COMPACT PLANAR ANTENNA ARRAY
FOR POINT-TO-POINT COMMUNICATION

MUHAMMAD HAZMI BIN MOKHTAR

UNIVERSITI TEKNOLOGI MALAYSIA

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MUHAMMAD HAZMI BIN MOKHTAR

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5.7 Analysis and Discussion

Table 5.2 Summary of CPAA results

Parameters		**Value (2.45 GHz)**	**Value (5.8 GHz)**
S_{11}	Minimum Value	-20.7 dB at 2.43 GHz	-17.4 dB at 5.81 GHz
	Value at 2.45 GHz	-9.2 dB	-15.7 dB
	Bandwidth	2.06 %	9.11 %
	Efficiency	28 %	36 %
Radiation Pattern	Realized Gain	1.03 dB	8.6 dB
	Directivity	6.54 dBi	13 dBi
	Polar Plot Pattern	Bidirectional	Bidirectional
	Front to back ratio	8.02 dB	10.62 dB
	3dB Beamwidth	H-Plane 81.4 ^{o}	H-Plane 25.9 ^{o}
		E-Plane 48 ^{o}	E-Plane 26 ^{o}
Antenna Size	Area Size	126 x 126	126 x 126
	Volume Size	126 x 126 x 3.655 = 58,026 mm^3	126 x 126 x 3.655 = 58,026 mm^3

Specially dedicated to my mom and dad,
Che Hawa bt Abdul Razak and Mokhtar Bin Sulaiman,
family and friends.

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ABSTRACT

Planar Antenna Array is often chosen due to its high gain, high directional, low profile, ease of fabrication and inexpensive to manufacture. However, not many related works have been done to design the planar antenna array in dual-band operating frequency. Futhermore, currently most of the microstrip antenna arrays are physically large and bulky in size. In this project, an approach for designing and developing a Compact Planar Antenna Array (CPAA) for point-to-point or bridging communication system has been done. The antenna was designed to operate at dual-band frequencies of 2.45 GHz and 5.8 GHz for unlicensed band applications. The CPAA was integrated with Perfect Electric Conductor (PEC) to improve the antenna gain and used as a ground plane to direct back radiation. The antenna miniaturization technique was developed using slotted structure design below the microstrip patch. The technique was used to create a second resonant frequency and miniaturization of antennas can be done at the same time. From the result obtained, the design of CPAA is 83% more compact as compared to conventional 2.45 GHz microstrip antenna array with the size of 126 mm x 126 mm. The developed CPAA gives the gain increment at both 2.45 GHz and 5.8 GHz at 9.78 dBi and 14.2 dBi respectively. The increment of 357% volume size has been recorded caused by the PEC located at quarter wavelength from the antenna. The overall performance shows the positive front-to-back ratio at both frequencies and this shows a significant result and justifies the antenna to be served as a point-to-point communication device.

ABSTRAK

Antena Jajaran Satah sering dipilih kerana ciri-cirinya yang bergandaan tinggi, berarah tinggi, berprofil rendah, fabrikasi yang mudah dan kos yag rendah untuk dihasilkan. Walau bagaimanapun, tidak banyak kajian yang berkaitan telah dilakukan dalam mereka bentuk antenna di dalam dua jalur operasi frekuensi. Tambahan pula, pada masa ini kebanyakan antena jajaran mikrojalur mempunyai fizikal yang besar dan saiz yang tebal. Di dalam projek ini, satu pendekatan untuk mereka bentuk dan membangunkan Antena Jajaran Satah Padat (CPAA) untuk sistem komunikasi pusat-ke-pusat atau penyambung telah dilakukan. Antena ini telah direka bentuk untuk beroperasi pada frekuensi-frekuensi dwi-jalur 2.45 GHz dan 5.8 GHz bagi aplikasi jalur yang tidak berlesen. CPAA telah digabungkan dengan Pengalir Elektrik Sempurna (PEC) untuk membantu meningkatkan gandaan antena dan digunakan sebagai satah bumi bagi memantulkan kembali sinaran belakang. Teknik pengecilan antena dibangunkan dengan reka bentuk slot di bawah struktur tampalan mikrojalur. Teknik ini digunakan bertujuan menghasilkan frekuensi salunan yang kedua dan memperkecilkan saiz antena pada masa yang sama. Daripada keputusan yang diperolehi, reka bentuk CPAA berkurangan saiz kawasan pada 83% lebih padat berbanding saiz antena konvensional 2.45 GHz dengan saiz 126 mm x 126 mm. CPAA yang dibangunkan menghasilkan peningkatan gandaan di kedua-dua frekuensi 2.45 GHz dan 5.8 GHz masing-masing pada gandaan 9.78 dBi dan 14.2 dBi. Pertambahan sebanyak 357% isipadu antena berpunca dari kehadiran PEC pada jarak suku gelombang dari antena. Prestasi keseluruhannya menunjukkan nisbah hadapan-ke-belakang yang positif pada kedua-dua frekuensi dan ini menunjukkan hasil yang signifikan serta mengesahkan penggunaan antena sebagai alat peranti komunikasi pusat-ke-pusat.

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LIST OF SYMBOLS

E	-	Electric Field
H	-	Magnetic Field
ε	-	Permittivity
ε_r	-	Relative Permittivity
ε_{eff}	-	Effective Permittivity
μ	-	Permeability
c	-	Speed of Light
f	-	Frequency
f_o	-	Operating Frequency
W	-	Microstrip Patch Width
L	-	Microstrip Patch Length
h	-	Thickness of the Dielectric
l_f	-	Inset fed length
l_w	-	Inset fed width
S_a	-	Length of Slot
S_b	-	Length of Slot Bend
S_c	-	Width of the Slot
R_{in}	-	Input Impedance
Λ_g	-	Guided Wavelength
Λ_o	-	Effective Wavelength
S_{11}	-	Return Loss
d	-	Distance between element
a_g	-	Airgap between CPAA
d_s	-	Diameter of hole
d_v	-	Diameter of Via

LIST OF ABBREVIATIONS

ISM	-	Industrial, Scientific and Medical
FR4	-	Flame Resistant 4
UV	-	Ultra Violet
CSA	-	Compact Slotted Antenna
CPAA	-	Compact Planar Antenna Array
PEC	-	Perfect Electric Conductor
DRA	-	Dielectric Resonator Antenna
WLAN	-	Wireless Local Area Network
CST	-	Computer Simulation Technology
BW	-	Bandwidth
EBG	-	Electromagnetic Band Gap
WiMAX	-	Worldwide Interoperability for Microwave Access

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless for point to point (P2P) communication or wireless bridge communication is the devices that connect two wired networks together over Wi-Fi. Pairs of bridges are used to create wireless link between two networks or P2P communication by allowing the devices on one network to see the devices on the others. For example, if an office has separate networks in two adjacent buildings, by adding a P2P communication to both networks and configuring the bridges to communicate, the office can unify the networks into one large setup.

Most wireless P2P communication devices come pre-installed with an antenna that can be upgraded to a larger antenna for extended long range Wi-Fi. A directional and high gain antenna must be used for longer distances P2P communication where it is placed line-of-sight between two locations. The condition of line-of-sight is important for the antenna which there is a direct and unobstructed path between a transmitting and a receiving device to extend their range.

High gain antenna is needed for P2P communication system [1-2]. Apart from high gain antenna, a compact and low profile antenna is an added advantage as it can be install in any location and position. A lightweight antenna would help in the ease of installation as well as it is cost effective. To meet these requirements, microstrip antenna is preferred. Despite all of the advantages such as low profile, light weight and simple to manufacture, microstrip antenna suffered from low gain properties. There are several techniques available for enhancing the antenna gain such as arranging single elements into an array [1-5].

Previous research shows that the microstrip antenna has the potential to be applied in point to point wireless communication system. In [1], a microstrip antenna array operating at 2.4 GHz for point to point communication using wireless LAN system has been reported. The antenna has a gain of 15.6 dBi. A microstrip patch antenna array at 5.8 GHz for point to point communication has also been reported in [2] where the gain of the antenna is 16 dBi. Furthermore, a high gain microstrip dipole antenna has been presented in [3]. The antenna is bidirectional where the gain is 10.2 dBi. A high gain microstrip array antenna has also been discussed in [4] where the gain of the antenna is 15.6 dBi. The antennas in [3] and [4] were operated at 2.4 GHz. Moreover, a high gain microstrip yagi array antenna has been reported in [5]. The antenna is operating at Wireless Local Area Network (WLAN) with a gain of 11.5 dBi.

1.2 Problem Statement

Microstrip array antenna is potentially useful for P2P wireless communication where this type of antenna offers high gain, light weight and low cost. The microstrip array antenna structure is very contemporary and an interesting study which is widely applied to increase the range and reliability mostly in the field of mobile communication. Currently, there are very few study reported [6-9] regarding the development of microstrip array antenna in a multi-frequency operation. Most of the P2P wireless communication antenna has a different antenna operates at different frequency. According to the Federal Communications Commission (FCC), WLAN frequency is allocated under unlicensed spectrum category, where it falls under the ISM band (802.11 a, b, g) covering 2.400 - 2.484 GHz and 5.150- 5.350 / 5.725- 5.825 GHz [10]. It is interesting to utilize both unlicensed spectrum frequency at 2.45 GHz and 5.8 GHz in the single antenna design for P2P communication. The dual band antenna can overcome the situation by offering only one antenna that is capable to operate simultaneously.

Other than that, most of the microstrip antenna array is also large and bulky in size [1-5]. The major limitation of conventional microstrip antenna array to design in compact mode is the half-wavelength inter-element spacing requirement for minimizing mutual coupling and spatial correlations. Indeed, this requirement is the primary reason that prevents those multi-antenna systems from being implemented in modern small-size wireless devices [11]. A size reduction technique for P2P microstrip antenna array is needed where the space usage in a base station can be effectively utilized.

1.3 Research Objectives

The main purpose of this research is to develop a compact and dual-band antenna by employing U-slotted structure in the antenna design. By applying the U-slotted structure underneath ground plane for the antenna, the dual-band frequency is obtained by the microstrip patch and microstrip slotted structure. The 4x4 elements of antenna array and perfect electric conductor are introduced to improve the gain of the antenna. Thus, the research objectives are:

i. To design, simulate, fabricate and analyze a dual-band Compact Slotted Antenna (CSA) at 2.45 GHz and 5.8 GHz ISM Band.

ii. To design, simulate, fabricate and analyze the dual-band 4x4 elements of Compact Planar Antenna Array (CPAA) at 2.45 GHz and 5.8 GHz ISM Band.

iii. To enhance the gain of the Compact Planar Antenna Array by incorporating Perfect Electric Conductor (PEC) at $\lambda/4$ wavelength.

1.4 Scope of Research

This research focused on the design and analysis of microstrip antenna that can satisfy the requirements in the section 1.3. First of all, FR-4 substrate with a thickness,*h* of 1.6mm, permittivity,ε_r of 4.6 and tangential loss of 0.019 are preferred as this substrate can be easily found, widely used and inexpensive in the market. Also the substrate can perform at acceptable performance for our desired operational frequencies.

Secondly, a planar structure antenna with microstrip array design is chosen in this study as it can be easily mount to any radio base station or device. The single element antenna is designed before it is assemble into 2x1, 2x2 until 4x4 microstrip array to generate the directional radiation pattern for point to point application. The antenna then will incorporate with Perfect Electric Conductor (PEC) to improve the antenna gain and used as a ground plane to direct back radiation.

Moreover, the dual-frequency ISM band at 802.11 a, b, g is the main design objectives as these tend to be a trend of future unlicensed frequencies antenna developments. In order to obtain the compact size of antenna, unique designs are needed to obtain the function of dual-band frequency and at the same time reduce the size of an antenna. The literature reviews from the related design antenna were compared in term of performance and its size.

The numerical design and analysis of the proposed antenna is performed using CST Microwave Software, which utilizes the Finite Integral Technique that applies the integral form of Maxwell’s equation integrated over time. In the end, this experiment are carries out in the Universiti Teknologi Malaysia Advanced Microwave & Antenna Laboratory. The antenna performance is tested and discussed in this thesis.

1.5 Organisation of the Thesis

This thesis is divided into six chapters. Chapter 1 provides a brief introduction of point to point (P2P) communication, the problem statement, the objectives and scope of the research as well as the organization of the thesis.

Chapter 2 explains the basic concepts and theories of the miniaturize microstrip slotted antenna and antenna array. The unique properties of the antenna array design are discussed. Previous works on compact microstrip antenna regarding its size and its performance were elaborated thoroughly in this chapter.

Chapter 3 discusses the project methodology, the designing process, simulation using Computer Simulation Technology (CST), fabrication and measured process of proposed antenna. This chapter also presents the theoretical calculation of the antenna design and the design specification expected according to the theory that was based on.

Chapter 4 finalizes the design and parameter of the Compact Slotted Antenna (CSA), as well as the parametric study of the proposed antenna. Basic antenna properties such as reflection coefficient, bandwidth, efficiency, radiation pattern, gain, antenna size and other antenna parameters were presented. Besides, the comparison between simulation and measurement results were also briefly discussed.

In Chapter 5, the Compact Planar Antenna Array (CPAA) was presented. CPAA is a 4x4 elements array of CSA. The results were analyzed and presented in a form of tables and graphs. The antenna then was incorporated with Perfect Electric Conductor (PEC) to improve the performance. The comparison results of CPAA with and without PEC from the simulation and measurement were also discussed.

Lastly, Chapter 6 concludes the finding of the project, key contributions and recommendations for future research.

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A contribution has been made by CSA design, where dual-band frequency operated in ISM band have been achieved. Moreover, the size reduction of 76% was recorded with respect to the size of an ordinary 2.45 GHz patch antenna. The good correlation between simulated and measured result are obtained.

Meanwhile, the development of CPAA shows the improvement in all aspects including the antenna size, front to back ratio and antenna gain. The CPAA size has been reduced greatly from 306mm x 306 mm for the conventional antenna array size to 126x 126mm which is a 86 % size reduction. The utilization of Perfect Electric Conductor for its final design helps to improve the overall performance of CPAA . The gain of CPAA with PEC was rose tremendously at lower frequency from 1.03 dB to 4.87 dB and gain in the upper frequency dominate the whole antenna with 9.84 dB gain. The overall performance shows the positive *F/B* ratio at both frequency and this shows the significant result and justify the antenna that can be served as a point to point communication device.

6.2 Key Contribution

In this research, 3 main contributions have been made, as listed below;

- A new Compact Slotted Antenna structure and Compact Planar Antenna Array structure with the ability of dual-band operating frequency of 2.45 GHz and 5.8 GHz ISM Band have been successfully fabricated.
- The novel size reduction of Compact Slotted Antenna with size reduction of 76% was recorded with respect to the size of an ordinary 2.45 GHz patch antenna.
- The novel size reduction of Compact Planar Antenna Array with size reduction of 86% from the theoretical geometry of the conventional antenna array operate at 2.45 GHz.

6.3 Future Research

The CPAA structure will be further investigated. A new material which can incorporate with CPAA which can provide a new independent path that reduce the transmission loss, increase the antenna gain and can be used as a ground plane to redirect the back radiation would be interesting to be explored. The new design should be smaller and less bulky in term of volume in the future. Moreover, a new modification of CPAA with certain frequency band rejector structure should be studied. By implementing the stop band at a certain frequency, it will allow the antenna to operate at desire frequency and avoid the influence of mutual coupling which is the major disturbance for the antenna array design. The antenna of CPAA is suitable for point to point WLAN application, it will be more exciting if CPAA design can cover the WiMAX frequency. This will increase the market value of the CPAA in the future.

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