THE INVESTIGATION OF POLARIZATION DIVERSITY IN MIMO SYSTEM AT 2.4 GHZ

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Abstract

This paper describes the concept of multiple input multiple output (MIMO) system using polarization diversity that can enhance the channel capacity and increase the data output performance of the system. The microstrip antenna array is designed, fabricated and measured at the desired operating frequency for this measurement. Computer Simulation Technology (CST) software is used to design and simulate the microstrip antenna array. The simulation and measurement data results are compared and discussed. The fabricated microstrip antenna is used to develop the Radio Frequency (RF) MIMO test bed system. The system measurement was conducted in Microwave Laboratory at Faculty of Electronic and Computer Engineering, University Technical Malaysia Melaka with the operating frequency of 2.4 GHz. The spatial diversity and polarization diversity are applied in measurement campaign to investigate the performance of the wireless MIMO channel. The data obtained from the measurement was post-processed using MATLAB software in order to calculate the MIMO channel capacity. The analysis focused on the effect of the MIMO channel capacity due to the proposed measurement setup configurations. The channel capacity was increased from 0.03 b/s/Hz to 0.09 b/s/Hz when polarization diversity is applied at both transmitter and receiver.

Keywords: *MIMO System, MIMO Channel Capacity, Polarization Diversity.*

I. INTRODUCTION

Wireless communication systems become more important as they provide flexibility and application user friendly. The technology of mobile communication and wireless local network (WLAN) are expending at fast rate which is to assure that the end users reach a maximum data transfer and a get a better quality of service. The Multiple Input Multiple Output (MIMO) system is introduced to improve the communication system without having an additional transmit power or larger bandwidth, this because the MIMO system can utilize the multipath propagation.

The use of antenna arrays in wireless communication systems provides many advantages. For example channel capacity can be greatly increased with increasing antenna array at both link [1] [2].

In Figure 1, source of the system will be voice or data transmitted from a computer while destination is a person listening or computer receiving data. The radio frequency (RF) component is included in the MIMO channel since they influence the end-to-end transfer function. Input data is converted to suitable signal for the transmitter and will be distributed through the channel [3].

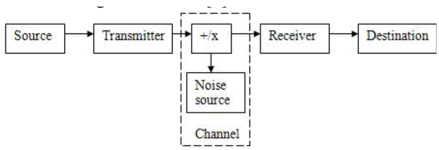


Figure1 : Classic Wireless Communication

MIMO channel describes the connection between the transmitters and receiver. The MIMO channel models can be divided into the non-physical and physical models [4][5].

Generally the MIMO system can be divided into two parts, which the first part is the digital signal processing (DSP) and representing as **Part A** in Figure 2. The second part is radio frequency (RF) device and representing as **Part B** in Figure 2. [6].

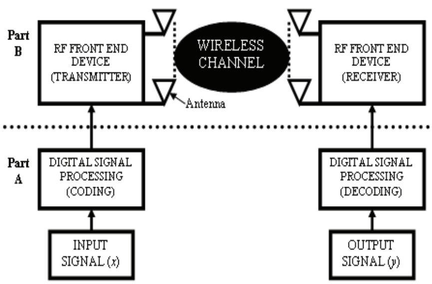


Figure 2: Block Diagram of Wireless MIMO System

This paper will discuss and analyzed the channel capacity effect to the wireless MIMO channel by using polarization diversity. The various configurations of polarization diversity applied at the both sides of transmitter and receiver has been studied.

II. DIVERSITY IN MIMO SYSTEM

Recently the diversity technique was used to enhance the wireless system. The propagation mechanism was an issued that degraded the wireless performance. So, the diversity technique was used in order to improve the wireless transmission by transmitting the information multiple times. Thus, increased the probability at receiver end where at least one of the signals will be received correctly [7].

The spatial diversity was referred as the technique that space apart the distance between the antennas[8]. The spatial diversity was been implemented in order to enhance the system performance. Such in [9], reported that the space diversity (spatial diversity) was an efficient technique for picocell (indoor to indoor) environment by achieving 14 b/s/Hz and 16 b/s/Hz capacities in 80% of the cases for 4x4 antenna configuration which spatial diversity created decorrelated signals between the antennas. The spatial diversity can be realized such in [10] implemented the spatial diversity by setup the antenna spacing to $\lambda/2$, λ and 2λ. In research[10], to increased the number of antennas elements, polarization has recently been accepted as the cost effective solution and also to obtain more uncorrelated channels.

Meanwhile, the polarization diversity can be describing the utilization of the antenna polarization of the system. By using the cross-polarization or polarization diversity, the polarization mismatch losses and degradation in the information MIMO performance can be avoided. The use of cross-polarization antennas to remain the data stream well separated [11]. In study [12], a microstrip U – slot patch antenna was used which it was capable to switching RHCP and LHCP. The antenna was equipped to the MIMO system. The results shows that, the system consist of hybrid polarization (different polarization among the antennas) has a better channel capacity compared to the single polarization (has the same polarization among the antennas). Besides using the RHCP and LHCP technique, the polarization also can be implemented by using directional antennas. It can be realized through setup the antenna a horizontal polarization and vertical polarization [13]. In [14], implemented the polarization diversity by placed the antennas horizontally or vertically polarized with neighboring ones orthogonal to each other.

III. MIMO SYSTEM MEASUREMENT

The measurement setup is done to characterize the channel in different environments and scenarios. The scenario can be Line of Sight (LOS), Non Line of Sight (NLOS) and obstructed Line of Sight (OLOS) [15]. As the transmitter and receiver have under no circumstance visibility, it is considered as NLOS scenario. For the LOS scenario is via versa of the NLOS scenario. As example of LOS scenario, the transmitter and receiver were located in the hallway which has visibility to each other's [8]. Such in [12], the NLOS can be accomplished by placing the transmitter and receiver at two adjacent laboratories.

So, the environment can also be described as indoor, outdoor, and outdoor to indoor or in anechoic chamber. Basically, the measurement for indoor environment is done in building. Such in [15], the measurement is conducted in building that is typically modern office building which is constructed with steel, concrete, dry walls, glass window and wooden door. As the [8] reported, the measurement is also conducted in building which the concrete is used to make floor and ceiling. The plasterboard with metal studs is used to make the walls.

IV. MIMO CHANNEL CORELLATION COEFFICIENT

Channel correlation between transmitter and receiver is calculated. Correlation coefficient is a measured of the linear relationship between transmitter and receiver [16]. Strong LOS usually considered as low-rank channel matrix and it will provide correlation between transmitter and receiver [17].

Thus, the mathematical equation that described the MIMO system can be expressed as Equation (1). x represents as the input signal and y represent as the output signal.

$$\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{n} \qquad (1)$$

where $\boldsymbol{H}$ in Equation (1) symbolized for the MIMO channel matrix and n was the noise in the system. The size of the MIMO channel matrix was depending on the number of transmits and receives antenna. Therefore, the Equation (2) shows the MIMO channel matrix, $\boldsymbol{H}$. N represented as the number of transmitting antennas and $\boldsymbol{M}$ represent as the number of receiving antennas.

$$\boldsymbol{H} = \begin{pmatrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{11} \\ \rho_{21} & \rho_{22} & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & \rho_{33} & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & \rho_{yx} \end{pmatrix}_{\boldsymbol{M} \times \boldsymbol{N}} \qquad (2)$$

ϱ_{yx} was the correlation coefficient between the output signals and input signals. The correlation coefficient can be expressed as Equation (3). cov_{yx} was covariance between output power and input power. While σ_y and σ_x were variance of output power, y and input power, x irrespectively. The interval of the correlation coefficient was from +1 to -1.

$$\rho_{yx} = \frac{cov_{yx}}{\sqrt{\sigma_{xx}}\sqrt{\sigma_{yy}}} \qquad (3)$$

Moreover, the correlation coefficient function was calculated based on the measurement data. There were three types of correlation coefficient functions such as complex correlation, envelope correlation and power correlation. Equation (4), (5) and (6) describe the correlation coefficient function. The complex correlation carried the information of amplitude and phase. For complex correlation, it used amplitude or power with same to the power correlation [18].

$$\rho_{complex} = \langle y, x \rangle \quad (4)$$

$$\rho_{envelope} = \langle |y|, |x| \rangle \quad (5)$$

$$\rho_{power} = \langle |y|^2, |x|^2 \rangle \quad (6)$$

V. CHANNEL CAPACITY ANALYSIS

MIMO channel capacity depends heavily on the statistical properties and antenna element correlations of the channel [19]. MIMO channel capacity is quantifies the maximum bit rate allowed by channel without error transmission [20]. Channel capacity is define by

$$C_{MIMO} = E\left\{ \log_2 \left(\det \left(I_{Nt} + \frac{\rho}{Nt} \left(HH^H \right) \right) \right) \right\} \quad (7)$$

Where $(.)^H$ is the hermitian operator defined by transposed conjugate matrix, E{.} is the expectation, ρ is signal to noise ratio (SNR) and I_{Nt} is is an n*m identity matrix. MIMO capacity increase by increasing angle spread factor for LOS and NLOS scenarios [21]. By calculating the eigenvalue of channel, capacity of the MIMO system is presented as:

$$C = \sum_{i=1}^{\min\{N,M\}} \log_2 \left(1 + \frac{E_s}{N_0} \cdot \frac{1}{N} . \lambda \right) \quad (8)$$

Where E_S/N_0 presents the ratio of signal energy to noise energy, n and m is transmitting and receiving antenna and λ is the eigenvalue.

VI. MEASUREMENT SET UP

Figure 3 shows the typical MIMO system. Eight units of 2×2 rectangular microstrip patch array antennas were fitted at transmitter and receiver. The d_o symbol represents the inter element spacing also known as antenna spacing. Meanwhile, the measurement was conduct in indoor environment with Line of Sight (LOS) condition. The system operating frequency was 2.4 GHz with noise floor was -76 dBm.

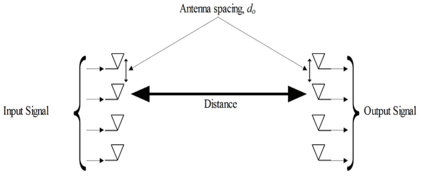
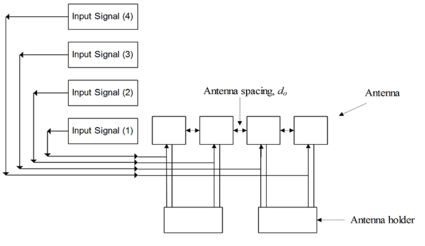
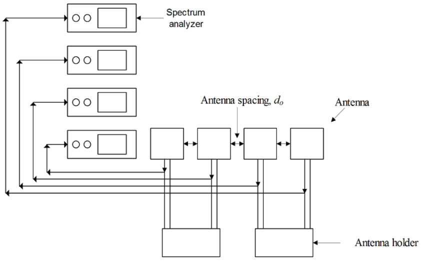


Figure 3 MIMO measurement setup

Figure 4(a) and Figure 4(b) show the details of the measurement setup at transmitter and receiver. At the transmitter side, there were four parallels of input signals that have magnitude in the range of 21 dBm to 23 dBm with the operating frequency at 2.4 GHz. The spectrum analyzer equipment was used to measure the receiving signals at the receiver sides.



(a)



(b)

Figure 4: Transmitter and receiver measurement setup

The polarization diversity can be realized by arrangement of the antennas horizontally or vertically polarized with neighboring ones orthogonal to each other [14]. The polarization diversity was applied to the typical MIMO system.

By using the concept of polarization diversity, the antenna setup can be divided into typical configuration, polarization diversity at transmitter, polarization diversity at receiver and both sides polarization diversity. The 2×2 rectangular microstrip patch array antenna was considered as linear polarized after the radiation pattern measurement. For the typical configuration, there were two types of configuration. First, all the antennas were fitted with vertical plane only and represented as A. Secondly, all the antennas were fitted with horizontal plane and represented as B. Figure 5 shows the antenna positioned at vertical plane and horizontal plane. Figure 6 and Figure 7 show the configuration A and B respectively.

a) Vertical Plane b) Horizontal Plane
Figure 5: Antenna Positioning

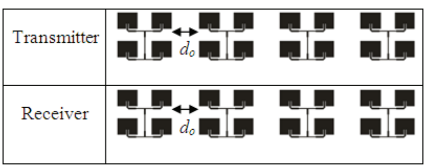


Figure 6: Configuration A

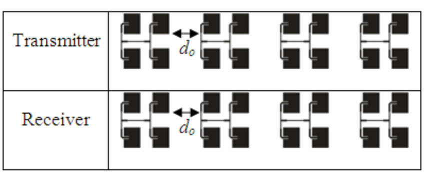


Figure 7: Configuration B

Then, the polarization diversity concept was applied to the transmitter side. Configuration C, D, E and F were representing as the polarization diversity applied at transmitter. Figure 8 and Figure 9 show the configuration C and D respectively. The configuration E and F was reported in[22].

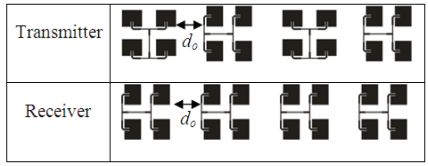


Figure 8: Configuration C

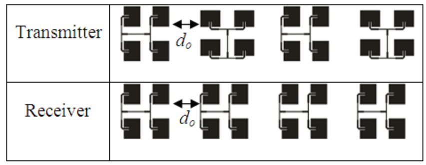


Figure 9: Configuration D

Afterward, the polarization diversity concept was applied to the receiver sides. This can be realized by swapping the antenna configuration at transmitter to the receiver sides. By this technique, the transmitter side only remains with no polarization diversity. Configuration G, H, I and J represented as the antenna configurations when polarization diversity was applied to the receiver side. Figure 10 and Figure 11 shows the antenna configuration when polarization diversity was applied to the receiver side which are configuration G and H respectively. The configuration I and J was reported in [22].

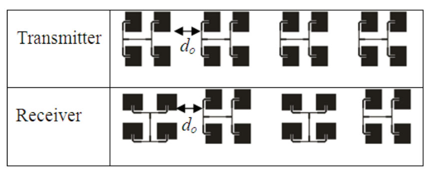


Figure 10: Configuration G

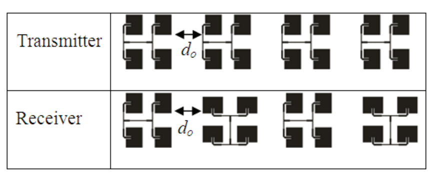


Figure 11: Configuration H

The next antenna configuration was polarization diversity at both sides. The configuration K, L, M and N were represented as the polarization diversity at both sides. Figure 12 and Figure 13 show the configuration K and L respectively. For configuration K at the transmitter side, the first and third antenna were fitted to the vertical plane. The second and fourth antenna were fitted at the horizontal plane. In the meantime, at the receiver side, the first and third antenna were fitted to the horizontal plane. The second and fourth antenna were set to the vertical plane. The configuration L has the same antenna configuration at the transmitter and receiver. The first and third antenna were positioned at the vertical plane. Meanwhile the second and fourth antenna were positioned at the horizontal plane. The configuration M and N was reported in [22].

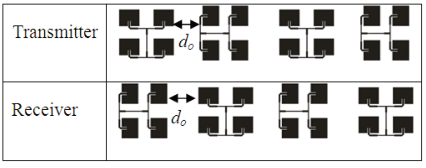


Figure 12: Configuration K

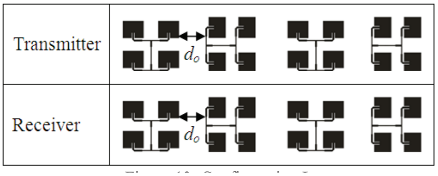


Figure 13: Configuration L

VII. MEASUREMENT RESULTS

Configuration A was chosen as the typical MIMO system since this configuration does not implement a diversity technique. So this configuration has d_o was λ and r_o was 15λ. The average channel capacity for the typical MIMO system was 12.24 b/s/Hz.

Figure 14 shows the average channel capacity of the typical MIMO system by changing the d_o. The value was increased 11.51 b/s/Hz to 12.50 b/s/Hz. The signals can be uncorrelated since used the spatial diversity in order to increase MIMO channel capacity.

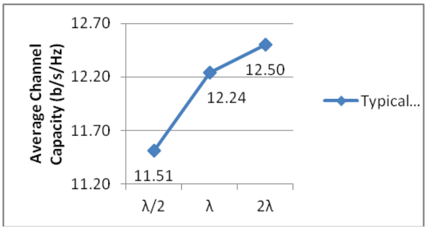


Figure 14: Average Channel Capacity for Typical MIMO System by changing the d_o

Based on the theoretical, the MIMO system that implemented polarization diversity has a potential in order to increase the channel capacity. Table 1 shows the average channel capacity of the typical MIMO system with polarization diversity as the d_o was λ and r_o was 15λ. The configuration C, I and N were having a finest average channel capacity compared to the typical MIMO system. The assortment of those configurations was upon the comparison between the typical MIMO systems in terms of average channel capacity [23].

Based on Table 1, configuration C and N has a better average channel capacity compared to the typical MIMO system which the difference was 0.03 b/s/Hz and 0.09 b/s/Hz irrespectively. However, configuration I show a lower average channel capacity compared to the typical MIMO system which the difference value of decrement was 0.06 b/s/Hz. In [24], the results show the channel capacity for system with polarization diversity has attained 21.3 b/s/Hz for without reflector in the measurement setup and recently the value of configuration C, I and N were below of that level [23].

The degradation of thee average channel capacity for configuration I might related to the imbalance power in the multiple antenna system. The antenna polarization for the vertical and horizontal plane has the different radiation pattern and will cause the imbalance power in the system [23]. The cause of this will leads to the degradation of the average channel capacity.

Table 1 Comparison of Average Channel Capacity between the Typical MIMO System and MIMO System with Polarization Diversity

Antenna Configuration	Average Channel Capacity (b/s/Hz)
Typical MIMO System	12.24
C	12.27
I	12.18
N	12.33

By referring to [23], configuration G with polarization diversity at the receiver has a higher average channel capacity compared to the typical MIMO system at the distance was 96λ with antenna spacing λ. The average channel capacity for configuration G was 11.71 b/s/Hz and the difference with the typical MIMO system was 0.49 b/s/Hz. The used of polarization diversity can reduce the mismatch losses at the receiver side. The mismatch losses happen because the signals that impinge on the surface of the physical path might change the polarity of the signals. The polarization diversity technique was used in order to increase the probability at the receiver side.

VIII. CONCLUSION

For the typical MIMO system that implemented the polarization diversity can improve the channel capacity. The average channel capacity also affected due to changing the antenna spacing. For example at the distance of 96λ, configuration G with the polarization at receiver with antenna spacing λ has surpassed the average channel capacity of the typical MIMO system. The channel capacity was increase when the spacing between antennas increases. Most of the configurations with polarization diversity show increment in channel capacity. However, the highest channel capacity was achieved when polarization diversity was applied at receiver side.

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