Avoidance of narrowband interference in UWB wireless sensor device using square low technology

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Abstract. Impulse radio ultra-wideband system has been adopted in wireless sensor networks research due to its high performance in conditions of active influence of various noises and interferences, the presence of reflections, etc. In this paper, this system represents a transmitter based on the controller STM32 and a receiver implemented using blocks of analog and digital processing based on FPGA. This paper focuses on a realisation of an additional device that can provide the avoidance of narrowband interference in ultra-wideband wireless sensor network system to improve a value of bit error rate. For this purpose, a real device with using square low technique has been developed. According to the results of experiments this approach enables to improve a dependence of the bit error rate on the signal-to-noise ratio.

1. Introduction

In recent years, wireless sensor networks (WSN) has attracted more attention by connecting information world and physics world together. The main task of the sensor networks is the control of the parameters of the systems, for example, a pressure, the temperature etc. A node of sensor network is a smart transmitter that provides the preliminary data processing. Also due to an additional requirement to ability to minimize power consumption in order to increase the lifetime of each transmission module, each smart transmitter can provide energy harvesting by thermal gradient [1-3]. The mentioned development directions of UWB WSN systems may find application in various fields [4-8].

Such sensor networks are often installed in complex industrial environment. The main area of implementation is the automotive industry, aircraft and shipbuilding. It is characterized by the presence of various reflections due to influence of a large number of metal surfaces. Many literatures shows that Ultra-Wideband (UWB) technique is one of the most effective technologies for WSN [9, 10]. A very short duration of UWB impulse provides a reduction of intersymbol interference in condition of multipath signal propagation.

Nevertheless, the effect of narrowband interference can significantly increase a bit error rate (BER). Therefore, the sensor network system will not be able to provide the declared performance.

Thus, the goal of this work is to develop the additional device that can provide a decrease of effect of narrowband interference (NBI) on UWB wireless sensor network system.

This paper is organized as follows: in the next section we present a description of a real UWB wireless sensor network system. Section III describes the model of technology for narrowband
avoidance and real device that can be implemented in practice. The experiments with using all system are presented in section IV. Conclusions and future work are given in Section V.

2. UWB wireless sensor network system
The network system consists of receiver module and transmitter module, which uses UWB signals for transmission of any information represented in binary form. The transmitter and receiver module structure with image of real device are shown in figure 1 and 2 respectively.

The transmitter of this system is based on the controller STM32. The following steps must be completed before a signal emission: calculation an 8 bits checksum, extension with a code sequence of 32 elements, adding a 1000 elements preamble, modulation stage [11]. For propose of reduction of complication and cost of receiving module structure the on-off keying (OOK) modulation is used.

![Figure 1. The transmitter module structure.](image1)

Initially, on the received side low-noise amplifier (LNA) executes gain of received signal. Then comparison between the received signal level and the reference voltage level is implemented using comparator. If the received signal after the LNA exceeds the reference voltage level, a high voltage level corresponding to a logical 1 is recorded with the D-trigger. An FPGA is used for further processing: demodulation, detection of packets using the preamble, inverse procedure of extension and comparison of checksums [12].

![Figure 2. The receiving module structure.](image2)

3. Square law approach
The following technology for avoidance of narrow band interferences can be employed. When the UWB pulse is transmitted, the received signal can be written by formula:

\[ r(t) = p(t) + n(t) + i(t), \]  

(1)

where \( p(t) \) is a received UWB pulse given by formula:

\[ p(t) = a(t) \cos(2\pi f_{UWB} t), \]  

(2)

where \( a(t) \) is the baseband equivalent of \( p(t) \).
Before the signal feeds to the UWB receiver, it can be processed in a square-law device. Typically, the power of an NBI is much higher than that of the background noise; hence, the effect of background noise can be neglected. Thus, after the square low device, the signal can be represented as sum of square of the UWB pulse, square of the NBI and product of the UWB pulse and the NBI. The first term in frequency domain is located in $[0, \Delta f_{\text{UWB}}]$ and $[2f_{\text{UWB}}-\Delta f_{\text{UWB}}, 2f_{\text{UWB}}+\Delta f_{\text{UWB}}]$. The second term in frequency domain is located in $[0, \Delta f_{\text{NBI}}]$ and $[2f_{\text{NBI}}-\Delta f_{\text{NBI}}, 2f_{\text{NBI}}+\Delta f_{\text{NBI}}]$. A useful signal is located at DC in coordinate axes as shown in figure 3. Thus, after the square low processing it is advisable to use a bandpass filter, which will remove the high frequency component and NBI component at DC. The bandpass of the filter should be approximately equal $[\Delta f_{\text{NBI}}, \Delta f_{\text{UWB}}]$ ([13, 14]).

![Figure 3. Power spectrum of the received signal after square low device.](image)

The real device was made using the structure, that represented in figure 4. Instead of the passband filter, a low-pass filter with a cut-off frequency equal 600 MHz and a high-pass filter with a cut-off frequency equal 50 MHz were used. Also due to the large filter attenuation coefficient the filtered UWB signal feeds to amplifier. The real scheme for avoidance of narrowband interference is shown in the figure 5. Thus, the main characteristics of the real UWB wireless sensor network system should be improved with using the square low technique.

![Figure 4. The structure of module of square low processing.](image)

![Figure 5. The real scheme for avoidance of narrowband interference.](image)

The following experiments were carried out to confirm the improvement of characteristics.
4. Experiment description

The testing setup represented in figure 6 were realized. During the experiment, the probability of bit error and value of signal to noise ratio was recorded. Additional error control mechanisms are disabled.

The massages with same content is transmitted to estimate the value of bit error probability. Physical layer packet rate is 100 packets per second. The long of each record is equal 10 minutes. That corresponds to the transfer of 60000 packets (2,34·10⁶ bits). The value of the signal-to-noise ratio is controlled using a set of attenuators or changing the distance between transmitter’s antenna and receiver’s antenna.

On the receiving side data is saved on PC and then processed in Matlab environment. Also the Agilent Technologies DSO9104A oscilloscope was used to monitor the experiment and record the waveform to estimate the signal-to-noise ratio. Also the reference value of voltage of comparator \( U_{\text{ref}} \) was set equal 1,412 mV and the threshold value for receiving the preamble \( Q \) was set equal 511 elements (half of length of the preamble).

Let us consider estimation of signal-to-noise ratio (SNR). The following method for estimating of SNR is proposed. Signal constitutes a UWB pulse, \( s(t) \). It is sampled at \( 1/T_s \) by oscilloscope. We define the mean value of signal power, \( P_s \), as [15]:

\[
P_s = \frac{1}{N_s} \sum_{i=0}^{N_s-1} s_i^2,
\]

where \( N_s \) is the number of samples.

The received signal represents a mixture of a useful signals \( s(t) \) and a random noise signals \( n(t) \). Thus, we recorded a waveform on the useful signal free space to estimate the mean value of noise power, \( P_n \).

\[
P_n = \frac{1}{N_s} \sum_{i=0}^{N_s-1} n_i^2.
\]

Then we define signal-to-noise ratio, SNR, as:

\[
SNR = \frac{P_s}{P_n}.
\]

Figure 6. Testing setup.
The proposed technique of measurement of SNR will be used during the experiment.

5. Results
The results are obtained according to the experiment description above. Figure 7, depicts the dependence of the bit error rate (BER) on the signal-to-noise ratio. Initially, were considered the case with using square-low technique, that represented by the solid line in the figure. Then were considered the case without using square-low technique, that represented the by the dash line in the figure. As observed in figure, a significant gain of bit error rate was obtained. Besides, for case of simple approach there is area between 16 dB and 24 dB in which the value of bit error rate can’t be lower than the value of bit error rate equal $10^{-5}$. However, for case of using square low technique this barrier is eliminated. Therefore, the experiment show, that square-low technique can help to avoid the narrowband interference in the real UWB wireless sensor device.

![Figure 7. Plot for value of SNR vs BER with using the square low technique and without using the square low technique for case of $Q = 511$ elements (half of length of the preamble) and $U_{\text{ref}} = 1,412$ mV.](image)

In this experiment was used the simple passive high-pass filter of second order. Thus, if you increase the order of the filter, the slope of frequency response will be steeper and, therefore, the value of BER will be improved even more.

In further work, the order of the filter will have to be increased, the gain of the amplifier will be increased, and all elements will be implemented on a common board.

6. Conclusion
In this paper, the realization of device, which can be employed in UWB wireless sensor network system for avoidance of narrowband interference, has been proposed. The basic of this realization is square-low technique. The experiment with using the real UWB wireless sensor network system demonstrates the improvement of value of bit error probability to compare with simple approach.

This real UWB system with using square-low technique can be apply in condition of complex industrial environment, which characterized by reflections due to influence of a large number of metal surfaces, for instance, in the automotive industry, aircraft, shipbuilding, etc. In addition, it can be apply in condition, which is characterized by presence of various narrowband signals.

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