On the Degradation of a UWB System Due to a Realistic TX-RX Antenna System

Minsik Jun and Taewon Oh

ABSTRACT—The ultra-wideband (UWB) signal radiation process in an antenna is different from that of a narrowband signal. In this paper, we study the degradation of the desired signal component according to the antenna structure and location of a receiver in a bipolar time-hopping UWB system. And we propose a receiver structure with an adaptive template waveform generator to compensate for the degradation caused by a realistic TX-RX antenna system.

Keywords—Degradation, realistic antenna system, ultra-wideband (UWB).

I. Introduction

In contrast to a narrowband wireless system using a carrier, a time-hopping ultra-wideband (TH-UWB) system uses a non-sinusoidal wave [4]. The radiation process of a non-sinusoidal signal between the transmitting (TX) and receiving (RX) antennas is significantly different from that of a sinusoidal signal. In the case of a narrowband system using a sinusoidal wave, the original waveform is maintained after passing through the TX-RX antenna system. In several papers on TH-UWB, it has been claimed that the received waveform passed through antennas is the first or second derivative of a transmitted waveform [2],[3]. However, the practical relationship between the input current to an antenna system and the generated field waveform is a function of several parameters such as antenna geometry, input current mode, and location of the receiver.

In this paper, we demonstrate that the receiving waveform is heavily distorted by the length of the radiator and the observation angle in a bipolar TH-UWB system using the 1st derivative Gaussian pulse. We also analyze how this distortion degrades the BER performance of TH-UWB system.

II. UWB Antenna System Model

In this paper, we obtain an impulse response of a TX-RX antenna system through an analytical method. We assume that the TX-RX antenna system considered in this paper is made up of a monopole and Hertzian dipole.

Figure 1(a) shows the geometry used to obtain an analytical relationship between the exciting current waveform $p(t)$ and the waveform of radiated electromagnetic field $E(t)$ in an observation point assigned by the spherical coordinates (ρ, θ, ϕ). Angle θ is the angle between directions to the observation point and antenna axis, L is the length of the antenna, and $R(l)$ is the distance to the observation point. In [6], the tangential far region electrical component of a monopole radiated field is presented as

$$E(\rho,\theta,t,L) = -\frac{Z_0}{4\pi}\frac{1}{\rho}\frac{\sin\theta}{1-\cos\theta}\left\{p\left(t-\frac{\rho}{c}\right)-p\left(t-\frac{\rho}{c}-\frac{L}{c}(1-\cos\theta)\right)\right\}. \tag{1}$$

In the Hertzian dipole antenna with a capacitive load, the voltage across a capacitive load of the RX antenna $s(t)$ is in proportion to the electric field strength $E(t)$ [3]. That is,

$$s(t) = K \cdot E(t). \tag{2}$$

Combining (1) and (2), the voltage waveform $s(t)$ is described using the exciting current waveform $p(t)$ as

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$$s(t) = -K\frac{Z_0}{4\pi}\frac{1}{\rho}\frac{\sin\theta}{1-\cos\theta}\left\{p\left(t-\frac{\rho}{c}\right)-p\left(t-\frac{\rho}{c}-\frac{L}{c}(1-\cos\theta)\right)\right\}. \tag{3}$$

Since the antenna system is a linear time-invariant (LTI) system, and the relationship between the input and output of the antenna system is described as (3), the impulse response of a TX-RX TH-UWB antenna system can be characterized as

$$a(t)\big|_{\text{given } \rho,\theta,\text{L}} = K_1\{\delta(t-K_2)-\delta(t-K_3)\}, \tag{4}$$

where K_1, K_2 and K_3 are the functions of ρ, θ, and L.

$$K_1 = -K\frac{Z_0}{4\pi}\frac{1}{\rho}\frac{\sin\theta}{1-\cos\theta},\quad K_2 = \frac{\rho}{c},$$
$$K_3 = K_2 + \frac{L}{c}(1-\cos\theta) = K_2 + K_d$$

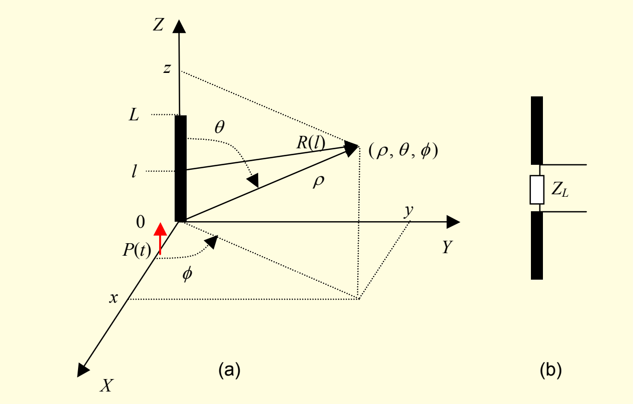


Fig. 1. (a) A monopole antenna excited by transient current p(t) and (b) a Hertzian dipole as an RX antenna.

III. Effect of the Antenna System

A bipolar TH-UWB system including a transmitter, receiver, antenna system, and channel is shown in Fig. 2. For convenience, the additive white Gaussian noise (AWGN) channel is located after the antenna system. The transmitting pulse $p(t)$ is a bipolar modulated TH-UWB signal with successive N symbols.

$$p(t;u) = \sum_{n=0}^{N-1} d_n(u)w(t-(nT_f+C_nT_c)), \tag{5}$$

where $w(t)$ is the 1st derivative Gaussian pulse, T_f is a frame time interval, C_n is a time hopping sequence within $0 \leq C_n < N_h$, T_c is a pulse width, and $d_n \in \{-1,1\}$ is the equal probable information data.

$$s(t;u) = p(t;u) * a(t) = \sum_{n=0}^{N-1} d_n(u)\{w(t-(nT_f+C_nT_c)) * a(t)\}, \tag{6}$$

where * is a convolution operator.

$$r(t;u) = \sum_{n=0}^{N-1} d_n(u)\{w(t-(nT_f+C_nT_c)) * a(t)\} + n(t;u), \tag{7}$$

where $n(t{:}u)$ is a zero mean AWGN with a variance $N_0/2$.

The output signal of a correlation type demodulator that exists in the m-th frame time interval $[(m-1)T_f, mT_f]$ is defined as $X(u)$:

$$\begin{aligned} X(u) &= \int_{(m-1)T_f}^{mT_f} r(t;u)\cdot v(t)dt \\ &= d_m(u)\int_{(m-1)T_f}^{mT_f}\{w(t-((m-1)T_f+C_mT_c)) * a(t)\} \\ &\qquad \cdot v(t-((m-1)T_f+C_mT_c))dt \\ &\quad + \int_{(m-1)T_f}^{mT_f} n(t;u)\cdot v(t-((m-1)T_f+C_mT_c))dt, \end{aligned} \tag{8}$$

where $v(t)$ is a template signal generated at the receiver and represents the 2nd derivative Gaussian pulse train. We assume that the receiver is well synchronized in time. Considering $X(u)$, we found that $X(u)$ consists of two random variables: a desired signal component and a noise component.

$$X(u) = x_D(u) + x_{AWGN}(u) \tag{9}$$

Let's define $w(t-\tau)*a(t)$ as $w'(t-\tau)$ for a constant τ and $\int_{(m-1)T_f}^{mT_f} w(t)\cdot v(t-\xi)dt$ as $R_{wv}(\xi)$. Since $x_D(u)$ is the m-th transmitting symbol,

$$x_D(u) = d_m(u)R_{w'v}(0). \tag{10}$$

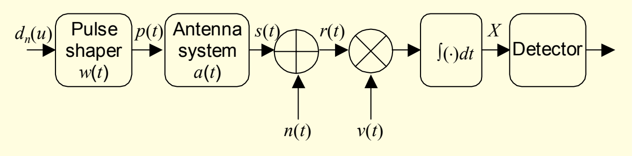
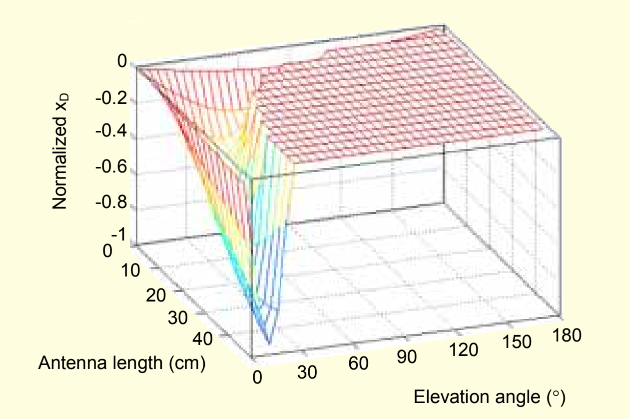


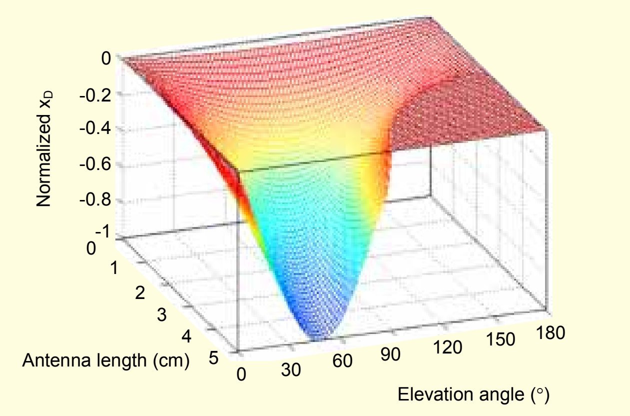
Fig. 2. A bipolar TH-UWB system under AWGN environment.

Table 1. Parameters for the TH-UWB system.

Parameter	Notation	Typical value
Mono pulse width	Tc	≈ 0.57ns
Wave impedance of free space	Zo	377 Ω
Distance between TX & RX antennas	ρ	4 m
The velocity of light	c	3×10^8 m/s



(a) $0<L<50$cm



(b) $0<L<5$cm

Fig. 3. Normalized value of x_D according to θ and L.

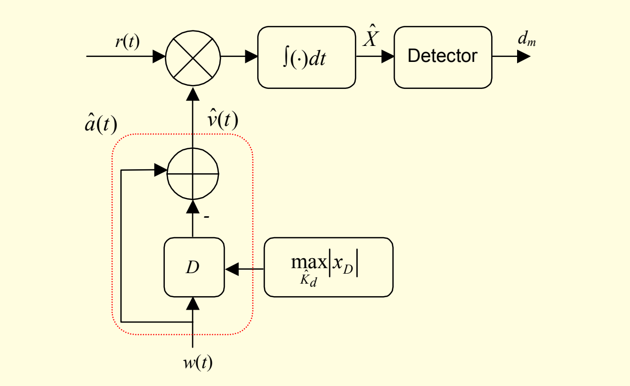


Fig. 4. A receiver structure with adaptive template waveform generator.

The desired signal component is a correlation of a template waveform and a received waveform distorted by the impulse response of the TX-RX antenna system. Using the parameters of Table 1, Fig. 4 shows the variation of x_D according to θ and L when the distance between TX antenna and RX antenna is fixed.

As a result of Fig. 3, we can understand that the change of an antenna impulse response degrades the desired signal quality in a bipolar TH-UWB receiver.

IV. Adaptive Template Waveform Generator

In this section, we propose an adaptive template waveform generator (ATWG) to solve the degradation of x_D. The ATWG traces an optimal state to generate a template waveform that is the same as a received waveform. We can rewrite x_D to make a time origin shift of (8).

$$\begin{aligned}&K_1\int_{c_mT_c}^{T_f}\{w(t-K_2)-w(t-K_3)\}\cdot v(t)dt\\&=K_1\int_{c_mT}^{T_f}\{w(t-K_2)-w(t-K_2-K_d)\}\cdot v(t)dt\end{aligned}\tag{11}$$

From (11), we know that the received waveform is made up of two $w(t)$’s with the time interval K_d. In order to have a template waveform be the same as a received waveform, the relation between ATWG input signal $w(t)$ and ATWG output signal $\hat{v}(t)$ must be

$$\hat{v}(t)=w(t)-w(t-\hat{K}_d),\tag{12}$$

where $\hat{K}_d$ is the estimated value that maximizes the absolute value of x_D.

From (12), the impulse response of ATGW $\hat{a}(t)$ becomes

$$\hat{a}(t)=\delta(t)-\delta(t-\hat{K}_d).\tag{13}$$

Therefore, ATWG can be embodied in three blocks: variable time delay, summation, and estimation blocks.

To analyze the bit error rate (BER) performance on a bipolar TH-UWB system with ATWG and without ATWG, the statistical properties of each component are derived. Supposing that the observation point does not change while successive N symbols are being transmitted, the mean and variance of the desired signal component are

$$E[x_D(u)]=0,\quad E\left[(x_D(u))^2\right]=(R_{w'v}(0))^2.\tag{14}$$

Component x_{AWGN} is the AWGN component at the demodulator output:

$$x_{AWGN}=\int_{(m-1)T_f}^{mT_f}n(t;u)\cdot v(t-(mT_f+C_mT_c+(L-1)\tau))dt\,.\tag{15}$$

Since $E[n(t;u)]=0$ and $E[n(t;u)n(s;u)]=N_0\delta(t-s)/2$, the variance of x_{AWGN} is

$$\sigma^2_{x_{AWGN}} = \frac{N_0}{2}\int_{(m-1)T_f}^{mT_f} v\left(t-\left(mT_f + C_m T_c + (L-1)\tau\right)\right) \cdot v\left(t-\left(mT_f + C_m T_c + (L-1)\tau\right)\right)dt = \frac{N_0}{2}R_{vv}(0). \quad (16)$$

In a bipolar modulated TH-UWB system, there is a bit in a frame time interval. The bit energy E_b is presented as

$$E_b = \left(R_{w'v}(0)\right)^2 \cdot T_f \ . \quad (17)$$

The AWGN energy N can be obtained from (16) multiplied with T_f and is presented as

$$N = N_0/2\left(R_{vv}(0)\right)^2 \cdot T_f \ . \quad (18)$$

Variable x_{AWGN} is a zero mean Gaussian random variable. The BER probability of bipolar modulated system is described in [1] as

$$P_b = Q\left(\sqrt{2\cdot E_b/N}\right) = Q\left(\sqrt{\frac{4}{N_0}\left(\frac{R_{w'v}(0)}{R_{vv}(0)}\right)^2}\right), \quad (19)$$

where $Q(x)$ is a standard Q function.

Figure 5 shows the BER performance result of a bipolar TH-UWB system with an ATWG. The figure shows that the BER performance is improved when the ATWG is adopted. However, the ATWG has a limitation when the desired signal component is attenuated seriously because it only compensates for a time delay due to a propagation delay internal to the antenna system.

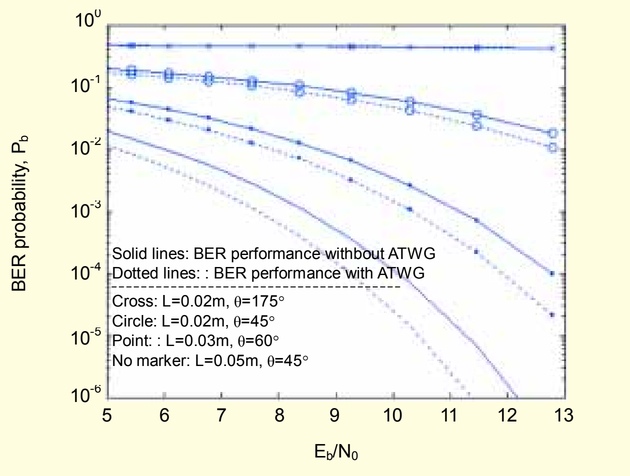


Fig. 5. Comparison between BER performances of the TH-UWB system with and without ATWG.

V. Conclusion

The role of a TX-RX antenna in a TH-UWB system is different from that in a narrowband system. The desired signal power degraded according to the antenna structure and the location of the receiver. Also, the BER performance of a bipolar TH-UWB system is critically affected by the antenna geometry and location of the receiver. A receiver with the proposed adaptive template waveform generator is proposed to solve the above problems.

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