Antenna Effects in Ultra Wideband Impulse Radio Transmission

Sathaporn Promwong and Thawatchai Sereewattanapong

Department of Telecomunication Engineering, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand.
Email: kpsathap, x2611316@kmitl.ac.th

1 Introduction

An ultra wideband impulse radio (UWB-IR) system can be extremely distorted through a channel even for free-space transmission because of antenna dispersion. This highly degrades the link budget performance. Therefore, the understand of antenna characteristics, which effects on waveform distortion, is necessary. This paper studies the waveform distortion due to antenna on free space transmission in UWB-IR system. The link budget evaluation formula attended from conventional Friis' transmission formula that takes into account the transmitted waveform, its distortion due to the antennas, the channel and the correlation receiver is proposed. This model is based on the Friis' transmission formula, adapted to the UWB-IR transmission system, in the sense that we derive the equivalent frequency transfer function of UWB-IR system [1]. Since the antennas are significant pulse-shaping filters in UWB-IR system, the broadband antennas are experimentally examined, especially focused on the effect of the received signal and the isotropic template waveforms. This scheme provides some useful physical insights and optimized design procedure with clear and accessible description of the UWB-IR link budget comprised of practical antennas.

2 UWB-IR Transmission Analysis

The free space transfer function $H_{\rm f}(f,d)$ can be written as

$$H_{\rm f}(f,d) = \frac{c}{4\pi f d} e^{-{\rm j}2\pi f d/c}. \tag{1}$$

Free space channel transfer function $H_{\rm c}(f)$ including the antennas is obtained by using the extension of Friis' transmission formula as

$$H_{\rm c}(f) = H_{\rm f}(f,d)\ \mathbf{H}_{\rm t}(f,\mathbf{\Omega}_{\rm t}) \cdot \mathbf{H}_{\rm r}(f,\mathbf{\Omega}_{\rm r}), \tag{2}$$

where $\mathbf{H}_a(f,\mathbf{\Omega}_a)$ ($a = {\rm r}$ *or* t) is a complex transfer function vector of the antenna relative to the isotropic antenna towards the $\mathbf{\Omega}_a = (\theta_a,\ \varphi_a)$ direction, i.e.

$$\begin{aligned} \mathbf{H}_a(f,\mathbf{\Omega}_{\rm a}) &= \mathbf{H}_a(f,\theta_a,\varphi_a) \\ &= \hat{\boldsymbol{\theta}}_a H_{a\theta}(f,\theta_a,\varphi_a) + \hat{\boldsymbol{\varphi}}_a H_{a\varphi}(f,\theta_a,\varphi_a), \end{aligned} \tag{3}$$

Unit vectors $\hat{\boldsymbol{\theta}}_a$, $\hat{\boldsymbol{\varphi}}_a$ express the polarization and are defined with respect to the local polar coordinates of the antennas.

The receiver input waveform $v_{\rm r}(t)$ is given by

$$v_{\rm r}(t) = \int_{-\infty}^{\infty} H_{\rm c}(f) V_{\rm t}(f) e^{j2\pi f t} {\rm d}f, \tag{4}$$

where $V_{\rm t}(f)$ is the spectral density of the transmitted waveform.

2.1 Correlation Time Waveform

The output signal-to-noise ratio (SNR) is dependent on the choice of the template waveform. The correlator output $v_\mathrm{o}(\tau)$ is therefore expressed as

$$v_\mathrm{o}(\tau) = \int_{-\infty}^{\infty} v_\mathrm{r}(t) h_\mathrm{w}(t-\tau)\mathrm{d}t, \tag{5}$$

where $h_\mathrm{w}(t)$ is the template waveform and τ corresponds to the timing of the template waveform, the optimum timing τ_o.

$$h_\mathrm{wm}(t) = \frac{\sqrt{2B} v_\mathrm{r}(\tau_\mathrm{o} - t)}{\sqrt{\int_{-\infty}^{\infty} |v_\mathrm{r}(t)|^2 \mathrm{d}t}}, \tag{6}$$

where B is the signal bandwidth, so that the output noise power is a constant as $N_0 B$, where $N_\mathrm{o}/2$ is the power spectral density of additive white Gaussian noise (AWGN).

2.2 Optimum Correlation Time Waveform

In this paper we have chosen $h_\mathrm{wc}(t)$ that is optimum for the isotropic and the constant gain antennas, i.e.

$$h_\mathrm{wc}(t) = \frac{\sqrt{2B} v_\text{r-iso}(\tau_\mathrm{o} - t)}{\sqrt{\int_{-\infty}^{\infty} |v_\text{r-iso}(t)|^2 \mathrm{d}t}}, \tag{7}$$

where the receiver input voltage for the case of isotropic antennas used in both sides $v_\text{r-iso}(t)$ can be written as

$$v_\text{r-iso}(t) = \int_{-\infty}^{\infty} H_\mathrm{f,d}(f) V_\mathrm{t}(f) e^{\mathrm{j}2\pi f t} \mathrm{d}f. \tag{8}$$

2.3 Transmission Gain

The transmission gain in this paper is defined as the peak amplitude of the correlator output with the considered antennas normalized by that with the isotropic antennas. Due to the normalization of template waveforms in Eqs. (13) and (14), this gain value represents the gain of SNR ratio. Therefore, the transmission gain of the received signal template case G_wm can be written as

$$G_\mathrm{wm} = \frac{\max | \int_{-\infty}^{\infty} v_\mathrm{r}(t) h_\mathrm{wm}(t-\tau) dt|}{\max | \int_{-\infty}^{\infty} v_\text{r-iso}(t) h_\mathrm{wc}(t-\tau) dt|}. \tag{9}$$

Similarly, the transmission gain of the isotropic template case G_wc can be written as

$$G_\mathrm{wc} = \frac{\max | \int_{-\infty}^{\infty} v_\mathrm{r}(t) h_\mathrm{wc}(t-\tau) dt|}{\max | \int_{-\infty}^{\infty} v_\text{r-iso}(t) h_\mathrm{wc}(t-\tau) dt|}. \tag{10}$$

The difference between the transmission gain of the received signal and the isotropic template cases also indicates the distortion quantity of the waveform.

3 Experimental Evaluation of UWB-IR Antenna Links

3.1 Transmitted Waveforms of UWB-IR

The effect of the waveform distortion is more obvious when the bandwidth is wider. We considered the transmitted waveforms that fully cover the Federal Communications Commission (FCC) frequency band, i.e., 3.1 – 10.6 GHz [2]. In this paper, the rectangular passband waveform are used as the transmitted waveforms.

3.1.1 Rectangular Passband Waveform

The rectangular passband waveform is the waveform with rectangular spectrum and its spectral density is defined as

$$V_{\mathrm{t,re}}(f) \quad = \quad \begin{cases} 1 & ||f| - f_c| \leq \frac{f_{\mathrm{b}}}{2} \\ 0 & \text{otherwise} \end{cases}, \tag{11}$$

where f_{c} is the center frequency and f_{b} is the spectral bandwidth. For satisfying the FCC spectral masks for indoor and outdoor limits, f_{c} and f_{b} are set to 6.85 and 7.50 GHz, respectively.

3.1.2 Root Raised Cosine Passband Waveform

The root raised cosine passband waveform is the waveform with root raised cosine spectrum and its spectral density is defined as

$$V_{\mathrm{t,ro}}(f) \quad = \quad \begin{cases} 1 & ||f| - f_c| \leq \frac{(1-\beta)}{2T} \\ A & \frac{(1-\beta)}{2T} < ||f| - f_c| \leq \frac{1+\beta}{2T} \\ 0 & \text{otherwise} \end{cases}, \tag{12}$$

$T = 1/f_{\mathrm{b}}$ is the reciprocal of the symbol-rate and $\beta = 0.3$ is the roll-off factor. For satisfying the FCC spectral masks, f_{c} is set to 6.85 GHz.

The normalized spectral densities of these waveforms compared with FCC spectral masks shown in Figs. 1.

3.2 Experimental Setup

The UWB-IR radio channel transfer function was measured as S_{21} in frequency domain by using a vector network analyzer (VNA) in an anechoic chamber. The VNA was operated in the response measurement mode, where Port-1 was the Tx port and Port-2 was the Rx port, respectively. Both Tx and Rx antennas were fixed at the height of 1.75 m and separated by 4 m.

4 Experimental Results

The channel transfer function of biconical–biconical link was measured and evaluated as function of the antenna pointing angle in the E-plane with rotation of Rx antennas. The transmission gain of each waveform satisfying each spectral mask are considered. For FCC spectral masks, the transmission gains of the rectangular passband waveforms, the root raised cosine passband waveforms satisfying are shown in Fig.3. Figure 4 show the transmission gains of the rectangular and root raised cosine passband waveforms satisfying common frequency band spectral mask, respectively. From these results, the UWB-IR transmission gain, using both the received signal and the isotropic template waveforms, gives us the quantitative measurement of the link budget. Since we have chosen the broadband antennas, the trend of the narrowband gain is reflected in the UWB-IR transmission gain. Another issue is the distortion of the waveform. The difference between the optimum and the isotropic templates is the measurement of the waveform distortion. It is obvious that the type of waveform in same frequency band has little distortion difference. The waveforms in FCC frequency band with wider bandwidth have more distortion than that in common frequency band.

5 Conclusion

This paper has presented how to evaluate the antenna effects in UWB transmission gain, which includes the transmit waveform, the antennas, the free space propagation, and the correlation

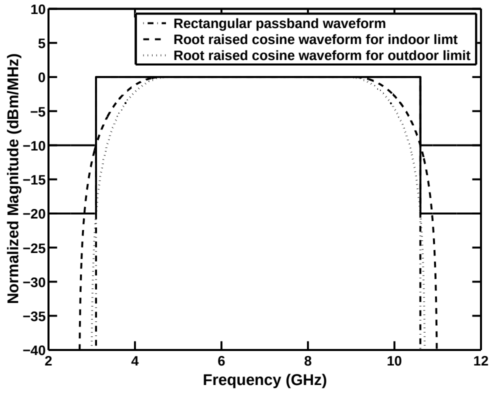

Figure 1: Normalized spectral densities compared with FCC spectral masks for indoor and outdoor limits.

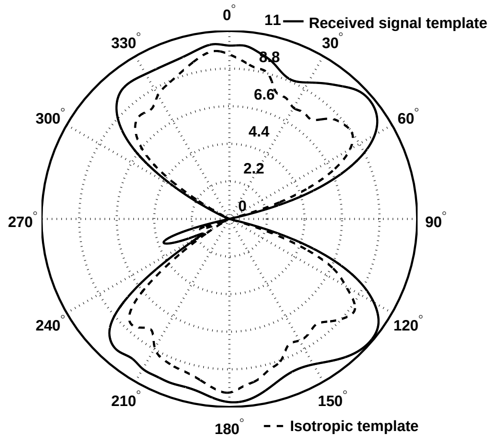

Figure 2: Transmission gain of rectangular passband waveform satisfying FCC spectral mask for biconical–biconical link.

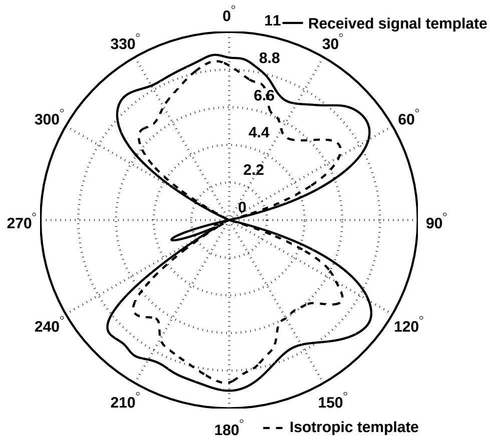

Figure 3: Transmission gain of root raised cosine passband waveform satisfying indoor FCC spectral mask for biconical–biconical link.

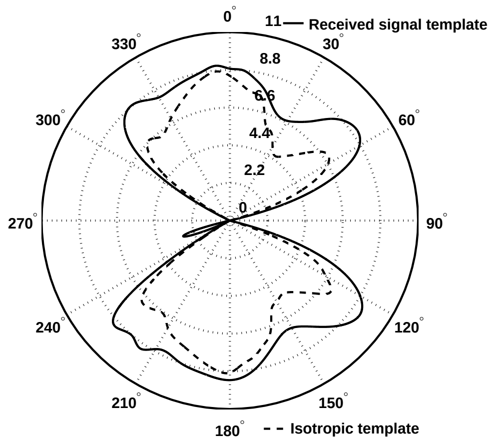

Figure 4: Transmission gain of root raised cosine passband waveform satisfying outdoor FCC spectral mask for biconical–biconical link.

receiver. By using the proposed definition, we have evaluated of the broadband antennas. This scheme may be effective especially to evaluate the deployable antenna with non-ideal frequency characteristics of return loss and directivity, as the overall performance can be evaluated only by the term of the UWB-IR transmission gain.

References

[1] S. Promwong, W. Hachitani, and J. Takada, "Free Space Link Budget Evaluation of UWB-IR Systems," in Proc. 2004 Int. Workshop Ultra Wideband Syst. / Conf. Ultra Wideband Syst. Tech. (Joint UWBST & IWUWBS 2004), Kyoto, Japan, pp. 312–316, May 2004.

[2] Federal Communications Commission, "Revision of part 15 of the commissions rules regarding UWB transmission systems," First Report, FCC 02-48, Apr. 2002.

[3] W. Hirt and M. Weisenhorn, "Overview and implications of the emerging global UWB radio regulatory framework," in Proc. The 2006 IEEE Int. Conf. on Ultra-Wideband, pp. 581-586, Sept. 2006.