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UWB Radio: Digital Communication with Chaotic and Impulse Wavelets

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SUMMARY Radio communications via channels already occupied by traditional telecommunication systems can be achieved by using ultra-wideband (UWB) radio where extremely wideband wavelets are used in order to reduce the power spectral density (psd) of transmitted signal. Since the recovery of these UWB carriers is not feasible, noncoherent demodulation techniques have to be used. The letter evaluates and compares the noise performances of the feasible noncoherent UWB modulation schemes, namely, that of the noncoherent pulse polarity modulation and the transmitted reference system.

key words: *digital communication, chaotic wavelet, UWB radio*

1. Introduction

The digital information to be transmitted is mapped to wideband wavelets of very short duration in UWB radio. The wavelets are fixed waveforms and chaotic signals in impulse radio [1] and chaotic UWB radio, respectively.

Since the recovery of UWB wavelets is not feasible, noncoherent demodulation schemes have to be used: (i) Pulse Polarity Modulation (PPM) with one wavelet and template detection, and (ii) Transmitted Reference (TR) system with two wavelets and autocorrelation detection. This letter compares the bit error rate (BER) of these systems.

2. PPM with Template Detection

In pulse polarity modulation one arbitrary but fixed waveform, denoted by $g(t)$, is used to carry the digital information [2]. Because of its excellent spectral properties, a bell-shaped Gaussian impulse is used [1].

In pulse polarity modulation, the information is carried by the sign of wavelet. Let $r_m(t) = g(t) + n(t)$ and $\tilde{r}_m(t) = \tilde{g}(t) + \tilde{n}(t)$ denote the received noisy signal before and after channel filtering, respectively. The information $\hat{b}_m$ is recovered by correlating $\tilde{r}_m(t)$ with a template signal $p(t)$ as shown in Figs. 1 and 2, where z_m is the observation signal.

The template signal is a windowing function

$$p(t) = \begin{cases} \frac{1}{\sqrt{\tau}}, & \text{if } |t| < \frac{\tau}{2} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where τ is the observation time period.

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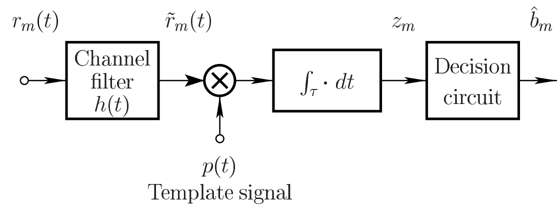

Fig. 1 Detection of pulse polarity modulation with a template signal $p(t)$.

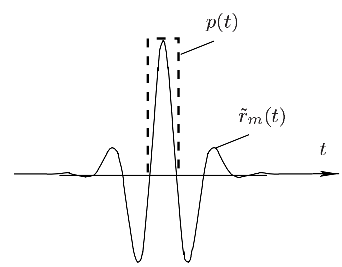

Fig. 2 Perfect alignment of received and template signal in a noise-free ideal channel where $\tilde{r}_m(t) = r_m(t) = g(t)$.

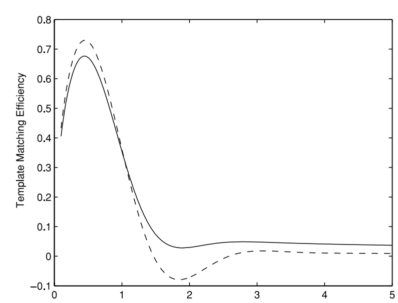

Fig. 3 Template matching efficiency as a function of the width of template signal. The RF bandwidths of bell-shaped Gaussian impulses are 2 GHz (dashed curve) and 2.5 GHz (solid curve).

The drawback of template detection is that the demodulator is very sensitive to errors in window width (see Fig. 3) and timing. Any error reduces the separation of message points in the observation space and results in a considerable performance degradation.

The BER of noncoherent pulse polarity modulation built with template detection is given by [2]

$$P_e = \frac{1}{2}\text{erfc}\left(e_{tm}\sqrt{\frac{E_b}{N_0}}\right) \tag{2}$$

where e_{tm} denotes the template matching efficiency which

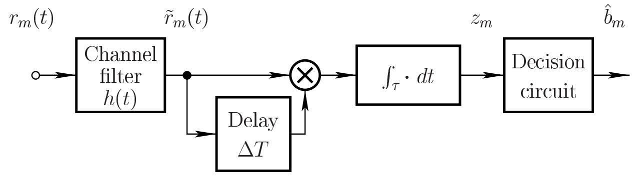

Fig. 4 Block diagram of TR autocorrelation receiver.

is, as shown in Fig. 3, a measure of timing errors.

3. Transmitted Reference (TR) System

In the TR system two wavelets, called chips, are used to transmit one bit information. The first chip serves as a reference, while the second one carries the information. Bit 1 is sent by transmitting the chip twice in succession. For bit 0, the reference chip is transmitted, followed by an inverted copy of the same signal.

The reference chip also serves as a test signal used to measure the actual channel characteristics. The TR systems are very robust, they can be used even in a time-varying channel.

Due to the special structure of TR signal, the information bits may be recovered from the sign of correlation measured between the reference and information bearing chips as shown in Fig. 4.

In contrast to template detection, in the autocorrelation receiver a *noisy* reference chip is correlated with a *noisy* information bearing one. The BER is obtained as

$$P_e = \frac{1}{2^{2B\tau}} \exp\left(-\frac{E_b}{2N_0}\right) \times \sum_{i=0}^{2B\tau-1} \frac{\left(\frac{E_b}{2N_0}\right)^i}{i\,!} \sum_{j=i}^{2B\tau-1} \frac{1}{2^j} \binom{j+2B\tau-1}{j-i} \qquad (3)$$

where τ denotes the energy capture time of autocorrelation receiver and $2B$ is the RF bandwidth of channel filter [3].

4. Comparison of the Noise Performances

The noise performance of pulse polarity modulation implemented with template detection is obtained from (2). Figure 5 shows the noise performance for different channel bandwidths and template matching efficiency.

The noise performance of a TR system built with an autocorrelation receiver, obtained from (3), is shown in Fig. 6.

5. Conclusions

The main advantage of template detection is that the template signal is a noise-free signal, its application results in a better noise performance if the template is perfectly matched to the UWB wavelet. However, even a small error in timing corrupts the noise performance, it may even prevent the communications. Because the UWB radio operates in the microwave frequency region, it seems to be very hard to fulfill the strict timing requirements.

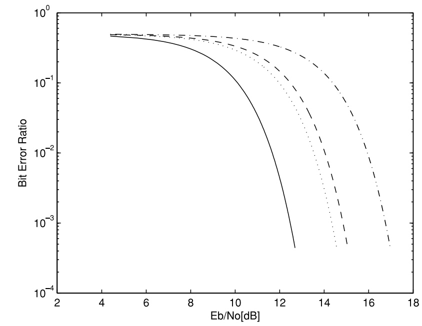

Fig. 5 Noise performance of pulse polarity modulation built with template detection. Solid curve: $2B$=2 GHz, e_{tm}=0.69; dotted curve: $2B$=2 GHz, e_{tm}=0.40; dashed curve: $2B$=500 MHz, e_{tm}=0.35 and dash-dotted curve: $2B$=500 MHz, e_{tm}=0.20.

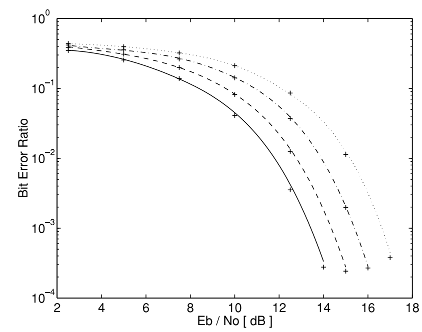

Fig. 6 Noise performance of a TR system built with autocorrelation receiver. From left to right $2B\tau$ is 8.5, 17, 34 and 68.

FM-DCSK and the TR modulation schemes offer an alternative noncoherent UWB modulation scheme that may be used with either chaotic or deterministic wavelets. TR system is very robust against the timing error and a TR signal may be demodulated by a simple autocorrelation receiver.

Comparing Figs. 5 and 6 we conclude that the noise performances of PPM and TR systems are very similar, for example, a PPM system with a timing error of 0.1 ns and a TR system with $2B\tau = 17$ have almost identical BER. Its value is 10^{-3}.

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