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Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

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[Title]

DESIGN AND DEVELOPMENT OF A FLEXIBLE PLANAR 5G FOUR ELEMENT MIMO ARRAY FOR SMARTPHONES

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A project report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours



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DECLARATION

I declare that this project report entitled " DESIGN AND DEVELOPMENT OF A FLEXIBLE PLANAR 5G FOUR ELEMENT MIMO ARRAY FOR SMARTPHONES " is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electronics Engineering Technology (Telecommunications) with Honours.



DEDICATION

I have a deep desire to honour and thank my kind and encouraging parent Encik Zulkapli bin Abdul Wahid and my mother Ummi kalthom binti Ramly by devoting this work to them, as they have been my primary source of motivation and support all the way through the process of bringing this project to fruition. I would also want to dedicate my effort to my siblings, who never fail to inspire me to grow as a person and pursue better opportunities in the years to come. My compassionate and good-hearted supervisor, DR. A K M ZAKIR HOSSAIN, is the source of much of my motivation and inspiration, and I have the deepest respect for him for the counsel and support he has provided. In conclusion, I would want to show my appreciation to Allah, the Most High, for rewarding my life in a way that is well above what I deserve.

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ABSTRACT

Here 4×4 MIMO configuration array with polarization diversity on a flexible substrate for smartphones. To propose and simulate a single element planar antenna on flexible substrate for 5G communication. Planar antennas, like microstrip antennas and printed circuit board antennas, have both active and passive parts on the same plane. This makes them two-dimensional (2D). The idea behind the planar antenna is to make it easier to connect and use with other antennas or communication systems. Because of this, the planar antenna fits the goals of this report because of how it works. The design for the proposed planar antenna was made with the software CST Studio Suite and a specific spectrum of less than 6 GHz. The sub-6 GHz spectrum band is a standard frequency for fifth-generation (5G) communication and a fairly new feature and compatibility for smart phones. The results of the simulation showed that the proposed antenna design works at a frequency of 3.5 GHz with an acceptable level of radiation efficiency. MIMO (multiple input, multiple output) technology is also built into the antenna, which improves its performance. This project will make 5G smart phones more useful to their users by making them better at what they can do.

ABSTRAK

Di sini 4×4 tatasusunan konfigurasi MIMO dengan kepelbagaian polarisasi pada substrat fleksibel untuk telefon pintar.Untuk mencadangkan dan mensimulasikan antena planar elemen tunggal pada substrat fleksibel untuk komunikasi 5G.Antena Planar, seperti antena microstrip dan antena papan litar bercetak, mempunyai kedua-dua bahagian aktif dan pasif pada satah yang sama.Ini menjadikan mereka dua dimensi (2D). Idea di sebalik antena planar adalah untuk memudahkan untuk menyambung dan menggunakan dengan antena atau sistem komunikasi lain.Oleh kerana itu, antena planar sesuai dengan matlamat laporan ini kerana bagaimana ia berfungsi.Reka bentuk untuk antena planar yang dicadangkan dibuat dengan perisian CST Studio Suite dan spektrum tertentu kurang daripada 6 GHz.Jalur spektrum sub-6 GHz adalah frekuensi standard untuk komunikasi generasi kelima (5G) dan ciri dan keserasian yang agak baru untuk telefon pintar. Hasil simulasi menunjukkan bahawa reka bentuk antena yang dicadangkan berfungsi pada frekuensi 3.5 GHz dengan tahap kecekapan radiasi yang boleh diterima. Teknologi MIMO (multiple input, multiple output) juga dibina ke dalam antena, yang meningkatkan prestasinya.Projek ini akan menjadikan telefon pintar 5G lebih berguna kepada pengguna mereka dengan menjadikannya lebih baik pada apa yang mereka boleh lakukan.

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LIST OF SYMBOLS

δ	- Voltage angle
°C	- Temperature
[]	- Brackets
%	- Percent
π	- Pi Constant
¢	- proportional to
Σ	- sigma
3	- epsilon
ſ	Intergal
i	imaginary unit
z	absolute value/magnitude of a complex number
00	Infinity
Δ	Increment
β	Beta
Ө	theta
σ	Sigma
μ	mu 🔥
ω	omega UTEN
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LIST OF ABBREVIATIONS

MIMO	- Multiple input, multiple output
AC	- Alternating current
CPW	- Coplanar waveguide
CST	- Computer simulation technology
DG	diversity gain
EEC	envelope correlation coefficient
EHF	- extremely high frequency
EIRP	- effective isotropic radiated power
ELF	- extremely low frequency
ЕМС	- electromagnetic compatibility
FEM	- finite elements method
FIT	- finite integration technique
GSM	- Global System for Mobile
HF	- high frequency
HFSS	- high frequency structure simulator
IEEE	- Institute of electrical and electronics engineers
IDE	- Integrated Development Environment
IFA	- inverted F antenna
TARC	- Total active reflection coefficient
SRMA	- sequentially rotating monopole antenna
VSWR	voltage standing wave ratio
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CHAPTER 1

INTRODUCTION

1.1 Background

5G technology will result in increased connection, high speed, and data throughput, all while maintaining exceptionally low latency. In terms of frequency of operation, 5G has two bands: sub-6 GHz (below 6 GHz bands) and millimetre wave. The millimetre wave band is found in various places of the world between 24 and 30 GHz. In the sub-6 GHz 5G spectrum, there are several subbands, including the lower band (700 MHz), mid band (3.4–3.6 GHz), and high band (4.8-6 GHz). Various nations and regions have selected unique sub-6 GHz bands for their projected 5G rollout activities. As a result of the shuttle's change in operating frequencies, all essential gear linked to base transceiver stations (BTS), handphones/smartphones, and other user equipment (UE) must be updated or tuned to match those chosen frequencies. Among the several components of such equipment, the antenna is one of the most crucial. The antenna acts as the primary gateway for any wireless interface by converting electrical impulses to electromagnetic radiation. As a result, a well-designed antenna will put less burden on other components such as power amplifiers (PAs), low noise amplifiers (LNAs), and so on Recently developed multiple input multiple output (MIMO) array methods and designs for smartphones allow for decreased crosstalk, excellent signal selectivity, and channel capacity in wireless signal transmission and reception. Furthermore, it has higher directivity, enhanced beamforming, and beam-steering capabilities by default. However, designing a MIMO antenna array that fits inside a smartphone along with the other circuitry elements without compromising the overall system's performance to cover the entire mid-range sub-6 GHz frequency range while maintaining MIMO performance in terms of port isolation, envelope correlation coefficient (ECC), diversity gain (DG), and SAR remains a challenge.

1.2 Problem Statement.

Due to the increased demand for wireless and mobile technologies, wired communication systems have gradually been superseded as the present communication system advances and evolves. In this transition phase, antennas, which are metallic devices that capture signals in the air, serve a critical function. Users all throughout the world require a variety of wireless apps. Aside from that, today's electronics are more likely to be mobile. As a result, the built-in antenna must be small enough to fit into the mobile device. Telecommunication devices are designed to function in a range of nations throughout the world. The purpose of this study is to create a small 2 2 MIMO array for cellular communication by employing a sequentially rotating monopole antenna (SRMA). An antenna is shown to have multiband features if it can operate in various frequency bands, such as the IEEE Bluetooth/ WLAN/ISM range of 2.4-6 GHz and the WLAN range of 5.15-6 GHz. The return loss criterion has been established at 10 dB, which corresponds to 95% of the antenna's matching efficiency.

1.3 OBJECTIVESSITI TEKNIKAL MALAYSIA MELAKA The aim of the study is:

1. To propose and simulate a single element planar antenna on flexible substrate for 5G communication.

2. To simulate a 4×4 MIMO configuration array with polarization diversity on a flexible substrate for smartphones

3. To fabricate the proposed 4×4 array and measure in real environment using VNA and anechoic chamber.

4. Benchmark the outcome with the current trends.

1.4 SCOPE OF PROJECT.

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The idea of this project is to design illustrate the qualities and capabilities of planar antennas, and its scope includes doing so. More over i will design 4 element antenna arrays it for the with a bandwidth 5GHz. For this project I will use flexible material and Rogers when designing it. Beside that i will show the specification of each material the will be use for this project. The software CST Studio Suite is used to complete the design of the antenna, and it is also capable of simulating the performance of the created antenna in the form of graphical data. In addition to this i will show some important parameter such as S-parameters, farfields both 2D and 3D , voltage standing wave ratio (VSWR) . Next, will also calculate the bandwidth, Envelope Correlation Coefficient (EEC), Directive Gain (DG), Total active reflection coefficient (TARC) . In conclusion, the scope of this research is limited to the mobile communications industry, namely the practical use of antennas.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION.

The latest technology for civilization of human intelligent was wireless communication .The term that been use wireless communication system is called 5G. It provides lower latency in conjunction with enhanced connection, quick speed, and an exceptionally high data throughput .As we known that the 5G based on OFDM (Orthogonal frequency-division multiplexing) that fall into several type of band that have been categories high band, middle band, lower band .Most of countries agree and have set benchmark or basic guideline on the range frequencies for each band .For high band the parameter is between 4.G to 6.Ghz, for middle band was between 3.4G to 3.6Ghz and lastly for lowest band is 700 Mhz. All this band was under category sub 6Ghz frequencies. Hardwires that are essential to interface to wireless digital networks, such as Base Transceiver Stations (BTS), handphones, and other similar devices, must be developed to meet the frequencies that are used in each country since each country uses a unique set of frequencies. As we known when talking about wireless communication system they were several main components that been used but the most basic is antenna. Antenna was a device that receives and/or sends radio electromagnetic waves. Most antenna designer using MIMO for their basic based when build their antenna. This is because MIMO may also be utilized to extend transmission range at a given data rate, a feature that has enormous practical significance. This type design been used on the latest technology in mobile phones communications.

To meet the essential requirements for 5G communication, the antenna arrays at both the basestation and mobile-station ends of the link must be designed appropriately. The most complex aspect of design is fitting a MIMO antenna array into the narrow area of a mobile device. This is true of every mobile device. Current observations of the state of the art classify MIMO antennas for sub-6 GHz 5G mobile phones into four distinct categories. These classes are determined by the mode of operation, number of antenna components, isolation circuitry used, and antenna layout. As a result, the majority of academics and antenna engineers feel that it is impossible to develop a MIMO array with few components, a broad bandwidth, little separation, and a simple design. It is recommended that 5G phones use a two-element reconfigurable MIMO. To create frequency diversity at 2.4 or 3.5 GHz, the single element is comprised of two radiating arms with meander lines that may be connected to or decoupled from the 50 feedline. The envelope correlation coefficient (ECC) values for 2.4 GHz and 3.5 GHz are 0.0056 and 0.0009, respectively. The antenna array provides at least 12 dB of minimum isolation. Apparently, a smartphone antenna with a two-element MIMO array may cover more than 400 MHz for two sub-6 GHz mid-bands running concurrently at 3.5 and 4.3 GHz. UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2.2 PREVIOUS PROJECT RESEARCH.

This chapter will review previous research and existing projects created using reference sources and guidelines such as journals, the internet, article writing, blogs, and scientific studies to gain an understanding of project design, conception, and any information that may be useful in improving the project. Several scholars have created and produced projects based on various concepts and designs. This chapter also discusses the research pertinent to this project.

2.2.1 Geometry of Microstrip (Printed) Antenna

A microstrip antenna is a form of antenna that may be manufactured on a printed circuit board (PCB) by the use of a photolithographic method. This type of antenna is also known as a printed antenna. The vast majority of microstrip antennas are made up of numerous patches that are arrayed in a two-dimensional pattern. The microstrip antenna that is most often seen is known as the patch antenna. A patch antenna is a narrowband antenna with a wide beam that is created by etching the pattern of the antenna elements into a metal trace that is attached to an insulating dielectric substrate, such as a printed circuit board, and then coupling a continuous metal layer to the other side of the substrate, which acts as a ground plane. Aside from that, microstrip antennas that are square, rectangular, circular, and elliptical in shape are typical, although any continuous design is acceptable. Some patch antennas are made up of a metal patch that is placed on top of a ground plane using dielectric spacers rather than a dielectric substrate. The structure that is produced by this method has a lower level of robustness but a greater bandwidth. Due to the fact that such antennas have a low profile and are sturdy, they are



into

mobile

radio

communications

equipment.

typically

included

Figure 2.1: The main key design of microstrip antenna

2.1.1 Planar antenna in sub-6 Ghz applications

As a result of the fast development of technology for wireless communication, the standards for 2G, 3G, and 4G have gained widespread adoption. Therefore, in order to expand the bandwidth of mobile phone antennas, a few different methods have been suggested. These methods include the use of matching networks with lumped components, the multimode resonance approach, and the frequency reconfigurable methodology. Additionally, for use in mobile device applications, a broadband antenna that had a number of different resonant modes was designed; nevertheless, the design called for a very wide clearing space. As a result, reducing the clearance area may be accomplished by advocating for a basic planar antenna and putting restrictions on its designs, such as folding the antenna into three-dimensional structures.

Table 2.1: Dimensions	of the	antenna	(unit:	mm). [1]	
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	با ملاك	mile, 1ª	- Ruis	$= \omega, \omega$	ىيەتىر ,س	91
Parameters	L1 **	L2	L3	L4	L5	L6
Values	12.9	28.7	4.4	21	6.5	5.5
Parameters	UNL7ER!	STL8EK	L9	AL10'S	LII	L12
Values	14.5	3	7.5	12.5	1.7	15
Parameters	L13	L14	L15	L16	w1	w2
Values	29.9	5	4	11	1	1.5
Parameters	w3	w4	w5	Ls1	Ls2	
Values	0.5	1	1	0.5	1	



Figure 2.2: Planar antenna design. [1]



The antenna is composed of one multi-branch driven strip and three parasitic grounded strips [1]. Additionally, the driven strip has three branches that are printed on the top surface of the **UNVERSITIEEXALABLE AND STATE** and linked to a 50 coaxial line at the feeding point. These branches are fed into the strip by the feeding point. After then, by activating a variety of different modes of operation, the antenna is able to cover the necessary frequency spectrum. The design procedure and working mechanism have both been analysed in great detail, and the findings of both the measurements and the simulations are in excellent accord with one another. Therefore, this design has a strong application value since it does not need lumped-element loadings and it has a broad bandwidth.

2.1.2 Broadband planar antenna for 5G communication

In recent times, mobile data has increased at an exponential pace owing to the vast number of registered users and their desire for high-quality multimedia content. This requirement has caused the number of registered users to skyrocket. As a result, mobile communication networks are transitioning towards fifth-generation (5G) systems, which are expected to provide data speeds ranging from 5 to 50 Gbps to satisfy the ever-increasing demand for data. A number of other antenna configurations, such as the high gain planar antenna and the substrate integrated waveguide (SIW) feed antenna, have been proposed. On the other hand, planar antennas may not be the best choice for long-distance millimeter-wave transmission, and SIW antennas are notoriously difficult to put together due to their complicated design..



Parameter	Value, mm	Parameter	Value, mm
а	1	L ₁	4.76
s	0.9	L ₂	1.34
h	0.4	L3	2
g	0.81	L4	2
d ₁	0.7	W ₁	0.5
d2	0.24	R	1
Lf	2.4	Ws	7
Wf	0.78	Lsub	7
Ls	3.5	Wsub	10

 Table 2.2: Antenna parameters and its value.



Figure 2.3: Structure of antenna. [2]

Therefore, the purpose of this paper is to present and analyse a 1 x 4 element antenna array along its feed network which consists of a spiral monopole surrounded by a boundary of vias for the purpose of limiting surface waves and inter-element coupling covers a wide band ranging from 23.76 to 42.15 GHz, with three distinct frequency bands including the most prominent 28/38 GHz 5G bands, and also significantly improves antenna bandwidth performance with the introduction of hexagonal parasitic patches [

2.1.3 Proximity coupled microstrip planar antenna

In comparison to the 4G standard, the radio frequency (RF) bandwidth that is used by the millimetre wave fifth generation (5G) network is much broader, which results in the delivery of a very significant performance gain for the 5G network. Since it has high gain, beam steerable emission patterns, and low profiles, thus, significant investigations of microstrip patch array antennas and phased arrays are being investigated as prospective contenders for

millimetre wave applications. For example, a microstrip patch antenna typically has a straightforward construction and a relatively tiny dimension, but it typically has narrow bandwidths of around 1 to 5 percent, but the design of a phased array may be rather challenging.



Figure 2.4: Single structure (A) and proximity coupled configuration (B). [3]

This research paper proposed a microstrip planar with proximity coupled with 6 x 5 dimension that operates from 27.5 GHz to 28.5 GHz with 28 GHz as the centre frequency and has 9.8 percent achievable bandwidth [3]. [3] This microstrip planar operates from 27.5 GHz to 28.5 GHz and has 28 GHz as the centre frequency. Additionally, it is small in size, has low levels of sidelobes, and has an antenna gain of 21.86 dBi on the H-plane and 21.95 dBi on the E-plane, both of which might be enhanced for phased array applications. Therefore, in terms of the structural stability required for 5G applications, it is particularly suited for integration since both the simulated and measured findings offer a large number of parallels.

2.1.4 Flexible co-planar waveguide for 5G

It is anticipated that the migration to a fifth generation network would maximise usage of frequency bands in the sub-6 GHz region. This will need broad range installations with comprehensive network coverage. Because of their ever-increasing prevalence, smart gadgets need to be linked not just to the internet but also to one another and to other similar devices so that they may continue to function normally. In addition, as the functionality of medical and wearable smart devices continues to grow, the area available for antenna integration will become more constrained. This necessitates the use of antennas that are pliable by their very nature and also have the additional virtue of being transparent, which enables them to be interfaced anywhere without contributing to the appearance of visual clutter.



Figure 2.5: Front view of proposed antenna. [4]

This paper focuses on the fabrication of a flexible transparent antenna with high gain and wideband properties using substrates made of either polyethylene terephthalate (PET) or an alternative substrate made of silver and tin oxide combination (AgHT-8) due to the combination's flexible and transparent characteristics [4]. The antenna is capable of achieving an average gain of 3 dBi and an impedance bandwidth of 40 percent. Additionally, the average efficiency of the antenna shows more than 80 percent for operating bands, and bending analysis

is carried out in order to identify promising outcomes by retaining its performance for sub-6 GHz in 5G and wireless local area network (WLAN) application.

2.1.5 Antenna designs and considerations overview

When categorising frequencies at the frequency boundary of 6 GHz that fall within the fifthgeneration bands, there are significant changes in the electromagnetic characteristics and the needs for communication. Bands with frequencies lower than 6 GHz are referred to as sub-6 GHz bands, whilst bands with frequencies more than 6 GHz are often referred to as millimetre wave bands. In order to obtain a high data rate during wireless transmission, the technique known as multiple-input and multiple-output, or MIMO, is necessary. Some designs and research demonstrate that cellular phones that feature multiple antennas are able to satisfy sub-6 GHz MIMO requirements. In addition, there are a few characteristics that could have an effect on the antennas that are used in 5G mobile phones. One of these is a larger battery capacity, which is required to meet the high-power consumption that is anticipated given that it is anticipated to have full screen ratios [5] and to maintain a longer working time for the user. After that, considering using phased antenna arrays as a means of compensating for the significant route losses that are inherent to millimetre wave communication is a good idea. In a nutshell, the design of antennas in order to support MIMO implementation and the integration of millimetre wave with existing antennas for sub-6 GHz bands play an important role in achieving higher wireless data rates performance of 5G cellular phones. This is because MIMO is a technique that allows multiple users to send and receive data simultaneously.

2.1.6 MIMO loop antenna array

The process of developing 5G technology now underway involves a large data capacity as well as a fast transmission speed. As a result, a number of different smartphone antennas have been suggested; however, they can only provide a limited bandwidth with a low isolation level or take up a significant amount of space on the mainboard. Therefore, a multiple-input multiple-output (MIMO) antenna design application is proposed in this paper to obtain a higher channel capacity and additionally to ensure that all antenna elements can fit into the limited space of a smartphone while still maintaining good isolation. This application is proposed to achieve these goals in order to obtain a higher channel capacity. Even if the complexity of antenna design will rise in terms of the number of antennas, MIMO technology will provide faster data rates as well as increased efficiency without requiring an increase in input power. This will allow 5G networks to be enhanced. In the study, MIMO antennas were proposed, each consisting of eight loop antennas placed on a separate side of the mainboard. The design able to achieve good S parameter results as seen in **Figure 2.5** with a wide operation band of 800 MHz (3.2–4 GHz) for Snn ≤ -10 dB and 1300 MHz (3–4.3 GHz) for Snn ≤ -6 dB [6].



Figure 2.6: Simulated Snn of S-parameter array. [6]

In Figure 2.6, an 8 x 8 MIMO array is formed by placing four corners of the mainboard by four pairs of the discrete-fed loop antennas. The frequency bandwidth and isolation level of the MIMO system are increased by the inclusion of modified arrow strips between neighbouring components. In addition to this, it has favourable qualities such as a broad bandwidth, high isolation, and an advantageous radiation pattern. In addition, a low-profile mm wave phased array that uses end-fire radiation is implemented so that it may be included onto the printed circuit board of a smartphone.



Figure 2.7: The proposed of 8-element antenna. [6]

2.1.7 Wideband Four-Port MIMO antenna array

Because of recent advancements in the 5G communication system operating at sub-6 GHz, it is now possible to get large channel capacity along with high data speeds by using MIMO

technology. Recent reports have detailed many forms of MIMO antenna arrays that have been developed to fulfil the prerequisites of 5G standards. The creation of a four-port MIMO antenna array that uses un-protruded multi slot (UMPS) isolating elements will be the focus of this project. However, it turns out that increasing the isolation between closely packed antenna is



Figure 2.8 displays a footprint that was planned to be 30 by 25 mm2 and was printed on a FR-4 substrate that was 1.6 millimetres thick (with a dielectric constant of 4.3 and a loss tangent of 0.0025) [7]. In point of fact, the suggested antenna is capable of achieving a gain of 3.5 dBi while also maintaining an efficiency of 85%. Additionally, it demonstrates an excellent radiation pattern of the central frequency in both the E-plane and the H-plane. Therefore, because of its good radiation characteristics, better diversity performance, and compactness, the proposed four-port MIMO antenna array is an excellent candidate for incorporation into the future wireless devices that will operate in the 5G New Radio (NR) sub-6 GHz and 5 GHz WLAN bands. Additionally, it is suitable for large antenna packing density, which will result in improved transmission and reception quality of signals.

2.1.8 Reconfigurable MIMO antenna for 5G applications

To satisfy the ever-increasing need for more connection, faster speed, and improved data rate with low latency, the wireless communication technologies that are now in use need to undergo significant advancements. Therefore, the sub-6 GHz band is the one that is favoured since it may give more efficiency in the utilisation of the spectrum that is accessible. In addition, the multi antenna system, also known as multiple input multiple output (MIMO), is a technological advancement that improves the channel capacity while simultaneously increasing spectral efficiency. Therefore, the purpose of this research paper was to present a frequency reconfigurable MIMO antenna with a quasi-planar mono-pole structure made up of two radiating arms for 4G and early 5G application [8]. This antenna was designed to cover frequency ranges at 2.0 - 2.7 GHz band and 2.57 - 4.27 GHz band respectively.



Figure 2.9: Configuration of proposed antenna. [8]

The antenna is also capable of switching between two resonance modes (mode 1 for 4G and mode 2 for 5G) via electronic, which are two PIN diodes, and has achieved 64 percent

bandwidth efficiency with 3.70 dBi and 4.2 dBi peak gain for both of the different modes it can operate in. Both modes are described below. Two quasi-planar monopole antennas are integrated and positioned diagonally opposite one another on the same substrate by employing a method called self-isolation. Validating the MIMO antenna's gain diversity, the MIMO system exhibited adequate isolation (>12 dB) in both modes when it was configured in this manner. The envelope correlation coefficient was also quite low. This demonstrates that the use of MIMO technology delivers a satisfactory performance in terms of diversity and is suitable for mobile communication. In conclusion, the port-to-port isolation is accomplished without the use of any external decoupling structures, which results in a MIMO antenna system that is both more effective and less complicated.

2.2.9Characteristic Mode Analysis in MIMO antenna and Millimeter-Wave system.

The latest improvements in wireless technology have led to an increase in the variety of available options for wireless network users. At the same time, there is a large rise in the amount of user data traffic brought on by high data rate demand. In a Several-Input Multiple-Output (MIMO) system, the transmitter and the receiver each have a number of antennas, which results in the generation of multiple uncorrelated channels between them and the production of a high data rate. Despite this, a low profile is necessary in order to facilitate operation across various frequency bands. A two-element MIMO antenna comprising L-shaped components with L slot planar inverted-F antenna (PIFA) type was presented in this research. The characteristics mode analysis (CMA) technique, sometimes referred to as the theory of characteristic mode (TCM), is one that is able to assist in the improvement of parameters and the design of a wide variety of antennas [9]. When using a complementary modified split ring resonator (CMSRR) at the ground plane, the isolation between the antenna elements was improved, showing a minimum

isolation level of 21 dB in sub-6 GHz and 24 dB in millimetre-wave bands. This helped to reduce the amount of mutual coupling that existed between the antenna elements.

Isolation technique	Resonant freq. (GHz)	Min. isolation (dB)	No. of ports
Decoupling slits and shielding wall	2.65	-17	2
Defected ground	2.1, 2.5, 3.5, 17.2	-4, -10	2 (4G)
			2 (5G)
Slot lines	3.5, 5.5, 7	-15, -28, -16	4
Suspended strip and open slots	2.2, 3.4	-19	2
Defected ground	3.8	-18.8	4
Metamaterial	3.5	-28	2
CMSRR BALAYS	3.5, 4.3, 27.5, 30.3	-32.3, -35.4, -27.23, -28.44	2

Table 2.3: Isolation technique used as comparison in the research paper. [9]

2.1.9 Wideband decoupled MIMO antenna

Fifth-generation (5G) communications are now in use and are seen as a substantial answer to the issues that cellular networks face in the modern day. The benefits of fifth-generation communications include high data speed, capacity, and ultra-low latency. The sub-6 GHz band and the millimetre-wave band are two important spectrums that have been selected for use by 5G wireless technologies. In order to get high gigabit data throughput, it is necessary for the user's equipment device to be capable of MIMO operation (which stands for multi-input and multi-output). Despite this, considerable mutual coupling develops between antenna ports when the antennas are situated in close proximity to one another and operate in the same frequency range. This results in a loss of sensitivity between the antenna ports.



Figure 2.10: Decoupled MIMO antenna geometry (A) and its position above the supporting metal plate (B). [10]

According to the information presented in the article [10], a MIMO antenna (Figure 2.10) is made up of two feeding mono poles, one common dipole, and distributed capacitance. For the purpose of the decoupling approach, the fundamental mode and the first higher-order resonant mode are both included into the same dipole. On the centre of the dipole, a capacitive load is placed, which results in an increase in the effective resonant. Both of the antennas are constructed on a flame retardant type 4 (FR4) substrate with dimensions of 35 millimetres by 5 millimetres by 0.4 millimetres, and mini-coaxial cables are soldered over a 0.5-millimetre feed gap between them. While the monopole mode can provide a frequency of 4.7 GHz and the common dipole can offer a frequency of 3.6 GHz in a half-wavelength, employing these two resonant modes may perform a frequency range of 3.3–5.0 GHz.
In conclusion, a self-decoupled 5G MIMO antenna that operates in the band between 3.3 and 5.0 GHz that is appropriate for thin bezel laptops has been described for use in laptop applications. The layout is symmetrical, and it consists of two feeding monopoles, one common dipole, and one capacitive load on the dipole centre. Additionally, it is built on a very small FR4 substrate that measures 35 mm x 5 mm. The decoupling method involves using the fundamental resonance of the dipole in addition to the original higher-order resonance in order to cancel out modes in the same dipole. Capacitive loading is used for the purpose of lowering the one-wavelength dipole mode and obstructing the counter phased currents generated by the half-wavelength mode, both of which contribute to enhanced isolation.

2.1.10 Quad-port dual band MIMO antenna

Recent developments have resulted in the creation of a great deal of 5G sub-6 GHz Multiple-Input Multiple-Output (MIMO) antennas for mobile terminals and base stations. In spite of this, integrating many antennas into mobile phones in such a way that they have strong isolation and a low envelope correlation coefficient is a challenging task. Mobile phones have inadequate internal space. According to [11], the use of a dual-band four-port MIMO antenna may facilitate multi-mode communication in addition to increasing the capacity of the system. [Citation needed] The suggested antenna may operate in the 3.5 GHz band (3.4–3.6 GHz) as well as the 5 GHz band (4.8–5 GHz), and it has a low envelope correlation coefficient (ECC), high gain, and excellent isolation. These characteristics allow the antenna to attain large channel capacities and fast transmission rates. A parasitic rectangular strip, a modified Z-shaped radiating strip, and an L-shaped feeding strip make up its construction.



Figure 2.11: Quad-port MIMO antenna structure (in millimeters). Prospective view (above) and single element (below). [11]

The dimensions of the main board are $150 \text{ mm} \times 75 \text{ mm} \times 0.8 \text{ mm}$, and the size of the side board is $150 \text{ mm} \times 6.2 \text{ mm} \times 0.8 \text{ mm}$. Four components are printed in a vertical orientation on each of the two side boards that are attached to the main board. The FR4 substrate that has tan=0.02 and r=4.4 printed on it was used for both the main board and the side boards. The side and main boards are bonded together using an adhesive made of metal. The antenna is able to

function in frequency bands ranging from 4.8 GHz all the way up to 5 GHz, with a frequency



range of 3.4 GHz to 3.6 GHz.

Figure 2.12: Measured and simulated total efficiencies and peak gain of the proposed antenna. [11]

The maximal peak gain at 3.6 GHz was measured at 4.7 dBi, while the maximum peak gain at 5 GHz was recorded at 5 dBi. Both of these values are adequate to fulfil the needs of the majority of mobile phone antennas. The overall efficiency that was tested is higher than 70 percent, and the isolation is greater than 16.5 decibels. The observed efficiency, on the other hand, is lower than what was predicted owing to the chamber's loss as well as the surplus of solder. In conclusion, the MIMO antenna that was presented is a strong contender for use in 5G mobile devices.

2.2 Comparison of previous research papers.

Authors	Research Title	Software	Main Features
[1]	Planar antenna in sub-6 Ghz applications.	High Frequency Structure Simulator (HFSS)	 Fully planar structure No lumped elements. Easy to be fabricate. Wider frequency band.
[2]	Broadband planar antenna for 5G communication	CST Microwave Studio Software	 Low transmission losses. High gain. Narrow beamwidth. Small size. Low cost.
[3]	Proximity coupled microstrip planar antenna.	CST Microwave Studio Software	 Simple planar structure. High gain. Narrow beamwidth. Can be extended for aperture coupled structures.
[4]	Flexible co-planar waveguide for 5G.	HighFrequencyStructureSimulator(HFSS)	 High gain. Flexible and transparent.

			3. High average efficiency.
[5]	Antenna designs and	-	-
	considerations overview.		

Authors	Research Title	Software	Main Features
[6]	MIMO loop antenna array	CST Microwave	1. Low isolation.
		Studio Software	2. Good radiation pattern.
	ALAL WALAYSIA MELPINA		3. High bandwidth
[7]	Wideband Four-Port	CST Microwave	1. Compact size.
	MIMO antenna array	Studio Software	2. Good radiation pattern.
	ىل مليسىيا ملاك	تي تيڪنيڪ	3. High efficiency value.
	UNIVERSITI TEK	NIKAL MALAYSI	4. Can be assimilate for future
			wireless system.
[8]	Reconfigurable MIMO	CST Microwave	1. Two switchable different
	antenna for 5G	Studio Software	modes.
	applications		2. Good isolation.
			3. High gain and efficiency.

[9]	Characteristic Mode	High	Frequency	1. 1	Large wideband coverage.
	Analysis in MIMO	Structure	Simulator	2. (Good isolation.
	antenna and Millimeter-	(HFSS)		_	
	Wave system.			3. (Covers sub-6 GHz band and
				1	millimeter-wave band.
[10]	Wideband decoupled	High	Frequency	1. 5	Small size.
	MIMO antenna	Structure	Simulator	2. 5	Symmetrical structure.
		(HFSS)		3. (Good isolation.
[11]	Quad-port dual band	High	Frequency	1. 1	High efficiency.
	MIMO antenna	Structure	Simulator	2. 1	High isolation.
	AN TEK	(HFSS)		3. 1	High gain
L	"Samme				
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CHAPTER 3

METHODOLOGY

3.1 Introduction

For the purpose of this chapter, we will be talking only about the planning and strategy that will be used to carry out the whole of this project. The processes that researchers follow to finish their job, such as describing, detailing, explaining, and forecasting events, as well as managing projects, are referred to as methodologies. In addition, the primary idea behind this project was derived from the findings of earlier research papers, and it is important to note that the development phase of the antenna calls for a combination of theoretical and experimental approaches.

3.2 Project Flow

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The bachelor's degree project, often known as the BDP, is a requirement for students in their final year and is divided into two stages: BDP I and BDP II. The students will use the Gantt chart as a guidance to ensure that they adhere to the time range that has been established and to ensure that the project is carried out in the correct manner. BDP I concentrate on the problem descriptions, goals, and material obtained from various publications and periodicals. In addition to this, BDP I focused a lot of attention on the system design of the project, making use of the suitable software and hardware.

A guideline that is based on a chart is the most important component that might provide you with an overview of the project. In order to accomplish the goal of the project, a chart will be created to display the beginning point, the examination and assessment of the information, and the consideration of the potential options. The Gantt chart (shown in figure 3.1) and flow chart (shown in figure 3.2) are both shown here.



3.2.1 Gantt Chart

Lecture Weeks														
Project Activities	week 1	week 2	week 3	week 4	week 5	week 6	week 7	week 8	week 9	week 10	week 11	week 12	week 13	week 14
Project Discussion with supervisor	-													
Report Drafting														
Compenent Buying									7					
Log Book Submission	BDP B								nid Ten					
Chapter 2 Literature Review Drafting	riefing								m Brea					
Project Design and Simulation									ž					
Project production	1													
ProjectTesting														
BDP 2 Presentation														

Figure 3.1: Gantt Chart of the project.



3.2.2 Flow Chart



Figure 3.2: Flow Chart of the project.

3.3 Software

3.3.1 CST Studio Suite



Figure 3.3: CST Studio Suite software 2021 version.

When doing high-performance three-dimensional (3D) electromagnetic analysis, it is possible to build, evaluate, and optimize electromagnetic (EM) components and systems with the help of the software that is included in the CST Studio Suite. The performance and efficiency of antennas and filters, the compatibility of electromagnetic fields and the interference of electromagnetic fields, the exposure of the human body to electromagnetic fields, the electromechanical effects in motors and generators, and the thermal effects in high-power devices are all examples of common electromagnetic issues. Consequently, the antenna construction and simulation findings for this project are rather useful and relevant when using this programmed. The majority of researchers working in the EM sector utilize it because of its adaptability and the various capabilities it offers.

BEST COURSES Adobe Busses B

3.3.2 Adobe illustrator

Illustrator is a programme for graphic design. Illustrator is used by graphic artists to produce vector graphics. Vector pictures and graphics are comprised of points, lines, forms, and curves based on mathematical formulae rather than a fixed number of pixels, and may thus be resized without loss of image quality.

3.4 Hardware

3.4.1 Rogers 3003 PCB



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The commercial market makes use of ceramic-filled polytetrafluoroethylene (PTFE) composites known as Rogers 3003 materials. These composites are used in microwave and radio frequency (RF) applications. It is constructed in such a way as to provide a high degree of electrical and mechanical stability. The dielectric constant stability of the Rogers 3003 printed circuit board (PCB) is remarkable from 3 to 40 GHz. This includes the elimination of the change in dielectric constant that occurs at normal temperature with PTFE glass materials. The PCB has dimensions of 114.3 mm x 152.4 mm, and it has a low loss factor of 0.0013 to 10 gigahertz. Because of this, it is ideal for use in bandpass filters, microstrip antennas, and voltage-controlled oscillators.

3.4.2Rogers 5880 PCB



Figure 3.6: Example of Rogers 5880 PCB

The Rogers 5880 printed circuit board is constructed out of a glass microfiber that has been bonded with PTFE compounds. These microfibers have been statistically oriented in order to maximize the advantages of fiber gain in the manner that is most advantageous for the producers of circuits and the end-use applications. The dielectric constant of these highfrequency laminates is the lowest of any product on the market, and the fact that they have such a low dielectric loss makes them ideal for high frequency and broadband applications in which dispersion and losses need to be reduced to the absolute minimum. Because of its low dielectric constant of 1.96 at 10 GHz, this PCB is suitable for use in broadband applications using microwave frequencies in the millimeters range. Such applications require that dispersion and circuit losses be kept to a minimum. Due to the fact that it has exceptionally low qualities of water absorption, it is also perfect for use in applications that take place in situations with high levels of humidity

3.4.3FR4

Figure 3.7: FR4

A kind of printed circuit board base material known as FR4 is one that is fabricated using a composite of flame-retardant epoxy resin and glass fabric. FR is an abbreviation for "flame retardant," and it indicates that the product satisfies the criteria of UL94V-0. Because it adheres well to copper foil and absorbs very little water, FR4 is an excellent choice for use in applications that need a material that is very versatile. FR4 may be used either as a copper-coated material for one- and two-layer printed circuit boards (PCBs) or as a Prepreg and core material for multilayer PCBs.

3.4.4 Kapton HN



Figure 3.8: Kapton HN

When it comes to applications that call for an all-polyimide film that maintains an outstanding balance of qualities throughout a broad temperature range, Kapton® HN is the material that comes highly recommended. There have been successful applications of Kapton® HN at temperatures ranging from -269°C (-452°F) all the way up to 400°C (752°F). Laminated, metallized, punched, or shaped Kapton® HN sheet may also have an adhesive coating applied to it. Pyromellitic dianhydride and 4,4'-diaminodiphenyl ether are the two components that undergo a polycondensation process in order to produce the polyimide polymer that makes up the substance. Kapton does not melt or burn and has good resistance to chemicals; the film is not compatible with any organic solvents that are currently known.

3.4.5 Glossy paper



Figure 3.9.1: Glossy Paper

Glossy Paper refers to coated papers intended to have a very smooth to glossy look. Examples include brochures, advertisements, flyers, one-sheets, photographic printing, and other presentation materials. There are several types of glossy paper, but they always fall into one of two categories: photo-gloss (mirror-like sheen) and softgloss (magazine-page sheen). Other factors to consider when selecting glossy paper include paper size availability, printer compatibility, and personal choice. While the purpose of all glossy papers is to improve the colour intensity and resolution accuracy of printing, different varieties lend themselves well to certain applications due to the presentation effect of each type of gloss coating, including soft gloss, gloss, and picture gloss.

3.4.6 SMA - 50 Ohm Connectors



Figure 3.9.2: SMA - 50 Ohm Connectors

The SMA connection (SubMiniature version A) is a coaxial connector with 50 ohm impedance. Visually, it resembles an F-type connection, which is often used for audio/video transmission, but its size and mechanical qualities are different, and it is utilised for applications such as RF communications up to 18 GHz. Due to its design, SMA connections offer a robust and lasting connection that reduces reflections and attenuation while dealing with microwave frequencies, making them an excellent option.

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3.5 .1Formulation Of Antenna

$$w = \frac{C_0}{2fc\sqrt{\frac{\varepsilon_r + 1}{2}}}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12 \frac{h}{Wp} \right]^{-\frac{1}{2}}$$

$$L_e = \frac{C_0}{2f_c\sqrt{\varepsilon_e}}$$

$$\Delta L = 0.412h \frac{(\varepsilon_e + 0.3) \left(\frac{W_k}{h} + 0.264\right)}{(\varepsilon_e - 0.258) \left(\frac{W_k}{h} + 0.8\right)}$$

$$L = L_e - 2\Delta L$$

$$L_g = 6h + L_k$$

$$W_g = 6h + W_k$$

$$F = \frac{F}{\left\{ 1 + \frac{2h}{\pi\varepsilon rF} \left[\ln \left(\frac{\pi F}{2h}\right) + 1.7726 \right] \right\}^{\frac{1}{2}}}$$
A MELAKA

3.5.2Formulation Of the MIMO performance parameters

$$ECC = \frac{|S_{11}^*S_{12} + S_{12}^*S_{22}|^2}{(1 - (|S_{11}|^2 + |S_{12}|^2))(1 - (|S_{11}|^2 + |S_{12}|^2))}$$
$$DG = 10\sqrt{1 - |ECC|^2}$$
$$TARC = \sqrt{\frac{|S_{11} + S_{12}|^2 + |S_{21} + S_{22}|^2}{2}}$$
$$MEG = 0.5 \left[1 - \sum_{j=1}^M |S_{ij}|^2\right]$$
$$CCL = -\log_2 \det(n)$$

$$CCL = -\log_2 \det\left(\eta\right)$$



CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter is divided into four pieces, the first of which is devoted to designing the antenna and entering its parameters. The other sections provide an overview of the simulation. The findings of the simulation are presented in the second part, and in the third section, the conclusions drawn from the study are discussed.



(A)

Figure 4.1: Patch antenna design. Front view (A) and side view (B).

Using the CST Studio Suite software, it is feasible to construct a patch antenna if one has the necessary knowledge and has obtained the necessary information from previous articles. Figure 4.1 illustrates the front aspect of the design that consists of a monopole feed with three tiny inward circular sides. Two of these sides are positioned on both sides of the X axis, while the third is located at the top position of the Y axis. In accordance with the specifications that have been defined for the design, the dimensions have been provided in Table 4.1.

N.N.	KA	
Parameter	Description	Value (mm)
W Alwn	Substrate Width	Wp + 0.15 x Wp
wp Dyla	Patch Width	ويتومر سيعار
Wf UNIVERS	Feed Width	1124 MELAKA
Lp	Patch Length	16
Lf	Feed Length	16
h	Substrate Height	0.51
t	Thickness of copper	0.035
r	Radius	3

Table

WALAYSIA 4

k	Port	extension	8.03
	coefficient		



Figure 4.3: S₁₁ parameter simulation result.



Figure 4.4: VSWR result.

The final design is developed as shown in Figure 4.2 once it has been verified that all criteria have been satisfied and the parameters have been optimized. Figure 4.3 presents a graph of the S11 parameters, which displays the value of operating frequency and return loss gain at 3.47 GHz and -12.89 dB respectively. Next, using Figure 4.4 as a reference, we can determine that the voltage standing wave ratio (VSWR) of the antenna is 1.58.



Figure 4.2: Perspective view of patch antenna.



Figure 4.5: Polar view of the antenna at $Phi = 0^{\circ}$.



Figure 4.6: Polar view of the antenna at $Phi = 90^{\circ}$.



Figure 4.7:FR4 Farfield result at 3.5 GHz in 3D.



Figure 4.7: Polyimide Farfield result at 3.5 GHz in 3D.



The recommended design for creating a MIMO system in a 4 x 4 arrangement can be seen in the figure that can be seen above labelled "Figure 4.8." A 5G smartphone typically has dimensions of 150×75 mm on the other. The patch antenna will be installed in the corner in a clockwise orientation, with the monopole feed pointing in the opposite direction. With the arrangement that has been suggested, there is a significant amount of unused space that may be put to use by positioning additional components, particularly in the centre.



Figure 4.9.1: parameter CST result with FR4.

This show FR4 substrate with each result port for on frequency for Sub 5G for all from 2GHZ to 8GHZ S11,S12,S13,S14,S21,S22,S23,S24,S31,S32,S33,S34,S41,S42,S43,S44





Figure 4.9.3: Parameter CST result with Polyimide substance.

This show Polyimide substrate with each result port for on frequency for Sub 5G for all from 2GHZ to 8GHZ \$11,\$12,\$13,\$14,\$21,\$22,\$23,\$24,\$31,\$32,\$33,\$34,\$41,\$42,\$43,\$44



Figure 4.9.4: VSWR result with Polyimide substance.

Polyimide design result in CST in between 3Ghz to7.5Ghz for the VSWR



Figure 4.9.5.: Polyimide product top view

This is the design product of 4x4 MIMO with using polyimide as substrate have for 4 SMA 500hm connector on each patch by soldering it is on top view.



Figure 4.9.5:Polyimide product bottom view

This is the design product of 4x4 MIMO with using polyimide as substrate have for 4 SMA 500hm connector on each patch by soldering it is on bottom view.



Figure 4.9.6:Fr4 product bottom view

This is the design product of 4x4 MIMO with using FR4 as substrate have for 4 SMA 50ohm connector on each patch by soldering it is on top view.



Figure 4.9.6:Fr4 product bottom view

This is the design product of 4x4 MIMO with using FR4 as substrate have for 4 SMA 500hm connector on each patch by soldering it is on bottom view.



Figure 4.9.7.1 FR4 product S11

At port S11 we got 3.5Ghz with-13db Lost



Figure 4.9.7.2 FR4 product S12

At port S12 we got 3.5Ghz with-23.92db Lost



Figure 4.9.7.4FR4 product S14

At port S11 we got 3.5Ghz with-13db Lost



Figure 4.9.7.5 FR4 product S21





Figure 4.9.7.6FR4 product S22

At port S22 we got 3.5Ghz with-20.07db lost



Figure 4.9.7.7 FR4 product S23



Figure 4.9.7.8FR4 product S24

At port S24 we got 3.5Ghz with-47.18db lost



Figure 4.9.7.9FR4 product S31



Figure 4.9.7.10 FR4 product S32

At port S32we got 3.5Ghz with-44.15db lost



Figure 4.9.7.11 FR4 product S33

At port S33 we got 3.5Ghz with-12.76db lost



Figure 4.9.7.12 FR4 product S34

At port S34 we got 3.5Ghz with-23.50db lost


Figure 4.9.7.13 FR4 product S41

At port S41 we got 3.5Ghz with-37.00db lost



Figure 4.9.7.14 FR4 product S42



At port S42 we got 3.5Ghz with-39.96db lost

Figure 4.9.7.16 FR4 product S44

At port S44 we got 3.5Ghz with-15.76.db lost



Figure 4.9.8.2 FR4 VSWR Port 2

At port S2 we got 3.5Ghz for VSWR



Figure 4.9.8.3 FR4 VSWR Port 3

At port S3 we got 3.5Ghz for VSWR



Figure 4.9.8.4 FR4 VSWR Port 4

At port S4 we got 3.5Ghz for VSWR



Figure :4.9.9.1Polyimide product Port S11

At port S11 we got 5.7Ghz with-10.03db lost because of the poor production



Figure :4.9.9.2 Polyimide product Port S22

At port S11 we got 1.75Ghz with-28.06db lost because of the poor production



Figure :4.9.9.3 Polyimide product Port S33

At port S33 we got 1.77Ghz with-13.26db lost because of the poor production



Figure :4.9.9.4 Polyimide product Port S44

At port S44 we got 3.5 Ghz with-12.76db lost because of the poor production



Figure :4.9.9.5 Polyimide product VSWR



At port we got 5.74Ghz for VSWR because of the poor production

CHAPTER 5

CONCLUSION

5.0 Conclusion

In conclusion, we choose all of the prior research that has been conducted on this subject and that has been published, and we make some findings based on that study. This chapter also includes information on the various techniques that the researchers of each publication used, as well as the solutions that they presented to the difficulties that arose as a result of their work. A comparison table is also supplied so that it may be easily distinguished from one another and arranged in the appropriate manner according to their various characteristics. Following that, Chapter 3 focused entirely on the technique of the project. The approach that is detailed in this chapter is designed expressly for the aim of making the workflow of the project more systematic and, as a result, cutting down on the number of mistakes that occur. Specifications are also provided for the project's usage of the appropriate software and hardware. In conclusion, the advancements made and the outcomes of this project are discussed in Chapter 4. The recommended design is emphasised after going through a number of iterations of trial and error, drawing reference and taking direction from earlier pieces. In addition, the simulations are monitored and analysed in order to reach the goals set for the project in order to attain the intended outcome. In BDP II, we will continue our previous research. With two types of materials, Fr4 and Kapton Hn, we were able to create the ideal design. Both products are manufactured with the same design. The production of polyimide was hampered by several obstacles, such as a lack of suitable production equipment. When the design is processed on the machine, we are unable to get its exact size and measurements. Copper will not separate from polyimide during etching process in the UTEM facility, thus we use a method other than manually cutting with scissors. This heavily effect the result we don get the targeted result that we want because of the poor product.

5.1 Future Works

For the future of our MIMO Antenna project, we must first build a higher quality product using the most suitable equipment. We must locate a firm that can create this sort of material and design with higher quality. In addition, I advocate utilising the same material and adding more thinner to the substrate in order to get a superior outcome. In addition, I proposed reducing the size of the design to get a better outcome. Next, we propose using a more sensitive receiver so that it can be read more accurately than the existing design. Next, maybe upgrade to 8x8 MIMO architecture. Recommend employing a better testing unit so that testing results are more

reliable.

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