Abstract—In this paper, four–elements multiple-input–multiple-output (MIMO) antenna is presented for ultra-wideband (UWB) applications. The proposed UWB MIMO array has dimensions of $40 \times 40$ mm$^2$ is printed on FR4 epoxy substrate with the dielectric constant of 4.4 and a thickness of 1.5 mm. Simulation and Experimental results of verify the improved impedance bandwidth of the proposed MIMO antenna which is larger than 7.5 GHz assigned by FCC regulations for UWB applications with isolation between the four ports better than 15 dB. The paper will describe the Partial Usage of Sub-channel (PUSC) modeling and mapping the subcarriers to the frame in orthogonal frequency division multiplexing (OFDM). The OFDMA symbol was divided into odd number and even number symbols for simulation purpose. MIMO systems offer high capacity over a SISO system which will be investigated. Moreover, The bit error rate (BER) performance of the MIMO-UWB system will be analyzed based on a low complexity MMSE.

Index Terms—MIMO, UWB antenna, Bit Error Rate, OFDM, SISO, MMSE.

I. INTRODUCTION

In recent years, ultra-wideband (UWB) communication systems have been investigated to meet the demand for high data rate in a limited range at a lower power level [1]. Since the Federal Communications Commission (FCC) allowed 3.1– 10.6 GHz unlicensed band, the UWB communication systems become more attractive to all researchers to design and fabricate antennas, capable of transmitting and receiving in this valuable frequency range [2].

Multipath fading is the main problem in UWB communication systems due to the reflection and refraction of electromagnetic waves between transmitter and receiver. This problem can be solved by using multiple-input–Multiple-output (MIMO) Technology [3].

MIMO Technology has attracted a significant attention for its well-known advantages of improving the data transfer rate, spectral efficiency, and transmission quality of the wireless communication systems, and also enhance the capacity of the system [4].

Combination of two technologies, UWB and MIMO communications, has provided a solution for the limitation of short range communications and they have the potential to increase channel capacities. Therefore, the combination of MIMO technology with UWB can effectively increase the data transfer rate and spectral efficiency.

There are different challenges in designing the MIMO antenna for UWB communication systems such as compactness in size and coupling minimization between antenna elements. Conventionally, in order to enhance the isolation between MIMO ports, a distance between elements should not be less than half lambda of the lowest operating frequency for achieving a greater isolation between elements and consequently will results in larger size of MIMO antenna which is not acceptable.

Various techniques have been used to reduce the mutual coupling between the antenna elements while maintaining their small electrical lengths such as using decoupling structures as reported in [5, 6]. Four different research topics on the design and analysis of compact planar UWB monopole antennas have been introduced for future wireless communications, namely, a planar super-wide-band (SWB) monopole antenna, a planar UWB antenna with band-notched characteristics, a planar UWB antenna with reconfigurable band-rejection features, and a planar UWB MIMO antenna [7].

In recent years, OFDM technique has attracted a lot of attention in the standardization of broadband wireless systems. The combination of OFDM with MIMO technique increases the spectral efficiency and improves link reliability. However, there are many problems that need to be overcome before OFDM finds extensive use in recent wireless communication systems such as still suffers from high peak to average power ratio problem [8]. Many techniques were introduced to solve this problem such as distortion schemes (clipping and filtering), Scrambling Schemes, Coding Schemes, partial transmit sequence and constant modulus algorithm [9].

In this paper, a compact planar $4 \times 4$ UWB-MIMO antenna $(40 \times 40$ mm$^2$) is presented to satisfy the bandwidth from 3 to 10.6 GHz for OFDM wireless applications. The antennas are designed to ensure that the mutual coupling among their elements should be less than -15 dB and a wideband isolation of more than 15 dB in the UWB frequency range is achieved by etching a new slot on the ground plane of the model. The BER performance of the MIMO-UWB system is analyzed based on a low complexity MMSE algorithm.
analysis and simulation results have been conducted for different cases of channel such as using Rayleigh fading channel, the measured and simulated channel matrix of 4×4 MIMO system in order to investigate the enhanced BER performance of the proposed UWB MIMO-OFDM system.

This paper is organized as follows, In Section II, UWB MIMO antenna is presented, In Section III, MIMO OFDM system model used for OFDM transmission is presented. Section IV introduces the capacity analysis of SISO and MIMO systems. Section V contains a discussion of envelops correlation coefficient diversity performance. Finally, section VII presents the conclusion of the paper analysis.

II. UWB MIMO ANTENNA DESIGN

In this study, The geometry of the proposed 4 × 4 UWB MIMO antenna with a small size of W × L = 40 × 40 mm² operating in the UWB range between 3.1 and 10.6 GHz, is shown in Fig.1. The proposed UWB MIMO antenna consists of four similar antenna elements which are symmetrically placed on FR4_ epoxy substrate with dielectric constant of 4.4 with loss tangent = 0.025 and thickness of 1.6 mm. Moreover, a rectangular slots are etched from the ground plane in order to reduce the electromagnetic coupling between antenna elements as shown in Fig.1.

![Fig. 1. Geometry and configuration of the antenna.](image)

The detailed dimensions of the proposed antenna are listed in Table. I. Fig.2 shows the layout of the proposed UWB MIMO antenna which is fabricated on low cost substrate with compact size 40 × 40 mm². The performance of the designed 4 × 4 UWB MIMO antenna has been validated using the electromagnetic full wave simulations. The commercial software HFSS v.13 was employed in the full wave simulations.

![Fig. 2. Fabricated layout of the proposed antenna (a) Top view, (b) Bottom view.](image)

Fig.3 shows a combination of the simulated and measured return and insertion loss of the proposed UWB MIMO antenna. It can be noticed from Fig.3 (a) that the proposed antenna can be worked as an UWB antenna since it covers a frequency range from 2.4 GHz to 12 GHz with return loss less than -10 dB. The insertion loss which represents the mutual coupling between antenna elements is less than -15 dB over the entire bandwidth of operation as demonstrated in Fig.3 (b).

![Fig. 3. Simulated S-parameters of proposed UWB MIMO antenna (a) Return loss (b) Insertion loss](image)

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III. MIMO - OFDM SYSTEM MODEL

A. Design for MIMO-OFDM Systems

A 4 transmit and 4 receive antenna case (resulting in a $4 \times 4$ MIMO channel) will be discussed. The channel is assumed to be a Rayleigh flat fading channel using a QPSK modulation scheme then a partial usage of subcarriers (PUSC) pilot downlink insertion.

B. Pilot insertion

Similar to [10] for WiMAX, one Resource block (RB) contains $N_b = 14$ sub-carriers over two OFDM symbols, containing 4 pilots and 24 data symbols. For a 10 MHz system, there are a total of $M = 60$ RBs. An OFDM block of size $N = 1024$ including useful subcarriers $N_u = M \times N_b = 840$ with QPSK modulation and surrounded by two guard bands (left and right guard bands) of 92 guard as illustrated in Fig.4 for the data structure of MIMO-OFDM [11].

![Fig. 4. Data structure of an OFDM block for a MIMO-OFDM downlink.](image)

The Inverse fast Fourier transform (IFFT) is applied for each symbol then cyclic prefix is inserted for each symbol. Moreover, the channel matrix of $4 \times 4$ MIMO system obtained from HFSS and practical measurements between antenna ports are added as a realistic channel model.

The channel matrix for the $4 \times 4$ system can be written as in (1)

$$\mathbf{H} = \begin{bmatrix}
S_{11} & S_{12} & S_{13} & S_{14} \\
S_{21} & S_{22} & S_{23} & S_{24} \\
S_{31} & S_{32} & S_{33} & S_{34} \\
S_{41} & S_{42} & S_{43} & S_{44}
\end{bmatrix}$$

Now, the reverse process is carried out by pilot removal and the cyclic prefix removal after the QPSK threshold detection is achieved. Channel estimation is necessary before the demodulation of OFDM signals by using MMSE algorithm. Channel estimation by pilot (PUSC) arrangement can be based on LS (least squares) and MMSE estimator. MMSE equalization is used to minimize the variance of the error signal which help to get better performance MMSE has been shown to perform much better than LS but MMSE is considered more complex. Considerable attempts have been done to improve the performance of LS and MMSE [12].

Finally, the output bits are compared with input bits to Calculate bit error rate which is plotted against signal to noise ratio in dB.

Fig. 5 shows the performance of OFDM system in two scenarios, the first scenario when the channel is AWGN (without fading) with MMSE equalization and the second scenario when the channel is rayleigh fading channel with MMSE equalization. It is clear from Fig. 5 that the BER in AWGN channel is degraded rapidly than that in rayleigh channel fading.

Fig. 6 shows the performance comparison of $4 \times 4$ MIMO system for different cases. The first case when the used channel is Rayleigh fading channel with MMSE equalization, the second case when the channel is represented by the scattering parameters (S-parameters) extracted from HFSS software for a four elements MIMO antenna, and the third case when the channel is represented by the measured S-parameters from the fabricated MIMO antenna shown in Fig.2. It can be noticed from Fig. 6 that the BER performance of $4 \times 4$ rayleigh channel model is degraded rapidly as the SNR increases and there is a slight difference between the BER performance of practical and simulated channel models of the proposed MIMO antenna.

![Fig. 5. performance comparison of BER between Rayleigh fading channel and AWGN channel.](image)

![Fig. 6. BER performance comparison of MIMO simulated and measured channel models.](image)
IV. CAPACITY ANALYSIS OF SISO AND MIMO

The channel capacity of a MIMO system with $N_t$ transmitting and $N_r$ receiving antennas can be increased by the factor of $\min(N_t, N_r)$.

According to Shannon capacity of wireless channels, the capacity of channel can be written as in (2) where $C$ is the Shannon limits on channel capacity and $\text{SNR}$ is signal-to-noise ratio [13].

$$C = \log_2(1 + \text{SNR}) \text{bits/s/Hz} \quad (2)$$

For a MIMO OFDM system, the channel capacity is as in (3)

$$C = \log_2(1 + \frac{\text{SNR}}{N_t}(HH^*) \text{bits/s/Hz} \quad (3)$$

Where $H$ is the combined channel matrix for the $4 \times 4$ system.

![Capacity comparison of MIMO and SISO system using the channel matrix of $4 \times 4$ MIMO system.](image1)

![BER performance comparison of MIMO simulated and measured channel models.](image2)

![Envelope correlation coefficient of the proposed MIMO antenna.](image3)

Fig. 7 shows the comparison between capacity of MIMO system and SISO system versus the average SNR, for $N_t = 4$ and $N_r = 4$ and illustrates the enhancement of capacity in case of MIMO which result from different paths between transmitter and receiver. Consequently, it allows sending more number of bits per second than SISO system.

Fig.8. shows Complimentary Cumulative Distribution Function (CCDF) at different signal to noise ratio (SNR) and it is obvious that there is a very high probability that the capacity obtained from the MIMO channel is increased by increasing the SNR. Furthermore, the capacity can be reached up to 18 bps/Hz in the case of 16 dB SNR.

V. CORRELATION COEFFICIENT

The envelope correlation of antenna array can be computed by using scattering parameters extracted from the antenna system.

The envelope correlation coefficient is denoted as $\rho_e$ and can be calculated by

$$\rho_e = \frac{\left| S_{11}^* S_{12} + S_{21}^* S_{22} \right|^2}{\left(1 - |S_{11}|^2 - |S_{21}|^2 \right) \left(1 - |S_{22}|^2 - |S_{12}|^2 \right)} \quad (4)$$

Fig.9 shows the envelope correlation coefficient between two adjacent ports of the proposed UWB MIMO antenna and it can be demonstrated that the maximum value of the envelope correlation coefficient over the entire UWB range is less than 0.002 and this indicates that the proposed antenna has a good diversity performance.

VI. CONCLUSION

The compact $4 \times 4$ MIMO antenna has been designed and validated to operate in UWB frequency range and the coupling coefficients between the four ports are all below -15 dB. The BER Vs. SNR curves have been investigated for the MIMO OFDM system based on realistic channel model, as expected, the bit error rate decreases by increasing signal to noise ratio. Thus, practical systems have been designed and capacity enhancement of MIMO OFDM system has been achieved and The envelop correlation of antenna also calculated.
REFERENCES


