

# **Faculty of Electrical and Electronic Engineering Technology**



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**Bachelor of Electronics Engineering Technology with Honours** 

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### DEVELOPMENT OF ELECTRONIC CONTROL AND INFORMATION SYSTEM FOR 5G BASE STATION ANTENNAS

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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



### DECLARATION

I declare that this project report entitled "Development Of Electronic Control And Information System For 5g Base Station Antennas" 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.

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# 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.

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### **DEDICATION**

To my beloved mother, Tee Yock Chu, my sister Keryn Kho Khai Lin to their support and encouragement when this project is on going. Besides that, I would like also send my appericate to my friends, Tan Kim Loong and Tan Chin Kwang and also my supervisor, Dr. Muhammad Inam Abbasi. Without their help and idea, the progression of this project will not go smoothly.



#### ABSTRACT

Base station antennas are important for us on this era because without them our network system cannot function which mean that we cannot call to our loves one by using smartphone and we also cannot surf the internet if there are no base station antennas. Therefore, networking becomes a necessity for us but without the help of the antenna, we cannot send or receive the information. Thus, this project will have research on the base station antennas with 5G. First of all, there has an introduction on the base station antenna, the problem statement, objective, and scope of this project will be mention. On the designing part, first of all, design the model of the reflectarray patch on simulation software and also build the hardware model. Then, observe and record the gain, parameter of the reflectarray patch at a different angle of the hardware model. Lastly, the results of the hardware will compare with the simulation results.

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#### **ABSTRAK**

Antena stesen pangkalan adalah penting bagi kita pada era ini kerana tanpanya sistem rangkaian kita tidak dapat berfungsi dan ini bermaksud bahawa kita tidak dapat menghubungi orang yang kita sayangi dengan menggunakan telefon pintar dan kita juga tidak dapat melayari internet jika tidak ada antena stesen pangkalan. Oleh itu, rangkaian menjadi keperluan bagi kita tetapi tanpa bantuan antena, kita tidak dapat menghantar atau menerima maklumat. Oleh itu, projek ini akan membuat penyelidikan mengenai antena stesen pangkalan dengan 5G. Pertama, ada pengenalan mengenai antena stesen pangkalan, penyataan masalah, objektif, dan ruang lingkup projek ini akan disebutkan. Pada bahagian reka bentuk, mula-mula adalah merancang model patch reflectarray pada perisian simulasi dan juga membina model perkakasan. Kemudian, perhatikan dan catat keuntungan, parameter dari patch reflectarray pada sudut yang berbeza dari model perkakasan. Terakhir, hasil perkakasan akan dibandingkan dengan hasil simulasi.

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# LIST OF SYMBOLS

0	-	Degree
θ	-	Theta
φ	-	Phi
$\pm$	-	Plus, and minus
GHz	-	Giga Hertz
dB	-	decibel
mm	-	millimetre



# LIST OF ABBREVIATIONS

5 <i>G</i>	-	Fifth Generation
LTE	-	Long-term Evolution
MIMO	-	Multiple-Input Multiple-Output
RAT	-	Radio Access Technology
OFDM	-	Orthogonal Frequency-Division Multiplexing
OFDMA	-	Orthogonal Frequency-Division Multiplexing Access
FFT	-	Fast Fourier Transform
IFFT	-	Inverse Fast Fourier Transform
FDTD	-	Finite-Difference Time - Domain
MLFMM	-	Multilevel Fast Multipole Method



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#### **CHAPTER 1**

#### **INTRODUCTION**

#### 1.1 Background

Nowadays, mobile telecommunication is important for everyone in the world. It helps us to connect easily and shorten the distance between peoples. Now, mobile telco not only can let us use to call to someone and also can let us see to someone that we love or we miss face to face through a mobile phone or a camera. This can be done because of the discovery of the wave. The wave can carry energy and become a signal. The wave can bring the signal to any place that we want. Therefore, the scientist invented the antennas that is a tool that can transmit the wave from a place to a place which is far apart. When the signal was discovered by the scientist, it only can transmit the sound wave which is 1G and now we reached 5G successfully. 5G not only can transmit sound. It also can transmit pictures, video, files and this is the basic function of 5G. 5G also can help us in the research of the selfdriving car or control a mechanical arm that is used in an operation in another place. All of this can be done because 5G has low latency so what we see from the monitor is almost simultaneously on-site.

In this project, we will focus on how to use electronic control to control the angle of the antenna and see whether the angle will give an effect on the transmission rate from the antenna. Besides that, we also will talk about the 5G, base station, and the reflectarray in this project. We will talk about the 3 things because we will use three things to complete the project model and make it into a useable model.

As we know, we are getting into a 5G era worldwide and our country, Malaysia also will take part in this action to improve our country's internet speed until can compare with the developed country. But 5G still did not know very much by the public in our country, maybe they know 5G and used it every day but many of us do not know what is it. So, some explanations and an introduction about the 5G will be given in this project.

This project will focus on the electronic control and information system of the base station antennas. There has a review of other articles and research papers to understand more about the antennas and base station and also 5G that will become the main trend of the world in future. Next, we design the hardware of the base station and also have simulation on the CST Studio software. Then, we will compare the results that get on the hardware and the simulation and further discussion on both of them. Lastly, we conclude the project that we did and give some solutions to overcome the problems that we facing and will be face in the future.

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### **1.2 Problem Statement**

Base station antenna is a common thing and can see it everywhere nowadays. The antenna also one of the important things in the base station but the antenna have a lot of types of the patch. With the advancement of communication systems towards 5G and 6G, the antenna design requirements are also getting complex. Apart from high gain and efficiency, beam steering is one of the cruicial requirements of such antennas. Reflectarray antenna is one of the types that is suitable for these advanced applications where beam sttering can be done either electronically or mechanically. Mechanical beam steering is easier and more accurate for base stations. However, the angle of the reflectarray patch should not adjust manually and should adjust automatically for more accuracy. There has a lot of frequency can be chosen but there sure have a most suitable frequency range for this project. Therefore, we need to troubleshoot the frequency range. In this project, it will use the Arduino Uno as a microcontroller to control the angle of the reflectarray antenna automatically and the frequency range used is from 24 GHz to 28 GHz and the resonant frequency fix on 26 GHz. The performance parameters of the antenna will be displayed on a screen attached to the EKNIKAL MALAYSIA MEL system. The project will also cover some aspects of reflectarray antenna design and optimization based on simulations carried out using CST Microwave Studio.

#### **1.3 Project Objective**

The objectives of this project are:

- To design the basic mechanically beam steerable reflectarray antenna using CST Microwave Studio
- b) To develop an electronic control for smart 5G base station antennas.

c) To design an information display system attached with the antenna to display live performance parameters.

# 1.4 Scope of Project

The scope of this project are as follows:

- a) The frequency use is considered is 26 GHz because the frequency of the 5G is under the frequency from 24.25 GHz to 52.6 GHz. This frequency band is also known as FR-2\_which is for mmWave spectrum.
- b) The model of the dielectric holder will print by 3D printer to save the cost of this project. The ink for the 3D printer is affordable for a university student.
- c) Arduino Uno used as a microcontroller to control the tilt angle automatically. It is necessary to programmed the Arduino Uno in order to control the tilted angle.
- d) Computer Simulation Technologies (CST) Microwave Studio used as simulation software to simulate the designed reflectarray.

#### **CHAPTER 2**

#### LITERATURE REVIEW

#### 2.1 Introduction

Base station antenna is important for signal transmission. It can let the signal transmit to further distance and let more devices receive the information in the signal. Therefore, this chapter will review a lot of the previous articles and research papers. From the previous paper and article, it will give some new idea that related with the electronic control and information system about the base station antennas.

#### 2.2 Review and Analyze Previous Researcher's Paper

2.2.1 Antenna Design for 5G Communications

The paper focuses on the 26 GHz band and discusses several problems linked to the antenna design process for 5G communications. This journal, they designed few types of antenna for different applications such as an antenna for mobile phones and an antenna for base stations. They also talk about the 5G channel in this journal. They used different configurations of the array which is 4x4, 8x8, 16x16, and run in the FDTD and MLFMM solver. As they concluded, some requirement for 5G is still daunting but still can be understanding and explore innovative solutions by using the simulations that can be used today.[1]



Figure 2-1: Optimized gain of the 8 elements antenna array



Figure 2-2: Comparison various setups of array gain

	FDTD	(K80 GPU)	MLFMM (parallel 8x)		
	RAM Simulation		RAM (GB) /	Simulation	
	(GB)	time	process	time	
4x4 array	0.4	2.4 min	0.7	6 min	
8x8 array	1.3	11min	2.9	1.1 hrs	
16x16 array	4.9	1.5 hrs	11.6	8 hrs	

**Table 2-1:** Computational concern: Single port over the frequency band of FDTD simulation times are recorded; All ports of MFLMM times are recorded for single frequency.

### 2.2.2 Millimeter Wave Beam Steering Reflectarray Antenna Based on Mechanical Rotation of Array

The design and analysis of a bean steering reflectarray antenna is the subject of this journal. The antenna is designed for 26 GHz and is based on the array rotating mechanically. In this research, the researchers use 2 methods to compare the results. The first method takes the measured value of the scattering parameter from the reflectarray unit cell by experimenting with different angles while the second method is doing the simulation on the computer and take the simulated results. Besides that, few kinds of researches are done by them by using different reflectarrays. The first reflectarray is 20×20 Elements Reflectarray is used in the research and the results get by measurement is 26.45dB a slightly different from the simulation result which is 26.7dB in 26G Hz and the reflectarray was tilted to 20°, they also move the tilt in few different angles and get the different results of each angle. In the last of the journal, the beam steering reflectarray antenna is best suited for applications that require wide beam scanning but aren't concerned with scanning speed. [2]



Figure 2-3: Estimated and simulated scattering parameters of reflectarray unit cells



Figure 2-4: Setup of the radiation pattern in anechoic box



Figure 2-5: Stages of surface current distribution in different tilt angles

### 2.2.3 A Review of High Gain and High Efficiency Reflectarrays for 5G Communications

This journal gives a review about how to get the high gain and high efficiency reflectarrays in 5G communications designs. Some designs were scrutinised at the unit cell to entire reflectarray levels in order to improve the highlighted parameters of 5G compatibility as well as the reflectarray antenna's adaptability in the future. The journal is divided into 2 sections: high gain reflectarray design techniques and high efficiency reflectarray design approaches. The part high gain reflectarray design techniques also have a few sub-parts which are different elements with the high gain reflectarray operation, full reflectarray based techniques, and critical analysis. The authors discuss in very detail and

clear each sub-part. It is also the same as in the techniques for high efficiency reflectarrays. This part also has a few sub-parts and in every sub-part discussed every detail in how to improve the reflectarrays to get higher efficiency. In the last word, 5G communications have a high value of research in the future. In the future, research in areas such as cost, material qualities, power expenditure associated with high frequencies, and alternative types of reflectarrays could be conducted. All of the researches are to let the 5G has its cost-effective and less complex design and last is give benefit to all people who used it.[3]



Figure 2-6: Consolidation of three types elements in a reflectarray

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Element shape 📑	Design	Frequency (GHz)	Phase swing (°)	Aperture Size $(\lambda^2)$	f/D	Efficiency (%)
UNIVERS Hexagonal [63]		KNIK 12.5	AL MAL 360	AYSIA MI 69.4		KA 60
Bow-tie [64]	+	30	360	39	0.59	57
I-shaped [65]	((1))	13	360	75.7	2.35	50
Dual rings [66]	0	16	360	250	0.9	52.36
parallel dipoles [67]	III	9.5	360	180	0.83	65
Hollow ring [68]	$\ominus$	12	333	3318	0.7	66.13
Fragmented [69]		11.2	300	245.5	1.1	65.5
Fractal [70]	ŗ	10	700	54.5	0.33	66
Concentric rings [71]		13.5	500	207.6	0.75	66
Dual band [72]	(H)	20/30	360/300	784/1765	0.618	66.5/50

Table 2-2: Elite performance reflectarray antenna work with picked components

		Gain enhancement by					
Parameters		tor		Туре			
	Sub-reflec	eeding tac	Microstrip	Dielectric	Metallic		
Gain	Η	Ň	Ν	Н	Η		
Loss	N	N	Ν	L	L		
Complexity	Η	L	L	Н	Η		
High frequency compatibility	L	Ν	L	Η	Η		

 Table 2-3: Synopsis of the primary gain improvement ways (Symbols represent as H=high, N=neutral, L=low)

### <u>2.2.4</u> Design and characterization of millimeter wave planar reflectarray antenna for 5G communication systems

The design and characterization of a millimetre-wave reflectarray antenna based on unit cells as a periodic reflectarray design at 26 GHz are discussed in this article. The journal had separated into 6 parts. First part is the introduction which is introduced the research, 5G and the components that will be used in the research such as reflectarray also will be introduced in this part. The second portion goes over the fabrication methods for unit cell reflectarray elements as well as a few possible design configurations such as rectangle patch, rectangular ring, circular ring, and so on. For the third part, the scattering parameter measurements and comparisons between simulated and measured findings for unit cells with characterization based on 5G antenna requirements are covered in this section. In fourth part present the periodic 20x20 reflectarray antenna design and impact of the slanted array for attaining the  $\theta = 40^{\circ}$ ,  $\phi = 0$  focused beams with some simulated results. The fifth part focused at how to get periodic reflectarray and radiation pattern measurements, which had been compared to modelling findings. In the last part which is the sixth part, the authors conclude for their work. [4]



Figure 2-7: Patch design configuration that used to investigate at 26G Hz. (A) Rectangular, (B) Rectangular with rectangular slot, (C) Rectangular with circular slot, (D) Rectangular Ring, (E) Circular Ring, (F) Unit cell with Infinite Boundaries.

a shi	NALAYSIA HE			
Unit cell design	Reflection loss (RL) (dB)	20% Bandwidth (BW) (MHz)	Phase sensitivity (σ) (°/GHz)	Phase error (e) $(\phi^{\circ})$
Rect. Patch	1.02	560	122	80
Rect. Slot	1.45	420	160	47
Circ. Slot	1.36	455	157	48
Rect. Ring	4.89	200	263	10
Circ. Ring	3.86	225.	238	13

Table 2-4: Measure figure of merit for various reflectarray design setups



Figure 2-8: Radiation patterns of 3D measurement for copular and cross-polar components. (A) Circular ring elements reflectarray, (B) Rectangular patch elements reflectarray.

# 2.2.5 A Review of Wideband Reflectarray Antennas for 5G Communication Systems

The design and experimental aspects of a reflectarray antenna for bandwidth improvement in microwave and millimetre wave frequency scopes are reviewed in this article. In the first part, they introduced 4 types of reflectarrays that are generally used to compare the performance of each antenna. The 4 types of antennas are dielectric reflectarray, metallic reflectarray, waveguide reflectarray, and microstrip reflectarray. This research also talked about the antenna for 5G. Array antennas are a better antenna for short-range communication at the moment because they can compensate for the issue of route loss. 2D arrays with big electrical holes that can restrict beamwidth are required for 5G operations. Many alternative antennas are offered in the new for 5G operation, but the primary goal is to achieve a wide bandwidth to enable the 5G system's high throughput. The second part is talked about how to improve the reflectarray bandwidth. The first way to enhance the reflectarray bandwidth is to use single and multi-resonance elements. The purpose of this method is to achieve a full phase swing of 360° using single resonance elements, removing the phase error constraint and allowing for increased bandwidth. Not only are single resonance, two-resonance, and multi-resonance techniques discussed in the journal, but this approach is also utilised to stretch the reflection phase to many full cycles, hence improving the linear phase bandwidth. Aside from resonance elements, the journal also mentions elements with open-ended stubs and connected delay lines, dual-band design, and other novel approaches. [5]



Figure 2-9: Double layer reflectarray with Ka/X-band of operation



Figure 2-10: Types of Reflectarrays

Parameters	ingle element Multi morning alamants	Combination of elements	pen ended stubs	Aperture coupled	single layer	Aulti Layer
Bandwidth	N	Н	N	H	N	H
Loss	N	Η	N	L	Н	L
Complexity	Н	H	L	Н	N	H
High frequency compatibility	N	L	N	N	L	N

Table 2-5: Outline of the major bandwidth improvement techniques

(Symbols represent H = high, N = neutral, L = low).

2.2.6 Design of a Circularly Polarized Reconfigurable Reflectarray Using Micromotors

An X-band circularly polarised reconfigurable reflectarray antenna was built utilising concentric dual split rings and physically rotated using a micromotor in this journal. The goal is to achieve phase reconfigurability while minimising cross-polarization and element loss. The results show the circularly polarized element is very stable responses in different angles of incidence which is from 0° - 180°. Next, the authors simulated the 15x15 element reconfigurable reflectarray antenna and the result of the radiation performance get from the simulation is very satisfying to them with less than 1 dB gain loss at the maximum scan angle which is 38° and the usable range is over 50°. They came to the conclusion that the circularly polarised reconfigurable reflectarray component with the concentric dual split ring spin by the micromotor has high performance at 8.3 GHz with smooth phase shift, minor cross-polarization, and low loss while The 15x15 element reconfigurable reflectarray antenna, on the other hand, has a decent performance, with a maximum gain of 26.43 dB and

a 62.9 % efficiency.[6]



Figure 2-11: Proposed reconfigurable part with a micromotor.



Figure 2-12: Simulated (a) phase and (b) amplitude response



Figure 2-13: Imitated (a) designs, (b) gains and aperture efficiencies of the reflectarray with various sweep points.

2.2.7 Polarization Diversity and Adaptive Beamsteering for 5G Reflectarrays: A Review

The numerous basic and advanced design abilities for polarisation diversity and beam-steering in the reflectarrays antenna are covered in great detail in this work. The design configuration necessary for polarisation diversity and adaptive beam-steering for a 5G reflectarrays antenna will be discussed in this paper. There are three parts to it. The first section is the introduction which is introduced the components needed in this article and explained each of the components such as 5G, reflectarrays, beam-steering and *etc*, and the main point of this article. The second section discusses several dual linear and dual circular polarised reflectarray designs. Last section is about some techniques that had been selected to get adaptive beam-steering in reflectarrays. In section2, polarisation diversity is defined as a state of process in which a single reflectarray can be employed for more than one polarisation. Then in this section, has 2 part which is dual linear polarized designs and dual circular polarized designs. Unit cells with orthogonal matching forms are required for dual
linear polarised designs, which consist of horizontal polarisation (HP) and vertical polarisation (VP), and their closeness in direction allows them to reflect the same frequency signals.

The key architecture of the unit cell element of reflectarrays determines the circular polarisation of dual circular polarised designs. The unit cell element must be designed in a circularly identical direction and the circularly polarised signals are reflected. The major goal of beam-steering is to achieve a large coverage area, which can be accomplished by increasing the number of main beams on a single reflectarray antenna, as discussed in the last section. They recommended the few materials of the reflectarrays which can be replaced for better beam-steering. The materials are electronically tuneable materials which are liquid crystals, ferroelectrics, and graphene for better beam-steering. Besides replacing the materials, components also can be replaced which is replace by the lumped components in the reflectarrays. The lumped components are PIN diodes, varactor diodes, and Radio Frequency Micro-Electromechanical Switches (RF-MEMS). In the end, the devise complexity is always a problem for millimetre wave beam-steering reflectarrays and it is always open doors for more possibilities in this field. [7]



Figure 2-14: Dual linear polarization consisting of different designs of unit cell elements.



**Figure 2-15:** (a) Graphene based reflectarray patch component (b) dynamic reflection stage scope of Graphene based patch component.

Parameters	Tunable Materials			Lumped Components		
WALAYSIA 40	Liquid Crystal	Ferroelectric	Graphene	PIN	Varactor	RF-MEMS
Beam Control	С	С	С	D	С	D
Biasing	Α	Α	Α	D	Α	D
Loss	Η	N	L	L	L	Η
Complexity	Ν	N	Н	H	Η	Η
High frequency compatibility	N	L	H	N	Ν	L

**Table 2-6:** Synopsis of adaptive beamsteering skill (Symbols represent as C = Continuous, A = Analog, D = Discrete/Digital, H = High, N = Neutral and L = Low)

# 2.2.8 An introduction to LTE Smart Base Station Antennas

Principles of phased antenna arrays, Beam steering using switched beam antennas, Beamforming with adaptive array antennas, and Precoding and Eigen beamforming systems are some of the technologies covered in this paper. The first section of Principles of Phased Antenna Arrays discusses phased array antennas, which use phase control at the radiating element to allow the beam to be scanned in space at various angles. In design the antennas, the antenna array patterns are one of the elements that give the effect to the antennas, so some designs had combines two types antennas, wire and aperture elements and can be manufactured on printed circuit boards or microstrips patches. The array factor patterns are spacing, phase shifts, and amplitude change between the elements. The next type of antenna is a switched beam antenna, which consists of an antenna array plus a basic beamforming network capable of creating numerous separate fixed beam directions. It selects the best beam dynamically for spatial selectivity based on channel conditions.

Butler matrix and Luneburg lens are two popular switched beam antenna devices. The Butler matrix is characterized by Jess Butler and Ralph Lowe in 1961 and its use in hybrid combiners and phase shifters. Rudolf Karl Luneburg of Dartmouth College recommended the Luneburg lens in 1944. Electromagnetic radiations, ranging from visible light to radio waves, can all be captured by the lens. The lens's variable refractive indices adjust and guide radiated waves from its surface in a specific direction, and the direction of the antenna beam can be evaluated by moving the radiating component around the lens's circle. Next is adaptive array antennas (AAA), the component key of AAA is planar arrays. The Planar array is a two-dimensional rectangular array that enables horizontal and vertical beam steering. Column pattern and mutual coupling, scanning angle constraints, radiating patterns, and the calibration port are all aspects that will affect the array. LTE permits various beamforming effects originating from channel precoding, and this effect is known as Eigen beamforming, according to this paper. Massive MIMO is a key technology for the 5G performance target. Massive MIMO allows for thinner, more concentrated, and highly directed beams, improving spectrum and energy efficiencies and promoting higher limitation. In conclusion, excessive transmitters and radiating antennas in monster arrays will be used in huge and full-dimension MIMO. [8]

Smart Antennas possess "Super Powers" to dynamically adjust their main beams and nulls directions



Figure 2-16: Beams and Nulls Steering



Figure 2-17: RF Path and radiation illustration of a four port Butter matrix antenna



Figure 2-18: Spectral capability improvements with facilitated MC-BF and diverged with 2x2 MIMO

## 2.2.9 Development of a Pin Diode-Based Beam-Switching Single-Layer Reflectarray Antenna

The design and testing of switchable reflectarrays for beam shaping with optimal reflection loss and increased bandwidth execution are discussed in this work. There has 2 majors' part in this paper which is Frequency Switchable Reflectarray Unit Cells and Switchable Periodic Reflectarray Design. The rectangular slot embedded patch components are designed, configured, and analysed in the part of the frequency switchable reflectarray unit cells, and they also design an electronic switching of a PIN diode-based devise. The PIN diode they use in the PIN diode-based design is Ga AS MA4GP907 PIN diode with 0.025pF of series capacitance and 4.2 low series resistance. The results they observed are maximum frequency tunability is 0.36G Hz and a dynamic stage scope of 226° were exhibited by the PIN diode-based unit cell estimations and the results they get are similar to the results in the simulation. In the switchable periodic reflectarray design part, they developed a mathematical model and applied it in the plan of the periodic arrays and play out the farfield measurements and they separate it into 2 sections to give more explanation about the procedure and result in details. The 2 sections of the second part are "Mathematical Modelling for the Periodic Reflectarray Design" and "Array Design and Far-Field Measurement". In conclusion, PIN diodes on the space and hole embedded resonant patch elements of reflectarrays can be used to plan switchable reflectarrays for beam shaping realisation. Beam switching can be utilized in a few utilizations, for example, the Earth observatory system. [9]



 Table 2-7: Correlation between simulated and measured acquire values.



**Figure 2-20:** Manufactured 6x6 component active array, biasing circuit and complete far-field plan for a useful reflectarray antenna.

## 2.2.10 Aspects of Efficiency Enhancement in Reflectarrays with Analytical Investigation and Accurate Measurement

This paper represents an audit of methods involved in the improvement effectiveness execution of the reflectarray antenna and it has 7 major sections in this paper. The first major section is the introduction which introduced the basic architecture of reflectarray antenna and a counterbalance feed square patch microstrip reflectarray. The second section which is Loss Quantification of Reflectarray Antenna, the origins of all possible disasters in reflectarray antennas are discussed, as well as their impact on efficiency execution. Next is the third section, this part is about the Background of the Common Techniques of Efficiency Improvement in Reflectarrays which is clarifying some regular proficiency improvement techniques in reflectarrays. This section has 4 parts, for the first part is Elements with Low Loss and Wide Reflection Phase Range, the second part is Sub-Wavelength Elements for Loss Reduction. The third part is Strategic Feeding Mechanism for Aperture Loss Reduction and the last part is Some Advanced Types of Reflectarray. In the fourth section, the main idea of this section is the Factors Affecting the Aperture Efficiency of the Circular Aperture Reflectarray Antenna this means the other factors have analysed the misfortunes that influence the reflectarray antenna efficiency. This section also has 3 part which is Effects of Different Feeds on the Aperture Efficiency, The Effect of Different Feed Distances on the Aperture Efficiency, and The Effects of the Feed Footprint on the Aperture Efficiency.

The fifth section is Aperture Efficiency of the Square Aperture Reflectarray Antenna. In this section, the efficacy expectation of the square gap reflectarray has been derived using a new mathematical formulation, and the results are compared to those of the circular gap reflectarray., and the outcomes are contrasted with the circular gap reflectarray. There are 3 parts in this section are Aperture Efficiency of the Conventional Square Aperture, Aperture Efficiency of the Square Aperture in a Diamond Shape, and Aperture Efficiency Comparison between Circular and Square Aperture Reflectarrays. The sixth section is A Practical Method to Accurately Predict and Measure the Efficiency of a Reflectarray Antenna which mean that the radiation design estimations square and circular opening microstrip reflectarray functioning at 26 GHz frequency are used to provide a practical technique for accurately anticipating and estimating the effective execution of a reflectarray antenna. This section has 3 parts which are Design and Analysis of the Pyramidal Horn Feed, Design Characteristics of the Unit Cell Patch Element and Design and Validation of the Circular, and Square Aperture Reflectarrays. The last section is the conclusion made by the authors. In conclusion, the paper's approach of testing and improving competency can be applied to any shape and type of reflectarray antenna. [10]

Element Type	Design	Loss (dB)	Phase Range (°)	Aperture Size (λ <sup>2</sup> )	Efficiency (%)
Hexagonal [42]	60	N.A	360	69.4	60
Bow-tie [22,43]	÷	-0.4	360	39	57
I-Shaped [20]	(00)	N.A	360	75.7	50
Dual Rings [44]	$\bigcirc$	N.A	360	250	52
Parallel Dipoles [45]	ψ	-0.2	360	180	65
Two Rings and Patch [46]		N.A	360	130	64
Three Rings [23]		N.A	500	163	66
Split Ring [47]	00	-0.3	360	187	55
Fractal [48]	KOY.	-0.45	700	54.5	66
Ring with Phase Delay Lines [49]	Q	-0.05	460	78	57.3

N.A = not available.





Figure 2-21: Sub-wavelength dividing in reflectarrays:- (a) expansion in number of component of elements in view of sub-wavelength dispersing, (b) sub-wavelength components with rakish pivot for circular

po	larıza	tion.	

Turna of Loss	Circular	Aperture	Square Aperture		
Type of Loss	Simulated	Measured	Simulated	Measured	
Feed (dB)	-0.1	-0.36	-0.1	-0.36	
Patch (dB)	-0.7	-0.84	-0.7	-0.84	
Illumination (dB)	-0.91	-1.19	-1.96	-2.21	
Spillover (dB)	-1.3	-0.41	-1.3	-0.41	
Total (dB)	-3.01	-2.8	-4.06	-3.82	
Total Efficiency	50%	52.5%	39.3%	41.5%	

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Table 2-9: Measurement of the loss performance for the chose reflectarray aperture at 26 GHz

# 2.2.11 Study on the Effect of Inset Feed Length on Radiation Characteristics of Rectangular Microstrip Patch Antenna

This paper discussed the effect due to changing the length of microstrip inset feed lines on return loss, gain, and directivity. This paper analysed a limited array of microstrip patch antennas with numerous, stacked layers without causing an increment in the trouble or intricacy. In the design specifications, they designed 2 types of patch antennas and used the CST Studio 2012 to do the simulation and analyse the results that get from the simulation, and have a further discussion about the results. The 2 types of patch antennas are single patch antenna and 1\*2 rectangular patch array antennas. In conclusion, the 1\*2 array antenna had a significant improvement in the MSA antenna gain, directivity, and efficiency.

[11]



Figure 2-22: CST Studio single patch microstrip antenna geometry



Figure 2-23: CST Studio 1x2 patch microstrip antenna geometry

Parameter	Design 2	Design 1
Resonant frequency (fr)	3.5 GHz	3.5 GHz
Retum loss (RL)	-33.70	-30.44
Bandwidth(B.W.)	94 MHz	70 MHz
Gain (G)	7.9 dB	5.3 dB
Directivity (D)	8.4 dBi	6.6 dBi
Efficiency (E)	94.04%	80.30%

**Table 2-10:** Comparison Table between the 2 deigns

2.2.12 A Broadband High-Efficiency Reconfigurable Reflectarray Antenna Using Mechanically Rotational Elements

A circularly polarised reconfigurable reflectarray antenna (RRA) was proposed in this journal for the X band. Here, The RRA utilised is a concentric dual split-ring RRA that can be precisely turned to achieve a constant 360°. The first section which is the introduction introduced the RRA which is a mix of the reflector and staged arrays and can accomplish adaptable radiation execution by controlling phase responses of individual components electronically or mechanically controlled. The second section is discussed about the RRA component and its stage and amplitude reactions. The results get in this section are satisfied to stage and sufficiency reaction with low reflection misfortune in wide frequency band by using the proposed RRA element. The third section is 15x15 manually rotated RRA prototype. The RRA prototype with a 15x15 manually rotated components is planned and created, the purpose is to confirm the exhibition of the proposed component plan. The outcomes show brilliant bandwidth execution with monotonically expanding gain in the band of interest. The next section is dynamic radiation execution of examined and shaped beams and it is divided into 2 parts for more experimental demonstration and the results. The 2 parts are the big angle of scanning beam performance and shaped beam synthesis. The fifth part deals with the design and estimates of a 756-element micromotor-controlled RRA. This section also has 2 part which is fabrication process of the RRA prototype and measurements of the RRA prototype. At the end of this part, the proposed elements can get less element amplitude loss and better stage resolution. Besides that, with the proposed RRA models, high acquisition radiations can be achieved with minimal quantization loss. The conclusion made is all the outcomes get in each part can approve well about the proposed plan and it is a down-to-earth acknowledgment for reconfigurable high-gain antenna applications. [12]



Figure 2-24: Created RRA model with 15x15 physically pivoted elements



**Figure 2-25:** Created micromotor-controlled RRA model with 756 elements. Left: RRA model; Upper right: control circuit board; Lower right: micromotor-controlled RRA components.



Figure 2-26: Measured (a) co- and (b) cross-polar parts of the communicated field in UV plane for the beam focused in the specular reflection bearing.

#### 2.2.13 Resonant Elements for Tunable Reflectarray Antenna Design

In this paper, the researchers had analysed accurately various setups of reflectarray resonant elements that can be utilized in the plan of passive and tuneable reflectarrays. By using the Finite Integral Method, the reflectarrays element's reflection loss and bandwidth exhibitions were investigated in the X-band frequency range, and the results were verified using waveguide scattering parameter measurements. The reflectarray element based on a rectangular patch with a circular slot is proposed in this paper. The outputs of reflection

misfortunes and bandwidth exhibitions of X-band elements are obtained by models and experiments.

The second section of this paper is the proposed reflectarray configuration and there have 2 parts in this section. The two parts are performance in terms of reflection loss and phase range. The gains in this part are achieved by utilizing variable-sweep slots in the patch element, so that while the attainable static direct stage range expands, the phase error commitment in the lowering of reflectarray bandwidth can be reduced by using the proposed slotted arrangement. Construct a tunable reflectarray antenna using PIN diodes in the next part. The shown outcomes suggest that the proposed opening setup with PIN diodes can successfully be used in the manufacture of tunable reflectarray antennas. In the last of this paper, the dynamic stage can be utilized to develop electronically controllable reflectarrays with reformist stage distribution using slots and PIN diodes, as demonstrated by the integration of slots and PIN diodes. [13]



Figure 2-27: Surface current circulation on (a) rectangular patch of reflectarray and (b) reflectarray rectangular patch component with open circular in the middle.



Figure 2-28: Manufactured unit cells rectangular patch elements implanted with various circular slots.

Desenant alament	D. d. d	]	Volume reduction		
Resonant element	Reflection loss (dB)	$f_o (GHz)$		Simulated (degrees)	at 10 GHz (%)
Rectangular patch	1.50	_	_	_	_
Circular slot ( $R = 1.5 \text{ mm}$ )	1.75	9.75	104	110	5.24
Circular slot ( $R = 2.0 \text{ mm}$ )	YS1 2.20	9.45	290	298	9.19
Circular slot ( $R = 2.5 \text{ mm}$ )	2.50	9.25	310	314	15.76
Circular slot ( $R = 3.0 \text{ mm}$ )	2.65	9.10	320	323	22.15

 Table 2-11: Execution correlation for various resonant components of reflectarray.

2.2.14 Design of a 28/38 GHz Dual-Band Printed Slot Antenna for the Future 5G Mobile Communication Networks

> This author recommends a dual-band printed slot antenna for future fifth-UNIVERSITITEKNIKAL MALAYSIA MELAKA

generation (5G) mobile communication networks, and the design of the dual-band printed opening antenna is 28/38 GHz dual-band printed opening antenna. They also mentioned the dimension that is used in the prototype antenna which is  $W \times L = 8 \times 7.5 \text{ mm}^2$  and the material used is RogerRT5880 of 0.127 mm thickness with the dielectric constant = 2.2 and loss tangent is 0.0009. The simulations of the proposed antenna are simulated by utilizing HFSS and Computer Simulation Technology (CST) Microwave Studio. The results show that the antenna is exhibited by omnidirectional examples, and that in the scored-frequency band of almost 31 GHz, there is a dramatic decrease in the antenna gain. To avoid interference between the 5G framework and other applications, an L-shaped area is scratched out in the feed line, resulting in a 30-35 GHz indentation. According to the conclusion of the article,

the proposed dual-band antennas have gained up to 7dBi with a serious decline in the scoredfrequency band of about 31 GHz.[14]



Figure 2-29: Calculation and measurements of the proposed dual-band 5G antenna, (a) 3D view,

(b) top and base perspectives.



Figure 2-30: CST Simulated Radiation examples of proposed double-band 5G antenna at (a) 28 GHz, (b) 38 GHz



Figure 2-31: Maximum acknowledged addition and total productivity of proposed dual-band 5G antenna.

### 2.2.15 Design and Analysis of a Low-Profile 28 GHz Beam Steering Antenna Solution for Future 5G Cellular Applications

This paper is the first-of-the-kind solution about the 28 GHz for the forthcoming 5G cellular communication is introduced exhaustively. This paper exhibits a low-profile 28 GHz staged array antenna reasonable for future 5G cellular handset gadgets. In section 2, it is the conceptual design and the 28 GHz antenna's outline is based on a few important parameters. In the last of this section, there proposed joining the exhibit along with the edge locales of the cell handset because of moderately irregular cooperation with the client's hand. Through the different positions and the angle of the handset, the array arrangement is profoundly compelling in covering the 5G cellular handset by the circular beam inclusion. The third section of the paper is the 28 GHz network matrix antenna array. It is about the geography of the lattice framework patch antenna, which incorporates a fan beam trademark that is appropriate for the discussed application. The next section is simulation and measurements which means that the mimicked and estimated parameters of the 28 GHz antenna solution will be discussed and depicted in this document. The finished RSSI map is contrasted and analysed with the current 4G LTE cellular framework in this current segment's outcome and it is simulated through the omnidirectional TX and RX radiation designs. From the correlation with the 4G LTE, due to the use of high addition, beam guiding antennas at 28 GHz, a generally limited difference in RSSI levels. In conclusion, since this is a new kind of design for 5G cellular handset devices at 28 GHz antenna, the arrangement is examined and analysed. Scarcely any specialized difficulties stay for the future work and this paper fills in as a rule for what's to come. [15]



Figure 2-32: Situation design of the 28 GHz antenna array inside the edge districts of the 5G cellular handset and its ideal inclusion.



Figure 2-33: 28 GHz network framework patch antenna geography. (a) Top view, (b) Side view,

(c) Phased-exhibit configuration



**Figure 2-34:** Simulated indoor RSSI levels for 4G LTE and 28 GHz 5G utilizing the proposed antenna geography. (a) 4G LTE, (b) 28 GHz 5G framework. Transmit Power indistinguishable.

#### 2.2.16 Five Disruptive Technology Directions for 5G

This article described 5 advancements that could prompt both compositional and segment problematic plan changes: device-centric architectures, millimetre wave, massive MIMO, smarter devices, and native support for machine-to-machine (M2M) communications. There classify 4 effects of new technologies when 5G cellular network is coming and the impacts are minor adjustments at both the hub and building levels, problematic alterations in the plan of a class of organization hubs, troublesome changes in the framework design, and troublesome changes that affect both the hub and structural levels. These impacts had given the potentially disruptive changes to the technologies on the design changes of the architectural and component. There have 5 potential disruptive change that could change the design of the architecture and component is device-centric architectures, millimetre wave (mmWave), massive MIMO, smarter devices, and native support for machine-to-machine (M2M) communications. In the device-centric architectures, there have 6 points highlighting the interruption of the design, and the focuses are base station thickness is increased rapidly, determined by the ascent of heterogeneous organizations, the requirement for expansion range leads to the concurrence of recurrence groups with

drastically unique engendering qualities within a similar framework, another idea named incorporated baseband which is identified with the idea of cloud radio access networks is arising, arising service classes, cooperative communication paradigms, utilization of more astute gadgets could affect the radio access organization.

The millimetre wave communication, there give 2 different ways to access more microwave range, and the ways have repurposed the spectrum and share the range using for example intellectual radio techniques. At the last of this part, mmWave requires extreme changes in the framework as it gives a solid effect on the both segment and engineering plan. The third part is massive MIMO and this could be referred to as "Large-Scale MIMO"/ "Large-Scale Antenna System". Massive MIMO is a kind of multiuser MIMO in which the number of antennas at the base station far outnumbers the number of devices per signalling resource. As we know, appropriation of massive MIMO for 5G could show a significant jump with the regard to the present cutting edge in the framework and part plan. Therefore, to legitimize its massive MIMO requires more research and development to overcome the challenges. that will face in the future and emphasized the things that mention above, and show realistic performance improvements. In the fourth section, smarter devices have discussed a portion of the potential outcomes that can be released by permitting the gadgets to assume more dynamic parts and how to plan the devices with a 5G design to increase the device smartness. Here are 3 distinct instances of innovations that could fuse into the smarter devices, and the examples is D2D, local caching and advanced interference rejection.

Last is the ramifications of more intelligent gadgets at a segment level is analysed and encourage the researchers about this direction can go further until the smarter devices have all the attribute of a troublesome innovation for 5G. The last section is native support for M2M communication, there have 3 points in this section to give more explanation and examples. The points are an enormous number of associated gadgets, high connection dependability, low latency, and ongoing activity. To conclude this section, the local help of M2M in 5G requires a huge change at the hub and the engineering levels. Therefore, research work should keep working until the solution is concrete and interworking. In the conclusion of this paper, the 5 disruptive research direction can prompt the major changes in the designing of cellular organizations. [16]



Figure 2-35: 5 disruptive heading for 5G considered in this article, characterized dependent on Henderson-



Figure 2-36: Illustration of the device-centric design.



Figure 2-37: Working areas as far as information rate vs. size of the population.

#### 2.2.17 Circularly Polarized Patch Antenna for Future 5G Mobile Phones

In this paper, a circularly polarised patch antenna for future fifth-generation (5G) cell phones was presented. There have 2 main areas to be discussed which are the miniaturization and beamwidth enhancement for a patch antenna. The goal of this work is to create a handheld CP patch antenna with a wide beamwidth and a high increase at low height plots for future 5G portable satellite communications. Besides that, the related parameter is done and studied on this angle to give more helpful data about the beamwidth upgrade methods applied to the proposed antenna. There have 3 main points about the design procedure is proposed to the antenna and the 3 points are antenna configuration, antenna performance and antenna design process and parametric studies. The first point antenna configuration shows the dimension used by the substrate and the patch and the material and the techniques used in the microstrip line. At the end of the section, the detailed antenna dimension is given. The second section is the antenna execution. Every simulation and results on the antenna are performed by business EM software called HFSS ver.12. The exhibition of the antenna can be seen through the VSWR, gain, axial ratio, and radiation design. The results of the VSWR, it measured by Agilent E5071C Network Analyzer while the others are measured by Satimo StarLab System.

The third section is the technique of antenna design and parametric investigations and has 2 parts in this section which are minimization and beamwidth enhancement. In the minimization part, mentioned 2 techniques to diminish the size of the antenna. The first technique is collapsing the radiating patch and it is a typical method to decrease the size. The principle behind this technique is that the antenna's feasible current path may be enlarged by collapsing the patch, and the patch's resonance can then be pushed down to a smaller frequency. The second technique is used the dielectric substrate. In the high dielectric substrate, although the antenna's size can be reduced, the bandwidth will be limited by the substrate beneath the patch. In the second part, two beamwidth enhancement techniques are used in the antenna. The techniques include encircling the radiating patch with a dielectric substrate and adding a metallic block to the antenna's back. There proposed 2 methods to investigate deeply the effect on the antenna. The first technique is to modify the thickness of the dielectric substrate that surrounds it. The dielectric substrate thickness that surrounds it is selected in 0mm, 1.5mm, 3mm, 4.5mm, and 6mm.

There can be presumed that the half force beamwidth doesn't increment persistently when the thickness is 4.5mm or more. The second technique involves changing the metallic block's stature and determining the relationship between the metallic block's height and the gain at low elevation angles owing to the half force beamwidth. The height of the metallic block is 0mm, 5mm, 10mm, 15mm, and 20mm. At the end of this part, it was suggested that the metallic block and dielectric substrate be used together to provide the antenna's projected optimum beamwidth. The findings demonstrate that a circularly polarised patch antenna may be utilised in 5G mobile phones for satellite communication applications. [17]



Figure 2-38: Model of the proposed antenna. (a) Top View (b) Base View



**Figure 2-39:** Various patch shape (a) circular patch (b) collapsed patch (c) collapsed patch with 4 spaces (d) collapsed patch with 8 spaces.

	Gain at	Frequency	AR Banduridth	3dB Boommidth	Patch	Length (Jonath)
	dBic	GHz	Bandwidth %	o	mm	λ.
Proposed antenna	5	3.77	3.05	124	22 (30)	0.276
Ref [7]	-0.6	1.575	0.76	132	46.5 (150)	0.25
Ref [8]	3.94	2.33	1.61	101	28 (28)	0.218
Ref [9]	6.5	2.33	1.07	<80	23 (30)	0.18
Ref [10]	6	1.525	0.65	83	66.62 (70)	0.34
Ref [11]	•	2.295	1.3	<90	33 (35)	0.25
Ref [12]	•	1.768	0.91	<90	48 (>50)	0.28
Ref [13]	•	2.306	0.41	80	40 (140)	0.31
Ref [14]	4.59	2.492	0.38	90	29 (45)	0.24
Ref [15]	4.7	1.114	1.53	100	30.5 (90)	0.11
Ref [16]	7.5	2.28	3.5	75	30 (90)	0.23
Ref [17]	2.5	1.07	1.6	96.4	19.6 (100)	0.18
Ref [18]	3.8	2.492	0.682	<85	11.35 (21)	0.1

Table 2-12: Execution of the proposed antenna and some leaving little-size antenna

2.2.18 Wideband-Reconfigurable Reflectarrays based on Rotating Loaded Split Rings

This paper is about the reflective periodic arrays with turning spiral phase-type elements dependent on the stacked split ring and the reflectarray component pivoted by utilizing the mini motors is investigated and examined. Then, at that point to examine the properties of the speed of electromechanical incitation, the mini motor-driven antenna components have been planned, manufactured, and tried in the X-band and the detailed to the utilization of the rotational instrument for the antenna components. The RRA, which is based on pivoting split-ring components and receptive stacking split rings, allows for more plan flexibility and the creation of arrays that can be changed across a broad frequency range. In the second of this paper which is the principle of operation, the proposed RRA comprises an intermittent array with stacked split-ring components and put on the hubs of the symmetrical three-sided grid with a period. The results are a planar stage formed front in the reflected CPW with the presence of a linear phase taper. Therefore, the wave can be reflected in an ideal bearing. The full-wave model is constructed and evaluated the reflection characteristics of the RRA in the following part, and it tends to upgrade the array parameters in the wide frequency range.

The fourth section is the Ka-band reconfigurable reflectarray. The math of the reflectarray as mentioned is dictated by advancing the same circuits. The parameter of equivalent circuits is optimized and afterward changed over into the mathematical boundaries of the array. The conversion of the equivalent circuits to the geometrical parameter is based on the mathematical model. In the fifth section is the experimental result. Due to some intricacy reasons, only have 2 reflective periodic surfaces (RPS) with frozen components success to created and tried and can be approved by the numerical model. The sixth section is the mini motor-driven antenna elements and it is analysed the turn of X-band RRA elements by utilizing the mini motors. The stepper motor used is AM0820 from MICROMOTM based on the PRECIstep in the mechanical parts and it is the technology with high dependability and high point exactness that appropriate for cutting edge situating applications such as in the clinical field, aeronautics field, and aviation field. In the conclusion of the paper, the measurement and simulation show a good result and the mini motor-driven antenna components exhibited the exchanging times is under 45ms in an open circle design. [18]



Figure 2-40: (a) Reflectarray dependent on pivoting loaded split rings (b) calculation of the split ring.



Figure 2-41: Identical circuit models for the dissipating of (a) v-polarized wave and (b) u-polarized wave.



Figure 2-42: (a) Minimotor-driven component, (b) transient portrayal arrangement.

2.2.19 A Novel Asymmetric Patch Reflectarray Antenna with Ground Ring Slots for 5G Communication Systems

The full-wave model is constructed and evaluated the reflection characteristics of the RRA in the following part, and it tends to upgrade the array parameters in the wide frequency range. The patch was developed by carefully shifting one vertical side to an enhanced tendency point, resulting in a square patch. The main purpose of this research paper is without utilizing any double patch or double-layer structure, to make a unit cell component for a reflectarray that has a twofold resonance reaction. The second section is the asymmetric patch unit cell element. In this section, the patch is created from a square patch element as the essential construction. The material used is low loss Rogers Rt/D 5880 and the dielectric constant is 2.2, thickness is 0.254mm and the length is 5.77mm at 26 GHz resonant

frequency. The materials act as the grounded asymmetric patch element in other means is the substrate of the antenna. There modified the asymmetric patch element with a round ring slot in the ground and the optimized parameter is taken and summed up. The first part of the second section is imbalance and cross-polarization. The dissymmetric patch component had a slanted side and an upward side. The vertical side polarized incident electric field (Ei) generated a diagonally flowing surface current (J). The effect of strong cross-polarization is reduced by reflecting component direction on the reflectarray surface. The second part of the section is the asymmetric patch element's experimental results. The experimental results are verified the embedded ground ring slots of asymmetric patch unit cell elements by using the scattering parameter measurements.

The third section is the reflectarray of asymmetric patch elements and the elements should have been plan appropriately with precisely progressive stage dissemination to get the legitimate collimation of the reflected signs. To demonstrate the consistency of the radiation patterns, the E-plane diagrams for reflect components direction at various frequencies are measured. These consequences of the patch reflectarray antenna had been taken through in an upward direction energized occurrence electric field. The asymmetric patch reflectarray antenna shows the polarization variety in its operation and offers a decent presentation on the vertical and level polarization. The fourth section is Receive signal strength (RSS) measurement. Not only have RSS measurement and also have RSQ which means is received signal quality. Both the RSS and RSQ are used to determine the chances of cell selection and handover. An indoor base station was tested with the asymmetric patch reflectarray antenna and it is measured the receive signal strength at a different distance. There used a standard 20 dB horn antenna as a receiver (Rx) and the distance between the transmitter (Tx) and Rx is set from 1m to 16m with a fixed stature of 2m. Anritsu MG 3694C is used as a signal generator before the Tx antenna and sign finder, Anritsu MS2720T is

associated with the Rx antenna. The aim is to look at how a reflectarray antenna improves RSS for indoor microcell regions.

The fifth section is a comparison of the unbalanced patch reflectarray antenna with other related work. Here, the topsy-turvy patch reflectarray elements are compared with others projects such as dual-band, dual-layer, and equivalent aperture square patch reflectarray antenna. The asymmetric patch reflectarray antenna in this work had a superior execution with a low intricacy configuration contrasted with the other related work that distributed. In conclusion, the reflection stage scope of the asymmetric patch reflectarray unit cell component had beyond the conventional range which is 360°. The reflection phase span can reach 650° with the unbalanced patch ground inserted opened circular ring. By using the asymmetric patch elements, the bandwidth execution of the reflectarray antenna can be enhanced and also supported the high-acquire activity with double linear polarization. Lastly, the designed reflectarray is suitable for 5G communications because it has extensive bandwidth, a straightforward plan, high addition, and double linear polarization operation at high frequency. [19]



**Figure 2-43:** (a) Development of unbalanced patch component from a square patch component; (b) Opened Ground ring; (c) Alignment of the unbalanced patch with opened ground ring.

Parameter	Value or Characteristic
Tx Power	23 dBm
Carrier Frequency	26 GHz
Tx Antenna	Reflectarray (This Work)
Rx Antenna	20 dB Standard Horn
Tx/Rx Height	2 m
Tx Polarization	Dual Linear
Distance	1 m to 16 m
Tx Antenna Beamwidth	6°
Rx Antenna Beamwidth	$14^{\circ}$

 Table 2-13: Attributes of RSS estimation arrangement.

Parameter	This Work	[35]	[4]	[36]	[19]	[37]	[38]
Technique	Asymmetric Patch	Dual band	-	Dual band	-	Transmitarray	Full Metallic
Frequency (GHz)	26	27/32	26	28/38	26	60	26
Patches in Unit Cell	141	4	1	4	1	4	1
Phase Span (°)	650	340/325	340	320/320	360	270	180
Array Elements	332	15×15	$20 \times 20$	$15 \times 15$	$20 \times 20$	$30 \times 30$	$14 \times 14$
Array Size (X2)	78.5	52.3/73	100	56.2/103	100	243.3	36.8
Gain (dB)	24.4	22.9/25.7	26.4	21/25.2	26.41	30.1	18.9
Max. Aperture Efficiency (%)	28	29/38	34		34	32.3	97.7 (Simulated)
Polarization	Dual Linear	Dual Linear	Single	Single	Single	Single	Single
Complexity	Low	Moderate	Low	Moderate	Low	High	High
1 dB Gain Bandwidth (%)	6.1	2.4/2.4	13.6	3.4/3.9	13.1	8.2	20 (1.5 dB) 4 (1 dB)
RSS Measurement	Yes	No	No	No	No	No	No

Table 2-14: Execution examination of unbalanced patch reflectarray antenna with other related works.

# 2.2.20 UNIVERSITI TEKNIKAL MALAYSIA MELAKA What Will 5G Be?

This paper discussed the topics which are identified the main challenges for future research and standardise 5G preliminary. Other than that, a comprehensive overview and the special issues in the paper are provided. At the beginning of this paper, the view is given to 3 main points of the 5G technologies which are ultra-densification, mmWave, and massive multiple-input multiple-output (MIMO). Then there will continue to discuss the important and concerning issues such as the fundamental transmission waveform, expanded virtualization of the network framework, and the needed to increase energy efficiency. Last will be given the discussion about the regulatory and standardization issues for the 5G and the innovation in the spectrum regulation and all of this is in the

introduction section (Section 1), part A. Next is the part B of this section, here will talked about the requirement for 5G. The first requirement is the data rate and it is needed to support the mobile data traffic. There have few ways to measure the data rate and can be the target to the 5G. The ways to measure the data rate are aggregate data, edge rate, and peak rate. Besides that, the requirement for the 5G is the latency. The latency of the 5G ought to have the option to help a roundtrip latency is around 1 ms. The third requirement is energy and cost, both of them should be no increase on a per-link basis and ideally is decrease. In part C of section 1 is the device types and quantities.

The second section is the key technologies to the 1000× data rate and there have 3 categories in the section. The first category is outrageous densification and offloading, it is to improve the region phantom proficiency. The most straightforward but extremely viable path is to build the organization limit it causes the cells to decrease. But when the densification increased, it will face some challenges. The challenges are base station densification gains, multi-RAT affiliation, portability backing, and cost. The second category is millimetre wave. There only have an obstacle that needs to overcome and it is the propagation issues. To overcome this issue, the solution is having a large array but narrow beams, utilizing the inheritance 4G network and a huge number of handset designs required. The third category is massive MIMO. The massive MIMO presents few special issues and the issues are pilot pollution and overhead decrease, design difficulties, full-measurement MIMO and height beamform, channel models, conjunction with little cells and, mmWave.

The third section is the design issues for 5G and there is important research to give support on this requirement. First part is the waveform: signalling and multiple access. The first point of this part is OFDM and OFDMA is the default approach because it is a normal approach to adapt to the chose frequency, proficient execution through FFT/ IFFT blocks and basic frequency-domain equalizers, incredible matching for MIMO. The second point is the drawbacks of OFDM. The disadvantages are the peak-to-average-power ratio (PAPR) in OFDM is higher than different arrangements, the spectral efficiency of OFDM is satisfied but further improvements are smaller, expected options in contrast to OFDM. The ways to replace the OFDM are time-frequency packing, non-orthogonal signals, filterbank multicarrier, generalized frequency division multiplexing (GFDM), single-carrier, and tunable OFDM. The second part is cloud-based networking. 2 technology trends that will become very important are network function virtualization (NFV) and software-defined networking (SDN). NFV empowers network work were generally attached to equipment machines to run on distributed computing foundation in a data centre. SDN is a network architecture in which the control and information planes are separated, network intelligence and state are logically centralised, and the application is separated from the hidden network infrastructure. The last part is energy efficiency. In order to get the energy efficiency, further research should be more focused on resource allocation, network planning, renewable energy, and hardware solutions.

The last section of this paper is spectrum regulation and standardization for 5G. This section has 3 parts that will be discussed. The first part is spectrum policy and allocation and there have some upsides and downsides of various ways to deal with range guidelines. The approaches are restrictive licenses, unlicensed range, range sharing, and market-based ways to deal with range allotment. The second part is regulation and standardization which is standardized 5G status and the 5G spectrum. The third part is economic considerations and there have 2 major challenges in this part. First is the rental of the base station is expensive and the backhaul is needed to interface them to the central organization. To reduce the rental, few ways are provided and it is infrastructure sharing, detached sharing, dynamic sharing, portable virtual organization administrators, and offloading. For the backhaul, 3 directions

to optimism, it which is fibre deployments worldwide continue to mature and reach further, wireless backhaul improve by leaps and bound through the innovation and competition and optimized the backhaul. In conclusion, many challenges remain that span all layers of the convention stack and execution. Wish that this article could help us push ahead on this road. [20]



Figure 2-45: mmWave enable network with phantom cells.

	SU-MIMO	FD-MIMO 16	FD-MIMO 64
Aggregate Data Rate (b/s/Hz/cell)	2.32	3.28	6.37
Edge Data Rate (b/s/Hz)	0.063	0.1	0.4

Table 2-15: FD-MIMO system level downlink reproduction result at 2.5 GHz. SU-MIMO with 4 antennasfor each base station. MU-MIMO with 16 and 64 antennas separately.

#### 2.3 Summary

Based on the previous research, we know that a lot of antennae can be used in the base station, and each antenna has it is good or bad. Therefore, the antenna should choose the most suitable base on what the experiment needs to do. Besides that, the base station also has few types mentioned in the review above. The base station that will be used is the base station that can control the angle of the antenna such as the review in [2].



#### **CHAPTER 3**

#### METHODOLOGY

#### 3.1 Introduction

In this chapter, we will talk about how we do the project. We start from the concept of the base station then is the flow chart. After the flow chart, the simulation will be done. After that, the hardware will be set up like the diagram below. After done the setup, the results will be taken and discuss furthermore.

#### 3.2 Methodology

Figure 3-1 is the flow chart of this project and will experiment. This project will use a reflectarray antenna as the transmission and the feed horn as a receiver. The base station is controlled by a microcontroller and micromotor. The reflectarray placed on a dielectric frame which is an insulating material that can allow the current flow through it. Then, the receiver, feed hood is placed to the opposite of the reflectarray. Then the reflectarray starts to tilt from  $0^{\circ}$  to  $\pm 30^{\circ}$  and record the azimuth (AZ) and elevation (EL) angle. Besides that, the gain also needed to be recorded. All the recorded results will be tabulated and analyzed. The design of the antenna will use the Computer Simulation Technology (CST) Microwave Studio. After finished the design, simulation also will be done in the CST Microwave Studio. Then, the simulated results will compare with the measured results from the hardware.



Figure 3-1: Flow Chart of the Base Station Modelling
### 3.2.1 Experimental setup

This section of the setup will be broken into two parts: simulation and hardware. In the simulation section, I'll use Computing Simulation Technologies (CST) Microwave Studio to create a 3D model of a reflectarray antenna. I needed to determine the dimensions for the substrate, patch, and ground before starting to design in CST. The method for calculating the dimension will be described in detail below. After you have all of the dimensions, you can begin designing it in CST. I'll run the simulation and record the findings once the design is complete. If the graph does not show the desired frequency, I will change the dimension to get the desired frequency of 26 GHz. After that, I'll take down all of the necessary information. This is the first substrate material's result. After finishing the first material, I'll repeat the process described above but change the substrate materials. For all of the different types of substrate materials, copper is used in the substrate of Roger RT5880, Rogers RO3003, and Rogers RT6002, as well as the patch and ground.

The first step in the hardware development is to purchase all of the necessary components, such as an Arduino Uno, an IC2 LCD, a motor, and so on. After that, all of the components were connected as shown in the diagram. After that, programming the Arduino Uno to allow the motor and LCD to move and show data. I had specified multiple angles in the software on the Arduino Uno so that I could receive varied outcomes from different angles. -  $10^{\circ}$ ,  $-20^{\circ}$ ,  $-30^{\circ}$ ,  $0^{\circ}$ ,  $10^{\circ}$ ,  $20^{\circ}$ , and  $30^{\circ}$  are the angles that I have set. And I'll place a base on the motor to serve as a base station, with the reflectarray mounted on top of it and operated by a button. When the button is pressed once, the motor will begin at  $-10^{\circ}$  and increase by  $10^{\circ}$  each time the button is pressed until the angle reaches  $30^{\circ}$ . Furthermore, when I hit the button, the LCD displays the percentage of bandwidth, gain, and tilted angle.

Design the antenna in unit cells first, then convert it to an 20x20 array in the CST for the reflectarray antenna. Then export it as a gerber file, convert it to PDF, and print it on dry film photoresist. After that, apply the photoresist on the antenna board and place both of them in the UV machine to allow the design to burn in on the photoresist-coated board's surface. After that, use the acid, sodium carbonate, to dissolve the undesired areas of the surface for around 90 seconds before washing it with clean water. As a result, submerge the board in Ferric Chloride to etches away the unprotected areas of the material, allowing the desired picture to be reproduced. Finally, wash the board with water and cut it to the desired size.



Figure 3-3: FR4 Board soak in the Sodium Carbonate



Figure 3-5: Front View of FR4 Board



Figure 3-7: Prototype of Base Station Hardware Model



Figure 3-8: Simulation Model for Rectangular Patch of RT5880



Figure 3-9: Simulation Model for Rectangular Patch of RO300



Figure 3-10: Simulation Model for Rectangular Patch of RT6002



Figure 3-11: Simulation Model for Circular Ring RT5880



Figure 3-13: Simulation Model for Circular Ring RO3003

### 3.2.2 Equipment Needed

# 3.2.2.1 Hardware Component



Figure 3-14: Micromotor- MG90S

MG90S is a metal gear micro servo motor, it can be used in RC Airplane, Quadcopter, or Robotics Arm. It is a small size motor with lightweight but has a high output power.



Figure 3-15: Microcontroller- Arduino Uno

Arduino Uno is a microcontroller board with an open-based under the Microchip ATmega328P microcontroller. It is developed by Arduino.cc. It consists 14 digital input/output (I/O) pins, 6 analogue inputs, 1 USB connection, 1 ICSP connector, 1 reset button and 1 16 MHz input.



Figure 3-16: Jumper Wire

The jumper wire is the wire that has pins that allow the wire to connect to other components or wires without soldering. Jumper wires have 3 types which are male-to-male, male-to-female, and female-to-female.

Figure 3-17: Reflectarray antenna

Reflectarray antenna usually consists of unit cells and is illuminated by a feeding antenna.



Figure 3-18: 16x2 LCD Display with IC2 Module

16x2 LCD Display with IC2 Module is used to display the datas or words that programmed in the Arduino Uno.



Battery act as a power supply to the base station.



Figure 3-20: Press Button

Press Button used to control the angle of the base station



Figure 3-21: Mounting Bracket

Mounting Bracket is used to hold the reflectarray antenna.

# 3.2.2.2 Software Used



Figure 3-22: Computer Simulation Technologies (CST) Microwave Studio

CST Microwave Studio is a 3D EM analysis software package for designing, analyzing, and upgrading electromagnetic (EM) segments and systems with highquality performance. This software was used in designing the antenna in this project.



Figure 3-23: Logo of Arduino IDE Software

Arduino IDE Software is software with an open-source and it is no difficult to compose code and transfer it to its Arduino board.

### 3.3 Method and Parameter of the Reflectarray Antenna

The unit cell of the antenna is utilised as the model for designing the reflectarray antenna, and it is then designed based on the unit cell. We need to fix the dielectric constant of the substrate material,  $\varepsilon$ r, and the substrate thickness, which is the height of the substrate and the thickness of the patch, to get the dimension of the unit cell. After we've rectified everything, we'll need to figure out how to calculate substrate length, substrate width, patch length, and patch width. The formula is used to perform the computation in the step below.

The first step is to calculate the **wavelength**,  $\lambda$  by using the formula  $\frac{c}{f_r}$ , where c is the speed of light and  $f_r$  is the resonant frequency where it is fixed at 26 GHz. Then, the width and the length of the substrate are used  $\frac{\lambda}{2}$  to get the value.  $\lambda = \frac{c}{f}$ 

The formula used to calculate the Width of the substrate, Ws and length of Substrate, Ls UNIVERSITI TEKNIKAL MALAYSIA MELAKA

$$Ws, Ls = \frac{\lambda}{2}$$

After getting all the values of the substrate, we start to calculate the dimension of the patch. Since the height of the patch is fixed, therefore we just need to calculate the length and the width of the patch. To calculate the **patch width** (**Wp**), the formula used is as below:

$$Wp = \frac{c}{2f_r \sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

After done with the patch width, then calculate the effective dielectric constant,  $\varepsilon_{reff.}$ 

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} [1 + 12\frac{h}{W}]^{-1} (-\frac{1}{2})^{-1}$$

Then, calculate the effective length, Leff

$$L_{eff} = \frac{c}{2f_r \sqrt{\varepsilon_{reff}}}$$

After done the effective length, extension length,  $\Delta L$  is calculated

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

Last is calculated the actual length of the patch, Lp

$$L = L_{eff} - 2\Delta L$$

The formula of the **port distance**,  $\lambda_g$  is as below, then divide the distance,  $\lambda_g$  by 4 to get the actual distance.



 $\epsilon_r$  is the permittivity of the dielectric substrate / dielectric constant

 $\lambda_g$  is port distance

All the length, width and height are in **mm** unit.

All the dimension for the patch and substrate is calculated and can start to design the reflectarray antenna in the CST Studio. After doing the design, we need to set the frequency range and the boundary condition. Different boundary conditions could help us to measure

differences of measurement such as magnetic field, electric field, open (add space) and *etc*. The boundary condition that used in this simulation is shown below.

🗌 Арр	ly in all directions			
Xmin:	magnetic (Ht = 0)	$\sim$	Xmax:	magnetic (Ht = 0) v
Ymin:	electric (Et = 0)	$\sim$	Ymax:	electric (Et = 0) ~
Zmin:	open	~	Zmax:	open ~
Cond.:	1000		S/m	Open Boundary

Figure 3-24: Boundary Condition for the Antenna Design

The boundary condition is set to produce the infinite boundary condition. The infinite boundary requirements have eliminated both finite-size and boundary effects from the design. After finished the antenna design, we need to design the port and the ground of the unit cell. The ground is the negative value of the patch height. For the port, first is need to calculate the port distance which is the most suitable distance for the port to receive the signal from the antenna.

### 3.4 Limitation of proposed methodology

This project has 3 limitations. The first limitation is lack of suitable equipment to do the experiment in laboratory. This is because in the experiment place does not have the equipment to collect the data. The next limitation is the used frequency range. The frequency range used in this project is 24 GHz to 28 GHz and the resonant frequency is 26 GHz. The frequency range is chosen because in this range is the common frequency range used in 5G antennas and other frequency range used by other networks like 4G. The antennas' angle is the final constraint. The angle is maintained between 0° to  $\pm 30^{\circ}$  because if the angle is too large, the flat reflector would struggle to receive the signal and the transmission rate will degrade.

#### 3.5 Summary

This chapter explains how to accomplish the work and what tools you'll need. The flow chart depicts all of the steps in the procedure, from base station setup to clear results. Aside from that, it demonstrated how to set up a base station, which included both hardware and software. Finally, all of the functionality of the components and software used in this project are explained.

# **CHAPTER 4**

# **RESULTS AND DISCUSSIONS**

## 4.1 Introduction

This chapter will go over the design of the reflectarray antenna as well as the simulation results. This section will go over the findings of the reflectarray design, such as the S-parameter, Bandwidth, Reflection Loss, and Phase. In addition, comparisons are made in this section. This section will compare the reflection loss in different substrate thicknesses, different materials, and different patch shapes.



Figure 4-1: Reflection Loss VS Frequency Graph of Rogers RT5880

First reflection loss is 2.2976dB for 0.127mm of the substrate thickness. Next is 0.63434dB for 0.254mm, 0.19129dB for 0.508mm, 0.09203dB for 0.787mm and last is 0.033888dB for 1.575mm when the frequency is 26 GHz. This show clearly that when the thickness increase, the reflection loss decreases in dB. Besides that, the bandwidth for 0.127mm is 0.408 GHz and 0.254mm is 0.9 GHz.



Figure 4-2: Reflection Loss VS Frequency Graph of Rogers RO3003

The first reflection loss is 2.9663dB for 0.13mm of the substrate thickness. Next is 0.87436dB for 0.25mm, 0.26577dB for 0.5mm, 0.13477dB for 0.75mm and last is 0.03858dB for 1.52mm on the frequency 26 GHz. This show clearly that when the thickness increase, the reflection loss becomes smaller in dB. Besides that, the bandwidth for 0.13mm and 0.25mm is 0.32 GHz and 0.688 GHz.



Figure 4-3: Reflection Loss VS Frequency Graph of Rogers RT6002

The first reflection loss is 3.2806dB for 0.124mm of the substrate thickness. Next is 0.896dB for 0.254mm, 0.49386dB for 0.508mm, 0.1441dB for 0.762mm and last is 0.04433dB for 1.524mm on the frequency 26 GHz. This show clearly that when the thickness increase, the reflection loss becomes smaller in dB. Besides that, the bandwidth for 0.124mm and 0.254mm is 0.312 GHz and 0.712 GHz.



Figure 4-4: Reflection Loss VS Frequency Graph of 3 Types of Materials

This graph shows the reflection loss of 3 types of materials. From the graph shows, RT6002 is the largest reflection loss which is 0.49386dB while the smallest reflection loss is RT5880 which is 0.19129dB. RO3003 is in the middle which is 0.2658dB. In this case, the least reflection loss is the best materials to use in the antenna. From the results, we know that RT5880 is the most suitable reflector antenna to be use in this project. Besides that, in the graph also mention the bandwidth that display as horizontal line. The bandwidth of the RO3003 is 1.572GHz, RT5880 is 2.028GHz and RT6002 is 0.948GHz. Thus, from the bandwidth we know that, RT5880 has the largest bandwidth and it is the most suitable to be use as antenna.



Figure 4-5: Reflection Loss VS Thickness Graph of 3 Types of Materials

Rectangular Patch	Reflection Loss (dB)				
Thickness, Hs (mm)	🏹 RT 5880	RT 6002	RO 3003		
0.13	-2.297557828	-3.28058787	-2.96633049		
0.25	-0.63433701	-0.8960091	-0.874358516		
0.5	-0.191288295	-0.49386148	-0.265771986		
0.7	-0.092032552	-0.14409489	-0.134768112		
1.5	-0.03388786	-0.04432471	-0.038581086		
Circular Ring Patch		Au in	0400		
Thickness, Hs (mm)		. G. V	5.		
0.254	-3.719946	-3.25677	-3.0802362		
UNIVERSITI	EKNIKAL MA	ALAYSIA ME	LAKA		

Table 4-1: Table of Reflection Loss and Different Thickness to the Rectangular Patch and Circular Patch

From the graph, it shows the reflection loss of rectangular patch shape with different thickness from 0.13mm to 1.5mm and different materials. From the graph, we noticed that RT5880 had the highest trend among all the materials. Next is RO3003 and last is RT6002.

In the table, we know that circular ring patch on the same thickness with the rectangular patch, reflection losses of the circular ring patch are higher than the rectangular shape very much. Therefore, rectangular patch more suitable to be an antenna compare with the circular ring patch.



Figure 4-6: Phase VS Frequency Graph of Rogers RT5880

The graph shows the different phase when the thickness of substrate changed from 0.127mm to 1.575mm on 26 GHz. When the thickness is 0.127mm, the phase on the frequency is 184.72°. On 0.254mm, the phase is 179.996°. While the phase is 171.94°, the thickness is 0.508mm. Then, on 0.787mm, the phase is 161.90°. Last is 141.80° on 1.575mm. From the graph, when the thickness increase, the phase on 26 GHz will decrease and the whole graph will become flatter than others.



Figure 4-7: Phase VS Frequency Graph of Rogers RT3003

The graph shows the different phase when the thickness of substrate changed from 0.13mm to 1.52mm on 26 GHz. When the thickness is 0.13mm, the phase on the frequency is 178.40°. On 0.25mm, the phase is 171.88°. While the phase is on 165.42°, the thickness is 0.50mm. Then, on 0.75mm, the phase is 152.64°. Last is 139.66° on 1.52mm. From the graph, when the thickness increase, the phase on 26 GHz will decrease and the whole graph will become flatter than others.



Figure 4-8: Phase VS Frequency Graph of Rogers RT6002

The graph shows the different phase when the thickness of substrate changed from 0.124mm to 1.524mm on 26 GHz. When the thickness is 0.124mm, the phase on the frequency is 180.55°. On 0.254mm, the phase is 175.16°. While the phase is on 158.85°, the thickness is 0.508mm. Then, on 0.762mm, the phase is 152.75°. Last is 139.45° on 1.524mm. From the graph, when the thickness increase, the phase on 26 GHz will decrease and the whole graph will become flatter than others.



Figure 4-9: Phase VS Frequency Graph of Different Types of Materials

The graph shows the different phase when the types of substrate changed from RT5880, RO3003 and RT6002. When the substrate is RO3003, the phase on the frequency is 165.42°. Next is the phase is on 171.94°, when the substrate is RT5880. Last is 158.85° on RT6002. From the graph, when the substrate materials changed, the phase on 26 GHz will depend on the properties of the materials. In conclusion, RT5880 is the most suitable used in this project because it has the largest phase value. Hence, it has bigger angle of radiation pattern.



Figure 4-10: Parameter Sweep Graph of Rogers RT5880



Figure 4-12: Parameter Sweep Graph of Rogers RO3003

# 4.2.2 Circular Ring Patch

The substrate thickness used in all circular ring patch is 0.254mm and different materials will be used to see the change of reflection loss and the phase.



In this graph, the material used is RT5880. The reflection loss is 3.71995dB on 26 GHz and the bandwidth is 0.1GHz.



Figure 4-14: Reflection Loss VS Frequency Graph of Rogers RO3003

In this graph, the material used is RO3003. The reflection loss is 3.08012dB on 26 GHz and the bandwidth is 0.22GHz.



Figure 4-15: Reflection Loss VS Frequency Graph of Rogers RT6002

In this graph, the material used is RT6002. The reflection loss is 3.25645dB on 26 GHz and the bandwidth is 0.22GHz.





Figure 4-17: Phase VS Frequency Graph of Rogers RO3003

When the frequency is 26GHz, the phase of this materials is 245.94°

and





Figure 4-19: Parameter Sweep Graph of Rogers RT5880



Figure 4-21: Parameter Sweep Graph of Rogers RO3003

### 4.3 Discussion

According to the project's flow chart, the project began with a simulation design using the formula provided to determine the dimension and the dimensions used in the simulation design as the length and width of the substrate and patch. Run the simulation and get the results after you have obtained all of the dimensions and finished the design. On 26GHz, the results are not accurate after the first time. As a result, the length or width of the patch must be adjusted to ensure accurate results on 26GHz. As a result, the outcomes are recorded. In this project, the patch has a rectangle and circular ring shape. All of the outcomes are compared in the figure above. In addition, waveguide ports are included in all antenna designs. To operate as a flatter reflector, the port is located above the antenna.

After finished with the simulation, you may go on to the hardware. Gather all of the necessary components, such as an Arduino Uno, a motor, and a Reflectarray Antenna, at the start of this section. After that, connected all of the components and programmed the Arduino Uno to allow it to operate the motor and move it in the desired angle, which is between -30° and 30° degrees in a 10° interval. A push button is required to control the motor's movement. When the button is pressed once, the motor will travel 10° from -30° to 30°. When the button is pressed, the LCD will additionally display the gain, percentage of the bandwidth, and angle for each angle.

To acquire the reflectarray antenna, first of all need to get the array design. The design used in this project is circular ring 20x20 array. Then, used the FR4 board to do the fabrication with the design. After that done the fabrication, place the array on the mounting bracket which the bracket is connected with the motor.

For rectangular shape of the patch, 3 types of materials are used in this project and the materials is Rogers RT5880, Rogers RT6002, Rogers RO3003. Then different thickness will be used for each material which is 0.13mm, 0.25mm, 0.5mm, 0.7mm and 1.5mm. Different thickness used to see the different of the reflection loss and phase for 1 material. Rogers RT5880 as an example, when the thickness is 0.127mm, the reflection loss is 2.2976dB. Next is 0.63434dB for 0.254mm, 0.19129dB for 0.508mm, 0.09203dB for 0.787mm and last is 0.033888dB for 1.575mm when the frequency is 26 GHz. Therefore, from the trend we know when the thickness decrease, the reflection loss increases in dB. Besides that, the bandwidth for 0.127mm is 0.408 GHz and 0.254mm is 0.9 GHz. The rest of the thickness does not have bandwidth because the reflection loss is too small to find the bandwidth.

Thus, comparison is done by compare the reflection loss on 26 GHz after combine the graph of all the materials. From the graph, it shows the biggest reflection loss is RT6002, which is 0.49386dB, while the smallest is RT5880, which is 0.19129dB. RO3003 is in the middle, which is 0.2658dB. In this instance, the materials with the lowest reflection loss are the best to employ in the antenna. Based on the data, we know that the RT5880 is the best reflector antenna for this project. Aside from that, the graph also shows the bandwidth, which is represented by a horizontal line. The RO3003 has a bandwidth of 1.572GHz, whereas the RT5880 has a bandwidth of 2.028GHz and the RT6002 has a bandwidth of 0.948GHz. As a result of the bandwidth, we know that the RT5880 has the largest bandwidth and is the best antenna to use.

Next is the phase different of the materials. The phase on the frequency is 165.42° when the substrate is RO3003. When the substrate is RT5880, the phase is on 171.94°. On RT6002, the last reading is 158.85°. The phase on 26 GHz will rely on the characteristics of the materials, as seen in the graph, when the substrate materials differ. Since, RT5880 has the highest phase value, the angle of the radiation pattern is larger. Therefore, RT5880 is the best choice for this project. Last, the parameter sweep is done to see the different of the reflection loss when the parameter is changed.

For the circular ring patch, the thickness only used 0.254mm and used same materials as the rectangular shape and the frequency used still is 26 GHz. For RT5880, the reflection loss is 3.71995dB and the bandwidth is 0.1GHz. The phase of this materials is 253.71°. The reflection loss is 3.08012dB, the bandwidth is 0.22GHz for RO3003 and the phase of this materials is 245.94°. Last is RT6002, the reflection loss is 3.25645dB, the bandwidth is 0.22GHz and the phase of is 245.49°. From all the values show on the above, RO3003 is suitable to use in circular ring patch design because it has the lowest values of reflection loss, biggest bandwidth and largest phase. Last, parameter sweep also done for this patch and see the different results when the parameter changed.

There are few limitations in this project. The first obstacle is a lack of sufficient laboratory equipment to conduct the experiment. This is due to the lack of data collection equipment at the experiment site. The frequency range employed is the next limitation. The resonance frequency is 26 GHz, and the frequency range utilized in this project is 24 GHz to 28 GHz. The frequency range was chosen because it includes the typical frequency range used in 5G antennas as well as other frequencies used by previous networks such as 4G. In addition, the materials used in the prototype model differ from those used in the simulation. This is due to the fact that the materials employed in the simulation are extremely expensive and difficult to get. Final constraint is the angle of the antennas. The angle is kept between  $0^{\circ}$  and  $\pm 30^{\circ}$  degrees because if it is too large, the flat reflector will have difficulty receiving the signal and the transmission rate will suffer.

Finally, there are some recommendations given to let this project become better. The first step is to employ distinct shapes or measurements so that future data can be used as a comparison or reference. The second step is to select a dual-band frequency or a frequency other than 26 GHz, as different frequencies have varied effects on the results. Finally, the unit cell's dual-linear or dual-circular polarized design can give polarization diversity on the reflectarray.
# 4.4 Summary

In this chapter, it shows the results for different thickness of the substrates and different shapes of the patch. Then all the results are tabulated and compared when the frequency is 26GHz for the both shapes of the patch which is rectangle and circular ring shape. Besides that, all the graph come with an explanation include the reflection loss graph and the phase graph. After that, the results discussed in the discussion part.



## **CHAPTER 5**

#### CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

Finally, the simulation software included in the CST Microwave Studio provides the needed outcomes for patch design. This project's strategy for obtaining the findings is effective. In the CST Microwave Studio, the expected results are obtained but we cannot do fabrication measurement due to lack of equipment. Therefore, all the results are verified by the simulations.

### 5.2 Future Works

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There are some recommendations for future improvements for other similar projects, so these types of projects could be better and more variations on this type of project. The following are some suggestions for improvement:

**I.** In all these types of projects, apply different shapes or measurements so that additional data may be used as a comparison or reference in the fu<u>t</u>ure.

- II. Choose dual-band frequency or a frequency other than 26 GHz because different frequencies have different properties on the outcomes.
- **III.** The dual-linear polarized or dual-circular polarized design of the unit cell can provide polarization diversity on the\_reflectarray,

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# APPENDICES

# Appendix A: Gantt Chart

Project Activities / Week	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
Discussion with Supervisor	Р								М					
PSM Proposal	S								Ι					
Literature Review	М								D					
Research on the Project Details									S					
Study for Project Progress	В								Е					
Submission Log Book	R								М					
Study for Raw Materials	Ι													
Methodology	Е								В					
Study for Expected Result	F								R					
Designing Circuit	Ι								Е					
PSM 1 Pre-Presentation	Ν								Α					
PSM 1 Presentation	G								K					

PSM 1 Gantt Chart

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		2.1			25									
Project Activities / Week	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
Discussion with Supervisor	1								М					
Experiment Setup		RA N							Ι	11				
Hardware Development		0					1		D					
Software Development		41	Nn						S					
Hardware Testing			1						Е					
Software Testing		2NL	14	ala	4			L. 7	М	naw	0			
Data Analysis			-	-		1.1		- C	. 6	1 - 4-	1			
Troubleshooting	_							1.4	В					
Result		INIV	ERSI	TITE	EKNI	KAL	MAL	AYS	R	ELAP	A			
Conclusion									Е					
PSM 2 Presentation									Α					
Submission Report									K					

PSM 2 Gantt Chart

## **Appendix B: Datasheet for All Materials**

## Rogers RT5880

		TYPICAL	VALUES						
PROPERTY	RT/duroi	d 5870	RT/duro	ld 5880	DIRECTION	UNITS	CONDITION	TEST METHOD	
PiDielectric Constant, E <sub>p</sub> Process	2.3 2.33 ± 0.0	3 02 spec.	2.2 2.20 ± 0.	20 .02 spec.	z z	N/A	C24/23/50 C24/23/50	1 MHz IPC-TM-650 2.5.5.3 10 GHz IPC-TM 2.5.5.5	
MDielectric Constant, E <sub>r</sub> Design	2.33		2.3	20	z	N/A	8 GHz - 40 GHz	Differential Phase Length Method	
Dissipation Factor, tan õ	0.00	05 12	0.0	004 009	z z	N/A	C24/23/50 C24/23/50	1 MHz IPC-TM-650, 2.5.5.3 10 GHz IPC-TM-2.5.5.5	
Thermal Coefficient of $\epsilon_r$	-11	.5	-1	-125		ppm/°C	-50 - 150°C	IPC-TM-650, 2.5.5.5	
Volume Resistivity	2 X 1	107	2 X	107	z	Mohm cm	C96/35/90	ASTM D257	
Surface Resistivity	2 X 1	107	3 X	107	z	Mohm	C/96/35/90	ASTM D257	
Specific Heat	0.96 (0	0.23)	0.96 (	(0.23)	N/A	J/g/K (cal/g/C)	N/A	Calculated	
	Test at 23 °C	Test at 100 °C	Test at 23 °C	Test at 100 °C	N/A				
Tensile Modulus	1300 (189)	490 (71)	1070 (156)	450 (65)	x	MPa			
	1280 (185)	430 (63)	860 (125)	380 (55)	Y	(kpsi)		ASTM DETR	
	50 (7.3)	34 (4.8)	29 (4.2)	20 (2.9)	x		<u> </u>	2011 0000	
ultimate stress	42 (6.1)	34 (4.8)	27 (3.9)	18 (2.6)	Y				
ultimate strain	9.8	8.7	6.0	7.2	х	94			
Greiningen ser ante	9.8	8.6	4.9	5.8	Y	~			
X	1210 (176)	680 (99)	710 (103)	500 (73)	x				
Compressive Modulus	1360 (198)	860 (125)	710 (103)	500 (73)	Y				
	803 (120)	520 (76)	940 (136)	670 (97)	z	MPa			
6	30 (4.4)	23 (3.4)	27 (3.9)	22 (3.2)	x	(kpsi)			
ultimate stress	37 (5.3)	25 (3.7)	29 (5.3)	21 (3.1)	Y	-	A	ASTM D695	
	54 (7.8)	37 (5.3)	52 (7.5)	43 (6.3)	Z				
	4.0	4.3	8.5	8.4	X				
ultimate strain	H3.3	3.3	7.7	7.8		. Autual	u. rou		
Moisture Absorption	0.0	2	0.0	02	N/A		.062" (1.6mm)	ASTM D570	
Thermal Conductivity				6A.L.B.		/ W/m/K		ASTM C518	
	27	****	3	1	X	SIM	METAR		
Coefficient of Thermal Expansion	28	3	48 237		Y Z	ppm/°C	0-100°C	IPC-TM-650, 2.4.41	
Td	50	0	500		N/A	°C TGA	N/A	ASTM D3850	
Density	2.3	2	2.	.2	N/A	gm/cm <sup>3</sup>	N/A	ASTM D792	
Copper Peel	27.2 (4.8)		31.2 (5.5)		N/A	pli (N/ mm)	1 oz (35mm) EDC foll after solder float	IPC-TM-650 2.4.8	
Flammability	V-0	D	V-	0	N/A	N/A	N/A	UL94	
Lead-Free Process Compatible	Ye	s Yes		N/A	N/A	N/A	N/A		

Specification values are measured per IPC-TM-650, method 2.5.5.5 (p) ~10GHz, 23°C. Testing based on 1 oz. electrodeposited copper foil. • values and tolerance reported by IPC-TM-650 method 2.5.5.5 are the basis for quality acceptance, but for some products there values may be incorrect for design purposes, especially microstrip designs. We recommend that prototype boards for specification limits, accept where noted.
 Typical values should not be used for propertication limits, accept where noted.
 Si unit given first with other frequencity used units in parentheses.
 The design Dk is an average number from several different tested lots of material and on the most common thickness/s. If more detailed information is required, please contact Rogers Corporation. Refer to Rogers' technical paper "Dielectric Properties of High Frequency Materials" available at http://www.rogerscorp.com.

Standard Thickness	Standard Panel Size	Standard Copper Cladding	Non-Standard Copper Cladding		
0.005° (0.127mm) 0.031° (0.787mm) 0.010° (0.254mm) 0.062° (1.575mm) 0.015° (0.381mm) 0.125° (3.175mm) 0.020° (0.508mm) Non-standard thicknesses are available	18" X 12" (457 X 305mm) 18" X 24" (457 X 610mm) Non-standard sizes are available up to 18" X 48" (457 X 1219 mm)	% oz. (18µm) and 1 oz. (35µm) electrodeposited and rolled copper foll	$\%$ or. (9 $\mu m)$ electrodeposited copper foll % or. (18 $\mu m$ ), 1 or. (35 $\mu m$ ) and 2 or. (70 $\mu m$ ) reverse treat copper foll 2 or. (70 $\mu m$ ) electrodeposited and rolled copper foll		
		Thick metal claddings may be available to customer service for more information of claddings and panel sizes	based on dielectric and plate thickness. Contact on available non-standard and custom thicknesses,		

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## **Rogers RT6002**

Typical Values

RT/duroid 6002 Laminates

Property	Typical Value	Direction	Units [1]	Conditions	Test Method
Dielectric Constant, sr Process	2.94 ± 0.04	Z	-	10GHz/23°C	IPC-TM-650, 2.5.5.5
Dielectric Constant, ɛr Design	2.94			8GHz-40GHz	Differential Phase Length Method
Dissipation Factor, TAN δ	0.0012	Z	-	10 GHz/23°C	IPC-TM-650, 2.5.5.5
Thermal Coefficient of ε <sub>r</sub>	+12	Z	ppm/ºC	10 GHz 0-100°C	IPC-TM-650, 2.5.5.5
Volume Resistivity	106	Z	Mohm cm	А	ASTM D257
Surface Resistivity	107	Z	Mohm	А	ASTM D257
Tensile Modulus	828 (120)	X,Y	MPa (kpsi)		
Ultimate Stress	6.9 (1.0)	X,Y	MPa (kpsi)	23°C	ASTM D638
Ultimate Strain	7.3	X,Y	%		
Compressive Modulus	2482 (360)	Z	MPa (kpsi)		ASTM D638
Moisture Absorption	0.02	-	%	D48/50	IPC-TM-650, 2.6.2.1 ASTM D570
Thermal Conductivity	0.60	4 A	W/m/K	80°C	ASTM C518
Coefficient of Thermal Expansion	16 16 24	X Y Z	ppm/°C	(10K/min) TMA	ASTM D3386 IPC-TM-650 2.4.41
Td 🔗	500		°C TGA		ASTM D3850
Density	2.1		gm/cm3		ASTM D792
Specific Heat	0.93 (0.22)	5	J/g/K (BTU/Ib/°F)	un rain	Calculated
Copper Peel	8.9 (1.6)	0	lbs/in (N/mm)		IPC-TM-650 2.4.8
Flammability			I MALAVO		UL94
Lead-Free Process Compatible	YES	LICHING	L MALATS	DACINIC EDATE	

Typical value are a representation of an average value of the population of the property. For specification values contact Rogers Corporation. S1 units given first, with other frequently used units in parentheses
 References: internal TRs 3824, 5016, 5017, 5035. Test were at 23°C unless otherwise noted.

STANDARD THICKNESS:	STANDARD PANEL SIZE:	STANDARD COPPER CLADDING:
0.005" (0.127mm) 0.010" (0.254mm) 0.020" (0.508mm) 0.030" (0.762mm)	18" X 12" (457 X 305mm) 18" X 24" (457 X 610mm)	$\%$ oz. (8.5 $\mu m)$ electrodeposited copper foil. $\%$ oz. (17 $\mu m)$ , 1 oz. (35 $\mu m)$ , 2 oz. (70 $\mu m)$ electrodeposited and rolled copper foil.
0.060" (1.524mm) 0.120" (3.048mm)		Unclad material 0.020" or greater is available. Thick metal claddings are available. Additional claddings and panel sizes are available. Contact customer service for more information.

The information in this data sheet is intended to assist you in designing with Rogers' circuit material laminates. It is not intended to and does not create any warranties express or implied, including any warranty of merchantability or fitness for a particular purpose or that the results shown on this data sheet will be achieved by a user for a particular purpose. The user should determine the suitability of Rogers' circuit material laminates for each application.

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# Rogers RO3003

Data Sheet								
Property	ו RO3003	Typical Value <sup>(1)</sup> RO3006	RO3010	Direction	Unit	Condition	Test Method	
Dielectric Constant, s <sub>r</sub> Process	3.00 ± 0.04	6.15 ± 0.15	10.2 ± 0.30	Z	-	10 GHz 23°C	IPC-TM-650 2.5.5.5 Clamped Stripline	
<sup>(2)</sup> Dielectric Constant, s <sub>r</sub> Design	3.00	6.50	11.20	Z	-	8 GHz - 40 GHz	Differential Phase Length Method	
Dissipation Factor, tan $\boldsymbol{\delta}$	0.0013	0.0020	0.0022	Z	-	10 GHz 23°C	IPC-TM-650 2.5.5.5	
Thermal Coefficient of s <sub>r</sub>	13	-160	-280	Z	ppm/°C	10 GHz 0-100°C	IPC-TM-650 2.5.5.5	
Dimensional Stability	0.01	0.5	0.5	X,Y	mm/m	COND A	ASTM D257	
Volume Resistivity	107	105	105		MΩ•cm	COND A	IPC 2.5.17.1	
Surface Resistivity	ALA 107	105	105		MΩ	COND A	IPC 2.5.17.1	
Tensile Modulus	900	2068	1500	X, Y	MPa	23°C	ASTM D638	
Water Absorption	<0.1		<0.1	-	%	D24/23	IPC-TM-650 2.6.2.1	
Specific Heat	0.9	0.86	0.8		J/g/K		Calculated	
Thermal Conductivity	0.50	0.79	0.95	-	W/m/K	80°C	ASTM C518	
Coefficient of Thermal Expansion	17 16 Wri 25	17 17 24	13 11 16	X Y Z	ppm/°C	-55 to 288°C	ASTM D3386-94	
Td sh	500	500	500	1. 10	°C TGA		ASTM D3850	
Density	2.1	2.6	2.8	S	gm/cm <sup>3</sup>	او در		
Copper Peel Strength	ER.\$217TI 1	ek <b>n</b> ik.	AL MAL	.AYSIA	Mb/in L	1 oz. EDC After Solder Float	IPC-TM-2.4.8	
Flammability	V-0	V-0	V-0				UL 94	
Lead Free Process Compatible	YES	YES	YES					



NOTES:

 Typical values are a representation of an average value for the population of the property. For specification values contact Rogers Corporation.

(2) The design Dk is an average number from several different tested lots of material and on the most common thickness/s. If more detailed information is required, please contact Rogers Corporation or refer to Rogers' technical papers in the Roger Technology Support Hub available at http://www.rogerscorp.com/acm/technology.

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# Data Sheet

Standard Thickness	Standard Panel Size	Standard Copper Cladding			
R03003:	R03003/R03006/R03010:	½ oz. (17µm) electrodeposited copper foil (.5ED/.5ED)			
0.005" (0.13mm)	12" X 18" (305 X 457mm)	1 oz. (35µm) electrodeposited copper foil (1ED/1ED)			
0.020" (0.25mm) 0.020" (0.50mm)	24" X 18" (610 X 457mm)	2 oz. (70µm) electrodeposited copper foil (2ED/2ED)			
0.030" (0.75mm) 0.060" (1.52mm)		Other claddings may be available. Contact customer service.			
R03006/R03010:					
0.005" (0.13mm)					
0.010" (0.25mm) 0.025" (0.64mm)					
0.050" (1.28mm)					



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