POLARIZATION RECONFIGURABLE ANTENNAS FOR SPACE LIMITED MULTIPLE INPUT MULTIPLE OUTPUT SYSTEM

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Specially dedicated to my beloved parent, Che Ah bt Saleh and Baharum b Hanapiah my late father, Osman b Bakar, my wife and daughter, Dyia Syaleyana bt Md Shukri and Dhiyaa Naqeesya, my parent-in-laws, and my siblings with love and care.

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ABSTRACT

Wireless communication undergoes rapid changes in recent years. More and more people are using modern communication services, thus increasing the need for higher capacity in transmission. One of the methods that is able to meet the demands is the use of multiple antennas at both link ends known as Multiple Input Multiple Output (MIMO) system. However, for the space limited MIMO system, it is relatively difficult to accomplish good performance by using conventional antennas. Therefore, to further improve the performance offered by MIMO, Polarization Reconfigurable Antennas (PRAs) can be adopted. The diversity in polarization can be exploited to increase channel capacity. Moreover, the use of PRAs can also provide savings in terms of space and cost by arranging orthogonal polarized together instead of two physically space separation antennas. Here, single and dual port PRAs are proposed. Two techniques are deployed to achieve the PRAs are slits perturbation (switches on the radiating patch) and alteration of the feeding network (switches on the ground plane). Switching mechanism (ideal and PIN diode) is introduced to reconfigure the polarization between left-hand circular polarizations, right-hand circular polarizations, or linear polarization, operating at wireless local area network frequency band (2.4 – 2.5 GHz). Furthermore, by exploiting the odd and even mode of the coplanar waveguide structure, dual ports PRAs are realized with the ability to produce orthogonal linear polarization (LP) and circular polarization (CP) modes simultaneously. Good measured port polarization isolations (S_{21}) of -16.3 dB and -19 dB are obtained at the frequency of 2.45 GHz for configuration A1 (orthogonal LP) and A2 (orthogonal CP), respectively. The proposed PRAs are tested in 2 x 2 MIMO indoor environments to validate their performances by using scalar power correlation method when applied as receiver in both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios. Channel capacity improvement has been achieved for spatial diversity (92.9% for LOS and 185.9% for NLOS) and polarization diversity (40.7% for LOS and 57.9% for NLOS). The proposed antenna is highly potential to be adopted to enhance the performance of the MIMO system, especially in dealing with multipath environment and space limited applications.

ABSTRAK

Dewasa ini, komunikasi tanpa wayar telah berubah dengan pesatnya. Semakin ramai orang telah menggunakan perkhidmatan komunikasi moden, sekaligus meningkatkan permintaan untuk kapasiti yang lebih tinggi. Salah satu daripada kaedah untuk memenuhi permintaan ini adalah dengan menggunakan beberapa antena di kedua-dua bahagian sistem perhubungan, iaitu menggunakan sistem Berbilang Masukan Berbilang Keluaran (MIMO). Walau bagaimanapun, untuk mencapai prestasi yang baik di dalam sistem MIMO ruang terhad dengan menggunakan antena konvensional secara relatifnya agak sukar. Maka, untuk meningkatkan prestasi MIMO, antena-antena dengan Pengutuban Boleh Ubah (PRAs) telah digunakan. Pengutuban kepelbagaian boleh dimanipulasikan untuk meningkatkan kapasiti saluran. Tambahan lagi, penggunaan PRAs juga boleh menjimatkan ruang dan kos, dengan meletakkan antena berpengutuban serenjang bersama berbanding dua antena berjarak dengan ruang. Di dalam kajian ini, satu dan dua pangkalan PRAs dicadangkan. Dua teknik telah diguna untuk menghasilkan PRAs, iaitu pengusikan belahan (suis di tampalan terpancar) dan pengubahan rangkaian suapan (suis di satah pembumian). Mekanisme suis (ideal dan PIN diod) telah diperkenalkan untuk mengubah pengutuban antena kepada pengutuban bulatan tangan kiri, pengutuban bulatan tangan kanan atau pengutuban lelurus, yang beroperasi pada jalur frekuensi rangkaian kawasan setempat tanpa wayar (2.4 – 2.5 GHz). Tambahan pula, dua pangkalan PRAs dengan kebolehan menghasilkan mod pengutuban serenjang lelurus (LP) dan bulatan (CP) dengan serentak telah dibangunkan dengan menggunakan ciri mod genap dan ganjil struktur sesatah pandu gelombang. Isolasi (S_{21}) pengukuran pengutuban pangkalan yang baik telah dicapai pada frekuensi 2.45 GHz, iaitu -16.3 dB untuk konfigurasi A1 (LP berserenjang) dan -19 dB untuk konfigurasi A2 (CP berserenjang). PRAs yang dicadangkan ini telah diuji di dalam senario garis penglihatan (LOS) dan bukan garis penglihatan (NLOS) untuk 2 x 2 persekitaran tertutup MIMO bagi mengesahkan prestasinya menggunakan kaedah hubung kait kuasa skalar apabila diaplikasikan sebagai antena penerima. Peningkatan kapasiti saluran telah dicapai untuk diversiti keruangan (92.9% untuk LOS dan 185.9% untuk NLOS) dan diversiti pengutuban (40.7% untuk LOS dan 57.9% untuk NLOS). Antena yang dicadangkan ini amatlah berpotensi untuk diguna bagi meningkatkan prestasi sistem MIMO, terutama dalam menangani persekitaran pelbagai arah dan aplikasi ruang terhad.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3GPP LTE	-	Third-Generation Partnership Project Long Term Evolution
AR	-	Axial ratio
AUT	-	Antenna Under Test
BW	-	Bandwidth
CDF		Cumulative Distribution Function
CPs	-	Circular Polarizations
CPW	-	Co-planar Waveguide
CST	-	Computer Simulation Technology
DC	-	Direct current
DG	-	Diversity gain
ECC	-	Envelope correlation coefficient
EP	-	Ellipse polarization
FET	-	Field Effect Transistor
IMT-Advanced	-	International Mobile Telecommunications-Advanced
LHCP	-	Left-Hand Circular Polarization
LOS	-	Line-of-sight
LP	-	Linear Polarization
LTE	-	Long Term Evolution
MIMO	-	Multiple-Input-Multiple-Output
NLOS	-	Non-Line-of-Sight
OFDM	-	Orthogonal Frequency Division Multiplexing
PRAS	-	Polarization Reconfigurable Antennas
RAs	-	Reconfigurable Antennas

RF	-	Radio-frequency
RF-MEMS	-	Radio-frequency microelectromechanical systems
RHCP	-	Right-Hand Circular Polarization
SISO	-	Single-Input-Single-Output
SNR	-	Signal-to-noise-ratio
SPDT	-	Single-polar-double-throw
SVD	-	Singular Vale Decomposition
UNIMAP	-	Universiti Malaysia Perlis
UoB	-	University of Birmingham
UTeM	-	Universiti Teknikal Malaysia Melaka
UTM	-	Universiti Teknologi Malaysia
VNA	-	Vector Network Analyser
WiMAX	-	Worldwide Interoperability for Microwave Access
WLAN	-	Wireless Local Area Network

LIST OF SYMBOLS

η	-	Noise
H	-	Channel Matrix
ρ_{mn}	-	Power correlation coefficient
cov_{mn}	-	Covariance between input and output
σ_{mm}	-	Variance of the input
σ_{nn}	-	Variance of the output
$\bar{x}$	-	Mean average input signal
$\bar{y}$	-	Mean average output signal
C	-	Channel capacity
ψ_n	-	Eigenvalue
h	-	Thickness of the patch
λ_o	-	Free space wavelength
r	-	Radius of the patch
r_e	-	Effective radius
f_r	-	Resonant frequency
ε_r	-	Relative permittivity
v_o	-	Free space speed of light
λ	-	Wavelength
ρ	-	Correlation coefficient

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction and Background

In the modern communication systems, there is a need and requirement to have single elements to be multi-functional and able to integrate with various operations. With the rapid growth and evolution of the telecommunication technology has leads to a change of the system conditions to meet current trends and demands from the end user; lower in cost, compact in size and light weight, with enhanced performance. Conventional antenna may face restrictions to meet the requirements and adapt to new conditions due to inflexible characteristics. One solution to overcome this issue is the use of reconfigurable antennas (RAs). The characteristics of the RAs such as frequency/bandwidth, radiation pattern and polarization [1], [2], is capable to be altered, thus providing additional functionality and flexibility to the systems.

The transmissions of the radio signal paths travelling from transmitter to receiver regularly experience the reflection/refraction phenomena caused by obstacles and obstructions such as buildings, vehicles and surrounding natures. For an indoor and confined environment, the occurrences of the reflection/refraction become more crucial and challenging due to wall, equipment and furniture. This phenomena might affect the transmitted signal, thus causing the signal to add up constructively or destructively and vary with different polarization and time while reaching at the receiver [3]. Accordingly, at particular occasions, the effective and reliable communication could be loss as the received signal may decrease and drop below the acceptable value. Therefore, one of the solutions to overcome this problem of multipath fading effect is by using single antenna that capable of offering various types of polarization modes. Polarization reconfigurable antennas (PRAs) are attractive due to the ability to control and switch the polarization between linear polarization (LP), left-hand circular polarization (LHCP) or right-hand circular polarization (RHCP). Besides reducing the fading effect, this type of diversity provides another several advantages such as immune to the interference and minimizing the polarization loss factor that eventually help to ensure the communication reliability.

The use of dual-polarized antenna [4–6] has been applied to several modern telecommunication applications for improving reception quality. In using this method, losses due to polarization mismatch can be reduced. The dual port antennas design can be achieved by co-locating orthogonal polarization together on the similar design. To further enhance the antenna performance, reconfigurable antenna is an effective solution. Although the antenna is excited with fixed dual polarization antenna, it is also capable of exciting between orthogonal LPs or orthogonal circular polarizations (CPs). Hence, instead of exciting with dual-polarized fix polarization, both polarizations also can be switched for selecting the best channel condition for that particular scenario and environment.

A lot of peoples nowadays have used modern communication services in their daily life routines, thus increase the demand and need for higher data rate and capacity in the transmissions. One of the technologies that able to provide capacity improvement is the use of multiple antennas at transmitter and receiver ends, known as Multiple-Input-Multiple-Output (MIMO) systems. Compared to traditional single-input single-output and single-input multiple-output systems, MIMO systems is higher diversity and ability to mitigate multipath fading, which provide higher capacity performance. This leads to more modern wireless communication systems to shift towards MIMO in order to accommodate the demand from the end users. MIMO system is capable of realizing higher throughput without required more bandwidth (BW) and additional power [7].

MIMO system is one of the key and important technologies for the future wireless communication system, such as Third-Generation Partnership Project Long Term Evolution (3GPP LTE), Worldwide Interoperability for Microwave Access (WiMAX), and International Mobile Telecommunications-Advanced (IMT-Advanced). The principal concept of the MIMO is to exploit and make use of space for enhancing the transmission quality and efficiency, consequently able to increase the data rates. Traditionally, MIMO system adopted space separated antenna to avoid mutual coupling between antenna elements [8]. However, for limited space MIMO systems, the mutual coupling between the adjacent antennas becomes more crucial, which could restrict and reduces the system performances [9].

To further enhance the overall performance and increase the speeds of the MIMO system, several techniques are being used such as advanced diversity schemes, smart antenna/beam forming, and new modulation technique such as space shift keying. Moreover, the link quality and reliability can be improved through employing RAs. The diversity special features, such as polarization and pattern, are exploited to increase the signal-to-noise ratio (SNR), which consequently improve the channel capacity [10].

1.2 Problem Statements

The revolution of the wireless communication technology has leads to the change of the system requirement and environmental conditions in order to meet the current demand. However, the inability of the antenna to accommodate and adapt to new operation scenario or feature, such as dealing with limited and confined volume space environment, can limit the system performance. Hence, having multifunctional antennas or reconfigurable antenna will provide additional level of functionality and capability in any particular wireless communication system. Conventional antenna design will face restrictions in following the new trends since the antenna characteristics are inflexible and fixed.

The capacity improvement in MIMO by using spatial diversity like spatial multiplexing, transmit diversity or receive diversity are subject to enough and availability of space [11]. Even though the spatial diversity are extremely potential to increase capacity through space-separated technique, but this technique is not suitable for space-limited MIMO applications such as mobile terminal, compact base station or portable access point due to space is not an advantage to be exploit [12]. Benefits of multiple channels are difficult to be obtained by using spatial diversity due to space limitation. In addition, a physically separation distance about half wavelength is required between two elements in order to have acceptable mutual coupling [13], which result in unsuitable for space-limited MIMO applications.

In space-limited MIMO system, it is relatively challenging to accomplish great performance by employing conventional antenna. Due to this limitation, reconfigurable antenna with polarization diversity is used to enhance the performance of MIMO system without required extra space, bandwidth and power. Hence, space resources can be save and utilize by co-locating orthogonal polarizations on the similar structure, which make the designed antenna more compact in size. Furthermore, it is extra cost saving compared to physically separated antenna [14]. However, the main challenge is to obtain sufficient isolation between two ports, whilst maintaining good impedance matching with desired polarization sense.

Although the utilization of space is enormously significant and highly potential to improve the channel capacity of the MIMO systems, how to design the antenna for the space-limited MIMO application with efficiently use the space resources is still needed to be further studied and investigated. Moreover, there is also a requirement for increased functionality within a confined volume which leads to a burden on today's wireless communication systems. Therefore, this project will focus on to design and study the effect of the reconfigurable antenna with polarization diversity in space-limited MIMO system.

1.3 Research Motivations

The topic is very significance as there are a lot of research currently has been done in improving and enhancing the capacity. According to Shannon-Hartley theorem, increase in bandwidth can increase the capacity. However, the disadvantages is bandwidth is very limited resources and costly. Besides that, the degree of modulation can be increased, but, it has the limitation. The use of reconfigurable antenna has been identified capable to increase the SNR, consequently improve the capacity.

The study can give the performance comparison of the MIMO systems when using reconfigurable antenna and non-reconfigurable antenna. The ability of the antenna to reconfigure into various type of polarization modes; LP, LHCP, RHCP and slanted LP, can be exploited to increase the SNR. In addition, the comparison is also made for space-separation MIMO and space-limited MIMO application. By co-locating orthogonal polarization on the similar structure, it could save cost and occupied less space, which make it suitable for space-limited MIMO applications such as portable access points. An investigation and study is carried out to determine the percentage of channel capacity improvement offered by proposed antenna by exploiting polarization diversity feature.

1.4 Research Objectives

The main focus of this research is to study on the effect and impact of deploying PRAs at the receiver end for space limited MIMO application. The impact is calculated in term of percentage of channel capacity improvement offered by the polarization reconfigurable antenna when comparing with non-reconfigurable antenna and space-separation MIMO. In order to accomplish this, the main focus is divided into 3 major objectives:

1) To design and develop a single port polarization reconfigurable antenna.
2) To design and develop a dual port polarization reconfigurable antenna.
3) To conduct the field experiment on channel capacity of 2 x 2 MIMO in an indoor environment.

1.5 Scope of the Research

The scopes began with gathering information, review and study the literature of related topics such as concept of polarization reconfigurable antenna, theory of MIMO system, and technique to achieve reconfigurability feature. It is also including technique of biasing such as type of switches and biasing components. This work aimed the antenna to be operated in WLAN frequency band (2.4-2.5 GHz). The antennas should have the capability to reconfigure the polarization between LP, LHCP and RHCP. The microstrip circular patch antenna is selected to be used as radiator for both single and dual port design to ensure fair comparison between techniques and for easier analysis. Moreover, the size of circular shaped antenna is slightly smaller than rectangular.

Slit perturbation and alteration of the feeding networks techniques are being used to design the single port antenna. It is much easier to achieve circular polarization for single feed antenna through perturbed and modified the antenna physical. Using this method, the switches and biasing network is inserted on the radiating element. Meanwhile, for the alteration of the feeding network, the CPW slotline feeding structure is selected because of easy integration with RF switches and uncomplicated of the biasing circuitry as it is placed on the ground plane. Furthermore, the special characteristic of CPW to accommodate odd and even mode is exploited to establish the second port on the similar structure, thus make it more compact and suitable for space-limited MIMO applications. To achieve the polarization reconfigurability features, PIN diodes are chosen as switches due to the lower in cost and its simplicity in biasing as compared to other type of switches.

The antenna is simulated using Computer Simulation Technology Microwave Studio and the optimization is done by using parametric study. The optimized design is fabricated and measured to validate the antenna. The single and dual port antenna is tested in the experiment of the 2 x 2 MIMO in real indoor environment. The effect of the designed polarization reconfigurable antenna in term of channel capacity is studied and analysed.

1.6 Outline of the Thesis

This thesis presents a progressive study on PRAs in space-limited MIMO applications and their potential advantages. This thesis is structured as follows.

Chapter 1 states the research background, problem statement, research objectives and scope of the research.

Chapter 2 reviews important concepts and theories of the RAs, particularly on PRAs. It touches in details of the technique in designing polarization diversity antenna and technique of biasing. This chapter also introduces the RF components, the selection of type of switches, and the theory of the polarization. Lastly, it explains on the background of the MIMO and the concept of the channel capacity measurement for evaluating performances of the MIMO systems.

Chapter 3 starts off with discussions of the research methodology. This chapter presents the flow of the works and describes the three main stages in order to achieve the research objectives. It explains on the design and simulation. In addition, it also discusses on the fabrication and measurement procedures. Finally, this chapter explains the method of capacity measurement and setup.

Chapter 4 presents on the design of the single port PRAs. Two techniques use are slits perturbation and feeding network modification. It discusses the design approach, switch configurations and design mechanism for both techniques. Method in achieving fixed operating frequency and widening the axial ratio (AR) bandwidth is also presented. The measurement results is comparing with simulation results.

Chapter 5 presents on the design approach, mechanism and configurations of the dual-ports PRAs. Good isolations are achieved by utilizing the odd and even mode of the CPW structure. The simulated and measured are fully documented and presented. The discrepancies are discussed and analysed.

Chapter 6 shows the result of the measurement and capacity analysis. It also explains in details the experimentation setup and scenario. MATLAB software is used for analysis and theoretical capacity evaluation. The hardware implementation is presented. The performance is reported in cumulative distribution function graph.

Finally, Chapter 7 summarizes the thesis with conclusions on all major findings and contributions. It discusses possible improvements and suggestions for future work.

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