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SNR Gain Analysis of Ultra Wideband Template Receiver for Wireless Personal Area Networks

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***Abstract*—In this paper, we evaluated the signal to noise ratio (SNR) gain of ultra wideband (UWB) receivers performance for wireless personal area network. The optimum and isotropic template receivers are considered based on the data measurement. The biconical antennas are used as the transmitter (Tx) and receiver (Rx) antennas. The rectangular passband, which is satisfied the full band of UWB signal definition and Federal Communications Commission (FCC) indoor and outdoor limit spectral masks, is used as the transmitted UWB signal. The channels are measured in an anechoic chamber by using a vector network analyzer (VNA). The SNR gains of optimal and isotropic template receivers are shown and compared in results.**

I. INTRODUCTION

Recently, ultra wideband (UWB) radio technology has become an important topic for microwave communication because of its low cost and low power consumption potentials [1]-[3]. The UWB is different from other radio frequency (RF) technologies. UWB transmits very short pulse and power spectral density (PSD) in the range of ultra wide frequency spectrum instead of using narrow band radio frequency in traditional RF tecnologies. The UWB is a unique and new usage of recently legalized frequency spectrum. The FCC specified that UWB signal has frequency spectrum ranging from 3.1 GHz to 10.6 GHz [4], and have a fractional bandwidth equal or greater than 0.20, or occupied bandwidth equal or greater than 500 MHz. The fractional and occupied bandwidth are defined as

$$\text{Fractional bandwidth} = \frac{2(f_{\rm H}-f_{\rm L})}{f_{\rm H}+f_{\rm L}}, \quad (1)$$

$$\text{Occupied bandwidth} = f_{\rm H}-f_{\rm L}, \quad (2)$$

where $f_{\rm L}$ and $f_{\rm H}$ are the lowest and highest frequencies at the -10 dB point, respectively.

The PSD of UWB signal does not exceed the FCC part 15 limits or -41.3 dBm/MHz, so that the PSD of UWB signal is considered as the noise for other radio communication systems. Therefore, the UWB radio technology can coexist with other RF communications without interference. Moreover, the UWB radio technology is an ideal candidate that can be utilized for commercial, short-range, low power, low cost indoor communication systems such as wireless personal area networks (WPANs) [5].

The Friis' transmission formula is widely used to calculate the free space path loss for narrowband communications [6]. After that, the complex form of Friis' transmission formula is developed for UWB communications [7]-[9]. The matched filter receiver is used as the UWB receiver [10]-[12]. Although, the rectangular waveform distorted by UWB free space channel is used to derive the theoretical SNR gains [13], there are no considerations about the measured channel and UWB antennas.

In this paper, we evaluated the SNR gains of UWB receivers performance. The optimum and isotropic template receivers satisfied constant noise power condition between input and output are considered. The biconical antennas are used as the transmitter (Tx) and receiver (Rx) antennas. The rectangular passband, which is satisfied the full band of UWB signal definition and FCC indoor and outdoor limit spectral masks, is used as the transmitted UWB signal. The channels are measured in an anechoic chamber by using a vector network analyzer (VNA). The frequency range of measurement is form 3 GHz to 11 GHz. The path losses are evaluated and investigated for considering the SNR gains. The SNR gains of optimal and isotropic template receivers are shown and compared. The results are discussed in the conclusion.

This paper is organized as follows. Section 2, the evaluation of SNR gain for UWB systems. Section 3, the UWB template receiver. Next, the evaluation results are illustrated in Section 4. Finally, the conclusions are discussed in Section 5.

II. SNR GAIN EVALUATION SCHEME FOR UWB SYSTEMS

A. UWB Signal Waveform Model

For UWB waveform signal, the rectangular passband waveform is considered as the UWB transmitted signal. The expression of UWB transmitted signal ($v_{\rm t}$) in time domain is given by

$$v_{\rm i}(t) = \frac{A}{f_{\rm b}}[f_{\rm H}{\rm sinc}(2f_{\rm H}t)-f_{\rm L}{\rm sinc}(2f_{\rm L}t)], \quad (3)$$

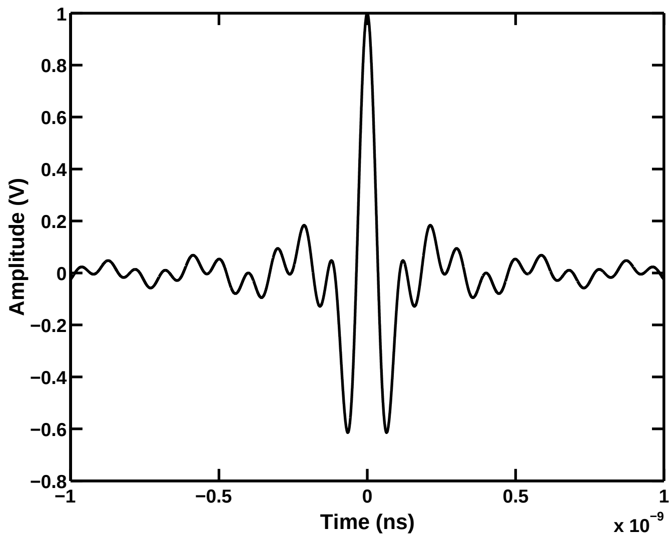

Fig. 1. Transmitted signal waveform of UWB.

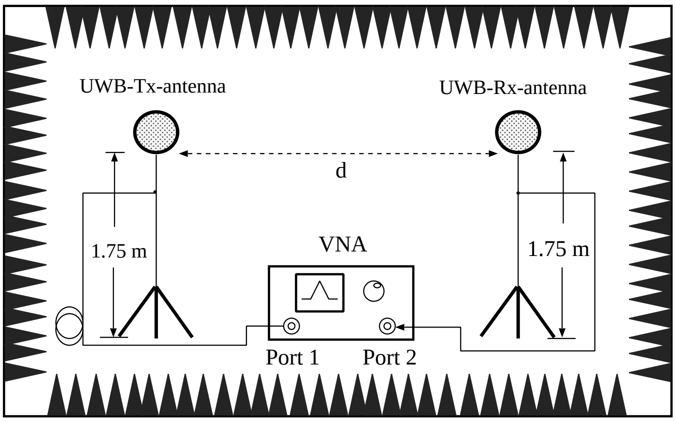

Fig. 2. The instrument setup.

where $A = 1$ V is the maximum amplitude, $f_{\rm b} = 7.5$ GHz is the occupied bandwidth, $f_{\rm L} = 3.1$ GHz and $f_{\rm H} = 10.6$ GHz are the minimum and maximum frequencies. This transmitted UWB signal is shown in Fig. 1.

B. Measurement System

The UWB channel transfer function is measured in frequency domain by using VNA in an anechoic chamber. The VNA is operated in the response measurement mode, where Port-1 and Port-2 are the Tx and Rx ports, respectively. Both Tx and Rx antennas are fixed at the height of 1.75 m and separated by 1 m. This measurement setup is shown in Fig. 2.

The biconical antennas are used as the Tx and Rx antennas. These antennas are chosen because they are easy to fabricate and have low distortion property. The geometry and dimensions of the antenna is shown in Fig. 3. 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. Only Rx antenna is

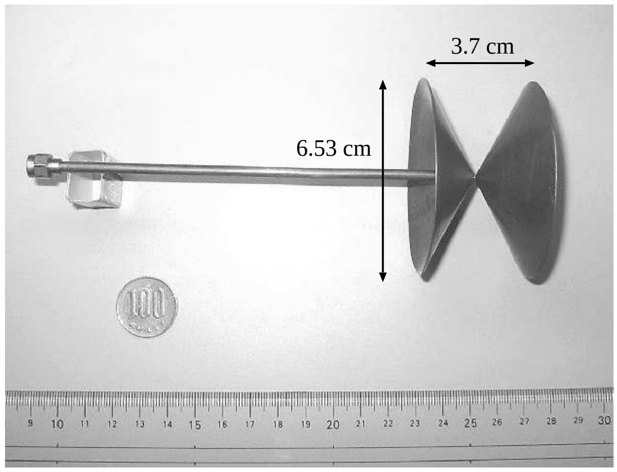

Fig. 3. Geometry and dimensions of the biconical antenna.

TABLE I
MEASUREMENT PARAMETERS.

Parameter	Value
Frequency range	3 GHz to 11 GHz
Number of frequency points	1601
Dynamic power range	80 dB
Tx and Rx antennas heights	1.75 m.
Distance between Tx and Rx antennas	1.00 m.
Rx rotation range	$0° - 360°$
Rx rotation step	$5°$
Polarization	horizontal

rotated from $0°$ to 360 $°$ with $5°$ rotation step. The horizontal polarization is measured.

The measurement parameters are listed in Table 1. It is note that the calibration of VNA is done at the connectors of the cables to be connected to the antennas. Therefore, all impairments of the antenna characteristics are included in the measurement results.

III. UWB TEMPLATE RECEIVERS

A. Optimum Signal Analysis

The template receiver is used at the receiver side as shown in Fig. 4. The optimum and isotropic template receivers satisfied constant noise power condition between input and output are considered. The optimum template receiver considered received signal from measured channel and it is an ideal case with maximum SNR gain, while the isotropic matched filter considered received signal from free space channel using Friss' transmission formula [7]-[9] with isotropic Tx and Rx antennas.

For constant noise power condition between input and output, the frequency transfer functions of optimum and isotropic template receivers, $H_{\rm opt}$ and $H_{\rm iso}$, are normalized as

$$\int_{-\infty}^{\infty} |H_{\rm opt}(f)|^2 {\rm d}f = \int_{-\infty}^{\infty} |H_{\rm iso}(f)|^2 {\rm d}f = 2f_{\rm b}. \qquad (4)$$

Therefore, the output noise power is a constant as $N_0 f_{\rm b}$, where $N_0/2$ is the PSD of additive white Gaussian noise (AWGN).

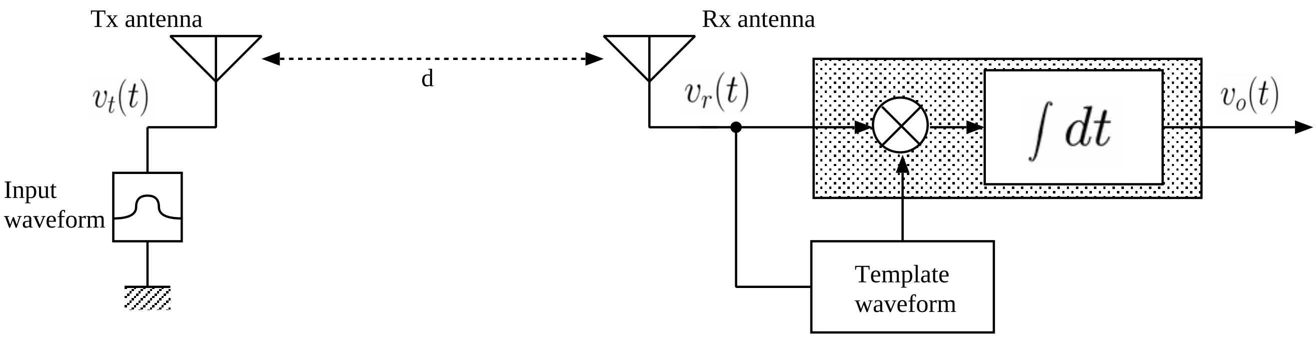

Fig. 4. Block diagram of SNR gain for UWB system.

Under this condition, the frequency transfer functions of optimum and isotropic template can be respectively written as

$$H_{\rm opt}(f) = \frac{\sqrt{2f_{\rm b}}V_{\rm r}^*(f)}{\sqrt{\int_{-\infty}^{\infty}|V_{\rm r}(f)|^2{\rm d}f}}, \quad (5)$$

$$H_{\rm iso}(f) = \frac{\sqrt{2f_{\rm b}}V_{\rm r-iso}^*(f)}{\sqrt{\int_{-\infty}^{\infty}|V_{\rm r-iso}(f)|^2{\rm d}f}}, \quad (6)$$

where * is the complex conjugate operator, $V_{\rm r}$ and $V_{\rm r-iso}$ are the spectral densities of received signals from measured channel and free space channel with isotropic Tx and Rx antennas, respectively. They can be evaluated from

$$V_{\rm r}(f) = H_{\rm c}(f)V_{\rm t}(f), \quad (7)$$

$$V_{\rm r-iso}(f) = H_{\rm f}(f)V_{\rm t}(f), \quad (8)$$

where $V_{\rm t}$ is the spectral density of transmitted signal calculated from

$$V_{\rm t}(f) = \int_{-\infty}^{\infty} v_{\rm t}(t)e^{-j2\pi ft}{\rm d}t, \quad (9)$$

H_c is the frequency transfer function of measured channel measured from Sec. 2.2 and H_f is the frequency transfer function of free space channel given by

$$H_{\rm f}(f) = \frac{c}{4\pi d|f|}e^{-j2\pi fd/c}, \quad (10)$$

where d is the distance and c is the velocity of light.

B. SNR Gain Analysis

Because of the frequency transfer functions of optimum and isotropic matched filter receivers are satisfied the constant noise power condition between input and output, the ratio between average powers of output and input signals of matched filter receiver, $v_{\rm o}$ and $v_{\rm r}$, is the SNR gain. Therefore, SNR gain can be defined as

$$G_{\rm SNR} = \frac{\int_{-\infty}^{\infty}|v_{\rm o}(t)|^2{\rm d}t}{\int_{-\infty}^{\infty}|v_{\rm r}(t)|^2{\rm d}t}. \quad (11)$$

The output signal of matched filter receiver can be computed from

$$v_{\rm o}(t) = \int_{-\infty}^{\infty} H_{\rm a}(f)V_{\rm r}(f)e^{j2\pi ft}{\rm d}f, \quad (12)$$

where $\rm a$ is $\rm opt$ or $\rm iso$, which is presented to optimum and isotropic, respectively.

The input signal of template receiver or received signal is calculated by using inverse Fourier transform of its spectral density

$$v_{\rm r}(t) = \int_{-\infty}^{\infty} V_{\rm r}(t)e^{j2\pi ft}{\rm d}f. \quad (13)$$

IV. Results

In this section, the evaluation results of SNR gains are shown. First, the path losses based on average power losses of received signal and output signals of optimum and isotropic template receivers are considered.

Figure 5 shows the path losses of received signal and output signals of optimum and isotropic template receivers along pointing angle from $0°$ to $360°$. The path losses at $0°$, $180°$ and $360°$ pointing angles are low because they correspond to the broadside direction of biconical antenna and they are high at $90°$ and $270°$ pointing angles. The path losses of output signals of both template receivers are lower than that of received signal. This improvement is considered in the term of SNR gain.

The SNR gains of optimum and isotropic template receivers along pointing angle from $0°$ to $360°$ are shown in Fig. 6. The average SNR gain of optimum and isotropic template receivers are about 2.99 and 2.56 dB, respectively. Therefore, the SNR gain of optimum template receiver is better that that of isotropic template about 0.43 dB. Considering this, the bit error rate performance of the optimum and isotropic template shown in Fig.7. It can be seen that the different is low. As described above, by this scheme, it becomes possible to detect several types of UWB signals.

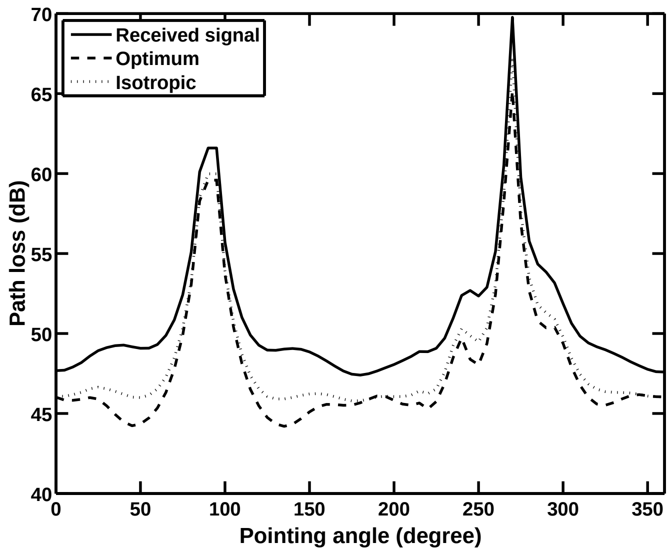

Fig. 5. Path loss of received signales and output signals of optimum and isotropic template receivers along pointing angle from 0° to 360°.

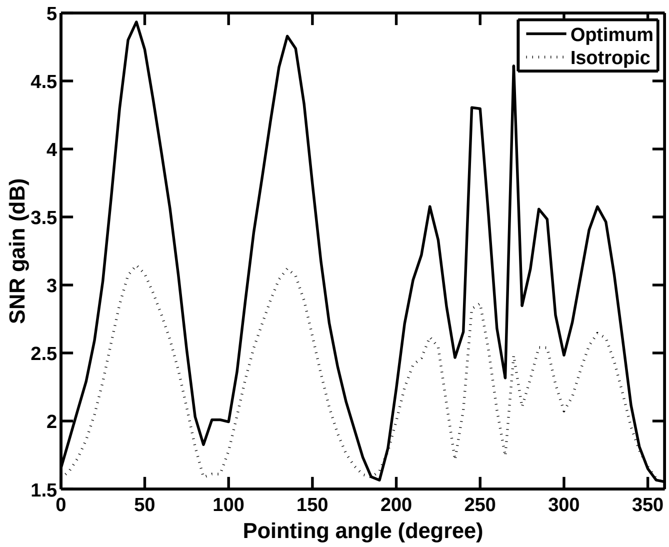

Fig. 6. SNR gains of optimum and isotropic template receivers along pointing angle from 0° to 360°.

V. Conclusion

In this paper, we discussed the SNR gains of UWB template receivers performance are evaluated for WPANs. The optimum and isotropic template receivers are considered. The biconical antennas are used as the Tx and Rx antennas. From the results, the SNR gains of optimum and isotropic template receivers are about 2.99 and 2.56 dB, respectively. The difference is low, that is only 0.43 dB. That because the channel is measured in the anechoic chamber, which can assume to be free space channel, and the biconical antennas have low distortion characteristics. In the future work, the SNR gains of indoor environment and other UWB antennas are investigated.

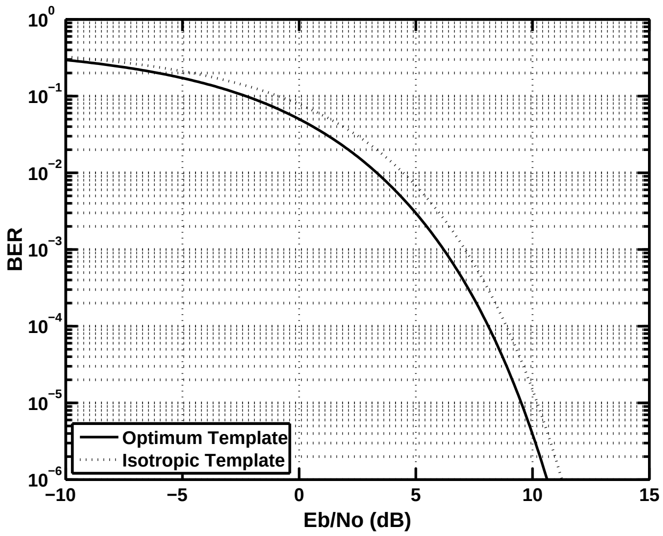

Fig. 7. Bit error rate of the optimum template and isotropic template performance are shown.

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