

Experimental Study and Analysis of Antenna Effects for UWB Radio Transmission

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Abstract—This paper present the transmission gain of UWB system based on the extended Friis' transmission formula. The template waveform is considered at the receiver side to maximize the SNR for evaluation. An experimental evaluation of the antenna transfer function needs the three types of broadband antennas. The technique gives very accurate results and is very useful for design and evaluation of UWB impulse radio transmission systems, especially for the evaluation of waveform distortion effects.

Keywords: UWB, link budget, transmission gain, Friis' transmission formula

I. INTRODUCTION

The propagation channel is in line of sight (LOS), Friis' transmission formula cannot be directly applied to the UWB radio as the bandwidth of the pulse is extremely wide. Furthermore, simple comparison between waveforms of transmitter and receiver is not significant because of the distortion of the waveform caused by the frequency response of the antenna.

In this paper, we discuss the free space link budget and transmission gain evaluation scheme for UWB impulse radio systems. This scheme is based on the Friis' transmission formula, adapted for UWB, in the sense that we would like to derive the equivalent antenna gain for UWB impulse radio systems. The transmission waveform and the receiver template waveform are keys for the extension of the Friis' transmission formula to UWB transmission signal.

II. THOERY

In this study, we focus on the link budget evaluation for UWB impulse radio system in free space.

A. Extension of Friis' Transmission Formula for UWB transmission System

The Friis' transmission formula [1] has been widely used, and can be applied to the calculation of these LOS channels.

$$G_{\text{Friis}}(f) = \frac{P_r(f)}{P_t(f)} = G_f(f)G_r(f)G_t(f), \quad (1)$$

where G_r and G_t are Rx and Tx antenna gain,

$$G_f(f) = \left(\frac{\lambda}{4\pi d} \right)^2 \quad (2)$$

is the free space propagation gain (less than unity in practice), $\lambda = \frac{c}{f}$ is the wavelength, c is the velocity of the light, f is the operating frequency, and d is the separation between transmitter and receiver antennas.

It is noted, however, that Eq. (1) is satisfied only at some certain frequency, and is not directly applicable to UWB systems. The Friis' transmission formula shall be extended to take into account the transmission signal waveform and its distortion as well [2].

Input signal $v_i(t)$ at the transmitter port is expressed as the convolution of an impulse input and the pulse shaping filter $h_i(t)$ as

$$v_i(t) = E_i \delta(t) * h_i(t), \quad (3)$$

where

$$\int_{-\infty}^{\infty} h_i^2(t) dt = \int_{-\infty}^{\infty} |H_i(f)|^2 df = 1. \quad (4)$$

Friis' formula is extended taking into account the transmission waveform as

$$H_{\text{e-Friis}}(f) = \frac{V_r(f)}{E_i} = H_t H_i H_r \cdot H_t, \quad (5)$$

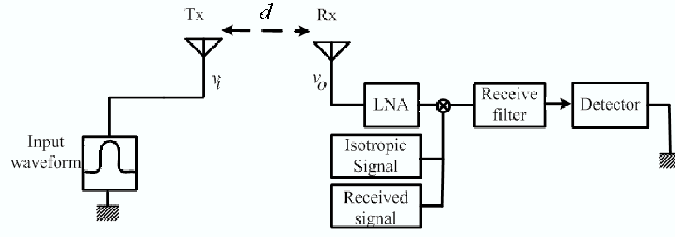


Fig. 1. Block diagram of transmission system for the extension of Friis' transmission formula to treat UWB signal.

where

$$\begin{aligned} \mathbf{H}_a &= \mathbf{H}_a(\theta_a, \varphi_a, f) \\ &= \hat{\boldsymbol{\theta}}_a H_{a\theta}(\theta_a, \varphi_a, f) + \hat{\boldsymbol{\varphi}}_a H_{a\varphi}(\theta_a, \varphi_a, f) \quad (6) \\ a &= r \text{ or } t, \end{aligned}$$

is a complex transfer function vector of the antenna relative to the isotropic antenna,

$$H_f = \frac{\lambda}{4\pi d} \exp(-jkd), \quad (7)$$

is the free space transfer function where

$$k = \frac{2\pi}{\lambda}, \quad (8)$$

is the propagation constant.

B. Correlation Receiver

Let us consider a correlation receiver shown in Fig. 1. The output SNR is dependent on the choice of the template waveform. The correlator output $v_o(\tau)$ is therefore expressed as

$$v_o(\tau) = \int_{-\infty}^{\infty} v_r(t) h_w(t - \tau) dt, \quad (9)$$

where $v_r(t)$ is the receiver input waveform which is inverse Fourier transform, and $h_w(t)$ is the template waveform. τ corresponds to the timing of the template waveform, and the optimum timing τ_o is chosen as

$$\tau_o = \arg \max_{\tau} v_o(\tau). \quad (10)$$

Hereafter $h_w(t)$ is normalized as

$$\int_{-\infty}^{\infty} |h_w(t)|^2 dt = 2B, \quad (11)$$

where B is the signal bandwidth, so that the output noise power is constant as $N_0 B$, where $\frac{N_0}{2}$ is power spectral density of AWGN.

Under the constraint of Eq. (11), $h_{wm}(t)$ maximizes $v_o(\tau_o)$ when $h_{wm}(t)$ is a time-reversed and scaled version of $v_r(t)$, i.e.

$$h_{wm}(t) = \frac{\sqrt{2B} v_r(\tau_o - t)}{\sqrt{\int_{-\infty}^{\infty} |v_r(t)|^2 dt}}, \quad (12)$$

where τ_o is usually chosen so that $h_{wm}(t) = 0$ for $t < 0$ to satisfy the causality. $h_{wm}(t)$ is called the optimum template waveform hereafter. It is noted that the link budget evaluation is identical to that in Ref. [5] when $h_{wm}(t)$ is used as the receiver template.

C. Isotropic Correlation Receiver

It is obvious from Eq. (12) that the optimum template waveform is not the simple time-reversed version of the transmitter waveform, but the channel characteristics including the antennas and the free space propagation. Therefore, it is not always feasible to adapt the template waveform to the angular-dependent antenna characteristics, since the waveform shall be generated at the clock rate of tens of gigahertz. Therefore, we consider a canonical template waveform $h_{wc}(t)$. In this paper we have chosen $h_{wc}(t)$ that is optimum for the isotropic and the constant gain antennas, i.e.

$$h_{wc}(t) = \frac{\sqrt{2B} v_{r\text{-iso}}(\tau_o - t)}{\sqrt{\int_{-\infty}^{\infty} |v_{r\text{-iso}}(t)|^2 dt}}, \quad (13)$$

where

$$v_{r\text{-iso}}(t) = \int_{-\infty}^{\infty} H_f(f) V_t(f) \exp(j2\pi f t) df \quad (14)$$

is the receiver input voltage for isotropic antenna including. The difference between the optimum and the isotropic templates indicates quantitatively the distortion of the waveform.

III. UWB ANTENNA TRANSFER FUNCTION MEASUREMENTS

A. UWB waveform Transmission

The effect of the waveform distortion is more obvious when the bandwidth is wider. We considered the impulse

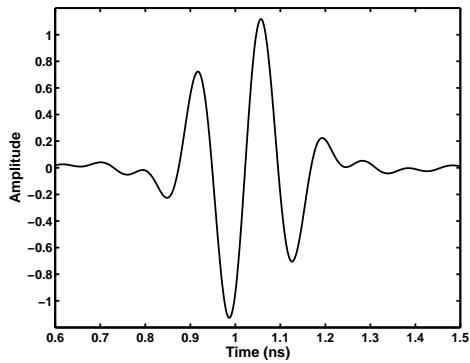


Fig. 2. The transmission waveform of UWB signal.

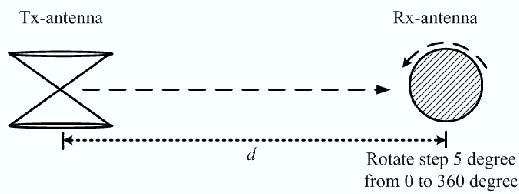


Fig. 3. Top view antenna setting.

radio signal that fully covers the FCC band [4], i.e., 3.1 ~ 10.6 GHz. The center frequency and the bandwidth were therefore set to be $f_0 = 6.85$ GHz and $f_b = 7.5$ GHz, respectively. The transmit waveform assumed in the simulation was a single ASK pulse with the carrier frequency f_0 . To satisfy the bandwidth requirement of f_b , the pulse length was set to be $\frac{2}{f_b}$. Then the signal was band-limited by a Nyquist roll-off filter with roll-off factor $\alpha = 0$ (rectangular window) and passband $(f_0 - \frac{f_b}{2}, f_0 + \frac{f_b}{2})$. Figure 2 shows the transmit pulse waveform. The transmission process of the pulse waveform is simulated based on the measured transfer function of the antenna.

B. Experimental Setup and Measurement Model

The VNA was operated in the response measurement mode, where Port-1 was the transmitter port (Tx) and Port-2 was the receiver port (Rx), respectively. Biconical antennas with the maximum diameter of 65.3 mm and the length of 37 mm are used both as the standard antennas and as AUT. The measurement was done in the anechoic chamber. Both Tx and Rx antennas were fixed at the height of 1.75 m and separated at a distance of 4 m.

Figure 3 shows the orientations of the S_{21} , transfer function measurement for Tx and Rx antennas. The Tx antenna is fixed at pointing angle 0° and the Rx antenna

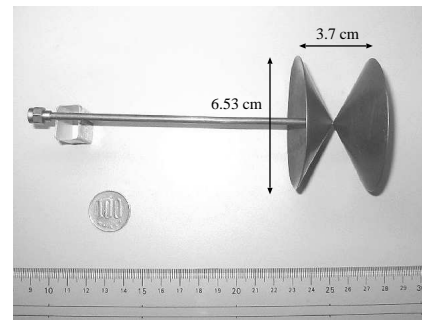


Fig. 4. Biconical antenna structure.

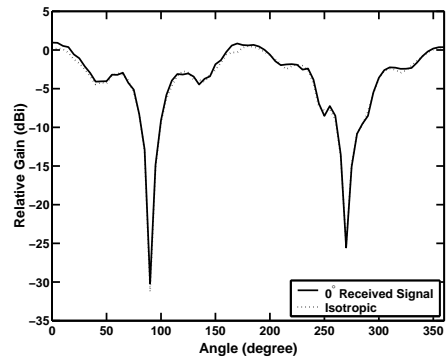


Fig. 5. Normalized UWB transmission gain for biconical-biconical link.

is rotated from pointing angle 0° to 360° with each step at 5° .

IV. EXPERIMENT RESULTS

In this section, standard broadband antennas and deployable antennas are used in the measurement for the link budget evaluation.

USA suggested the use of a biconical antenna, and log-periodic antenna for the frequency ranges of 30 – 200 MHz, 200 – 960 MHz, and 0.96 – 18 GHz, respectively, for the compliance test of UWB transmitters [6]. We chose these two kinds of antennas, operating in the same frequency range.

1) *Biconical Antenna*: First, the same biconical antennas were used at both Tx and Rx sides. Figure 5 shows the normalized UWB transmission gain as a function of antenna pointing angle in E-plane. Well-known 8-shaped patterns were obtained. Two template waveforms were used for comparison, and the difference was rather small. The phase center of the biconical antenna is the feed point and it has theoretically the frequency independent gain at the broadside direction, and that is why the waveform distortion effect is small compared with the isotropic template.

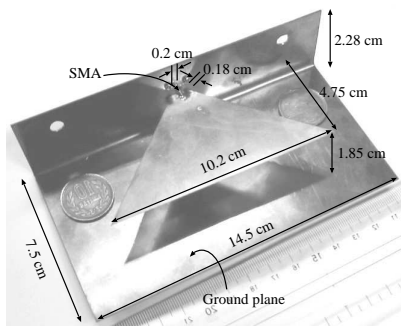


Fig. 6. Trapezoidal antenna with L-shaped ground plane.

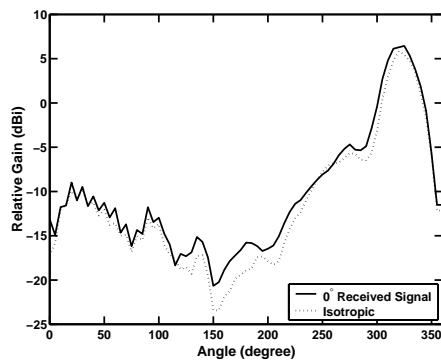


Fig. 7. Normalized UWB transmission gain for biconical-trapezoidal link.

2) *Trapezoidal Antenna*: A trapezoidal antenna with the L-shaped ground plane has been introduced by Duzdar and Kompa [7] and was later modified by Eskelinen [3]. We have chosen this antenna just for the ease of the fabrication. The structure and dimensions of the antenna is shown in Fig. 6. The element shape itself is similar to that of a bow-tie antenna, but the L-shaped ground plane is parallel to the trapezoidal element to achieve the unidirectional characteristics.

Figure 7 shows the normalized UWB transmission gain pattern for biconical-trapezoidal link in E-plane. Note that 0° and 270° are the top and the broadside of the antenna, respectively. The peak is found at 320° . Therefore, the peak is elevated from the broadside of the antenna toward the top. The gain is relatively high, and the difference between two templates is small. As Refs.[1] consider the waveform transmission applications, the waveform distortion seems to be small.

V. CONCLUSION

This presented the evaluation scheme for UWB transmission gain, which includes the transmit waveform, the antennas, free space propagation, and the receiver corre-

lator template. By using the definition, we have evaluated two types of broadband antennas. The performance can be evaluated only by the UWB transmission gain.

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