Evaluation of Free Space Link Budget in UWB Impusle Radio

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1 Introduction

Recently, an ultra wideband (UWB) impulse radio draws much attention due to its potential low cost and low power consumption properties.

The Federal Communications Commission (FCC) is currently working on setting emission limits that would allow UWB communication systems to be deployed on an unlicensed band following the Part 15 rules for radiated emissions of intentional radiators [1]. The UWB radio channel bandwidth for handheld wireless communications isfrom 3.1 GHz to 10.6 GHz. The UWB transmitter sends a pulse with a channel bandwidth of this wide and the receiver collects the power of the received signal for rebuilding the pulse. Since the power spectrum density level of UWB signal may be below the noise level of the receivers for other systems, UWB radio technology can exist with other RF technology without interference. The narrowband wireless systems, Friis' transmission formula is used for the line-of-sight (LOS) link budget evaluation [2]. However, it is not directly applicable to the UWB-IR system as the bandwidth of the pulse is extremely wide. Moreover, the effect of the waveform distortion shall be quantitatively considered in the link budget evaluation.

In this paper, we discuss the free space link budget evaluation scheme in the term of transmission channel for the UWB systems that takes into account the transmitted waveform, its distortion due to the antennas, the channel and the correlation receiver. This scheme is based on the Friis' transmission formula, adapted to the UWB-IR, in the sense that we derive the equivalent transmission gain of the UWB systems. The transmission is the keys for the extension of the Friis' transmission formula for the UWB systems [3, 4]. Experimental investigations are done for different types of the antennas.

2 Free Space Transmission Analysis for UWB System

In narrowband systems, the link budget of the free space propagation loss is usually estimated by using Friis' transmission formula [2]. This formula is expressed as a function of the frequency. Moreover, the waveform may be distorted due to the frequency characteristics of the antenna.

The Friis' transmission formula shall be extended to take into account the transmission signal waveform and its distortion as well [3].

Input signal $v_\mathrm{i}(t)$ at the transmitter port is expressed as the convolution of an impulse input and the pulse shaping filter $h_\mathrm{i}(t)$ as

$$v_\mathrm{i}(t) = E_\mathrm{i}\delta(t) * h_\mathrm{i}(t), \tag{1}$$

where

$$\int_{-\infty}^{\infty} h_\mathrm{i}^2(t)\mathrm{d}t = \int_{-\infty}^{\infty} |H_\mathrm{i}(f)|^2\,\mathrm{d}f = 1. \tag{2}$$

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

$$H_{\text{e-Friis}}(f) = \frac{V_\mathrm{r}(f)}{E_\mathrm{i}} = H_\mathrm{f}(f)H_\mathrm{i}(f)\mathbf{H}_\mathrm{r}(f)\cdot\mathbf{H}_\mathrm{t}(f), \tag{3}$$

where

$$\begin{aligned}\mathbf{H}_a &= \mathbf{H}_a(\theta_a,\ \varphi_a,\ f)\\ &= \hat{\boldsymbol{\theta}}_a H_{a\theta}(\theta_a,\ \varphi_a,\ f) + \hat{\boldsymbol{\varphi}}_a H_{a\varphi}(\theta_a,\ \varphi_a,\ f),\\ a &= \mathrm{r}\ or\ \mathrm{t},\end{aligned} \tag{4}$$

The complex transfer function vector of the antenna relative to the isotropic antenna,

$$H_{\mathrm{f}} = \frac{\lambda}{4\pi d}\exp(-\mathrm{j}kd), \tag{5}$$

The propagation constant.

$$k = \frac{2\pi}{\lambda}, \tag{6}$$

The received waveform $v_{\mathrm{r}}(t,d)$ can be found by using

$$v_{\mathrm{r}}(t,d) = v_{\mathrm{t}}(t) \otimes h_{\mathrm{Friis}}(t,d), \tag{7}$$

where $v_{\mathrm{t}}(t)$ is the transmitted signal waveform, $\otimes$ is the convolution operator, $h_{\mathrm{Friis}}(t,d)$ is the impulse response of the extension of Friis' formula defined as:

$$h_{\mathrm{Friis}}(t,d) = \mathcal{F}^{-1}\{H_{\mathrm{Friis}}(f,d)\}, \tag{8}$$

where $\mathcal{F}^{-1}\{\cdot\}$ is the inverse Fourier transform.

3 UWB Channel Transfer Function Measurement

3.1 Transmitted Waveform Model

The effect of the waveform distortion is more obvious when the bandwidth is wider. We considered the impulse radio signal that fully covers the FCC band [1], i.e., $3.1 - 10.6$ GHz. The center frequency and the bandwidth were therefore set to be $f_0 = 6.85$ GHz and $f_{\mathrm{b}} = 7.5$ GHz, respectively. The transmitted 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 $2/f_{\mathrm{b}}$. Then the signal was band-limited by a Nyquist roll-off filter with roll-off factor $\alpha = 0$ (rectangular window) and passband $(f_0 - f_{\mathrm{b}}/2,\ f_0 + f_{\mathrm{b}}/2)$. The frequency spectrum is given as

$$V_{\mathrm{t}}(f) = \begin{cases} \mathrm{sinc}\left[\frac{2(f-f_0)}{f_{\mathrm{b}}}\right] & ||f| - f_0| < \frac{f_{\mathrm{b}}}{2} \\ 0 & \text{otherwise} \end{cases}. \tag{9}$$

3.2 Measurement Model

The UWB 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.

We used a biconical antenna as the Tx antenna. We have chosen this antenna for ease of the fabrication, as well as its low distortion property. The upper cone is connected to the center conductor of a coaxial line while the lower cone is connected to the shield conductor. The maximum diameter is 65.3 mm and the length is 37 mm. We changed only the Rx antennas to compare the transmission gain properties. The experimental parameters are listed in Table 1. It is noted that the calibration of VNA is done at the connectors of the cables to be connected to the antennas. Therefore, all the impairments of the antenna characteristics are included in the measurement results.

Table 1: Experimental setup parameters.

Parameter	**Value**
Frequency range	3 GHz to 11 GHz
Number of frequency points	1601
Dynamic range	80 dB
Tx antenna height	1.75 m
Rx antenna height	1.75 m
Distance between Tx and Rx	4 m
Rx rotation range	0° to 360°
Rx rotation step	5°
Rx rotation cut	E- or H-plane

3.3 Results

In this section, the two typical broadband antennas are used in the measurement for the link budget evaluation. One is the biconical antenna, which is with low dispersion. The other is the log periodic dipole antenna (LPDA), which is highly dispersive. USA suggested the use of a biconical antenna, a log-periodic antenna, and a double-ridged guide horn for the frequency ranges of $30-200$ MHz, $200-960$ MHz, and $0.96-18$ GHz, respectively, for the compliance test of UWB transmitters [5]. We chose these two kinds of antennas, operating in the same frequency range. Recently, many UWB antennas have been proposed for the short range communications and radars. antenna that is commercially available and a trapezoidal antenna with an L-shaped ground plane that is easily fabricated.

3.3.1 Biconical Antenna

First, the same biconical antennas were used both at Tx and Rx sides. The gain and group delay of antenna at 0°, 30° and 60° pointing angles are shown in Figs.1 and 2, respectively.

3.3.2 Log-Periodic Dipole Antenna

A log-periodic dipole antenna (LPDA) is also used at broadband. It also has a frequency-independent gain. Different from the biconical antennas, however, the dispersion characteristic of the LPDA is rather big, since the phase center changes with frequency due to the resonance of the dipole elements [6].

We used a commercial LPDA, Watkins–Johnson's AR7-15A. The antenna has been designed to operate in the range of 1 to 12.4 GHz. Figures 3 and 4 show the gain and group delay of antenna at 0°, 30° and 60° pointing angles, respectively.

4 Conclusion

This paper has presented how to evaluate the link budget of UWB transmission, which includes the transmit waveform, the antennas, the free space propagation, and the correlation receiver. By using the definition, we have evaluated two types 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 transmission waveform.

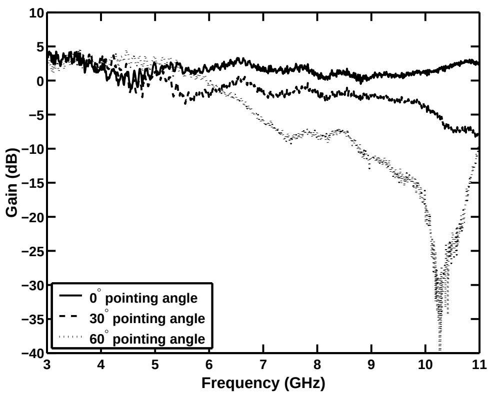

Figure 1: UWB antenna gain for biconical–biconical link.

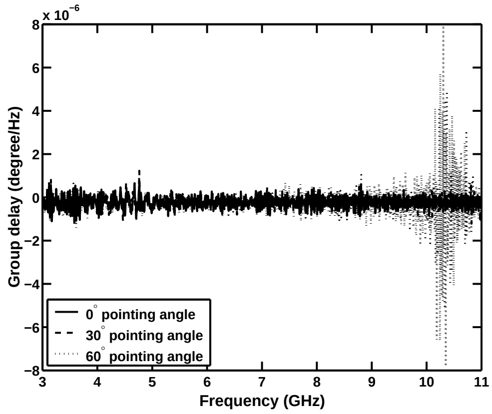

Figure 2: UWB group delay for biconical–biconical link.

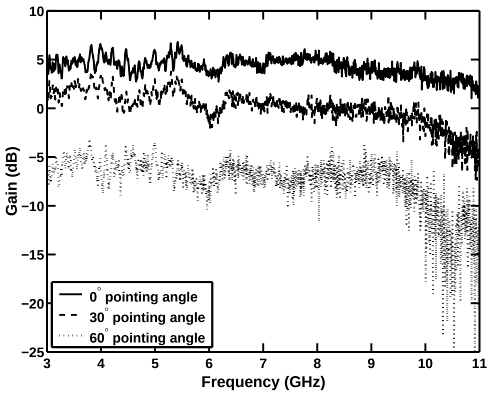

Figure 3: UWB antenna gain for biconical–LPDA link.

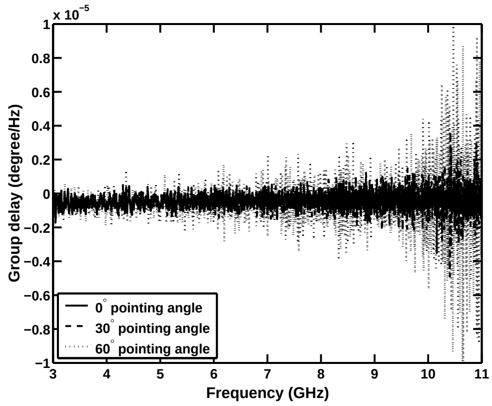

Figure 4: UWB group delay for biconical–LPDA link.

References

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