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Multiple Antennas Effect on UWB Rake Receiver Performance

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ABSTRACT

This paper discusses the enhancement of the proposed UWB antenna design that can be used in wireless UWB systems. The small antenna design was simulated by CST software to present the performance of the main antenna parameters. The return loss is less than -10 dB from 3.5 GHz to 10.8 GHz which is covering the UWB bandwidth. This antenna was applied in multiple-in multiple-out (MIMO) scheme in indoor transmission/reception system to improve the propagation bit rate or to increase the channel capacity. After that, the effects of multiple antennas have been evaluated in terms of error bit probability in the wireless rake receiver using maximal ratio combining (MRC) technique through channel models CM1 and CM4.

Key words: Multiple antennas, wireless rake receiver, UWB indoor channel models.

1. INTRODUCTION

The UWB technology is the promise solution for wireless communications. This technology supports the short range reception devices for high data rate propagation. During indoor propagation there are multi-path fast fading signals and this characteristic challenges the performance of wireless systems [1]. The range and antenna used are proportional to the transmission speed and channel capacity. The final report of the Federal Communications Commission (FCC) has been licensed to apply the low power spectral density (PSD) at level -41.3 dBm/MHz for spectral range of 3.1—10.6 GHz [2].This low PSD made the UWB systems coexist with other narrow-band devices that interfere in signals or pulses. Now a day high performance devices need to be designed to have ability to overcome the obstacles for operation under both line of sight (LOS) and non line of sight (NLOS) conditions [3].

We considered UWB transmitted signal reaches the receiver antenna passing through the multi-path channel with noises and interferences. The high gain antenna reduces the reflection coefficient and passing most of the incident power to the rake receiver. Rake receiver is capturing the signal energy by combining technique to support the desired signals. For UWB reception system, 4 x 4 MIMO antennas are presented in [4] and each one has size of 60 x 60 mm^2 printed on same substrate of FR4 epoxy material and dielectric constant (ε) is 4.4. The performance of 2 x 2 MIMO-UWB has been evaluated in [5] through line-of-sight (LOS) and non line-of-sight (NLOS) in underground gold mine and the channel capacity decreases up to 10 Gbps at 10 meters distance. Circular antenna arrays were designed in [6] to improve the wireless channel capacity in indoor propagation and the capacity is less than 5 bits/sec/Hz at SNR of 10 dB.
In this paper, the modified antenna design can be used in rake receiver structures of four fingers, firstly, to evaluate the wireless channel capacity through a NLOS of 10 meters range, secondly to evaluate the system performance by reducing the error bit probability. The remaining sections of this work are organized as follows: Section 2 briefly explains the UWB transmission that is including the modulation and spread spectrum techniques. Section 3 describes the indoor channel modeling. Section 4 presents the proposed antenna design which used in wireless UWB systems. Section 5 includes the multi-path rake receiver. The error bit probabilities reducing with respect to SNR are presented in section 6. Then conclusions are made in section 7.

2. UWB TRANSMISSION METHODOLOGY

We consider a time hopping-UWB (TH-UWB) system with bi-phase shift keying (BPSK) modulation. The information is generated randomly by binary source as in Figure 1 that to be transmitted at a symbol rate of $1/T_b$ bits/sec. The bi-phase modulation in time-hopping spread spectrum (TH-SS) technique is shown as an example in Figure 2.

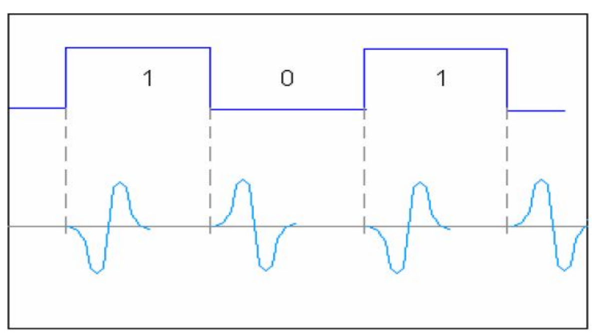

Figure 1: BPSK modulated waveform

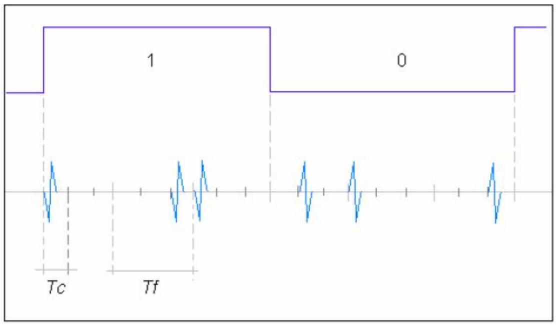

Figure 2: TH-UWB with Bi-phase modulation

The UWB signal $\{P_T(t)\}$ and modulated signal $\{Y(t)\}$ are mathematically defined as [7]:

$$P_T(t)=\left(\frac{t}{\tau}\right)e^{-2\pi(t/\tau)^2} \tag{1}$$

$$Y(t)=\sum_{j=-\infty}^{\infty} W(t-jT)(2d_j-1) \tag{2}$$

where τ is the shape vector, T is the bit time, dj is the binary data, and W is the pulse waveform. For one user the TH-UWB signal using bi-phase signal can be expressed as:

$$S_{tr}(t)=\sum_{j=-\infty}^{\infty} W_{tr}(t-jT_f-c_jT_c)(2d_{j/N_s}-1) \tag{3}$$

where T_f is the frame duration, c_j is each user pseudorandom code, d is the binary data, and N_s is the number of pulses transmitted for each bit.

3. INDOOR MULTI-PATH PROPAGATION

The $S_{tr}(t)$ signal passes through a multi-path channels and the channel models parameters should be based on a modified Saleh-Valenzuela (S-V) channel model for indoor multi-path propagation as reported in [8]. One important benefit of a wireless system is to increase the channel bit rate capacity with no extending the bandwidth or maximize the transmitted signal power. By using multiple antennas at the input of UWB rake receiver as shown in the configuration of Figure 3, the system performance will be improved by reducing the error bit probabilities (P_e). In the MIMO system, we consider two random signal vectors, one for the input signal (s) to the channel and one for the output signal (q) from the channel [1].

$$q = Hs + w \tag{4}$$

where $s = [s_1, s_2, s_3, \ldots s_M]^T$ is the transmitted signal vector up to M (number of omni-directional transmitted antennas), $q = [q_1, q_2, q_3, \ldots q_N]^T$ is the received signal vector up to N (the number of omni-directional received antennas), w is the Gaussian noise vector with zero mean and equal variance, and H is the M × N channel matrix .

$$H=\begin{bmatrix} h_{1,1} & \cdots & h_{1,N} \\ \vdots & \ddots & \vdots \\ h_{M,1} & \cdots & h_{M,N} \end{bmatrix} \tag{5}$$

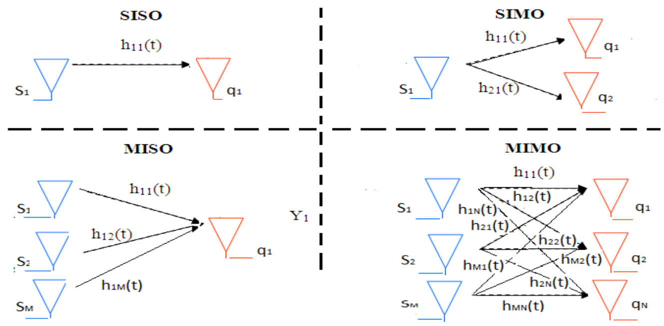

Figure 3: Configuration of multiple and single UWB antennas

The capacities of the single-input single-output (SISO), multiple-input single-output (MISO), and multiple-output multiple-input (MIMO) systems (bits per sample) for indoor, UWB wireless bandwidth (B) are given by [9]:

$$C_{SISO} = B\log_2(1+\lambda\times SNR) \tag{6}$$

$$C_{MISO} = B\log_2\left(1+\frac{SNR}{M}\sum_{m=1}^{M}\lambda_m\right) \tag{7}$$

$$C_{MIMO} = L\times B\log_2(1+\lambda\times SNR), \tag{8}$$

where L is the number of channels, SNR is the signal-to-noise ratio, and λ is a non-zero eigenvalue of the M x N matrix. The SNR at the receiving antennas is defined as the ratio of the desired power of the received signal to 25% of the noise plus interference power, so that the SNR is related to and is proportional to antenna gain $G(\theta, \phi)$ when the noise distribution is uniform [10], where θ is the elevation angle, and ϕ is the azimuth angle for the antenna radiation patterns.

2. THE PROPOSED UWB ANTENNA AND SIMULATED RESULTS

The antenna was designed based on rectangular patch antenna with dimensions in mm as illustrated in Figure 4 of printed patch on one side of the Taconic TLY-5 substrate material and on the other side the planar ground plane is printed up to 11.25 mm. The feed line used is the microstrip feed line and there is a gap of 0.75 mm between ground plane and radiator (patch). The printing material is copper of 0.035 mm to make good integration with other system elements. After completing the design, CST MW studio software was used to simulate the proposed antenna. The patch is slotted at the lower edge and upper edge to extend the impedance bandwidth to be suitable for UWB system applications. The simulated results are shown in Figure 5 of return loss which covers the UWB frequency range (3.1-10.6 GHz) and Figure 6 of omni-directional radiation pattern which gives reliability for user at mobile applications. The important part of this design is the antenna high gain that used in this work to enhance rake receiver performance. The antenna gain is shown in Figure 7 that was considered in the simulation process. This antenna is referred to as a microstrip patch antenna with low return losses at the input of the transmitting antenna (R_{Tx}) and at the output of the receiving antenna (R_{Rx}). The Friis transmission formula (9) shows the relationship between the input power of the transmission antenna (P_{Tx}) and the output power of the receiving antenna (P_{Rx}) when the antennas are separated by distance d [11].

$$\frac{P_{Rx}}{P_{Tx}} = (1-|R_{Tx}|^2)(1-|R_{Rx}||G_{Rx}G_{Tx}| \qquad (9)$$

$$|\hat{\rho}_{Rx}.\hat{\rho}_{Tx}|^2 \left(\frac{\lambda}{4\pi d}\right)^2$$

where G_{Rx} is the gain of the receiving antenna, G_{Tx} is the gain of the transmitting antenna, λ is the operating wavelength, and $|\hat{\rho}_{Rx}.\hat{\rho}_{Tx}|^2$ is the polarization matching factor between the antennas.

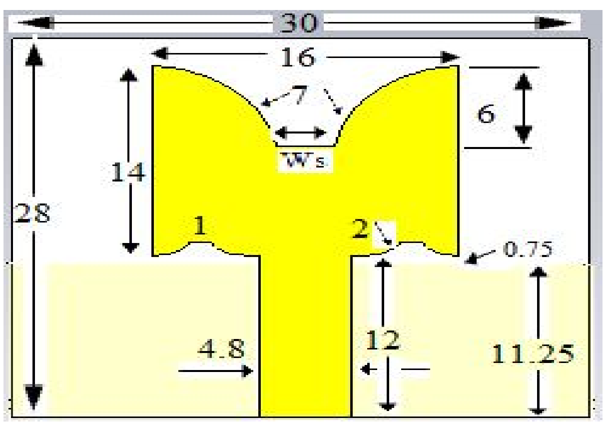

Figure 4: UWB antenna simulated design

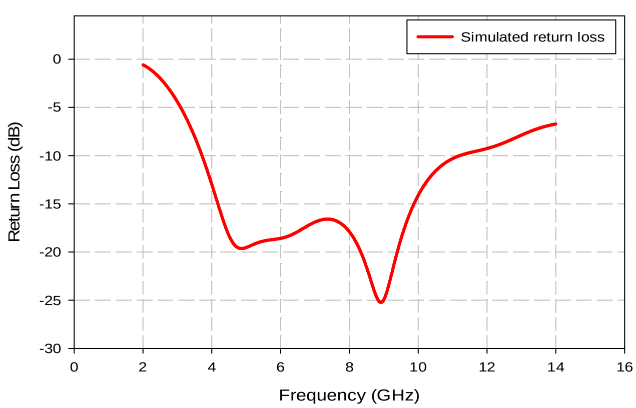

Figure 5: Simulated return loss of the proposed antenna

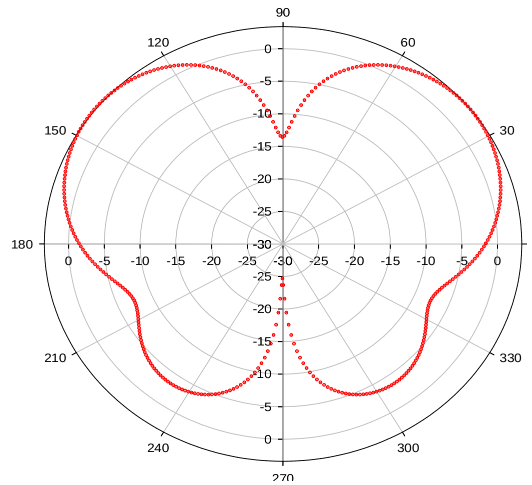
Figure 6: Omni-directional radiation pattern

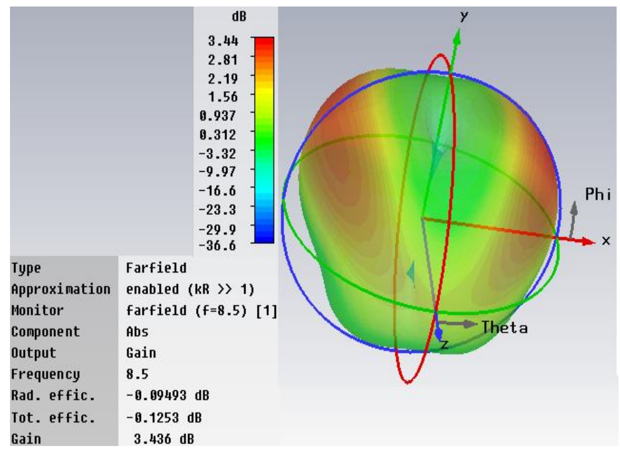

Figure 7: 3-D Radiation pattern to show the antenna gain

5. THE MULTI_PATH RAKE RECEIVER MODEL

After transmitting through the wireless channel models, then passing the proposed antenna, the multi-path affected received signal r(t) with n(t) of AWGN at the receiver's input is represented as:

$$r(t)=s(t)*h(t)+n(t) \qquad (10)$$

where $*$ is the convolution operator and n(t) is zero mean white Gaussian noise with two sided power spectral density $N_o/2$ [12]. Due to indoor reflections, diffractions, and scattering from obstacles, a radio signal channel can consist of many copies of originally signals having different amplitudes, phases, and delays.

$$r(t)=P_{Rx}\sum_{j=-\infty}^{\infty}\sum_{l=0}^{L}\sum_{k=0}^{K_l}\alpha_{k,l}C_jW_{tr}(t-jT_f-c_jT_c-\tau_{k,l}) .(2d_{j/N_s}-1)+n(t) \qquad (11)$$

According to Figure 8 the output signal from each correlator {$r_d(t)$} can be written as follow:

$$r_d(t)=\int_0^T r(t)\ p(t-\tau)dt \qquad (12)$$

where p(t-τ) is the template signal which is the same as the transmitted signal. The $r_d(t)$ signal is sampled at sampling duration of T_s up to get $r_d(qT_s)$. q = 1, 2, 3….D

The tap weight vector of the received signal is assumed to be $w = [w_1, w_2, w_3,\ldots.w_d]^T$ and the input signal vector of the taps is

$$r(qT_s)=[r_1(T_s),r_2(2T_s),r_3(3T_s),\ldots\ldots r_d(qT_s)]^T \qquad (13)$$

For evaluation of the desired signal, there are three different combining techniques in rake receiver of ultra wideband (UWB) communication systems: MRC, EGC, and SC. These techniques are coherent if the phase of the channel tap is recovered and non coherent if the phase of the channel tap is not recovered [13]. As the MRC is better than the other techniques, therefore, we used it in simulation process for combining the outputs of fingers to get Y_{tot}. Hence, Y_{tot} passes to the decision circuit to decide whether the transmitted bit is 0 or 1.

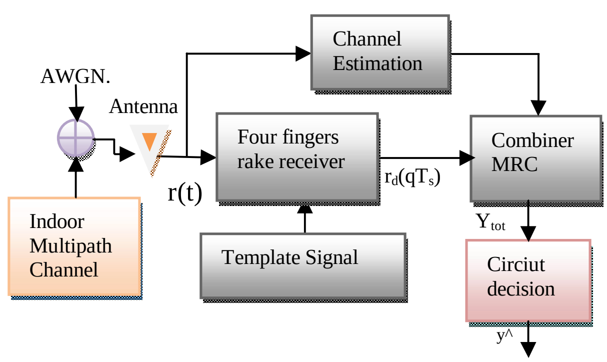

Figure 8: Block diagram of the proposed rake receiver with M fingers

6. THE SYSTEM PERFORMANCE BY CHANNEL CAPACITY AND ERROR BIT PROBABILITY SIMULATED RESULTS

The proposed antenna was applied in the reception system of rake receiver contains four fingers. The input signal to the receiver {r(t)} is copied to four copies according to the number of fingers and each copy is delayed by delay time (τ), supposing that the first delay time for the first finger is zero. These copies are multiplied by generated template signal and integrated to make dispreading and demodulation for the time hopping spread spectrum BPSK transmitted signal. Partial rake receiver is used in this simulation rather than all rake and selective rake receivers, because of lower cost and less complexity with log-normal fading channel. In partial rake receiver, the arriving paths are selected for the first non-zero M paths and these paths are normally with high energy. The output of fingers is signals of different attenuated, shifted, and delayed received signals. To combine these signals, MRC combiner is used with a perfect channel estimation to find the position of the first arriving path. The output of receiver combiner is passing through a decision circuit to the pulse is 1 or 0. The simulation results for channel capacity are shown in Figure 9 and Figure 10 for SISO, SIMO, and MIMO channels with SNR of 10 dB. The high proposed gain antenna improved the channel capacity when using multiple antennas. The high bit rate attained by using several antennas at the transmitter and receiver for indoor wireless systems. Also the simulation was carried out using partial rake receiver by MATLAB with four fingers under CM1 and CM2 channel models that received the TH-BPSK-UWB transmitted signal. The high gain antenna and four fingers enhanced reducing the complexity of receiver rather than optimizing the SNR. To show the system enhancement, Figure 11 clears the decreasing of P_e at increasing the number of antennas used through CM1 of short range LOS multi-path channel. In addition, Figure 12 provides the P_e performance for channel model CM4 (NLOS) in range of 10 meters.

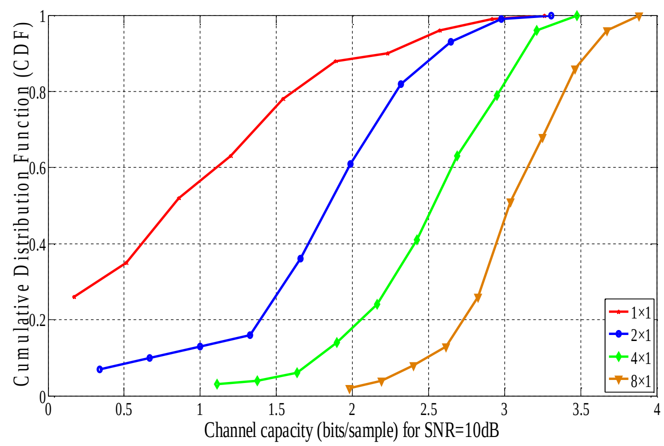

Figure 9: Reception channel capacity with single antenna in SISO and MISO channels

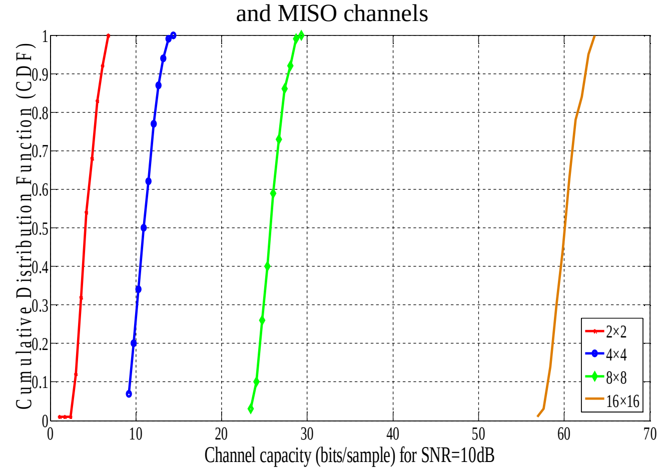

Figure 10: Reception channel capacity with multiple antennas in MIMO channels

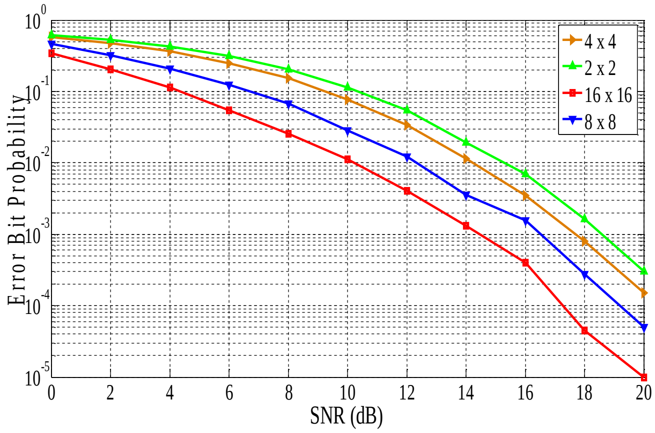

Figure 11: The error bit probability performance against SNR of four fingers at M x N multiple antennas during CM1

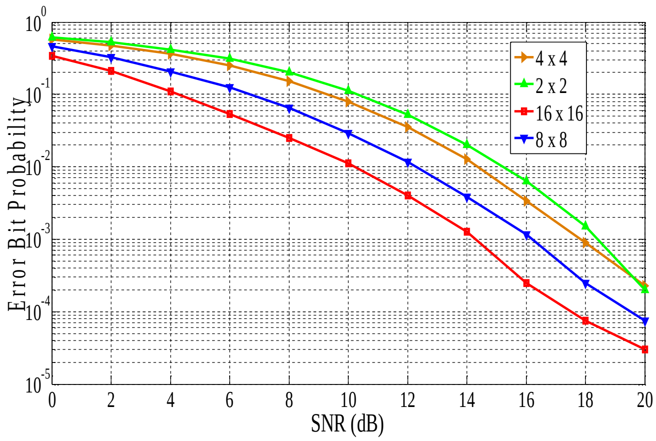

Figure12: The error bit probability performance against SNR of four fingers at M x N multiple antennas during CM4

7. CONCLUSIONS

The multiple antenna effect has been evaluated in this work on UWB rake receiver scheme. The proposed antenna was designed with small dimensions to be suitable in use for wireless small modern or future systems. Several antennas can be arranged in array at the reception part of the system to maximize the reception gain by reducing the reflection of incident power. The MIMO channel capacity is improved over the SISO technique. Increasing the number of MIMO antennas is evaluated in this research to get higher bit rate at 16 x 16 MIMO scheme. The ouput of antenna array is passing to the rake receiver of four fingers to make four copies of received signal. At the output of reception system, error bit probability is decreased according to SNR values when the wireless signals are passing through CM1 and CM2 channel models.

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