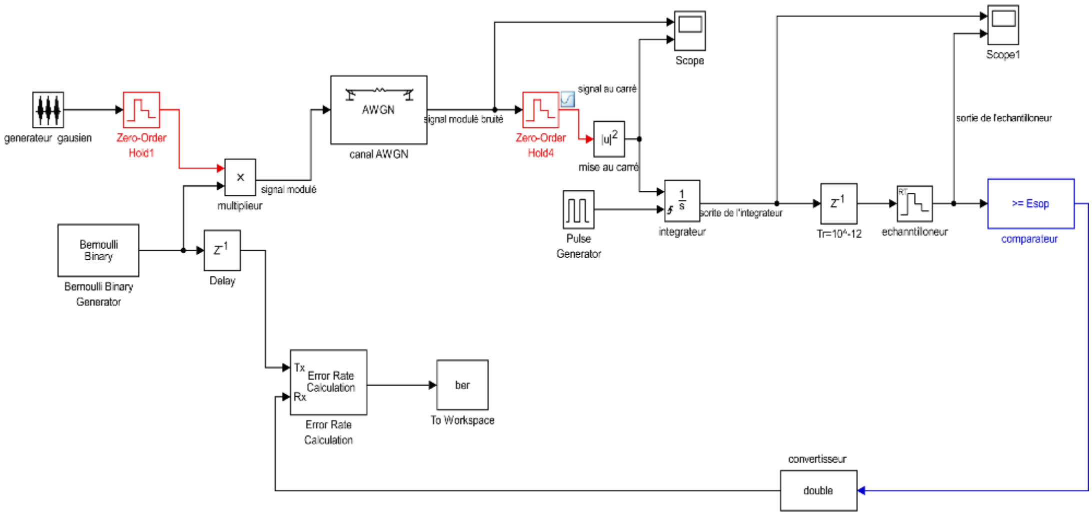


**Fig. 9 –** The proposed architecture of the transmission and reception chain in Simulink

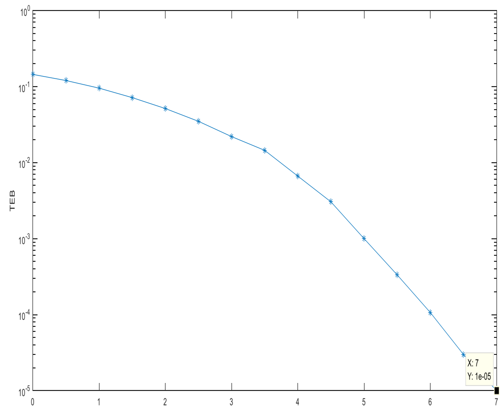


**Fig. 10 –** Performance of the transmission and reception chain in terms of bit error rate as a function of SNR

significantly reducing the BER of system. For example, when the SNR = 7dB the BER = $10^{-5}$ which is relatively very low.

The proposed system can be a good choice for THz application because of its low cost and simplest structure as well as low consumption. So, it is very suited for transition over wireless system in which energy consumption is considered as a main problem. For these raisons we suggested the proposed system.

## 7. CONCLUSIONS

We have designed on Matlab Simulink software a simple architecture to improve the binary error rate in the presence of white Gaussian noise. and to do this we based on a statistical study to calculate the threshold energy $Es_0$ and we introduced a delay time $T_r = 10^{-12}$ s = $T_b$/100 at the output of the integrator which allowed the sampler to well sample the maximum values of the energies which correspond to the sending of the logical bit 1 or the logical bit 0. Finally, our solution is simple enough to be implemented in devices with low complexity and low power. This fits well with the simplicity of the systems.

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# Аналіз та проектування надширокосмугового некогерентного трансивера для UWB імпульсного радіозв'язку в терагерцовому діапазоні

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Інтерес до терагерцової (THz) технології пов'язаний з різними додатками, такими як виявлення об'єктів, спектроскопія, безпека та телекомунікації. Однак однією з проблем THz технології є реалізація ефективного зв'язку між передавачем і приймачем. Техніка модуляції, наприклад, мультиплексування з ортогональним поділом частот (OFDM), вже використовується в THz діапазоні. Однак найбільш широко використовуваний метод передачі, а саме передача з амплітудною модуляцією (OOK), створює кілька проблем при виявленні високошвидкісних даних. Насправді, метою роботи є розробка в Matlab Simulink ланцюга передачі на основі детектора енергії, який часто використовується для передачі радіоімпульсів, оскільки програми, орієнтовані на надширокий діапазон, набагато менш складні для реалізації та споживають мало енергії. У зв'язку з цим ми представляємо детектор енергії з модифікацією затримки, який дозволить зразку оптимально вибрати максимальні рівні енергії, що відповідають відправці логічного біта 1 і логічного біта 0. Ми обрали детектор енергії з модуляцією OOK в каналі адитивного білого гаусова шуму (AWGN). Запропонована система має невелику вартість, високу продуктивність і низьке енергоспоживання, тому її можна ефективно використовувати для THz системи.

**Ключові слова:** Некогерентний приймач, Детектор енергії, OOK, Адитивний білий гаусів шум (AWGN).