Experimental Model of UWB Antenna Performance with Laptop Computers

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1 Introduction

The antennas of the ultra wideband (UWB) communication systems are significantly pulse-shaping filters [1]. Any distortion of the signal in the frequency domain causes the distortion of the transmitting pulse shape. Consequently, this will increase the complexity of the detection mechanism at the receiver [2]. Moreover, low cost, geometrically small and still efficient structures are required for typical wireless applications. Therefore, the antenna design for UWB signal radiation is the one of main challenges [3].

This paper presents the experimental model of UWB antenna performance with laptop computers in an indoor channel are analyzed for the 3.1 GHz to 10.6 GHz frequency band. The rectangular passband waveform, which satified the Federal Communication Commission (FCC) [4] definition of UWB signal and FCC spectral masks for the indoor limits, are considered. The characteristics of indoor propagation channel are very complicated and difficult to predict. Therefore, the performances of UWB antenna signal shall be considered. In addition, we considered the matched filter at the receiver side to maximize the signal to noise ratio (SNR). The UWB antenna transfer function, the UWB signal waveform of the UWB systems are evaluated. The transmission gain and the correlation coefficient are presented and discussed.

2 Description of Measurement System

The basis analysis of UWB propagation channel measurement campaign with laptop computers performed we carry out at the department of information engineering, faculty of engineer, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand. The measurements were conducted in a conventional room. The frequency responsed measurements of the indoor UWB propagation channel were performed using a vector network analyzer (VNA). The channel was swept from 3 GHz to 11 GHz, where Port-1 was the transmitter port (Tx) and Port-2 was the receiver port (Rx), respectively. The Tx antenna is a Biconical antenna with the maximum diameter of 65.34 mm and the length of 37 mm. For the Rx antenna, the Skycross antenna (SMT-3TO10M-A) [5] is used to consider the distortion of the UWB waveform. Both of the Tx and the Rx antennas are fixed on laptop computers at the height of 0.20 m from the table. The Rx antenna is separated at a distance from 0.60 m to 2.40 m.

3 Theory of UWB transmission system

3.1 Friis' Transmission Formula for UWB system

The Friis' transmission formula [6] is first expressed in terms of power [7]. Then it is extended in terms of the transmission signal waveform to consider the transfer function H_{Friis}. Defining the transmitted and received power signals as P_{r} and P_{t}, respectively, and assuming the polarization of transmitter and receiver antennas match perfectly. We obtain

$$H_{\text{Friis}}(f,d)=\frac{P_{\text{r}}(f)}{P_{\text{t}}(f)}=H_{\text{f}}(f,d)\cdot H_{\text{r}}(f)\cdot H_{\text{t}}(f),$$

where H_{f} is the transfer function of free space, H_{r} and H_{t} are the transfer functions of the Tx and the Rx antennas, which are implicit functions of directions, and d is the transmitter-receiver (Tx-Rx) separation distance. The transfer function of free space can be written as

$$H_{\text{f}}(f,d) \;=\; \frac{1}{4\pi|f|d}\exp(-j2\pi f t_d), \tag{1}$$

where $t_d = d/c$ is the delayed time and c is the velocity of light. The received waveform $v_{\text{r}}(t,d)$ can be found by using

$$v_{\text{r}}(t,d)=v_{\text{t}}\otimes h_{\text{Friis}}(t,d), \tag{2}$$

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

$$h_{\text{Friis}}(t,d) \;=\; \int_{-\infty}^{\infty} H_{\text{Friis}}(f,d)df, \tag{3}$$

the spectral density function $V_{\text{r,f}}$ and the waveform in the time domain $v_{\text{r,f}}$ and $v_{\text{r,Iso}}$ of the received signal can be expressed as

$$V_{\text{r,f}}(f,d) \;=\; V_{\text{t}}(f)\cdot H_{\text{c}}(f,d), \tag{4}$$
$$V_{\text{r,Iso}}(f,d) \;=\; V_{\text{t}}(f)\cdot H_{\text{f}}(f,d), \tag{5}$$
$$v_{\text{r,f}}(t,d) \;=\; \mathcal{F}^{-1}\{V_{\text{r,f}}(f,d)\}, \tag{6}$$
$$v_{\text{r,Iso}}(t,d) \;=\; \mathcal{F}^{-1}\{V_{\text{r,Iso}}(f,d)\}, \tag{7}$$

where $\mathcal{F}^{-1}\{\cdot\}$ denotes the inverse Fourier transform and H_{c} is the measurement channel. At the receiver side, the matched filter is introduced to maximize the SNR of the receiver output, as follows:

$$H_{\text{MF}}(f)=\frac{\sqrt{2f_{\text{b}}}\cdot V^{*}_{\text{r,f}}(f,d)}{\sqrt{\int_{-\infty}^{\infty}|V_{\text{r,f}}(f,d)|^2df}}, \tag{8}$$

and for the isotropic case,

$$H_{\text{MF,Iso}}(f)=\frac{\sqrt{2f_{\text{b}}}\cdot V^{*}_{\text{r,Iso}}(f,d)}{\sqrt{\int_{-\infty}^{\infty}|V_{\text{r,Iso}}(f,d)|^2df}}. \tag{9}$$

The spectral density function $V_{\text{MF,f}}$, $V_{\text{MF,Iso}}$ of the signal and time domain waveform $v_{\text{MF,f}}$, $v_{\text{MF,Iso}}$ at the matched filter output can be written as

$$V_{\text{MF,f}}(f,d) \;=\; V_{\text{r,f}}(f,d)\cdot H_{\text{MF}}(f), \tag{10}$$
$$V_{\text{MF,Iso}}(f,d) \;=\; V_{\text{r,f}}(f,d)\cdot H_{\text{MF,Iso}}(f), \tag{11}$$
$$v_{\text{MF,f}} \;=\; \mathcal{F}^{-1}\{V_{\text{MF,f}}(f,d)\}, \tag{12}$$
$$v_{\text{MF,Iso}} \;=\; \mathcal{F}^{-1}\{V_{\text{MF,Iso}}(f,d)\}, \tag{13}$$

taking its maximum as

$$\max_t v_{\text{MF}}(t) \;=\; \int_{-\infty}^{\infty} V_{\text{MF}}(f)df, \tag{14}$$

transmission gain including the effect of the waveform can be obtained as Eq. (14). For the normalization, the reference isotropic antenna with $H_{\text{Iso}}(f)$ of 1 is considered. The transmission gain of the optimum matched filter signal, G_{of} and the transmission gain of the isotropic matched filter signal, G_{if} can be founded from Eq. (15)

$$G_{\text{UWB}}=\max_t v_{\text{MF}}(t)\Big/\max_t v_{\text{MF,Iso}}(t). \tag{15}$$

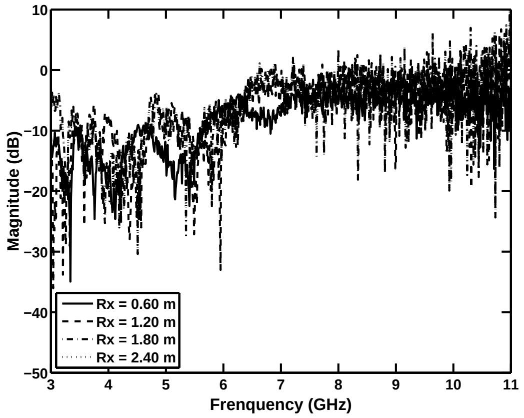

Figure 1: Antenna transfer function for UWB antenna of each distance: magnitude.

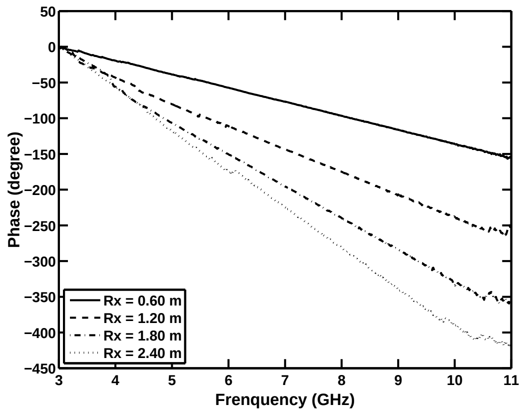

Figure 2: Antenna transfer function for UWB antenna of each distance: phase.

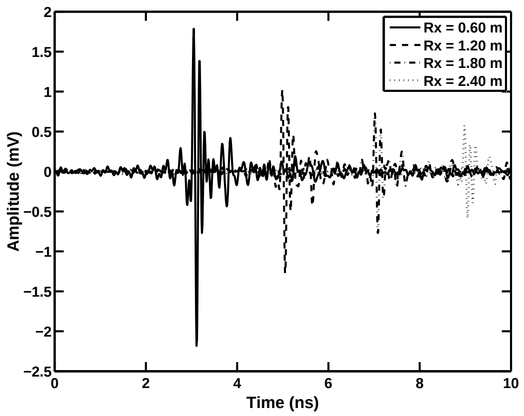

Figure 3: Received signal waveform at the antenna output.

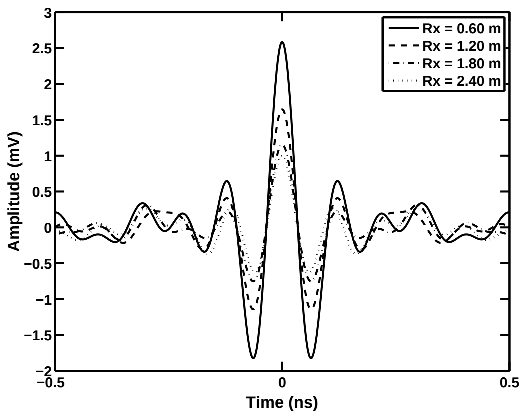

Figure 4: Received signal output of matched filter: optimal.

3.2 Correlation coefficient

The correlation coefficient can be considered as the ratio between the cross correlation between the transmitted and received signal waveforms and the square root of multiplication between auto correlation of transmitted and received signal waveforms, which can be written as below.

$$\rho(\mathrm{d}) = \frac{max|r_{\mathrm{ab}}(\tau)|}{max\sqrt{|r_{\mathrm{a}}(\tau)r_{\mathrm{b}}(\tau)|}}, \tag{16}$$

where r_{ab} is cross correlation between signals a and b and $r_{\mathrm{a}}, r_{\mathrm{b}}$ is auto correlation of signals a and b, respectively.

4 Experiment results and discussion

In this section, the UWB antenna performance is evaluated by using MATLAB program. The antenna transfer function, the received waveform, the output from optimum matched filter, the transmission gain and the correlation coefficient are investigated.

Fig. 2 and Fig. 3, show the magnitude and phase of the antenna transfer function of the UWB channel at 0.60, 1.20, 1.80 and 2.40 m., respectively. We can see that the phase at each distances the radiation pattern changes from frequency to frequency, which may result in the waveform distortion. Fig. 4 shows the received signal waveforms, which used the UWB signal

Table 1: The tranmission gain of the optimum matched filter and isotropic matched filter signals and the correlation coefficient of each distance.

Tx-Rx distances (m)	G_{of}[dBi]	G_{if}[dBi]	correlation coef.
0.60	−8.59	−11.53	0.84
1.20	−12.51	−16.07	0.77
1.80	−15.60	−20.51	0.66
2.40	−16.85	−21.73	0.58

model follow as [8]. Fig. 5 shows the output of matched filter is optimized for each individual scenario, and the results correspond to the maximum available gain. Table 1 summarizes the overall gain with respect to the isotropic antennas case. Since the gain at the most of the frequencies was below unity, the dB value of the gain is negative. By using the approximate matched filter, the gain has been degraded. For the correlation coefficient value of the impulse responses between the received signal and the approximate matched filter using the isotropic antennas, the case of 0.60 m is higher than others.

5 Conclusions

In this paper the experimental model of UWB antenna performance with laptop computers are presented. The rectangular passband, which satisfied the FCC definition of UWB signal are consider. At the receiver side, the matched filter are proposed to get the maximum SNR. Therefor, the transmission gain and the correlation coefficient are investigated. Furthermore, this scheme is useful for the evaluation of various UWB antenna for the WPANs technology. Also, the typical UWB antenna is evaluated.

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