Symbol-wavelength MMSE gain in a multi-antenna UWB system

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Abstract

Ultra wideband (UWB) technology has the potential to provide high speed data services. These speeds can be greatly increased by using multiple input multiple output (MIMO) techniques. Multiple antennas are used to achieve spatial diversity and these antenna elements must be separated properly to have uncorrelated communication signals. The separation can be on the scale of a symbol wavelength ([speed of light]/[symbol rate]). We have designed a printed circular disc monopole and measured the UWB radio channel. Finally, we used the measurements to show the minimum mean squared error (MMSE) performance gain which occurs when the receiver antennas are separated on the scale of a symbol wavelength.

Keywords: MIMO systems, adaptive equalizers, antenna measurements

1 Introduction

UWB technology seems to be an efficient solution for the ultra high-speed data services (i.e. speeds up to 480 Mbps) in wireless personal area network (WPAN) environments (i.e. in ranges of ≈ 10 m). This is because of its low cost and very simple architecture. Recently the Federal Communication Commission (FCC) allocated a very wide spectrum of 7.5 GHz (i.e. from 3.1 GHz to 10.6 GHz) for UWB applications. UWB technology uses two different modulation techniques to cover entire UWB spectrum, one technique is Impulse-UWB, which uses a very short duration pulses to transmit data over a large bandwidth and the other is a multi-carrier UWB technique [1]. The FCC defines UWB as a signal with either a fractional bandwidth of 20 percent of the center frequency or a minimum of 500 MHz [1].

Important recent work shows the dependence of correlated interference on antenna element spacing [2].

The authors defined a parameter called chiplength ([speed of light]/[chip rate]), which can be used to separate antennas in a multi antenna system to have uncorrelated interference at the antenna branches. Similar work describes the separation of the receiver antennas on the scale of a signalling wavelength to achieve spatial multiplexing [3]. Chamchoy et al. showed that there is a high degree of correlation between the channels when the antennas are separated based on half the carrier wavelength [4]. In this paper we investigated the MMSE performance of an UWB system in a line of sight (LoS) scenario, when the receiver antennas are separated on the scale of a symbol wavelength (λ_T) to have uncorrelated communication signals at the receiver. The uncorrelation is showed in terms of MMSE gain with increasing separation.

This paper is organized as follows: section 2 describes the system model, section 3 is about the designed antenna for UWB applications, section 4 is about UWB channel measurements, section 5 contains the simulation results of the MMSE equalizer, followed by conclusions and references [5].

2 Two-by-Two System and Channel Model

The two-by-two system and channel model will be discussed in this section.

2.1 Channel Model

The two-by-two baseband channel model consists of four baseband impulse channels between two users and two receive antennas and it is given by

$$\mathbf{h}(t) = \left(\begin{array}{cc} h_{11}(t) & h_{12}(t) \\ h_{21}(t) & h_{22}(t) \end{array} \right) \qquad (1)$$

and its Fourier transform representation is

$$\mathbf{H}(f) = \left(\begin{array}{cc} H_{11}(f) & H_{12}(f) \\ H_{21}(f) & H_{22}(f) \end{array} \right). \qquad (2)$$

2.2 System Model

The two-by-two system model is shown in the Figure 1. In this paper we consider the uplink of the UWB system with two receive antennas and two simultaneous users [6]. The data is a zero-mean random process and is passed through a pulse shaping filter for transmission into the channel. The signal transmitted from user j is of the form

$$s_j(t) = \sum_{n=-\infty}^{\infty} d_j(n) \, p(t - nT) \qquad (3)$$

where j represents the user number, either 1 or 2, $d_j(n)$ is binary data which takes values of $\{-1, 1\}$ and the pulse shaping filter $p(t)$ is a raised cosine type with 100% excess bandwidth. Finally the data signal from the users is transmitted through a baseband channel, whose impulse response is given by $\mathbf{h}(t)$ and its equivalent frequency domain representation is $\mathbf{H}(f)$. The
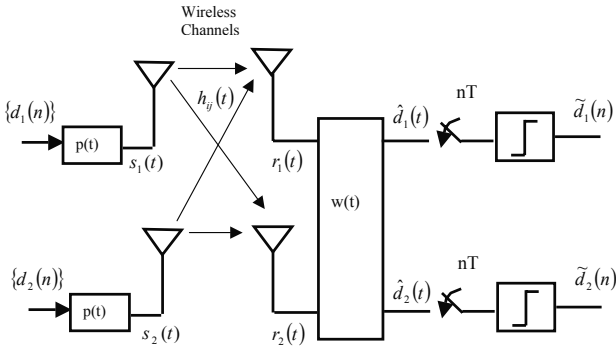

Figure 1. *Two-by-Two system and channel model*

signal at the receiving antenna is the convolution of the transmitted signal and the baseband channel impulse response plus noise and is given by

$$\mathbf{r}(t) = \mathbf{h}(t) \otimes \mathbf{s}(t) + \eta(t) \qquad (4)$$

where $\otimes$ denotes matrix convolution and $\eta(t)$ is a zero-mean additive white Gaussian noise. The received signal at the antenna is passed through a receiving filter whose impulse response is $\mathbf{w}(t)$. The output of the receiving filter is the convolution of $\mathbf{r}(t)$ and $\mathbf{w}(t)$ (i.e. $\mathbf{w}(t) \otimes \mathbf{r}(t)$). The receiving filter coefficients are updated based on the MMSE criterion determined during training. The received signal $\mathbf{r}(t)$ and the receiving

filter $\mathbf{w}(t)$ are given by

$$\mathbf{r}(t) = \left(\begin{array}{c} r_1(t) \\ r_2(t) \end{array} \right) \qquad (5)$$

$$\mathbf{w}(t) = \left(\begin{array}{cc} w_{11}(t) & w_{12}(t) \\ w_{21}(t) & w_{22}(t) \end{array} \right). \qquad (6)$$

3 Antenna Design

In order to make UWB channel measurements we need antennas that have a very wide impedance bandwidth and near omni-directional characteristics for the entire UWB spectrum. We searched for small UWB antennas which have the potential for use in UWB devices [7, 8]. Finally we simulated and fabricated the printed circular disc monopole antenna specified by Liang et al. [7]. The parameters specified are modified slightly because we used a substrate with a different thickness. The length and width of the designed antenna is 50 mm and 42 mm respectively. The antenna simulations were performed using CST Microwave Studio and antennas were fabricated on an FR-4 substrate whose dielectric constant is 4.2. A picture of the fabricated antenna is shown in Figure 4. The antennas were measured using an HP 8510B Vector Network Analyzer (VNA) and the SWR plot of the measured and simulated curves is shown in Figure 2. It is clear from Figure 2 that the designed antenna has an SWR of 2.2:1 or better in the specified band.
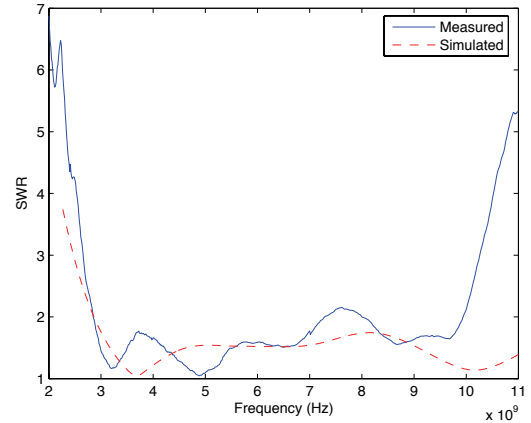

Figure 2. *Comparison of measured and simulated SWR*

4 UWB Channel Measurement

The channel measurement procedure and the experimental setup used to measure UWB channels will be discussed in this section.

4.1 Experimental Setup

The transmitting and receiving antennas are connected to the two ports of the VNA using coaxial cables of length about 2 m and the system is calibrated including the cables, so the losses in the cables can be neglected and the response obtained on the VNA is the combined UWB channel and antenna response. The transmit (Tx) and receive (Rx) antennas are in an LoS scenario and kept at a height of 120 cm from the floor and the distance between Tx and Rx antennas is approximately 60 cm, but varies as receiver antenna element 2 (Rx_2) is moved. The antenna elements at the receiver are separated on the scale of a symbol wavelength as shown in Figure 3.

4.2 Channel Measurement Procedure

UWB channel measurements are performed using frequency domain measurement technique [9]. The channel's complex frequency response data from the HP 8510B VNA is collected using a computer running LabVIEW® software which is connected using a GP-IB interface. These measurements were performed in a research laboratory environment. Frequency domain measurements are obtained by sweeping the VNA from 3 GHz to 10 GHz in 801 points with a frequency step of 8.75 MHz and the time domain impulse responses are obtained by taking the inverse fourier transform. The users and the receiver antenna element 1 (Rx_1) are placed in a fixed position while the receiving antenna element 2 (Rx_2) is moved away from the Rx_1 on the scale of symbol wavelength ($\lambda_T = 2, 4, 8, 12, 16, 20$ and 24 cm). At each position of Rx_2 four radio channels were measured.

5 Simulation Results

The measured channel impulse responses were loaded into MATLAB® for simulating the receiver. Figures 5 and 6 show the plots of the filter coefficients and the squared errors when the receiver antennas are separated on $\lambda_T = 2$ cm and $\lambda_T = 4$ cm respectively. Results shows that there is decrease in the MMSE values as the spacing between the antenna elements increases in an LoS scenario. And it is clear from Figure 7 that when the receiver antennas are separated by
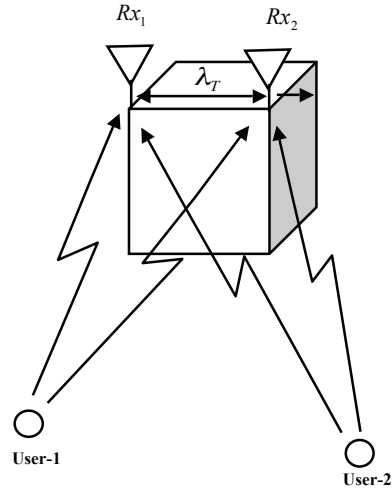

Figure 3. *Measurement setup for the two-by-two system case*

Figure 4. *Picture of the fabricated antenna*

a symbol wavelength ($\lambda_T = 4$ cm) almost all the diversity gain is achieved. Even if we increase the antenna separation to multiples of the symbol wavelength there is no significant improvement in MMSE value.

6 Conclusions

UWB channel measurements are obtained using a VNA in the frequency domain. The MMSE for an UWB system is simulated when the receiver antennas are separated on the scale of a symbol wavelength based on the measured UWB channel impulse response. The results show that in LoS scenarios the value of the MMSE decreases when the separation between the receiver antenna elements increases and if the separation increases to more than one symbol wavelength, there
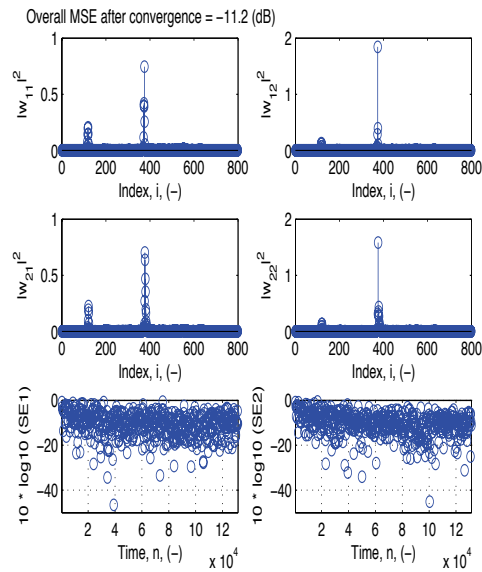
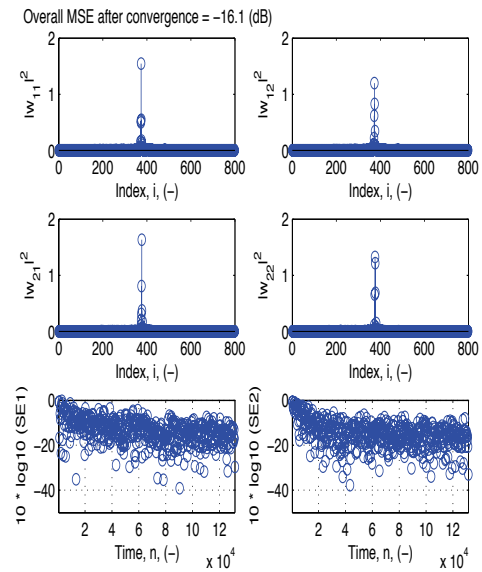**Figure 5.** *Filter coefficients and Squared error plots for $\lambda_T = 2\ cm$*

Figure 6. *Filter coefficients and Squared error plots for $\lambda_T = 4\ cm$*

is no significant improvement in MMSE.

7 Acknowledgements

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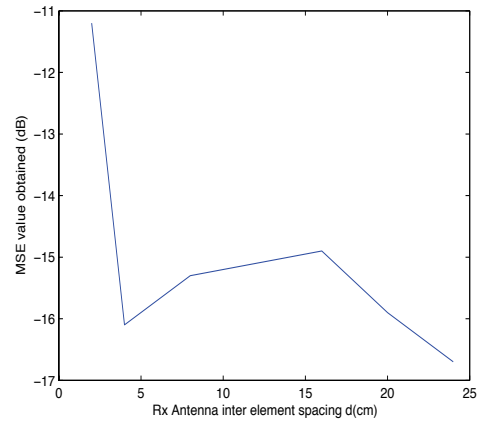
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