1 X 4 ARRAY ANTENNA FOR WIRELESS LOCAL AREA NETWORK (WLAN)

FUAD HASSAN ADAN

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FEBRUARY 2022

To my beloved parents, thank you.

ACKNOWLEDGEMENT

Foremost, I would like to acknowledge the Almighty God for His benevolence and for granting me wisdom and perseverance not only in the time of research and writing of this thesis, but indeed, throughout my life.

I express, with heartfelt appreciation, my gratitude to my supervisor Assoc Prof. Dr. Noorsaliza Binti Abdullah, for her sincere and invaluable intellectual guidance extended to me throughout the time of my postgraduate studies. My sincere appreciation goes to the Ministry of Education Malaysia and Faculty of Electrical and Electronic Engineering in Universiti Tun Hussein Onn Malaysia for offering me the opportunity to study here in Malaysia. I extend my appreciation to all my friends for their unwavering support and who have stood by my side through so many tough times.

Last but not least, special thanks to my beloved mother and sister for their blessings and unflinching insistence, who have always encouraged me to never stop achieving my goals in life. To my beloved Sister Faduma Haji Hassan Thank you very much Without you after Allah I will never reach this goal.

ABSTRACT

In this project, a 1 x 4 wide band rectangular patch array antenna proposed and designed at frequency 2.4GHz for Wireless Local Area Network (WLAN) applications. The antenna will be designed using optimization and study of features. To construct the desired antenna, some strategies for optimizing the Microstrip Patch Antenna are investigated and executed. An antenna array is a radiating system, which consists of individual radiators and elements. Each of this radiator, while functioning has its own induction field. The elements are placed so closely that each one lies in the neighboring one's induction field. Therefore, the radiation pattern produced by them, would be the vector sum of the individual one When designing these antennas, keep in mind the spacing between the elements as well as the length of the elements in relation to the wavelength. Microstrip patch array antenna developed still face problem with low gain , narrow bandwidth , high complexity and low efficiency therefore, this project proposes 1x4 microstrip patch array antenna that suitable for wireless local area network (WLAN) and provides less complexity, high gain, large bandwidth by using defected ground structure(DGS) technique and slots that suitable point to point communication system. The goal of this research is to create an antenna with higher gain, higher directivity, a wider bandwidth, and good efficiency using array antenna techniques, to propose array antenna that have wide bands using defected ground method and to compare the antenna performance using different techniques. The goal of this project can theoretically be achieved by using a high-quality substrate such as RT Duroid 5870, which has a low relative permittivity or dielectric constant and a higher substrate that will maximize bandwidth. but in this project using FR-4 substrate, which does not have high quality and high dielectric constant finally achieved high performance result using array antenna techniques and parametric studied. This is because the bandwidth of a Rectangular Microstrip Patch Array Antenna is determined by the dielectric constant and the substrate height. The antenna's efficiency will be improved by a low loss-tangent. The patch array also has a better directivity than the single patch. All the simulation design process has been conducted by using CST Studio Suite Software. The 1 x 4 microstrip patch array antenna has simulated gain of 6.33dBi at 2.4 GHz with the wide bandwidth 514MHz and efficiency more than 72%. Therefore The expected result from this project is achieved which was a high gain, better directivity, larger bandwidth and high efficiency.

ABSTRAK

Dalam projek ini, antena tatasusunan tampalan segi empat tepat jalur lebar 1 x 4 dicadangkan dan direka pada frekuensi 2.4GHz untuk aplikasi Rangkaian Kawasan Setempat Tanpa Wayar (WLAN). Antena akan direka bentuk menggunakan pengoptimuman dan kajian ciri. Untuk membina antena yang dikehendaki, beberapa strategi untuk mengoptimumkan Microstrip Patch Antena disiasat dan dilaksanakan. Tatasusunan antena ialah sistem penyinaran, yang terdiri daripada radiator dan elemen individu. Setiap radiator ini, semasa berfungsi mempunyai medan aruhan sendiri. Unsur-unsur diletakkan begitu rapat sehingga setiap satu terletak di medan aruhan jiran. Oleh itu, corak sinaran yang dihasilkan oleh mereka, akan menjadi jumlah vektor bagi individu Apabila mereka bentuk antena ini, perlu diingat jarak antara unsur-unsur serta panjang unsur-unsur berhubung dengan panjang gelombang. Antena tatasusunan tampalan jalur mikro yang dibangunkan masih menghadapi masalah dengan perolehan rendah, lebar jalur sempit, kerumitan tinggi dan kecekapan rendah oleh itu projek ini projek ini mencadangkan antena tatasusunan tampalan jalur mikro 1x4 yang sesuai untuk rangkaian kawasan tempatan tanpa wayar (WLAN) dan memberikan kurang kerumitan, keuntungan tinggi, besar lebar jalur dengan menggunakan teknik struktur tanah (DGS) cacat dan slot yang sesuai dengan sistem komunikasi titik ke titik. Matlamat penyelidikan ini adalah untuk mencipta antena dengan keuntungan yang lebih tinggi, arahan yang lebih tinggi, lebar jalur yang lebih luas, dan kecekapan yang baik menggunakan teknik antena tatasusunan, untuk mencadangkan antena tatasusunan yang mempunyai jalur lebar menggunakan kaedah tanah yang cacat dan untuk membandingkan prestasi antena menggunakan teknik yang berbeza. . Matlamat projek ini secara teorinya boleh dicapai dengan menggunakan substrat berkualiti tinggi seperti RT Duroid 5870, yang mempunyai ketelusan relatif rendah atau pemalar dielektrik dan substrat yang lebih tinggi yang akan memaksimumkan lebar jalur. tetapi dalam projek ini menggunakan substrat FR-4, yang tidak mempunyai kualiti tinggi dan pemalar dielektrik tinggi akhirnya mencapai hasil prestasi tinggi menggunakan teknik antena tatasusunan dan parametrik yang dikaji. Ini adalah kerana lebar jalur Antena Tatasusunan Tampalan Jalur Mikro Segi Empat ditentukan oleh pemalar dielektrik dan ketinggian substrat. Kecekapan antena akan dipertingkatkan dengan tangen kehilangan yang rendah. Tatasusunan tampalan juga mempunyai arahan yang lebih baik daripada tampung tunggal. Semua proses reka bentuk simulasi telah dijalankan dengan menggunakan Perisian CST Studio Suite. Antena tatasusunan tampalan jalur mikro 1 x 4 telah mensimulasikan keuntungan sebanyak 6.33dBi pada 2.4 GHz dengan lebar jalur lebar 514MHz dan kecekapan lebih daripada 72%. Oleh itu, hasil yang diharapkan daripada projek ini tercapai iaitu keuntungan yang tinggi, kearaharah yang lebih baik, lebar jalur yang lebih besar dan kecekapan yang tinggi.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

DGS	–	Defected Ground Structure
WLAN	–	Wireless Local Area Network
CP	–	Circular Polarization
RL	–	Return Loss
CST	–	Computer Simulation Technology
Fo	–	Operating frequency
GHz	–	GHz
mm	–	Millimeter
SNR	–	Signal Noise Ratio
λ	–	Free space wavelength
C	–	Speed of light
Γ	–	Reflection coefficient
Er	–	dielectric constant of the substrate
BW	–	Bandwidth
VSVR	–	Voltage Standing Voltage Ratio
dB	–	Decibels
Ω	–	Ohm
θ	–	Theta
ε	–	Permittivity
η	–	Efficiency
ER	–	Efficiency antenna

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

In recent years, the development of telecommunication system has given to a variety of services including wireless local area network (WLAN) [2] long term evolution (LTE) [3] and laptops or cell phones. Antennas are mostly used for wireless communication. The most available antennas like microstrip patch antenna [4], monopole antenna [5], dipole antenna [6], array antenna[7], loop antenna [8] and aperture antenna[9]. Even yet, for real-time applications, microstrip patch antennas ensure low-profile, compact, and cost-effective manufacture. An antenna is a conductor of electricity. It can be used as a transducer and for transmission and receiving. An antenna array is a collection of individual antennas that transmit and receive radio waves. The array antenna is primarily used to improve the performance of communication systems and to eliminate interference from various directions [9]. It has a better gain and directivity..

WLAN is a wireless computer network that connects two or more users in a confined area, such as a home, school, computer lab, or business building, using a wireless approach. The majority of current WLANs are based on IEEE 802.11 specifications and branded as Wi-Fi [10]. There are two primary modes of operation for IEEE 802.11: infrastructure and ad hoc. Mobile units communicate directly peer-to-peer in ad hoc mode. Mobile units connect in infrastructure mode through an access point that acts as a bridge to other networks. Printed antennas are lightweight, low-cost, and simple to integrate on a circuit board, making them perfect for situations when it is desired to avoid using an antenna. antennas are required for compact transceivers to be used in point-to-point WLAN links and they are a very active and significant research area.

The usage of high-speed data in wireless communication is posing a greater challenge in the design of devices and components to be more compact while maintaining excellent performance. An antenna that can operate at a specific working frequency is required as one of the most crucial pieces in wireless communication devices to ensure that communication runs smoothly [11]. Microstrip antennas are a common form of antenna used in these devices. This is owing to a number of benefits, including light weight, low profile, and inexpensive fabrication costs [3]–[5]. The antenna is also well-suited to wireless communication needs since it can be integrated with other parts or components [12].

Microstrip architectures are widely used for component construction, especially in low frequency areas. Microstrip antenna radiation loss, for example, is still an issue in the low frequency band, but it is much lower than in the upper band, i.e. millimetre-wave. However, microstrip-based devices, including antennas, have some shortcomings, such as a narrow bandwidth response, low radiation efficiency, and high transmission loss [5], [13]. Many scholars have offered several strategies to address these disadvantages, resulting in improved performance.

High-gain antennas with directional radiation characteristics are used in applications such as high-speed moving target detection, see-through wall applications, radar altimeters, and coal mines, among others. An antenna array is a collection of radiating elements arranged in an electrical and geometrical form to offer high gain and direct radiation patterns without increasing the electrical size of the radiating element [9].

In this project is proposed and designed microstrip patch array antenna for WLAN application. The resonant frequency of proposed antenna is 2.4GHz. This antenna is designed in FR4 substrate with 4.3mm thickness, The array configuration is featured with a novel corporate microstrip line feed structure to provide better impedance matching to the constituent radiating elements. The antenna geometry uses the rectangular patch element which is tapered by means of step in width transition at the patch-feed interface and the deflected ground metalized on the bottom part of the substrate to enhance bandwidth of the antenna.

1.2 Problem statement

There are number of types of antenna and microstrip antenna is the most commonly used to support wireless local area network communication due some advantages such as lightweight, low profile ,conformable and low-cost ,easily also both achieved both circular and linear polarization , these attributes are desirable when considering antenna for Wlan systems [10], [11] . on the other hands, this antenna has low gain and narrow bandwidth those become its famous disadvantage. however various methods associated with microstrip antenna can be done to tackle these drawbacks, such as microstrip patch array antenna technique, this antenna is one of the antenna provide higher gain compared the single patch element antenna due to having more than one radiation element.

Currently there are many antennas which based on microstrip patch array antenna. In the Previous Microstrip Array antenna for WLAN Application [2], [12]–[15] has been design using different techniques however, it has been needed to require less complexity design, high gain, large bandwidth and simple design therefore this project proposes 1x4 microstrip patch array antenna that suitable for wireless local area network (WLAN) and provides less complexity, high gain, large bandwidth by using Defected ground structure(DGS) technique[32], Metamaterial, meander line, Topology and defected ground plane are the methods that could be used to achieve compact size of the antenna. Amongst them, defected ground structure[DGS] is most simple and cost effective. Therefore, in this project this technique is thoroughly investigated. Many applications require radiation characteristics that may not be achievable by a single element.

1.3 Objectives

These are objectives of this project

a) To design microstrip patch array antenna that operates 2.4GHz for WLAN application.

b) To propose wideband Antenna by using defected ground structure (DGS) and slots.
c) To analyse and compare antenna performance With and without defected ground structure(DGs)

1.4 Scopes of study

The scope of the project is divided into three main parts.

Firstly, a review of previous design will be analyzed and studied in order to have a knowledge related to this title. Which is to study different antenna of microstrip patch array antenna for WLAN Application to investigate the complexity, gain, and methods of the design and this antenna is be designed and analyzed by using CST Studio Suite Software. The basic parameter of an antenna such as reflection coefficient, gain, Radiation pattern and efficiency.

Secondly, the scope is to develop microstrip patch array antenna that can operate frequency range 2GHz until 4GHz by using FR4 substrate as a substrate material. This FR4 has been chosen because its cheap and available at the market.

Lastly, will compare antenna performance by compared the parametric analysis

1.5 Outline of the report

This report of Master project consists of 5 chapters describing all the work that has been done in this project.

First chapter provides introduction and information regarding the project, this project paper presents project background, problem statement, and objective.

Second chapter literature review is discussed the concept of this project and this theory will be contrasted and a few other journals and paperwork, that related to the title. In this chapter researchers will attempt to overcome and create new outline of

the product. They additionally, tell about their points of interest and disservice this item.

Third chapter has been explained the method, material, substrate and estimation to design the antenna. Therefore, this chapter explains the methodology of this project that shows the designing procedure and step to design the antenna using CST microwave studio software.

Fourth chapter tells about the result from the simulation process. Furthermore, in this section will discuss about the result of the parametric study such as reflection coefficient, Gain, efficiency, and beam steering. All the design and simulation results is simulated and analyse using CST Studio Suite Software. Also, all the collecting data are from in term of graph and table to make it easier to be understood.

Finally chapter 5 is conclusion , the researchers attempt to close about this task and offer if that has some suggestions to conquer this issue.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter a detailed comprehensive literature review on array antenna techniques is discussed. Previous studies on microstrip patch array antenna for WLAN applications methods and The Review microstrip current use of antennas in wireless technology, most important parameters with relative equations, principle operations and factors affecting Microstrip patch antenna are explained in this chapter. Various antenna configurations are also described.

2.2 Reviews of Microstrip Antenna

All of the antennas investigated in this thesis have a microstrip construction. Since 1950, microstrip antennas have gotten a lot of attention [15]. As shown in Figure 2.6, the microstrip antenna is made up of a printed patch on a dielectric substrate with a full ground plane. Originally, a coaxial probe feed or a microstrip line feed were used to excite such antennas. Feeding strategies have changed dramatically during the last few decades. patch shapes, substrate configurations and array structure have been invended. Figure 2.1 shows the field distribution between the patch and the ground plane contributes to the electrical antenna dimension which bigger compared to the physical dimension. A patch, half wavelength and connected to a microwave source has created the positive and a negative charge distribution on the upper and lower surface of Jb and Js [15][16]

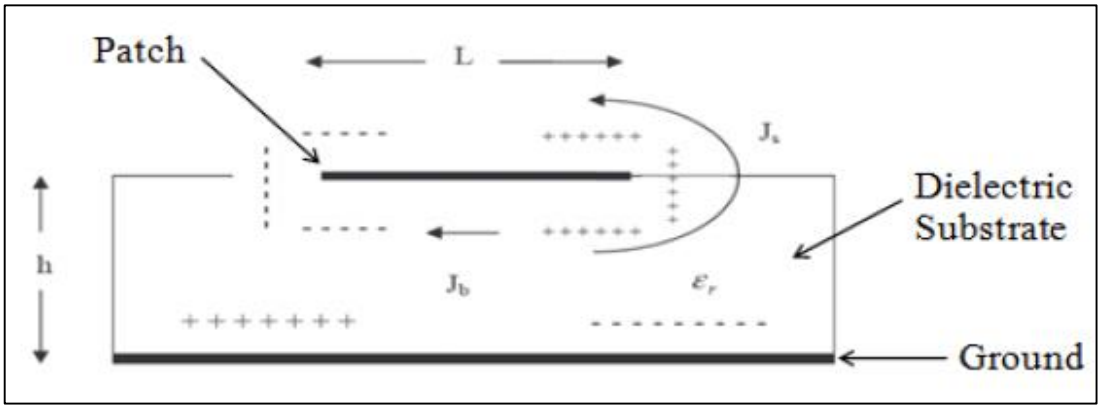


Figure 2.1: Microstrip antenna current and charge distribution [15]

The patch thickness is selected to be very thin, $t << \lambda o$. Usually the height of the substrate is $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$ with a dielectric constant range of $2.2 \leq \varepsilon r \leq 12$. There are few losses consideration of the microstrip antenna that cannot be neglected such as space wave loss, surface wave loss, dielectric loss and conductor loss. Apart from that, the microstrip antennas are increasing popularity due to the low-profile structure. Besides, it is successfully used in wireless application as summarized in Table 2.1 [15] have discussed the principal

advantages of the microstrip patch antenna. The advantages are:

(a) Light weight and low volume.

(b) Low profile and ease of fabrication.

(c) Low fabrication cost, hence can be manufactured in large quantities.

(d) Support linear and circular polarization.

(e) Ease of integration with microwave integrated circuits (MICs).

(f) Capable of dual and triple frequency operations.

(g) Mechanically robust when mounted on rigid surfaces.

Instead of advantages, Kraus (Marhefka, 2002) has discussed some of the microstrip patch antennas disadvantages as compared to conventional antennas. The disadvantages are:

(a) Narrow bandwidth

(b) Low efficiency

(c) Low Gain

(d) Extraneous radiation from feeds and junctions

(e) Poor end fire radiator except tapered slot antennas

(f) Low power handling capacity.

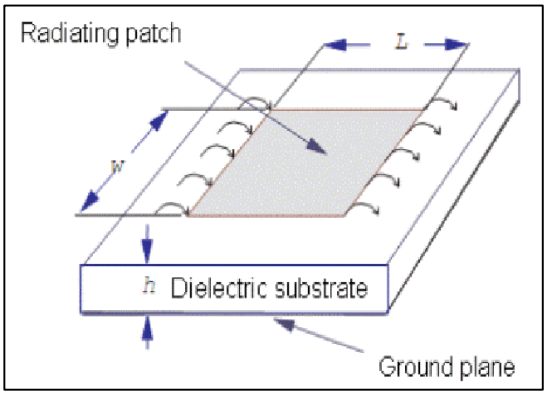
(g) Surface waveexcitation

Tale 1.1: Some Applications of Microstrip Antenna

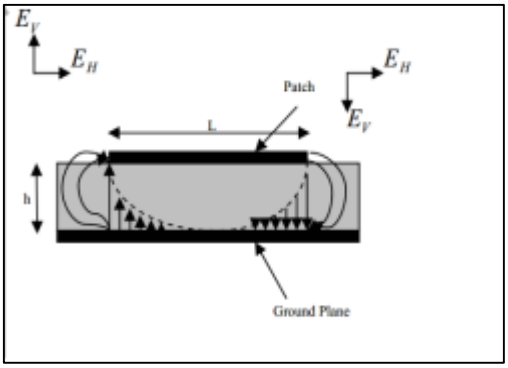
Application	Systems
Aircraft	Radar Communications, navigations, altimeter and landing systems
Missiles	Radar, fusing and telemetry
Satellites	Communication, direct broadcast TV, remote sensing radars and radiometers
Ships	Communications, Radar and navigation
Land Vehicles	Mobile satellite telephone and mobile radio
Others	Biomedical system and intruder alarm

2.2.1 Rectangular Patch

The rectangular patch antenna is the most common used by the researcher. It is due to the ease of design, analyze and fabrication. However, there are five basic steps to be followed in designing rectangular antenna. As can be seen in Figure 2.2 , the patch is attached to the two different dielectrics of substrate and the air. The electric field lines are residing in the substrate and partly in the air. By that, the effective dielectric constant is accounted for [16].



(a)



(b)

Figure 2.2 The Effective Length of Rectangular patch antenna[16]

2.2.2 Circular Patch Antenna

Instead of rectangular design, circular patch antenna as shown in Figure 2.3 also has received a lot of attention either as single element or in arrays as well[16]. The dielectric constant (εr), height of substrate (h) and frequency (f) are the main parameters for changing a circular patch antenna:

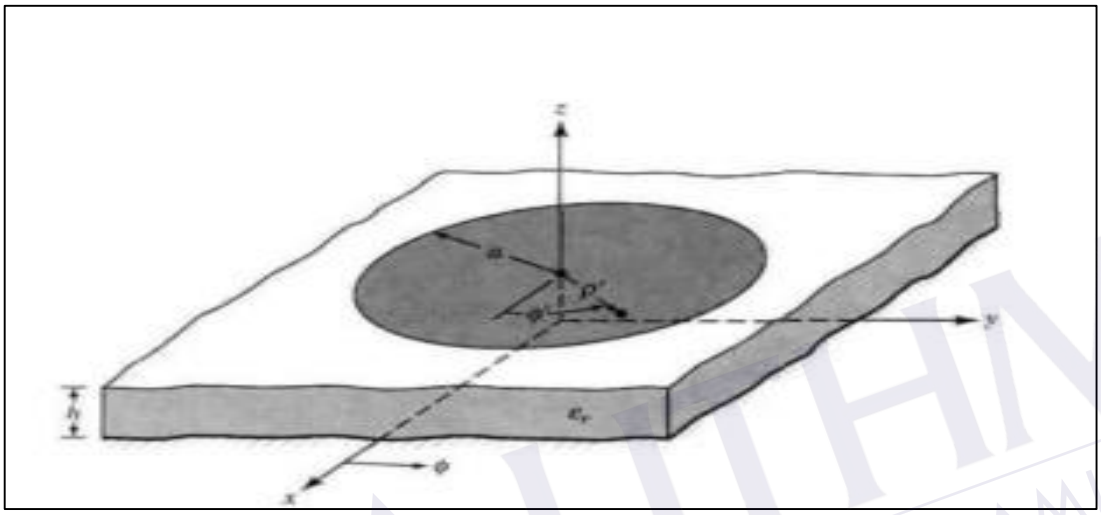


Figure 2.3: Geometry circular microstrip patch antenna[16]

2.3 Defected Ground Structure

Defected ground structure (DGS has been realized to improve by its characteristics [e.g. the impedance matching]. Several slots are embedded in the ground of the micro strip patch antenna so that the size is reduced, the impedance band and gain is enhanced [25]. A prominent ground structure named defected ground structure (DGS) has as of late been researched and observed to be a basic and effective method to decrease the antenna size.

The portion of slot close to the corners will by and large occupy the current around these corners. There is a two combination of presents a net stage move. Defected ground plane has one dimensional electromagnetic band-hole structures and planned dependent on this idea [22], [23]. Moreover, this unfortunate radiation reduces front to back radiation and can prompt to decrease directivity. There is another confinement that can be approach works just for micro strip patch antenna, despite the way that this still covers an extensive variety of antenna, for instance micro strip based-

devices. Micro strip patch antennas are that it has low profile, light weight, and give the ability for incorporation with monolithic microwave integrated circuit designs. Defected ground plane resonates at frequency 2.45GHz, while the same antenna without defected ground plane resonates at frequency 3.5GHz.

DGS's filtering properties can be applied to antennas to reduce mutual coupling between antenna array members and undesirable responses (like filters). Because it can eliminate side lobes in phased arrays, enhance the performance of couplers and power dividers, and lower the response to out of hand signals for both transmit and receive, this is the most prevalent application of DGS for antennas. The slot antenna and DGS phase shift behaviours are combined in an interesting application. Similar to a parabolic reflector antenna, an array of DGS elements can be set on a flat surface and lighted by a feed antenna. The exciting signal is re-radiated by each element, but a phase shift can be included into the structure to compensate for the distance between each unit and the feed. The re-radiating parts add to the loss, but the ease of a flat form factor is appealing for transportable equipment or applications that require a low-profile.

DGS can also aid with amplifier design because it has various appealing qualities that can help to increase amplifier performance. For starters, the DGS structure is exceedingly simple and easy to mimic or manufacture, making it ideal for periodic structure design. Second, the stop band feature can be utilised to reduce particular harmonics. Various DGS studies have been published in the literature, not only for analysing the effect of defects but also for implementing defects in various architectures in microwave devices. It might be prudent to review past DGS studies first, and then discuss the study's contribution. When the line should not be disrupted, the first application that comes to mind is Defected Ground Structure (DGS). With changes in the current distribution on the ground side and the alignment of the fields between the ground and the line, a defect on the ground can modify the propagation properties of a transmission line.

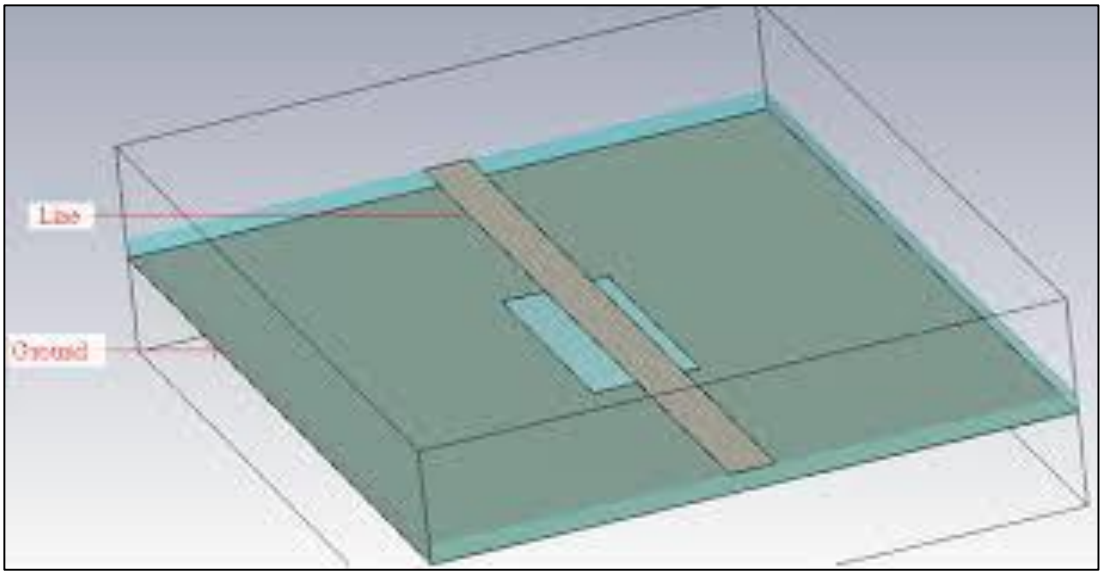


Figure 2.4: Defected ground plane for micro strip line [22]

2.4 Previous research on microstrip patch array antenna

In the section will discuss detail in the previous research work in microstrip patch array antenna especially will focus 1 x 4 array antenna that related this project.


Figure 2.5: Structure 1X4 Microstrip array antenna with DGS[32]

Design and Characterization Analysiskof Microstrip Patch Array Antenna with Dumbbell shaped DGS for ISM Band Applications was proposed and designe in this study[32] Figure 2.5 Shows 1 X 4 Microkstrip Array Antenna with Defected ground structure. Defected Ground Structure is used above the Wave Port. Defected GroundkStructure is Creating Defect in the Ground plane of the antenna. Due to Defected Ground Structure, there is change in the Current Distribution of antenna. . It is found that the experimental results match the

REFERNCE

[1] W. Abbas A. A Zaidi AND A. Baghdad "Patch antenna with improved performance using DGS for 28GHz applications, " *2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS), 10.1109/WITS.2019.8723828.*

[2] B. Ramya, C. Supratha, and S. Robinson, "Design and Analysis of Comb Shape Microstrip Patch Array Antenna for Wlan Applications," *ICTACT J. Commun. Technol.*, vol. 9, no. 1, pp. 1702–1705, 2018, doi: 10.21917/ijct.2018.0249.

[3] A. M. Aburgiga, N. M. Shebani, A. R. Zerek, and A. F. Kaeib, "Simulation and Analysis of Microstrip Patch Antenna for WLAN Applications," *19th Int. Conf. Sci. Tech. Autom. Control Comput. Eng. STA 2019*, pp. 660–665, 2019, doi: 10.1109/STA.2019.8717278.

[4] S. Palanivel Rajan and C. Vivek, "Analysis and design of microstrip patch antenna for radar communication," *J. Electr. Eng. Technol.*, vol. 14, no. 2, pp. 923–929, 2019, doi: 10.1007/s42835-018-00072-y.

[5] P. Lin, "WWAN Handset Antenna," 2012.

[6] W. Yang, Y. Pan, S. Zheng, and P. Hu, "A Low-Profile Wideband Circularly Polarized Crossed-Dipole Antenna," *IEEE Antennas Wirel. Propag. Lett.*, vol. 16, no. c, pp. 2126–2129, 2017, doi: 10.1109/LAWP.2017.2699975.

[7] B. T. P. Madhav, T. Venkateswara Rao, and A. Tirunagari, "Design of 4-element printed array antenna for ultra-wideband applications," *Int. J. Microw. Opt. Technol.*, vol. 13, no. 1, pp. 8–17, 2018.

[8] M. K. Mandal and Z. N. Chen, "Compact dual-band and ultrawideband loop antennas," *IEEE Trans. Antennas Propag.*, vol. 59, no. 8, pp. 2774–2779, 2011, doi: 10.1109/TAP.2011.2158790.

[9] P. Mei, S. Zhang, and G. F. Pedersen, "A Dual-Polarized and High-Gain X-/Ka-Band Shared-Aperture Antenna with High Aperture Reuse Efficiency," *IEEE Trans. Antennas Propag.*, vol. 69, no. 3, pp. 1334–1344, 2021, doi: 10.1109/TAP.2020.3026429.

[10] A. S. Al-Hiti, "Design of rectangular microstrip patch antenna for WLAN and WiMAX applications," *ARPN J. Eng. Appl. Sci.*, vol. 14, no. 2, pp. 433–438, 2019.

[11] H. Werfelli, K. Tayari, M. Chaoui, M. Lahiani, and H. Ghariani, "Design of rectangular microstrip patch antenna," in *2nd International Conference on Advanced Technologies for Signal and Image Processing, ATSIP 2016*, 2016, no. March, pp. 798–803, doi: 10.1109/ATSIP.2016.7523197.

[12] A. Izzuddin, A. Dewantari, E. Setijadi, E. Palantei, E. T. Rahardjo, and A. Munir, "Design of 2.4 GHz Slotted SIW Array Antenna for WLAN Application," *Proceeding - 2020 Int. Conf. Radar, Antenna, Microwave, Electron. Telecommun. ICRAMET 2020*, pp. 70–73, 2020, doi: 10.1109/ICRAMET51080.2020.9298646.

[13] A. Hassanien, W. Swelam, and M. H. A. El Azeem, "16x8 wideband microstrip planar array antenna for E-band millimeter-wave 5G high speed WLAN and broadband internet applications," *2017 IEEE Antennas Propag. Soc. Int. Symp. Proc.*, vol. 2017-Janua, pp. 2613–2614, 2017, doi: 10.1109/APUSNCURSINRSM.2017.8071815.

[14] X. Qing, J. Shi, and Z. N. Chen, "Metamaterial-based omnidirectional circularly polarized antenna array for 2.4-GHz WLAN applications," *2016 10th Eur. Conf. Antennas Propagation, EuCAP 2016*, pp. 3–5, 2016, doi: 10.1109/EuCAP.2016.7481710.

[15] C. Supratha and S. Robinson, "Design and Analysis of Microstrip Patch Antenna for WLAN Application," *Proc. 2018 Int. Conf. Curr. Trends Towar. Converging Technol. ICCTCT 2018*, vol. 1680, no. JANUARY, pp. 457–461, 2018, doi: 10.1109/ICCTCT.2018.8550979.

[16] Y. Panneer Selvam *et al.*, "A Patch-Slot Antenna Array with Compound Reconfiguration," *IEEE Antennas Wirel. Propag. Lett.*, vol. 17, no. 3, pp. 525–528, 2018, doi: 10.1109/LAWP.2018.2801124.

[17] E. Balzovsky, Y. Buyanov, V. Koshelev, and E. Nekrasov, "Dual-Polarized Antenna Sub-Array of 2×2 Elements for Measurements of Short Electromagnetic Pulses," *MATEC Web Conf.*, vol. 155, pp. 2–7, 2018, doi: 10.1051/matecconf/201815501003.

[18] Y. Ipekoglu, O. M. Yucedag, S. Saraydemir, and H. Kocer, "Microstrip patch antenna array design for C-band electromagnetic fence applications," *ELECO 2015 - 9th Int. Conf. Electr. Electron. Eng.*, pp. 355–358, 2016, doi: 10.1109/ELECO.2015.7394587.

[19] I. F. Chen and C. M. Peng, "Dual-band patch antenna array for WLAN

applications," *2018 IEEE Int. Symp. Electromagn. Compat. 2018 IEEE Asia-Pacific Symp. Electromagn. Compat. EMC/APEMC 2018*, pp. 387–389, 2018, doi: 10.1109/ISEMC.2018.8393804.

[20] Q. Liang, B. Sun, and G. Zhou, "Multiple Beam Parasitic Array Radiator Antenna for 2.4 GHz WLAN Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 17, no. 12, pp. 2513–2516, 2018, doi: 10.1109/LAWP.2018.2880208.

[21] M. Farran *et al.*, "Compact Printed Parasitic Arrays for WLAN Applications," *IEEE Antennas Wirel. Propag. Lett.*, vol. 15, no. c, pp. 918–921, 2016, doi: 10.1109/LAWP.2015.2481084.

[22] X. B. Sun and M. Y. Cao, "Low mutual coupling antenna array for WLAN application," *Electron. Lett.*, vol. 53, no. 6, pp. 368–370, 2017, doi: 10.1049/el.2016.4563.

[23] K. Rojanasaroch and T. Laohapensaeng, "Bi-directional circular patch array antenna for WLAN applications," *2nd Jt. Int. Conf. Digit. Arts, Media Technol. 2017 Digit. Econ. Sustain. Growth, ICDAMT 2017*, pp. 39–42, 2017, doi: 10.1109/ICDAMT.2017.7904930.

[24] A. G. Ambekar and A. A. Deshmukh, "E-shape microstrip antenna for dual frequency wlan application," *Prog. Electromagn. Res. C*, vol. 104, no. June, pp. 13–24, 2020, doi: 10.2528/pierc20060204.

[25] C. Z. U. Hasan, A. A. Khan, M. Fahim-Al-Fattah, M. A. Amin, and S. Mohammad, "A novel quad-band microstrip patch antenna for WLAN, WiFi, WiMAX applications," *2017 9th IEEE Int. Conf. Commun. Softw. Networks, ICCSN 2017*, vol. 2017-Janua, pp. 718–721, 2017, doi: 10.1109/ICCSN.2017.8230205.

[26] H. Nawaz and I. Tekin, "Ten switched-beams with 2 × 2 series-fed 2.4 GHz array antenna and a simple beam-switching network," *Int. J. RF Microw. Comput. Eng.*, vol. 30, no. 6, pp. 1–11, 2020, doi: 10.1002/mmce.22184.

[27] A. Bharathi, M. Lakshminarayana, and P. V.D. Somasekhar Rao, "A quad-polarization and frequency reconfigurable square ring slot loaded microstrip patch antenna for WLAN applications," *AEU - Int. J. Electron. Commun.*, vol. 78, pp. 15–23, 2017, doi: 10.1016/j.aeue.2017.05.015.

[28] B. Maity and S. K. Nayak, "Wideband CPW-fed U-Shaped Antenna array for WLAN and WiMAX applications," *2020 11th Int. Conf. Comput. Commun. Netw. Technol. ICCCNT 2020*, pp. 9–12, 2020, doi:

10.1109/ICCCNT49239.2020.9225562.

[29] D. Prabhakar, P. Mallikarjuna Rao, and M. Satyanarayana, “Design and Performance Analysis of Microstrip Antenna using different Ground Plane Techniques for WLAN Application,” *Int. J. Wirel. Microw. Technol.*, vol. 6, no. 4, pp. 48–58, 2016, doi: 10.5815/ijwmt.2016.04.05.

[30] M. Jusoh, T. Sabapathy, M. F. Jamlos, and M. R. Kamarudin, “Reconfigurable four-parasitic-elements patch antenna for high-gain beam switching application,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 79–82, 2014, doi: 10.1109/LAWP.2013.2296491.

[31] T. Sabapathy, M. F. Jamlos, R. B. Ahmad, M. Jusoh, and M. I. Jais, “A reconfigurable microstrip rectangular parasitic array antenna,” *IEEE Symp. Wirel. Technol. Appl. ISWTA*, pp. 372–375, 2013, doi: 10.1109/ISWTA.2013.6688807.

[32] S. Dharmpatre and M. Sutaone “ Design and Characterization Analysis of Microstrip Patch Array Antenna with Dumbell shaped DGS for ISM Bandapplications” urkish Journal of Computer and Mathematics Education.Vol.12 No.9 (2021), 2652– 2663.