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UWB Coherent Receiver Performance in a Vehicular Channel

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ABSTRACT

Due to the very short duration of the UWB pulse, its energy is very low, which requires the receiver to have a very good sensitivity for better signal detection, but this parameter is always in contradiction with low power consumption. Depending on the type of application we can consider either coherent or non-coherent detection. The coherent architecture is based on the correlation of the received pulse with a locally generated signal called "Template". The non-coherent architecture is based on the recovery of the energy of the received pulse. In this paper, we propose a comparison of these two main receiver families in order to justify our choice of a coherent receiver for UWB detection in the road domain.

Key words: pulse, UWB, coherent receiver, non-coherent receiver

1. INTRODUCTION

The rapid evolution of road detection technologies [1][2][3][4][5] in terms of speed, complexity and diversity of the environments encountered poses challenges for manufacturers to ensure the compromise between complexity, efficiency and cost. This leads them to seek high-performance solutions for effective detection at a lower cost.
There are many technologies for detecting obstacles in the urban area, but UWB technology[6][7][8] remains among the solutions that can effectively meet a number of needs in this field, thanks to its ability to withstand disturbances due to its very high bandwidth and the possibility, not only to detect a human presence, but also to locate it ... The principle of UWB detection [9][10] is based on the emission of low power signals with a very wide bandwidth, allowing to obtain high data rates and also distance measurements; separating the obstacle from the UWB radar [11][12][13]; very accurate. At reception, the signals can be received in different ways using two main types of receivers: either coherent UWB receivers using the correlation principle [14]; or non-coherent receivers [15] [16] based on the detection of energies
Numerous works concerning the performance of UWB radio receivers [17][18][19] were presented; Most of the UWB receivers discussed in the literature are non-coherent receivers which can offer a good compromise between performance and complexity [20] but the good performance of these receivers is penalized by their low sensitivity; moreover, this type of receiver operates without information on the state of the channels [21], which can reduce their performance in certain environments, in particular in areas where there is a large variation in propagation phenomena; like urban areas for example. For UWB detection systems used in vehicular environments which require prior recognition of the state of the channel due to phenomena of multipath, distortion, pathloss..., the coherent receiver may be the best choice, thanks to a very good sensitivity to noise [22] [23].
In this paper we describe a reduced-complexity coherent receiver for a UWB pulse signal. The proposed receiver works with channel state information by exploiting the multipath diversity offered which makes it suitable for the V2V communication context.
The first part of this article deals with a comparison of UWB receivers to justify the choice of the coherent receiver. In the second part we discuss the signal model used and the type of channel chosen, and then we present the coherent receiver before discussing the results of the simulation, and finally a conclusion.

2. UWB RECEIVERS

In free space, the received signal is noisy and attenuated due to propagation phenomena, which makes the task of traditional receivers difficult [24]. In the case of UWB signals, two main reception techniques can be applied: coherent reception [25], based on correlation, and non coherent reception [26], based on energy detection. Each family of these receivers has advantages and disadvantages on which we have based our choice of receiver.

2.1 Coherent Receiver

Coherent reception is based on the principle of signal delay recognition using correlation with a reference signal which provides good performance, but whose complexity is a major disadvantage [26] [27][28].

The coherent receiver is based on the correlation principle, and requires storage in memory of the phase recording of all the transmitted pulses which will be considered as templates. The reception chain by correlation consists of a bandpass filter which attenuates the unwanted signal located outside the useful band, a correlator operating on the filtered signal and a decision element which makes a choice on the information received according to the result of the correlation.

The following figure1 shows the different components of a coherent receiver.

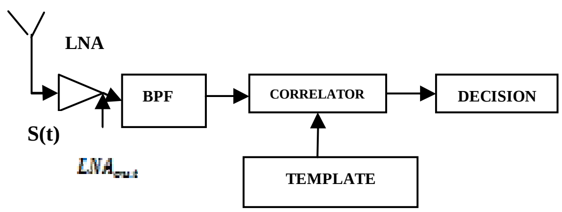

Figure 1: The Block Diagram of the Coherent Receiver

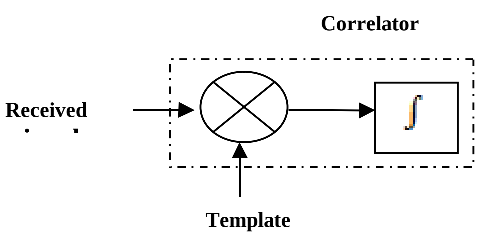

Figure 2: The Block Diagram of the Correlator

The correlator (figure 2)consists in multiplying the received signal

R (t) by the template T (t), this product is applied to the input of the integrator, whose output is:

$$R_T(t)= \int_0^t R(t) * T(t) \quad (1)$$

Coherent integration improves the signal-to-noise ratio because the sum of the signal voltages due to coherent pulse integration is the algebraic sum of the individual voltages of the integrated pulses. If the received pulses are coherently integrated, the output signal will therefore have signal-to-noise power ratio N times greater than that of a pulse [29][30].

$$\left(\frac{S}{N}\right)_N = \sum_{k=1}^{N} \left(\frac{S}{N}\right)_K \quad (2)$$

To demonstrate the improvement of the signal to noise ratio in the case of coherent integration, we consider a radar return signal.

$$R(t) = S(t) + n(t) \quad (3)$$

With S (t) is the return of the radar signal and n (t) is an additive noise signal white with variance σ^2.

Finally, the coherent integration of n_p pulses is given by [21] [29]:

$$I_{n_p}(t)= \frac{1}{n_p} \sum_{m=1}^{n_p} R_m(t) = \sum_{m=1}^{n_p} \frac{1}{n_p} [s(t) + n_m(t) = s(t) + \sum_{m=1}^{n_p} \frac{1}{n_p} n_m(t) \quad (4)$$

Here the total noise power is equal to σ^2. More precisely,

$$\sigma^2_{n_p} = E[(\sum_{m=1}^{n_p} \frac{1}{n_p} n_m(t))(\sum_{l=1}^{n_p} \frac{1}{n_p} n_l(t))^*] \quad (5)$$

$$\sigma^2_{n_p} = \frac{1}{n^2_p} \sum_{m,l=1}^{n_p} E[n_m(t) n_l^*(t)] = \frac{1}{n^2_p} \sum_{m,l=1}^{n_p} \sigma^2_{ny} \cdot \delta_{ml} = \frac{1}{n_p} \sigma^2_{ny} \quad (6)$$

Where $\sigma^2_{n_p}$ is the power of single impulse noise and δ_{ml} is zero for m ≠ 0 and the unit for m=0. According to Eqs (4) and (6) the signal power after the coherent integration is constant, while the noise power is reduced by the factor $\frac{1}{n_p}$. Therefore, the SNR after coherent integration is improved by n_p[29].

Coherent reception requires high power consumption, yet it offers a better error bit detection rate, a significant improvement in the signal-to-noise ratio and better sensitivity [28], and thanks to the use of all phase information; it allows to extract the maximum amount of information using a low gain value for the LNA.

2.2 Non Coherent Receiver

Several non coherent receiver architectures exist [32].They are all based on a recovery of the energy of the received pulse. This method of reception is the least complex.

The principle of non coherent reception is based on the integration of the instantaneous power [33] of a pulse during its duration Tτ. Its complexity consists in the analysis of the non-linearities of the squarer and of the integrator [34].

The following figure 3 shows the block diagram of a non coherent receiver based on an energy detector.

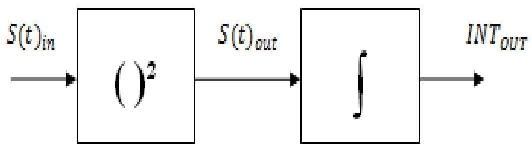

Figure 3: Block Diagram of a Non Coherent Receiver based on Energy Detector.

This detection consists in squaring the received pulse which will be integrated later

$$S(t)_{out} = (S(t)_{in})^2 \quad (7)$$

$$\text{Energy} = INT_{out}(t) = \int_0^{\tau} S(t)_{out}(t)dt \quad (8)$$

Non-coherent integration remains less effective than coherent integration. In fact, the gain from non-coherent integration is always less than the number of pulses integrated in a non-coherent manner. This loss of integration is called post-detection loss of detection [29][35].

The $\left(\frac{S}{N}\right)_N$ required to achieve a specific detection probability with a particular false alarm probability when the n_p pulses are integrated non-coherently [29].

$$\left(\frac{S}{N}\right)_N = \left(\frac{S}{N}\right)_1 * I(n_p) \quad (9)$$

Where $\left(\frac{S}{N}\right)_1$ the signal-to-noise ratio of a single is pulse and $I(n_p)$ is the integration improvement factor.

The value of the integration improvement factor can be calculated based on the value of probability of detection and that of the false alarm according to the following model [28][33].

$$[I(n_p)] = 6.79(1+0.253P_d)\left(1\frac{\log\frac{1}{P_{fa}}}{46.6}\right)\log(n_p)$$
$$(1-0.140\log(n_p) + (0.018310\log(n_p)^2)$$

(10)

And the non-coherent integration loss in dB is given by the following equation [28]:

$$[L_N]_{dB} = 10\log(n_p) - [I(n_p)]_{dB} \quad (11)$$

The pulses integrated with a non-coherent integration suffer losses that will increase with the number of pulses emitted.

Non-coherent receivers are recognized by their low energy consumption and less complex architecture, however they have many disadvantages such as low sensitivity, problems of integration losses, short range, and they remain less effective for real detections because they only use envelope information and not phase information [27][33].

2.3. Choice of Receiver

In our case, one of the criteria for choosing the right receiver architecture for the vehicular environment is the best sensitivity of the system beyond its power consumption and simplicity. By comparing the receivers studied, we can see that the correlation coherent receiver is the best for our application because despite its design difficulty, it has a very good sensitivity which allows maximizing the probability of detection in urban areas.

3. RESULT AND DISCUSSION

3.1 Signal Model

Considering an impulse signal (t) generated on transmission; this signal is modeled as the first derivative of the Gaussian impulse (monocycle). Its temporal representation is given by the following equation:

$$S(t) = -2a\left[\left(\frac{t}{\tau^2}\right)exp\left[-\left(\frac{t}{\tau^2}\right)\right]\right] \quad (12)$$

Where a is a normalization constant and τ is the constant used to adjust the width of the pulse.

The following figure 4 represents the pulse emitted in the time domain.

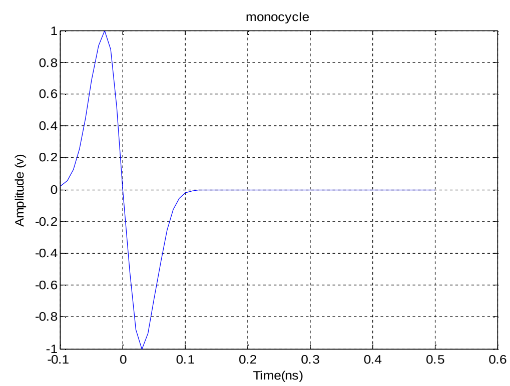

Figure 4: Time Representation of the Emitted Impulse

Assuming that the signal is transmitted on a multipath vehicle channel with an impulse response [36].

This channel follows a Rayleigh distribution and models the temporal dispersion of the time-varying vehicular channel which is used in the case where there is no direct line of sight (NLOS propagation) [37][38]. It is represented by the following mathematical formula [39].

$$h(\tau,t) = \sum_{k=1}^{K} a_k^t \, \delta(\tau - \tau_k) \quad (13)$$

With k: number of echoes and a_k^t are uncorrelated Gaussian random processes [39].

3.2. Received Signal

The received signal corresponds to the channel transformed transmitted signal, which is characterized by the combination of the noise with the convolution between the transmitted signal and the channel impulse response:

$$R(t) = s(t)*h(t) + n(t) \quad (14)$$

With s (t) is the transmitted signal, h (t) represents the impulse response of channel v2v and n (t) is the Gaussian additive white noise.

The following figure 5 shows the signal at the output of the vehicle channel.

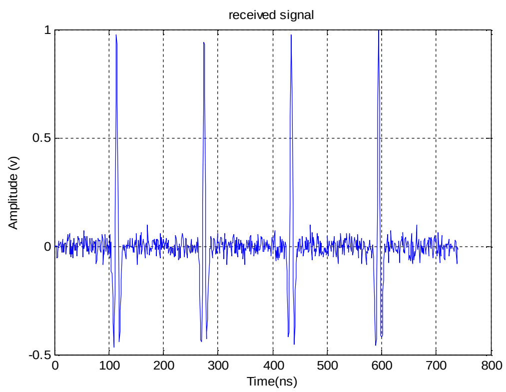

Figure 5: The Signal Received

3.3. Coherent Reception

Coherent reception is based on the correlation principle, in which case the transmitted pulses always start at the same phase of their reference cycle. It consists in multiplying the received signal r (t) by the template T (t), and then applying this product to the input of the integrator according to the following formula:

$$R_T(t) = \int_{t1=0}^{t} R(t)s(t).dt1 \quad (15)$$

The figure 6 below shows the result of multiplication of the received signal with the template.

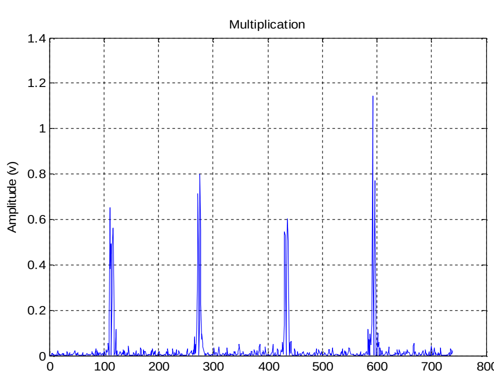

Figure 6: Multiplication of the Signal Received with the Template

Integration into a coherent receiver requires that the phase of the received signal be preserved. That is to say that the phase of the signal received must remain constant relative to the phase of the template [21] in order to be able to extract as much information as possible with better precision.

In the following figure 7, we present the result of the integration:

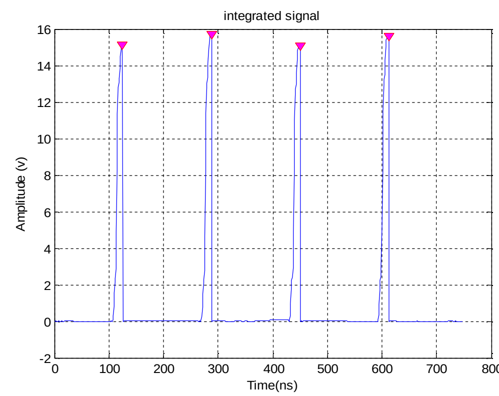

Figure 7: The Integrated Signal

Finally, the comparator allows the comparison of $R_T(t)$ with a threshold: if $R_T(t)$> threshold, we decide that the expected signal is indeed present at the input of the receiver and that it is absent otherwise.

In our case, we were able to detect all the impulses emitted. That's because they exceed our detection threshold of 12. This threshold can be adjusted at will and can take a value as positive as zero or negative.

4. CONCLUSION

In this article, we have compared the different UWB receivers, then presented and simulated the different parts of a coherent UWB receiver; in order to develop a UWB radar receiver capable of detecting targets in an urban environment reliably and accurately at low cost.

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