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# MODULATION DIVERSITY IN ULTRA-WIDEBAND SYSTEMS FOR INCREASED THROUGHPUT

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## ABSTRACT

***Currently Ultra-wideband (UWB) technology has drawn huge attention of researchers as well as of communications industry. For generic pulse based UWB systems, Pulse Position Modulation (PPM) or Pulse Amplitude Modulation (PAM) are most suitable signal formats. For UWB systems Binary PAM can also be thought of Binary Phase Shift Keying (BPSK) modulation. To date, only purpose of combining PPM and BPSK is to remove spectral lines in the Power spectrum density (PSD) of UWB transmission since these spectral lines can badly affect other already present narrowband services. Because of using bipolar pulses, at the receiver template signal also should be changed. In this paper it is shown that in addition to offering better spectral characteristics bipolar pulses can also offer better BER performance. Explanation is given and result shows that bipolar pulses can give 4 dB SNR gain.***

***Key words- Ultra-wideband, Correlator receiver, Modulation diversity***

## 1. INTRODUCTION

UWB communication technology has many potential advantages, including the delivery of high bit rate by sharing a large amount of spectrum with many other services. This has made UWB a very good candidate for flexible multiuser wireless communication systems. Because of its very large bandwidth it may provide robustness against fading. Another additional flexibility feature of UWB is its scalability; a shift of the operating frequency range can be obtained by modifying the UWB monocycle pulse shape. The main challenge of designing UWB systems is not to hamper other existing services and of course the UWB system also must be able to provide reliable communication despite the presence of many other Narrowband Interferences. The accepted method to materialize this objective is to maintain the PSD of UWB transmission below such limit [1], so that UWB radiation appears to be noise like to all other existing services. Another target of UWB system design is to eliminate the spectral lines. To achieve this, bipolar pulses should be used [2].

## 2. SYSTEM MODEL

The transmitted signal can be represented by,

$$S_{tr}(t) = A\sum_{i=-\infty}^{\infty} a_i w_{tr}(t - iT_f - b_i\tau) \tag{1}$$

Bipolar pulses may be considered as a combination of Pulse Position Modulation (PPM) and Binary Phase Shift Keying (BPSK). For PPM-only case, transmitted pulses are

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always positive but for combination of PPM and BPSK, transmitted pulses are positive for 'bit 0' and negative for 'bit 1'. $T_f$ is Frame duration and $W_{tr}(t)$ is the first order Gaussian monocycle with duration $T_p$. For bit 0, $a_i = +1$ and $b_i = 0$; for bit 1, $a_i = -1$ and $b_i = +1$; and $\tau = \frac{T_f}{2}$. Also, discrete impulse response of the channel is assumed to be,

$$h(t) = \sum_{l=0}^{L-1} \alpha_l \delta(t - lT_m) \tag{2}$$

Where, $\alpha_l$ is amplitude attenuation factor, $l$ is the path number, $L$ is the number of resolvable paths, $T_m$ is the path resolvability and $\delta$ (t) is the *Dirac delta* function. In this simulation $T_p$=1 ns. Also, dense multipath environment is considered, that means, $T_p > T_m$. It can be noticed that $LT_m >> T_f$, which means there will be severe Inter Symbol Interference.

In this study $\Delta$-K arrival time model [3] is used. According to this model the probability of arrival in one time slot (bin) depends upon whether there was an arrival in the previous time slot. According to [4] the probability of having a path in bin $i$ *is given by* $\lambda_i$, if there was no path in bin $(i-1)$ or by $K\ \lambda_i$, if there was arrival in bin $(i-1)$. If the measured (empirical) probabilities are given by $r_i$ then the arrival probability for path $i$ for analytical model can be expressed by [4],

$$\lambda_i = \frac{r_i}{(k-1)r_{i-1} + 1} \quad for\ \ i \neq 1\ where\ \lambda_1 = r_1 \, . \tag{3}$$

For our simulation we used $K = 0.5$ and set probability of occupancy $r = 0.5$ for all $i$ [5], and assumed that path arrivals with time difference of 800 ps are resolvable ($T_m$ = 800 ps). Also, it was assumed that any path with delay more that 20 ns has very little or no influence because power is assumed to be exponentially decaying [3], *i.e.*$E[\alpha_1^2] = \zeta_0 e^{-\delta t}$. Where, $\delta$ is the amplitude decay factor and $\zeta_0$ is used to normalize path gain to unity.

The received signal is,

$$r(t) = S_{tr}(t) \otimes h(t) \Rightarrow r(t) = A \sum_{i=-\infty}^{\infty} a_i \sum_{l=0}^{L-1} \left\{ \alpha_l w_{rx}(t - iT_f - b_i\tau - lT_m) \right\} + n(t) \tag{4}$$

Where, $\otimes$ represents convolution and $W_{rx}(t)$ is the derivative of $W_{rx}(t)$. In this work the received pulse was assumed to be 2$^{nd}$ order Gaussian monocycle. The effects of antennas can be modeled as a differentiation operation [6]. Therefore it is well justified to assume that the pulse waveforms in the channel are the first derivative of the generated pulses and the pulses in the receiver front end is second derivative.

The classical RAKE receiver has M arms, each a correlation receiver with a different delay (Figure 1). It is assumed that Receiver knows the delays of each path. Receiver was locked to the strongest path and as it is clear form the channel model described, the path that comes first is the strongest. In our analysis it is assumed that $M<L_p$. Here $L_p = [\frac{T_f}{T_m}]$ is the maximum possible number of pulses per pulse repetition period. Since most of the desired signal energy will be contained in this interval and increasing number of RAKE fingers means increase in receiver complexity; the assumption that $M<L_p$ is logical. For this simulation a four (M=4) finger RAKE with maximal ratio combining is used. A portion of the receive signal is shown in Figure 2.

Now, in the correlator receiver, the received signal is correlated with template waveform, $v(t) = w_{rx}(t) \pm w_{rx}(t-\tau)$. For PPM-only case '-' is used and for a combination of PPM and BPSK '+' is used. Upon sampling the received signal can be written as, $r[n] = s[n] + g[n]$ . Where, $g[n]$ is the desired signal and $g[n]$ represents any form of distortion prior to Analog to Digital Converter (ADC). When we perform the correlation against the template signal $v[n]$ (Same form as $s[n]$), the output of the receiver for *i-th* pulse is given by,

$$y_i = \sum_{n=(i-1)N_f}^{iN_f-1} \sum_{k=0}^{M-1} r[n+kN_l]v[n] = s'[i] + g'[i] \tag{5}$$

Where, $s'[i]$ is the contribution from $s[n]$ and $g'[i]$ is the contribution from $g[n]$. $N_l = [\frac{T_f}{T_s}]$ where $T_f$ and $T_S$ are frame duration and sampling interval respectively and $[\ ]$, represents integer floor. Also, $N_l = [\frac{T_m}{T_s}]$. Now, $s'[i] = \sum_{k=0}^{M-1} d_i c_k \gamma \beta_k = c^T (d_i \gamma \beta)$ , and $g'[i] = \xi[i] + \sum_{k=0}^{M-1} c_k n_k$ . Here, $\gamma = R_{w_{rx}}(0)$ is the average power of a transmitted pulse. $d_i \in \{-1, 1\}$ is dependent on transmitted information. If 'bit 0' is transmitted then $d_i$ is '1' and if 'bit 1' is transmitted $d_i$ is '-1'. $c=[c_1 c_2 \cdots c_M]^T$ is the weight vector used by the linear combiner and $\beta = [\beta_1\ \beta_2 \cdots \beta_M]^T$ is the channel gain vector. $\xi$ is the multipath distortion due to overlapping of arrived pulses in dense multipath environment and $n_k$ are the sampled noise process at the output of the correlators. So, we have the following decision rule,

$$\begin{aligned} H_1 &: D_i = 0 \quad if\ y_i > 0 \\ H_2 &: D_i = 1 \quad if\ y_i < 0 \end{aligned} \tag{6}$$

Here $d_i$ is the $i^{th}$ decoded pulse. To focus on the influence of template signal it is assumed that one pulse conveys one bit information. But for practical systems one bit information is conveyed by many successive pulses according to some spreading technique.

## 3. RESULTS AND EXPLANATION

Simulation results are shown in Figure 3. Results show that a combination of PPM and BPSK can consistently offer better BER performance. As an example, for BER of $10^{-5}$, it can be seen that bipolar pulses provide 4 dB Signal to Noise Ratio (SNR) gain. This outcome can be explained from Figure 4. In this figure (a), (b), and (c) represents transmitted signal, received signal and the template signal respectively. All combinations of two consecutive bits are considered for both the unipolar and bipolar cases. This is a very simplified representation of the actual scenario to explain clearly. Here no overlapping of pulses is considered and only two bits are plotted. This situation can be assumed to be taking place at the first finger of RAKE receiver. Similar situation should also occur in other fingers. Elliptical contours in the figure represent '*favorable*' contributions from the correlation operation in the receiver and rectangular contours represent '*unfavorable*' contributions. Also these contours are shown only for '*unintended contributions*' due to multipath not for '*intended contributions*'. By '*intended contribution*' we mean, for example, for first bit in the case of 0-0 (unipolar), as the contribution due to correlation operation of first arrived pulse and positive pulse of the template signal. But the contribution due to the correlation of third arrived pulse and negative pulse of template signal is unintended. The notation 0-0 means that first bit is '0' and second bit is '0'. Because of highly multipath UWB environment there is now way to get rid of this *unintended contribution* during the correlation. From the figure it is clear that for unipolar case there are more *unfavorable* contributions than bipolar case. This is the reason why the bipolar pulses can give substantially better BER performance compared to unipolar transmission.

## 4. CONCLUSION

In this paper simulation is run for two different scenarios. Firstly, pulses were position modulated and in the second approach a combination of PPM and BPSK is used. These two different scenarios demand template signals of different format at the receiver. It is shown that combination of PPM and BPSK gives better BER performance than PPM-only case. Convincing explanation shows that this outcome is well justified. The SNR gain can also be thought of originating from modulation diversity.

## 5. REFERENCES


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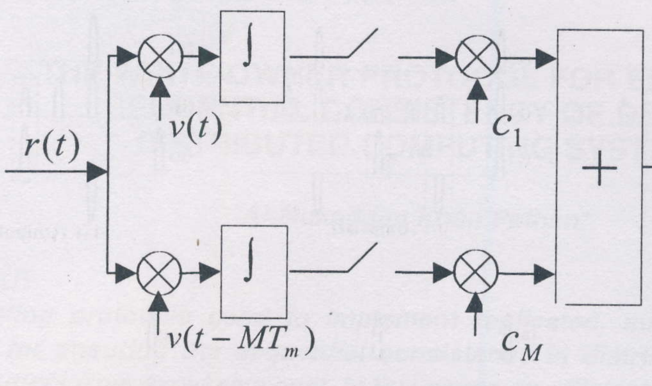


**Figure 1:** RAKE receiver

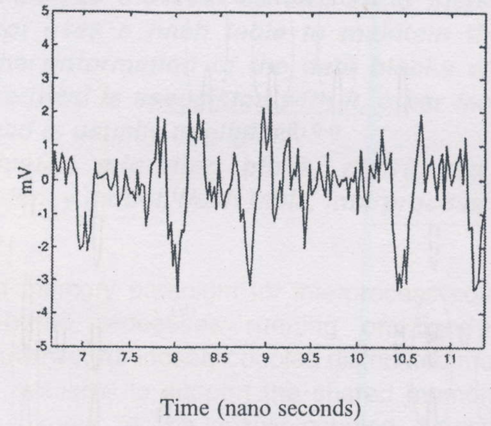


**Figure 2:** Received signal

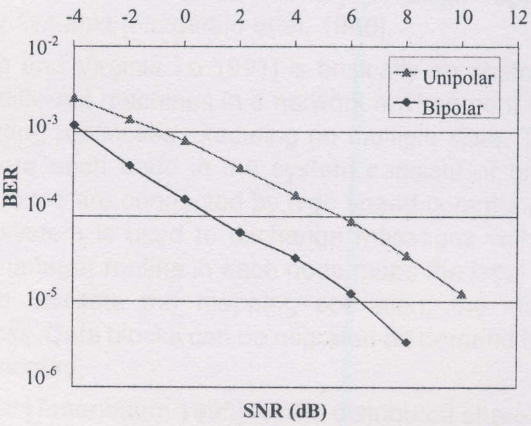


**Figure3:** Simulation result

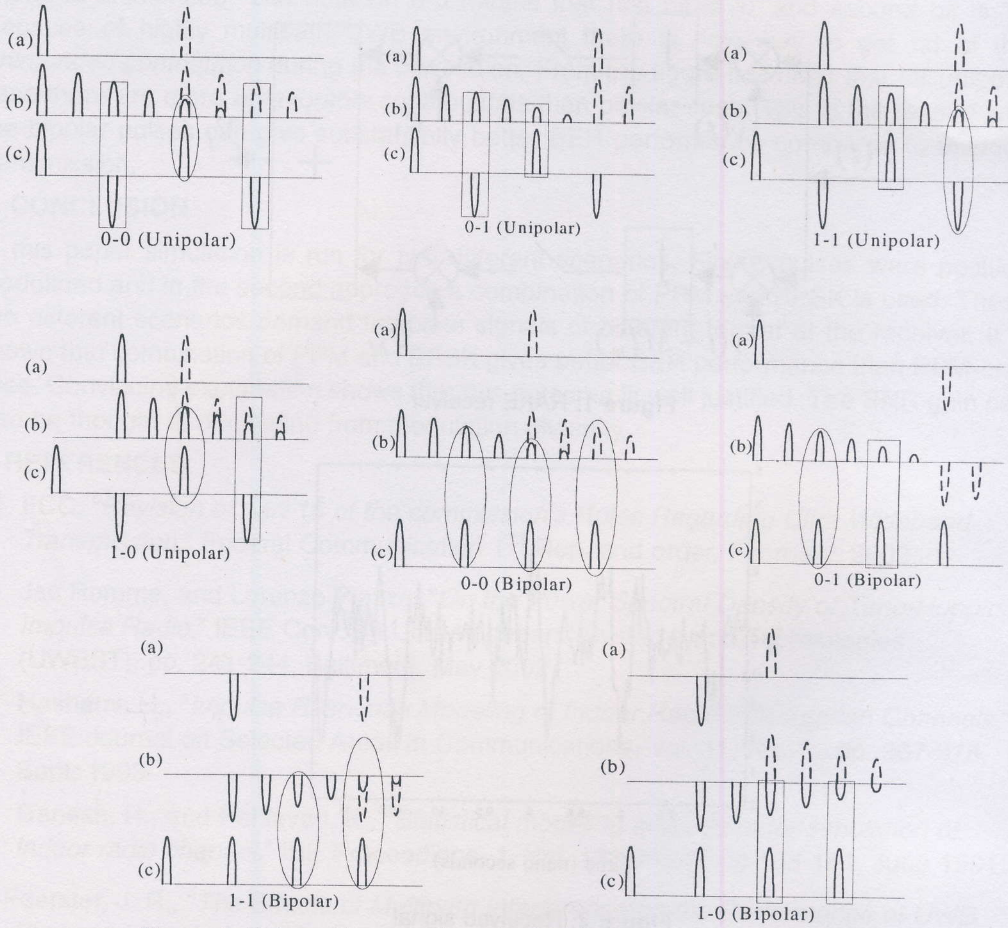


**Figure 4:** Schematic scenario at the first finger of the RAKE receiver