International Journal of Navigation and Port Research
Vol.31, No.2 pp. 159~163, 2007 (ISSN-1598-5725)

Performance Analysis of TH-BPPM and TH-BPAM UWB System and the Applications in Data and Image Transmission

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Abstract : *In this paper, we mainly analyze the performance of two ultra wideband communication systems, the classical Time Hopping Binary Pulse Position Modulation (TH-BPPM) UWB system and the Time Hopping Bipolar Pulse Amplitude Modulation (TH-BPAM) UWB system. The performance of TH-BPPM and TH-BPAM is analyzed in detail under an ideal AWGN channel and a correlation receiver. We use the power spectral density function to get the expression of BER of these two UWB systems. It yields simple and exact formulas relating the performance to the system parameters. The analysis shows that TH-BPPM suffers performance degradation with respect to TH-BPAM. Furthermore, we give the computer simulation of both data and image transmission and our simulation results also prove our theoretical analysis.*

Key words : *Ultra wideband (UWB), Time hopping binary pulse position modulation (TH-BPPM), Time hopping bipolar pulse amplitude modulation (TH-BPAM)*

1. Introduction

Ultra Wideband (UWB) technology proposed in (Scholtz, 1993) is currently being investigated as a promising solution for high-capacity wireless personal area network (WPAN). The very small power spectral densities (PSD) of UWB systems ensure only minimal mutual interference between UWB and other communication applications(Jang, 2006) The high data transmission rate makes UWB technology attractive for multimedia communications.

Much interest has been aroused in the UWB system to replace the short-range wireless communication system such as Bluetooth, Zigbee and WLAN etc. Also, the UWB system extends its application to Home Network, AV machinery, wireless headset, wireless 1394, and wireless USB. Furthermore, with high precision ranging and positioning characteristics, the UWB technique would be a promised candidate for in-ship short-range wireless networks, collision avoidance radar operating on 22GHz and 70GHz radio frequency, and construction of an in-ship-asset management system by using its ranging properties.

Several modulation techniques have been proposed for UWB signals, such as pulse position modulation (PPM) and a variety of pulse amplitude modulations (PAM), including binary phase-shift keying (BPSK) and on - off keying (OOK). TH combined with PPM was originally proposed for UWB systems (Scholtz, 1993)(Win and Scholtz, 1998). Currently, TH-BPAM UWB systems get little attention comparing with the TH-BPPM UWB systems, although it has some characteristics in some conditions, such as simplicity and better performance (Piazzo, 2004)(Yue et al., 2003). Analysis of the performance for TH-BPPM UWB systems and TH-BPAM UWB systems, in terms of bit-error rate (BER) under AWGN channel, is given here.

Our purpose is to provide an analytical method for calculating the average probability of bit error of UWB systems, and then to evaluate the performances of different UWB modulation schemes in the general case. In this paper, we derive the average BER expressions for TH-BPPM and TH-BPAM UWB systems in an additive white Gaussian noise (AWGN) environment based on a power spectral density function (PSD) technique and also use UWB system with image transmission to compare the performance. The AWGN channel model is important in its own right for some UWB applications and is a necessary intermediate step for future work. We evaluate precisely the performances of the two kinds of UWB systems employing BPPM and BPAM scheme and compare the average BER of these systems. The comparisons, based on the theoretical analysis, provide important and valuable suggestion for choosing appropriate UWB modulation schemes in practical applications.

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2. System Model

The data bit waveform employed to transmit the *k*th bit can be compactly written as follows:

$$g_{c_k}(t) = \sum_{n=0}^{N_s-1} w(t - nT_f - c_{k,n}T_c) \tag{1}$$

where $w(t)$ is the short pulse, called the monocycles with duration of T_w such that $\int_{-\infty}^{\infty} w(t)dt = 0$. T_f is the frame time, we set that there are N_s pulses per frame, $c_k = \{c_{k,0}, \cdots c_{k,N_s-1}\}$ is the *k*th time hopping sequence with period N_p and $0 < c_k < N_h$, T_c is the time-shift unit incurred by the TH sequence. We assume that the energy of both waveforms is normalized to unity, implying that the energy of the monocycle is normalized to $1/N_s$.

In order to transmit a sequence of i.i.d.(identity independent distribution) bits b_k uniformly distributed in $\{+1, -1\}$, the amplitude of the data bit waveform is modulated by the bit, realizing a BPAM transmission and yielding the following transmitted signal:

$$\begin{aligned} s(t) &= \sqrt{E_b} \sum_{k=-\infty}^{\infty} b_k g_{c_k}(t) \\ &= \sqrt{E_b} \sum_{-\infty}^{\infty} b_k \sum_{n=0}^{N_s-1} w(t - nT_f - c_{k,n}T_c) \end{aligned} \tag{2}$$

The corresponding transmitted signal in TH-BPPM scheme can be expressed as follows:

$$\begin{aligned} s(t) &= \sqrt{E_b} \sum_{k=-\infty}^{\infty} b_k g_{c_k}(t - d_k\delta) \\ &= \sqrt{E_b} \sum_{-\infty}^{\infty} \sum_{n=0}^{N_s-1} w(t - nT_f - c_{k,n}T_c - d_k\delta) \end{aligned} \tag{3}$$

where $d_k \in (0, 1)$ is the data bit, E_b is the transmitted energy per bit δ is the time-shift unit for BPPM scheme and $\delta \le T_w$.

3. BER Performance Analysis

3.1 Performance Analysis

We model the channel as an ideal attenuating channel with additive noise. The ideal channel greatly simplifies the analysis while still allowing grabbing important aspects. Though we use the ideal AWGN channel model, the shape of the signal is still distorted by the antenna system because of the huge bandwidth. The receiver antenna can be modeled as a differentiator. We denote the received monocycle by $w'(t)$ and assume that it has duration $T'_m \le T_c$. The useful received signal can be written as (Piazzo, 2001)

$$s'(t)\sqrt{E'_b} \sum_{k=-\infty}^{\infty} b_k g'_{c_k}(t) \text{ and} s'(t)\sqrt{E'_b} \sum_{k=-\infty}^{\infty} g'_{c_k}(t - d_k\delta) \tag{4}$$

where $g'_{c_k}(t)$ is the received data bit waveform obtained by replacing $w(t)$ by $w'(t)$ in (1), and E'_b is the received energy per bit.

The received signal can be written as $r(t) = s'(t) + n(t)$, since we can declare the transmitted signal and the received signal by the context, we will ignore the suffix of the received signal and write like

$$r(t) = s(t) + n(t) \tag{5}$$

For simplicity, we first take the TH-BPAM into consideration. When the disturbance is AWGN, the optimum receiver correlates the received signal with the template signal of the data bit waveform in order to take the decision. The decision variable can be written as

$$r_k = \int r(t) g_{c_k}(t)\, dt = \int [s(t) + n(t)] g_{c_k}(t)\, dt = s_k + n_k \tag{6}$$

where $s_k = \int s(t) g_{c_k}(t)\, dt$, $n_k = \int n(t) g_{c_k}(t)\, dt$.

Thus, the decision variable has a useful signal part s_k, and a noise part n_k. We can define the SNR at the decision device as $SNR = \frac{E\{s_k^2\}}{E\{n_k^2\}}$. In the deduction of SNR, we assume that TH code c_k is already known to the receiver. We show the calculation process of the two parts in SNR like below:

$$\begin{aligned} s_k &= \int s(t) g_{c_k}(t)\, dt = \int \sqrt{E_b} \sum_{h=-\infty}^{\infty} b_h g_{c_k}(t)\, dt \\ &= \sqrt{E_b} b_k \int g_{c_k}^2(t)\, dt = \sqrt{E_b} b_k \end{aligned} \tag{7}$$

where $E\{s_k^2\} = E_b$.

Since both $n(t)$ and $g_{c_k}(t)$ are independent random quantities. Thus

$$\begin{aligned} E\{n_k^2\} &= E\left\{\int_t n(t)g_{c_k}(t)dt\int_\tau n(\tau)d\tau\right\} \\ &= E\left\{\int_t\int_\tau n(t)n(\tau)g_{c_k}(t)g_{c_k}(\tau)dtd\tau\right\} \\ &= \int_t\int_\tau E\{n(t)n(\tau)\}E\{g_{c_k}(t)g_{c_k}(\tau)\}dtd\tau \\ &= E\left\{\int_t\int_\tau R_n(t-\tau)g_{c_k}(t)g_{c_k}(\tau)dtd\tau\right\} \end{aligned} \tag{8}$$

here, we set $t=\theta+\tau$

$$\begin{aligned} E\{n_k^2\} &= E\left\{\int_\theta R_n(\theta)\left[\int_\tau g_{c_k}(\theta+\tau)g_{c_k}(\tau)\,d\tau\right]d\theta\right\} \\ &= E\left\{\int_\theta R_n(\theta)R_{g_{c_k}}(\theta)\,d\theta\right\}=\int P_n(f)\,E\left\{|G_{c_k}(f)|^2\right\}df \end{aligned} \tag{9}$$

So we get the SNR which is computed as

$$SNR_{TH-BPAM}=\frac{E_b}{\int P_n(f)E\left\{|G_{c_k}(f)|^2\right\}df} \tag{10}$$

where $G_{c_k}(f)$ is the Fourier Transform of the template signal $g_{c_k}(t)$ and $P_n(f)$ is the noise spectrum. For AWGN case, we have $P_n(f)=N_0/2$.

In the case of TH-BPPM UWB system, we set the template signal of the receiver correlator to be

$$v_c(t)=g_{c,0}(t)-g_{c,1}(t)=g_{c,0}(t)-g_{c,0}(t-\delta) \tag{11}$$

The correlator output is calculated as:

$$\begin{aligned} r_i &= \int r(t)\,[g_{c,0}(t)-g_{c,1}(t)]\,dt \\ &= \int\,[s(t)+n(t)]\,[g_{c,0}(t)-g_{c,0}(t-\delta)]\,dt \\ &= s_0-s_1+n_o-n_1,\quad i\in(0,1) \end{aligned} \tag{12}$$

where

$$s_i=\int s(t)g_{c_k,i}(t)dt,\ n_i=\int n(t)g_{c_k,i}(t)dt$$

So we can get (F. Ramirez-Mireles, 2001)

$$SNR=\frac{E\{(s_o-s_1)^2\}}{E\{(n_o-n_1)^2\}} \tag{13}$$

We also give the calculation process of the two parts in SNR as follows:

$$\begin{aligned} E\{(n_0-n_1)^2\} &= E\left\{(n_0-n_1)\int n(t)v_c(t)dt\right\} \\ &= E\left\{\int_t\int_\tau n(t)n(\tau)v_c(t)v_c(\tau)dtd\tau\right\} \\ &= \int_t\int_\tau R_n(t-\tau)E\{v_c(t)v_c(\tau)\}dtd\tau \\ &= E\left\{\int_t\int_\tau R_n(t-\tau)v_c(t)v_c(\tau)dtd\tau\right\} \\ &= E\left\{\int_\theta R_n(\theta)\left[\int_\tau v_c(\tau+\theta)v_c(\tau)d\tau\right]d\theta\right\} \\ &= E\left\{\int_\theta R_n(\theta)R_{v_c}(\theta)d\theta\right\} \end{aligned} \tag{14}$$

Then we can get

$$E\{(n_0-n_1)^2\}=E\left\{\int_\theta P_n(f)\,|\,V_c(f)\,|\,^2df\right\} \tag{15}$$

Since $v_c(t)=g_{c,0}(t)-g_{c,1}(t)=g_{c,0}(t)-g_{c,0}(t-\delta)$,

we have

$$\begin{aligned} &V_c(f)=G_{c,0}(f)\left(1-e^{-2j\pi\delta f}\right)\ \text{and} \\ &|V_c(f)|^2=|G_{c,0}(f)|^2(2-2\cos(2\pi\delta f))=|G_{c,0}(f)|^2 4\sin^2(\pi\delta f) \end{aligned} \tag{16}$$

$$\begin{aligned} E\{(s_o-s_1)^2\} &= E\left\{(s_o-s_1)\int s(t)\,v(t)\,dt\right\} \\ E &= \left\{\int s(t)\,v(t)\,dt\int s(\tau)\,v(\tau)\,d\tau\right\} \\ &= E\left\{\left[\sqrt{E_b}\,(1-R_{g_c}(\delta))\right]\right\}=E\left[1-R_{g_c}(\delta))\right]^2 \end{aligned} \tag{17}$$

So we get the SNR which is computed as:

$$\begin{aligned} SNR_{TH-BPPM} &= \frac{E\{(s_o-s_1)^2\}}{E\{(n_o-n_1)^2\}} \\ &= \frac{E_b\left[1-R_{g_c}(\delta)\right]^2}{E\left\{\int_\theta P_n(f)\,|\,V_c(f)\,|\,^2df\right\}} \\ &= \frac{E_b\left[1-R_{g_c}(\delta)\right]^2}{4\int_\theta P_n(f)\sin^2(\pi\delta f)E\left\{\,|\,G_{c,0}(f)\,|\,^2\right\}df} \end{aligned} \tag{18}$$

$$SNR_{TH-BPPM}=\frac{E_b}{\int_\theta P_n(f)E\left\{|G_{c,0}(f)|^2\right\}\left[\frac{2\sin(\pi\delta f)}{1-R_{g_c}(\delta)}\right]^2df} \tag{19}$$

According to the values of SNR we calculated above, we can get the BER of the TH-BPAM and TH-BPPM UWB system, respectively. The BER equation can be expressed as $BER=\frac{1}{2}erfc(\sqrt{SNR/2})$, $erfc(x)=\frac{2}{\pi}\int_x^{+\infty}e^{-\epsilon^2}d\epsilon$ (A. J. Viterbi, 1995). We can see from the BER expression that the TH-BPAM will achieve the better performance.

Comparing the TH-BPAM UWB system with the TH-BPPM UWB system, we can see the BPAM system is more efficient. This is a simply a function of the type of modulation method, whereas BPPM, when separated by one pulse width delay for each pulse position, is an orthogonal modulation method. We can illustrate the advantage of BPAM scheme. Since BPPM must always delay pulses, in the limit when pulses are transmitted continuously BPPM must always 'waste' the time when pulse are not transmitted. If BPPM delays by one pulse width, then BPAM can send twice the number of pulses and, thus, twice the information, thus achieving a system which, given all other things being equal, has twice the data rate. Another benefit of using this BPAM method is that the mean of σ is zero. This has the important benefit of removing the comb lines or spectral peaks. Simulation parameters are shown in Table 1.

Table 1 Simulation Parameters

Parameters	Value
Simulation Tool	Matlab 7.0 Simulator
Frame Time, T_f	10 ns
TH Chip Time, T_c	1 ns
Gaussian 2nd pulse width, T_p	0.5 ns
Pulse Repetition, N_s	2, 4

3.2 Simulation Results

In this section, we give the simulation results of both data transmission and image transmission. In Fig. 1 is the BER performance of TH-BPAM and TH-BPPM with N_s equal to 2. In Fig. 2 is the BER performance of TH-BPAM and TH-BPPM with N_s equal to 4. We can see from the BER curves, that the performance of TH-BPAM is better than TH-BPAM in both cases, and we can have about 1～2dB gains when the BER is around 10^{-6}. The recovered image with TH-BPAM and TH-BPPM are shown in Fig. 3 and Fig. 4 at $N_s = 2$, E_b/N_o=1dB and 5dB, respectively. The TH-BPAM shows better performance. Because E_b/N_o is 5dB, the performance of the figures are much better than the case with E_b/N_o=2dB. So from the figures, the total difference is not so much. But the TH-BPAM still has the better performance (noise points are smaller). This can be seen from the bit error rate from computer simulation.

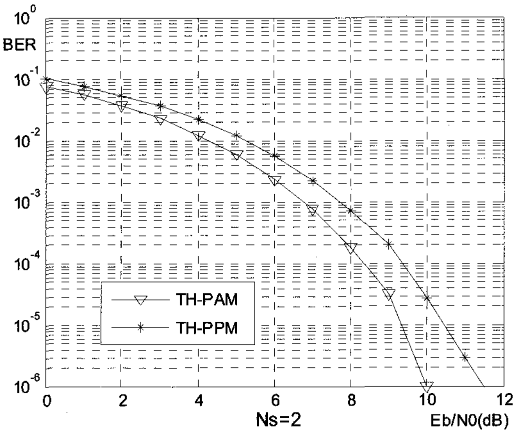


Fig. 1 BER performance of TH-BPAM and TH-BPPM ($N_s = 2$)

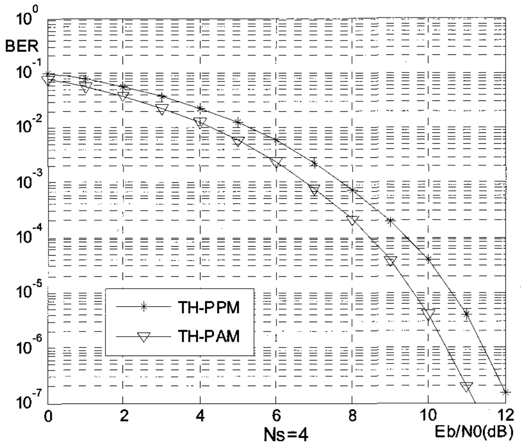
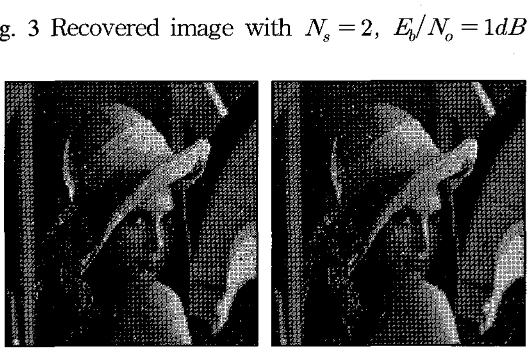


Fig. 2 BER performance of TH-BPAM and TH-BPPM ($N_s = 4$)

(a) TH-BPAM (b) TH-BPPM

Fig. 3 Recovered image with $N_s = 2,\ E_b/N_o = 1dB$



(a) TH-BPAM (b) TH-BPPM

Fig. 4 Recovered image with $N_s = 2,\ E_b/N_o = 5dB$

4. Conclusion

In this paper the BER performance of binary TH-PPM UWB system and bipolar TH-PAM UWB system is analyzed in ideal AWGN channel. Computer simulation results over data and image transmission show that the BER performance of binary TH-BPAM scheme is better than that of the TH-BPPM system. And for the TH-BPPM scheme, the modulation time-shift δ should be designed carefully so that we can get the suitable PSD function which decides the performance of the system. In the future study, we'll deal with performance analysis under the multipath environments.

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Received 1 January 2007
Accepted 31 March 2007