DIELECTRIC RESONATER ANTENNA WITH ARRAY

By

NUR AMALINA BINTI MOHAMAD TERMIZI

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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August 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NUR AMALINA BINTI MOHAMAD TERMIZI

ABSTRACT

Dielectric Resonator Antenna with Array or more widely known as DRA is the latest invention of resonant antenna specializing in long distance communications. It creates sufficiently strong electromagnetic field at large distance which made radio communication to transmit signal through a long distance communications possible. Nowadays, with the challenging development, there exist a demand to produce compact antenna without added cost and complexity. This compact antenna must be able to accommodate the increasing data rates and higher gain with low loss power consumption. Dielectric Resonator Antenna (DRA) is the latest invention that is capable of fulfilling all these demands by its own unique characteristics such as light-weight, small size, wide bandwidth and high directivity. Array technique will be the most crucial part of this project as the antenna will be arrayed with the purpose of acquiring higher directivity. Thus, the main aim of this project is to prove that through this array technique, the directivity of antenna can be further improved. Moving on, this project involves two main parts which is simulation of the antenna using Computer Simulation Software (CST) followed by fabrication of the antenna as hardware. The antenna will be designed using the Computer Simulation Tools (CST) before it is sent for fabrication. Once the fabrication process is completed, test and measurement process will be carried out to observe the antenna performance. This test and measurement process involves three main crucial parameters which is directivity, bandwidth and radiation pattern.

ACKNOWLEDGEMENTS

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LIST OF ABBREVIATIONS

DRA	Dielectric Resonator Antenna
CDRA	Cylindrical Dielectric Resonator Antenna
CST	Computer Simulation Tools
MSDRA	Multi-Segment Dielectric Resonator Antenna
GA	Graduate Assistant

CHAPTER 1
INTRODUCTION

In this introduction section, Dielectric Resonator Antenna (DRA) with Array will be introduced briefly through several essential aspects such as background of study, problem statement, objective, scope of study, relevancy of the project and scope of project.

1.1 Background of Study

The history of antenna started in the period of 1920-1929 where the antenna began to take specialized forms suited to their applications. The developments may therefore be classified according to application areas such as broadcasting, telecommunications, navigational purposes and research [1]. During early 1980s, the research on Dielectric Resonator Antenna (DRA) began with the invention of Dielectric Resonator Antenna in basic shapes such as cylindrical, hemispherical and rectangular [2-4]. Analysis on crucial parameters such as radiation pattern, gain, bandwidth, efficiency and else made it apparent that Dielectric Resonator Antenna (DRA) will be a better alternative in the future replacing the traditional low-gain antenna.

One of the best techniques used to acquire higher gain and directivity is by applying the concept of DRA with Array. The proposed design of DRA with Array will be simulated using CST Software and further fabricated.

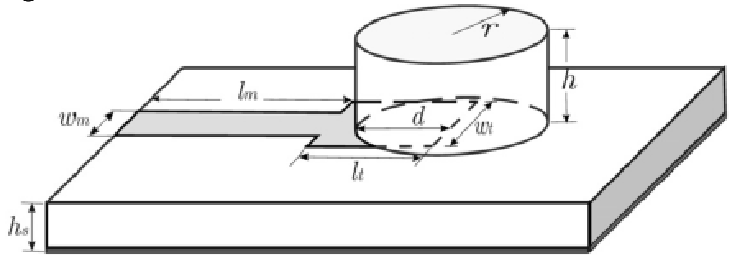


Figure 3: A configuration example of a Cylindrical Dielectric Resonator Antenna

1.2 Problem Statement

1.1.1 Problem Identification

Researchers are also emphasizing into inventing a compact antenna which is light weight and small in size in order to create a portable wireless devices [2]. Dielectric Resonator Antenna (DRA) with Array will be studied thoroughly to discover the attractive parameters that will be useful in achieving the target.

Dielectric Resonator Antenna (DRA) with Array is seen as one of the recent inventions that conform to all the needed requirements in producing a compact antenna. Fabricated from low-loss and high dielectric constant materials, DRA has been widely used all around the world. Its light-weight and small size made it a compact antenna that is portable and more flexible antenna. This is very essential since in this time frame of increasing data rates and larger bandwidth, a compact antenna will be very useful for users.

1.2.2 Significance of Project

The main focus of this project is to design a resonant antenna namely Dielectric Resonator Antenna (DRA) with Array which is capable to accommodate the increasing data rates. Dielectric Resonator Antenna (DRA) with Array is carefully designed with the important specifications to produce a better performance especially in long distance transmission. Crucial parameters such as bandwidth, gain, radiation efficiency, and several others will also be improved to ensure that the low-loss power and high temperature stability can be maintained [3].

By applying the concept of array in Dielectric Resonator Antenna (DRA), a higher gain can be acquired which will then leads to more improved parameters in the antenna. All the possible alternatives and measures in producing an optimum resonant antenna will be studied thoroughly in this project. CST Software will be fully-utilized in coming out with a design of Dielectric Resonator Antenna (DRA) with Array. Further work will be related to fabrication and simulation of the proposed design.

1.3 Objective and Scope of Project

1.3.1 Main Objective

Among the main objectives of this projects are:

- To analyze the previous research on the technology of Dielectric Resonator Antenna (DRA) with Array.

- To conduct the Computer Software Tools (CST) prior to antenna design process.

- To create a design of Dielectric Resonator Antenna (DRA) with Arrays that will improves the gain and bandwidth of the antenna.

1.3.2 Scope of Project

To start the project, this literature review will be an important measure in elaborating the important parameters and specifications in designing a Dielectric Resonator Antenna (DRA) with Arrays. Then, more specific focus will be into designing DRA with Arrays using CST Software [2]. However, it is very crucial to acquire a meticulous understanding about this subject of antenna before starting to design DRA. Fabrication and stimulation will further take place in near future time which will requires a lot of knowledge and help from the supervisor and Graduate Assistant (GA)

1.4 Relevancy of Project

This Dielectric Resonator Antenna (DRA) with Array project is seen as a very essential invention that will brings many advantages to the industry such as broadcasting, telecommunication and others. Dielectric Resonator Antenna (DRA) is capable of accommodating the escalating data rates that is being used in the industry nowadays. Industries such as telecommunication are growing rapidly these days and this will guide to the invention of many more modern products that involves long distance transmission. This will eventually lead to the necessities of more compact antenna with wider bandwidth and higher data rates to address these latest inventions.

1.5 Feasibility of Project

This project is estimated to be completed in 2 semesters which is January'12 Semester and also May'12 Semester. The objective is to propose a new design of Dielectric Resonator Antenna (DRA) with Arrays and also to fabricate this new design which would be the most challenging part in this project. System testing and improvement should also be conducted from time to time to ensure that this design of DRA is feasible. Based on the description above, it is very clear that this project will be feasible to be carried out within the time frame.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction to Antenna

Over these past recent years, Dielectric Resonator Antenna or more widely known as DRA has been researched comprehensively to discover its capabilities as the latest invention replacing the previous type of antenna. This leads to the recent advances in Dielectric Resonator Antenna that has been widely acceptable in the market. Dielectric Resonator Antenna is a resonant antenna that is used as one of the medium of transmission that creates sufficiently strong electromagnetic fields. As we know, the concept of antenna is implied in long distance transmission which requires wire communication and radio communications to transmit the signal.

2.2 Dielectric Resonator Antenna (DRA) Overview

Dielectric Resonator Antenna is fabricated using low loss and high dielectric constant materials and has been widely used as filters and oscillators. Its small size and light weight characteristics offers low cost and high temperature stability [4].

There are several types of antennas that are available nowadays which includes isotropic antenna, dipole antennas, aperture antennas, directive beam antenna and else [5]. Each of this type of antenna has its own specifications that differentiate each and every type of antenna.

2.3 Properties of Dielectric Resonator Antenna (DRA)

This section is intended to focus on the properties of Dielectric Resonator Antenna (DRA) that brought it further ahead compared to other types of antenna. Below are some of the properties and advantages of Dielectric Resonator Antenna (DRA);

2.3.1 Light Weight

One of the most widely known important properties of Dielectric Resonator Antenna (DRA) is its light weight that makes it a compact antenna. Research has shown that in order to significantly reduce the size of antenna, one of the best alternatives is to fabricate those using materials with very high permittivity [6]. The light weight and small size of DRA can be achieved using high permittivity material that will lower down the resonant frequency of DRA.

2.3.2 Radiation Pattern

The basic idea of radiation patter is depicted as a graphical representation of radiation pattern. Radiation pattern most commonly refers to the directional dependence of the strength of the radio waves from the antenna.

In most antennas, there will be some angle where the radiation is at its maximum point. For example, in directive antenna, it is targeted to direct the radio waves in one specific direction which is called main lobe. The direction which has the stronger radiation is referred as Major Lobe. Meanwhile, the other lobes with weaker radiation are named Minor Lobes [7].

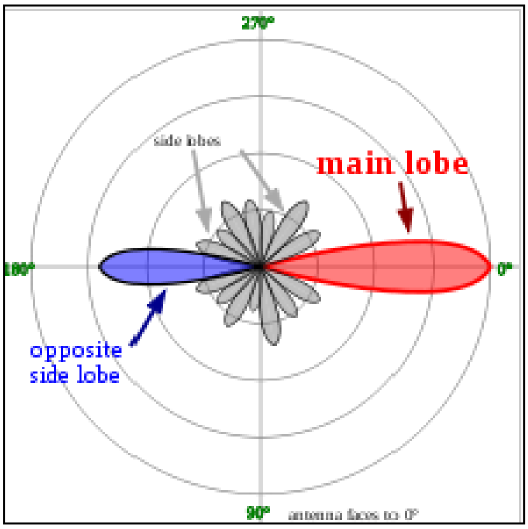


Figure 4: Example of Main Lobe and Side Lobe

2.3.3 *Radiation Efficiency*

After some introduction on radiation pattern, we are now able to measure the radiation efficiency of antenna. This is where DRA is very advantageous because DRA has a very high radiation efficiency that can reach up to 95% at a time.

2.3.4 *Gain*

When the antenna losses are included, this becomes the antenna gain [8].

$$G = \quad \eta . \frac{Power\ Density\ at\ d\ in \max direction}{\frac{P_T}{4\pi d^2}} \qquad [1]$$

where

P_T is the power applied to the antenna terminals

$4\pi d^2$ is the area of shape with radius d

η is the total antenna efficiency which included resistive and taper losses of the antenna.

2.4 Dielectric Resonator Antenna (DRA) with Arrays

The next section will be focusing on DRA with arrays. Research has shown that in many cases with a single element DRA, desired characteristics cannot be achieved. As for example, high gain, wide bandwidth and directional radiation pattern cannot be acquired with a single DRA [9]. Single element DRA usually results in low value of directivity. This eventually leads to the invention of DRA with arrays.

2.5 Advantages of Dielectric Resonator Antenna (DRA) with Arrays

The main advantage of utilizing this DRA with Array technique is higher gain and directional radiation pattern [10]. To determine the best feeding mechanism for the DRA with arrays, specifications such as the required gain, bandwidth and fabrication method shall be studied first. There are many feeding mechanism available for usage such as microstrip feed [11], coaxial probe [12] and dielectric image line [13]. However, it has been proven that microstrip feed line is most frequently used due to its ease of fabrication and low cost aspects. The microstrip-fed linear array has been proven to produce radiation pattern with higher gain and low side lobe levels [14].

2.6 Challenges in Dielectric Resonator Antenna (DRA) with Arrays

There are also several challenges that have to be overcome in fabricating DRA with Arrays such as minimizing the power loss dissipation and meeting the bandwidth specifications. In the fabrication process, some losses might occur and causes error in the results measurement [15]. Constraints in ensuring the DRA with Array will meet the specified bandwidth have to be looked into details during design process. Many trials and error process shall be conducted to come out with the best design and dimensions before fabricating the real DRA with Arrays.

2.7 Linear Arrays

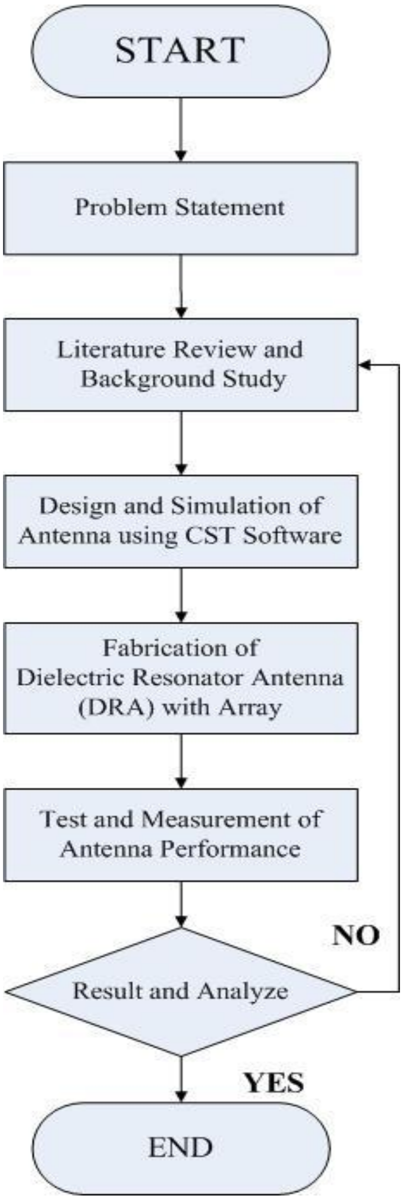
Linear array are formed when an antenna array has elements arranged in a straight line [16]. There are various type of linear array of Dielectric Resonator Antenna (DRA) such as dielectric image-guide-fed DRAs at K band, probe-fed DRAs with parasitic elements at L band, slot-fed arrays at Q band and several microstrip-line-fed-arrays [].

Furthermore, this concept will also be useful in reducing the sidelobe which is the unwanted lobe by adjusting the amplitude values. Meanwhile, phase excitation is adjusted to steer the peak of the beam to a desired location [28]

CHAPTER 3
METHODOLOGY

3.1 Flow Chart

Flow chart is constructed to produce a brief explanation on the process flow of the project.



3.2 Brief Explanation of the Flow Chart

3.2.1 Problem Statement

Some brief explanation on every process in the flow chart above will be discussed in this section. Firstly, problem statement is defined as the concrete explanation of the current situation that leads to the problem. The focus of this project is pertaining on the wireless local area network (WLAN) based on IEEE 802.11 standards. The main challenge is to produce an alternative antenna that can accommodate the increasing data rates nowadays. This alternative must be able to replace the traditional antenna by providing more enhanced parameters such as higher gain, increased bandwidth, improved radiation pattern and others.

3.2.2 Literature Review and Background Study

Next, focus will be placed on literature review and background study. This is the most crucial part of the project where research and studies have to be done in order to fully understand the subject. Journals, conference proceedings, books and articles will be reviewed in details to gain information about the subject. The information will be used to write a good literature review and background study regarding the introduction to basic fundamentals of antenna in specific details. This is a major step in directing the main focus towards DRA with Array as the chosen alternative in overcoming the issue stated in the previous problem statement. Earlier history on the development of DRA is also researched thoroughly to improve the outcomes of the project.

3.2.3 Design and Simulation of Antenna using CST Software

Computer Simulation Technology (CST) Software will be used to design and conduct simulation of Dielectric Resonator Antenna (DRA) with the proposed design. Computer Simulation Technology or better known as CST Software is used across the industries to accomplish challenging application areas [22]. It consists of several components that can be used for various range of industries . Among these components are namely CST Microwave Studio, CST EM Studio, CST Design

Studio, CST PCB Studio, CST Cable Studio and CST Particle Studio. In constructing a Dielectric Resonator Antenna (DRA) with Array, CST Microwave Studio will be utilized in designing the antenna.

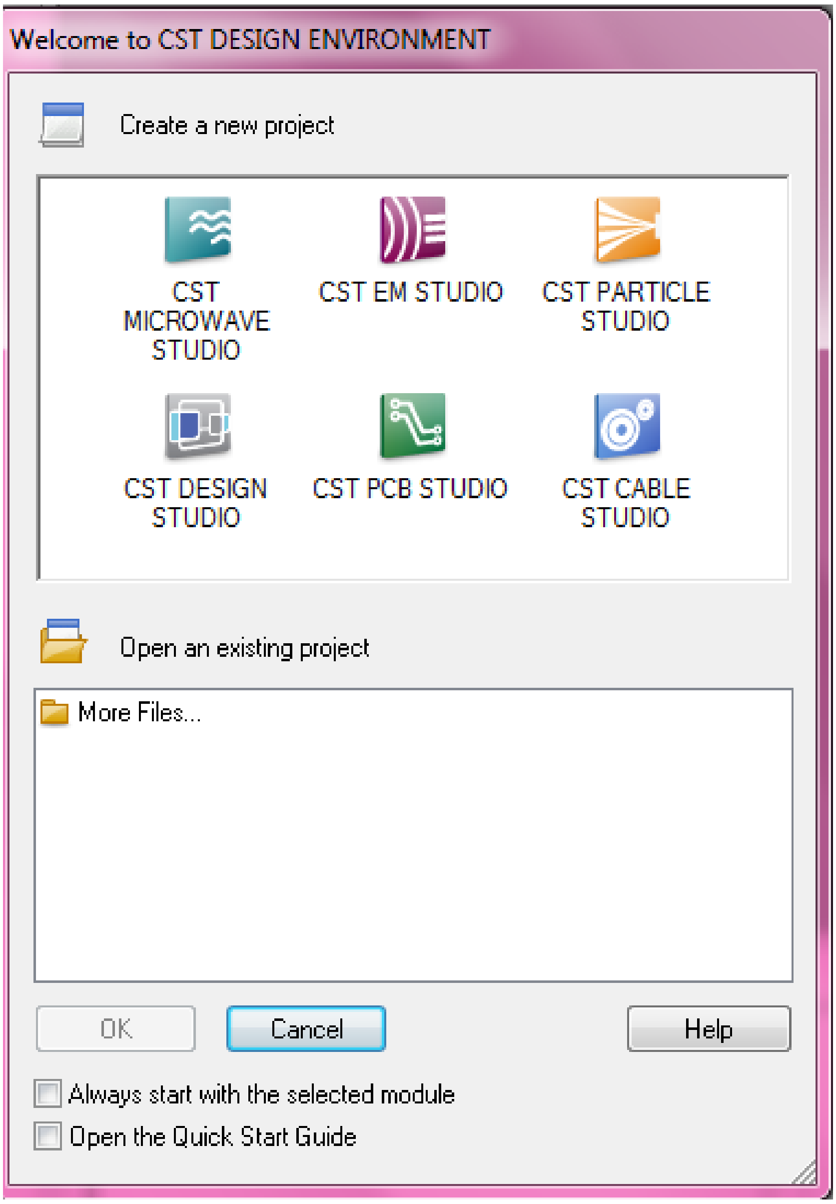


Figure 5: Popup Window to Create a New Project

Prior to designing the DRA, one must be able to master the basic skills of Computer Simulation Technology (CST) Software such as Geometric Construction Steps, Common Solver Settings, S-Parameter and Farfield Calculation and Patch Antenna Array.

To start designing a DRA with array, specific dimensions for each part of the design shall be determined first. A complete design consists of several layers such as substrate, ground, feed line, and slots for the DRA. The materials used for every layer is very crucial to ensure optimum performance of the antenna simulated. First, we define the substrate and ground layer. In this design, material FR4-Lossy with thickness of 1.6 mm is used for the substrate.

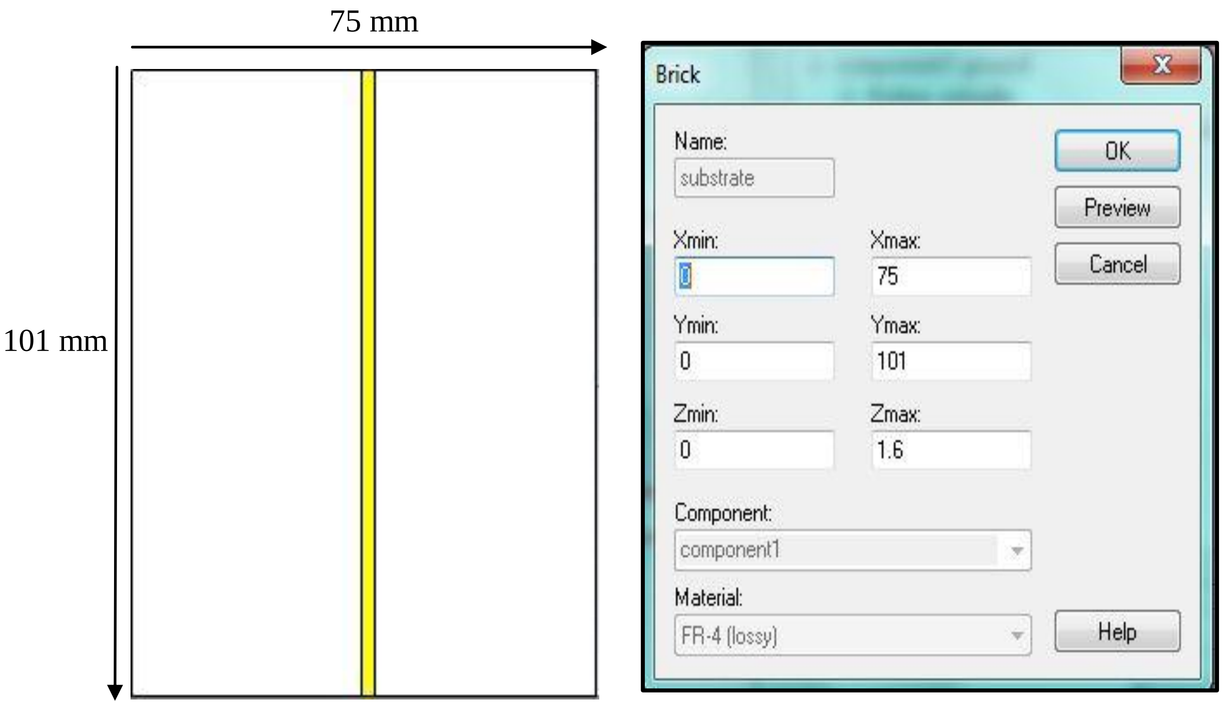


Figure 6: Substrate Layer and its Dimensions

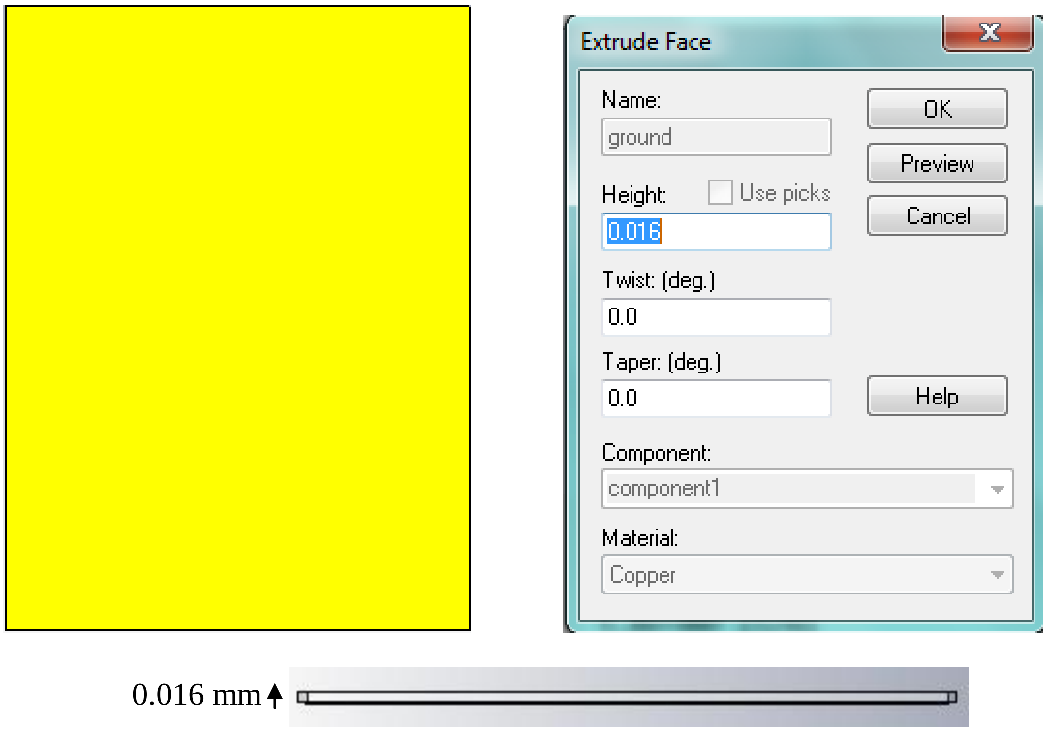


Figure 7: Ground Layer and its Dimension

Microstrip line is then chosen as the feeding mechanism due to its ease of fabrication and easy integration with circuits and other attractive features.

Figure 8: Microstrip Line and its Dimensions

Another useful feature that is added into this design is the addition of slots aperture in the ground plane to excite the DRAs [18]. In this design, three small rectangular slots are placed in the ground plane upon which the DRA is placed and fed by a microstrip line beneath the ground plane. The advantage of having this slot aperture coupling is to minimize the amount of spurious radiation beneath the ground plane and also to isolate the radiating aperture from any unwanted coupling from the feed [30]. However, precautions have to be taken in determining the length and width of the rectangular slots.

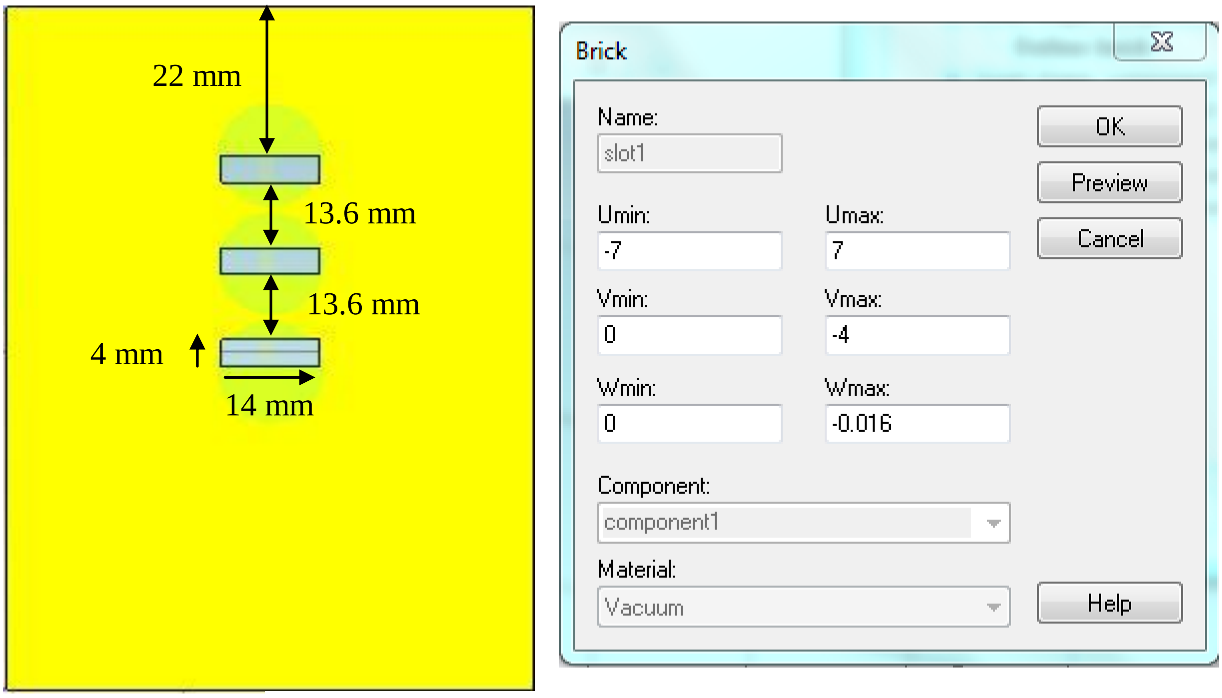


Figure 9: Adding rectangular slots on the board

Preceding the design after adding in the microstrip feed line and rectangular slots aperture, the DRAs will now be placed on top of the ground plane. Cylindrical Dielectric Resonator Antenna (CDRA) is chosen over other available shapes such as rectangular or hemispherical [20]. Their compact and small size of CDRA makes it ideal for use in filters especially when microstrip feed line is applied to the antenna. It also gives the designer a wide control over the most suitable dimensions for the DRA. The dielectric constant ε_r of 55 is chosen for this design.

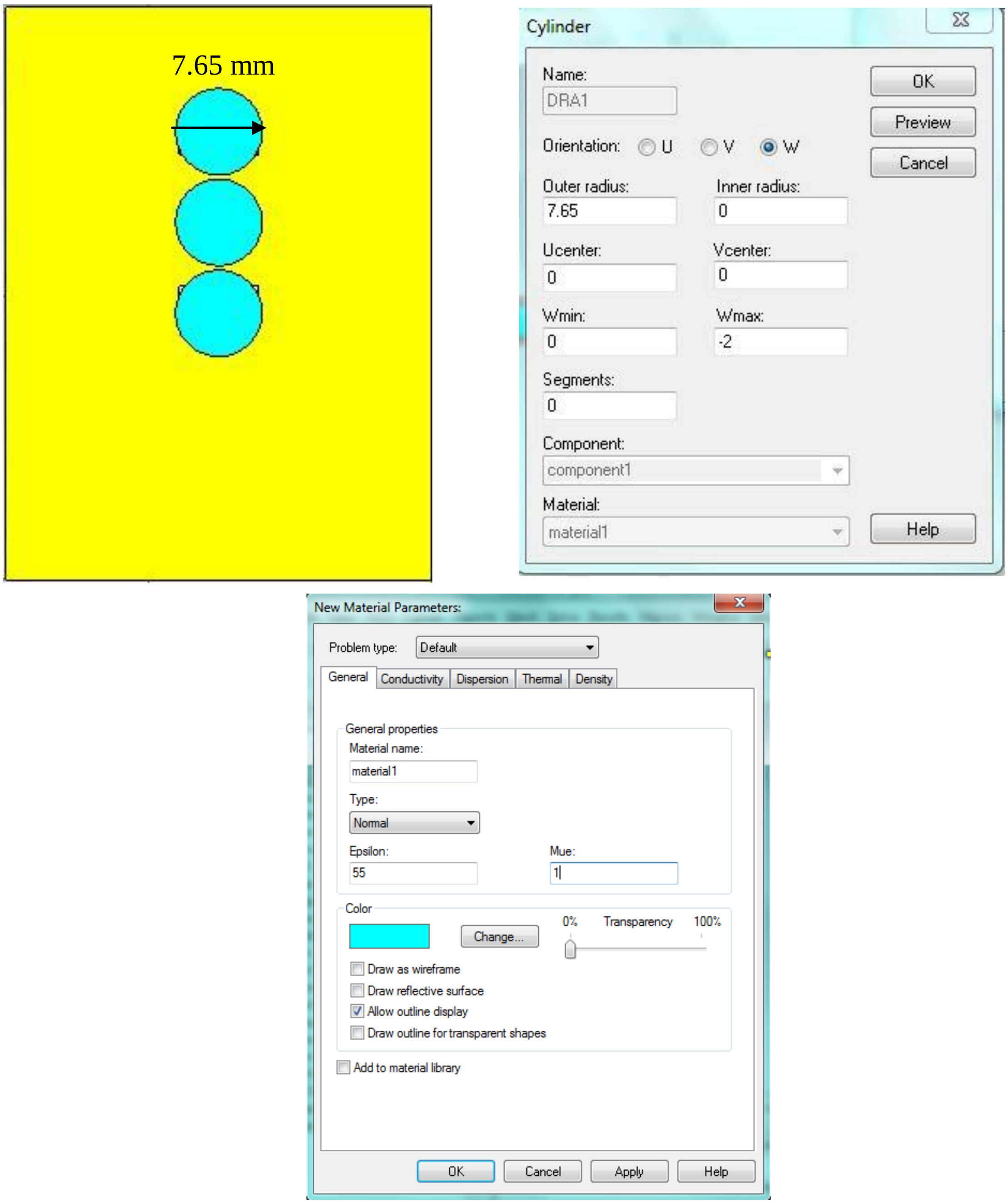


Figure 10: DRA with Array Layer

Once the constructions of layers are completed and port is created, the simulation shall be started. This will usually take a few minutes. Once the simulation is finished, the progress window will disappear and a simulation of a patch antenna using the transient solver is successfully created. The results can be viewed in 1D Results (Port Signals, S- Parameters) which will display the incident and reflected wave amplitudes at the waveguide port versus time.

Meanwhile, the primary result for the antenna is the S11 Parameter that will appears in |S| dB folder from the navigation tree. S11 Parameter is very crucial for determining the resonance frequency of the antenna. From here, we will begin adding up the antenna in array forms in order to produce a Dielectric Resonator Antenna (DRA) with Array.

3.2.4 Fabrication of Dielectric Resonator Antenna (DRA) with Array

Fabrication will be started once the design work is completed using Computer Simulation Technology (CST) Software. Desired specifications such as sizes and types of materials such as printed circuit board (PCB) will be measured and determined carefully. This is important to prevent any error during the cutting process. A PCB cutter is used to cut the PCB according to the measured size.

3.2.5 Test and Measurement of Antenna Performance

Test and measurement of antenna performance was started after the completion of fabrication. Upon attaching the port on the antenna, the measurement process is started with network analyzer and followed by spectrum analyzer. This testing and measurement process was conducted in the lab under the supervison of Mr. Adz Jamros. Network analyzer will be used to measure the S11 performance of the antenna meanwhile spectrum analyzer is merely focused on measuring the radiation pattern of the antenna in E-Field and H-Field.

3.3 Tools and Equipments

The fabrication processes requires several components and devices such as DRAs, PCB Board, SMA Connector, Spectrum Analyzer and Transceiver Modem. Figure 2 below shows the specifications of each components and devices.

Table 2: Tools and Equipment

Tools and Equipments	Specifications
PCB (75 mm x 101 mm)	Front side (FR4-Lossy), Back Side (Copper)
Cylindrical DRA (3 pieces)	Diameter = 7.65 mm, Height = 3 mm
SMA Connector	Etched to the microstrip line of the antenna
Transceiver Modem	
Spectrum Analyzer	
Reference Antenna (5 GHz)	Can cover up to 5.7 GHz

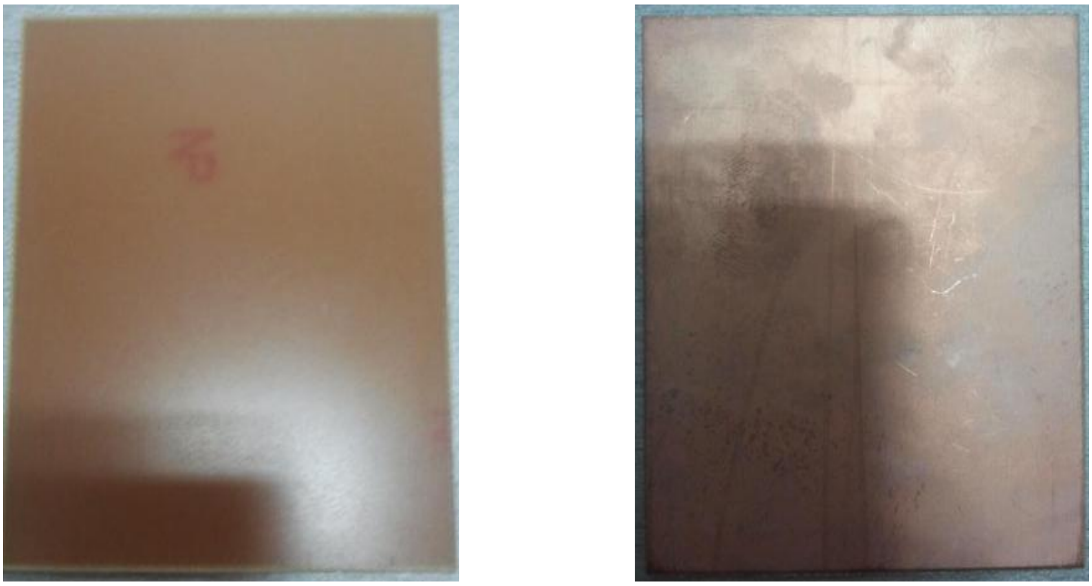


Figure 11: PCB Back Side (Copper) and Front Side (FR4-Lossy)

Figure 12: SMA Connector

Figure 11: Reference Antenna

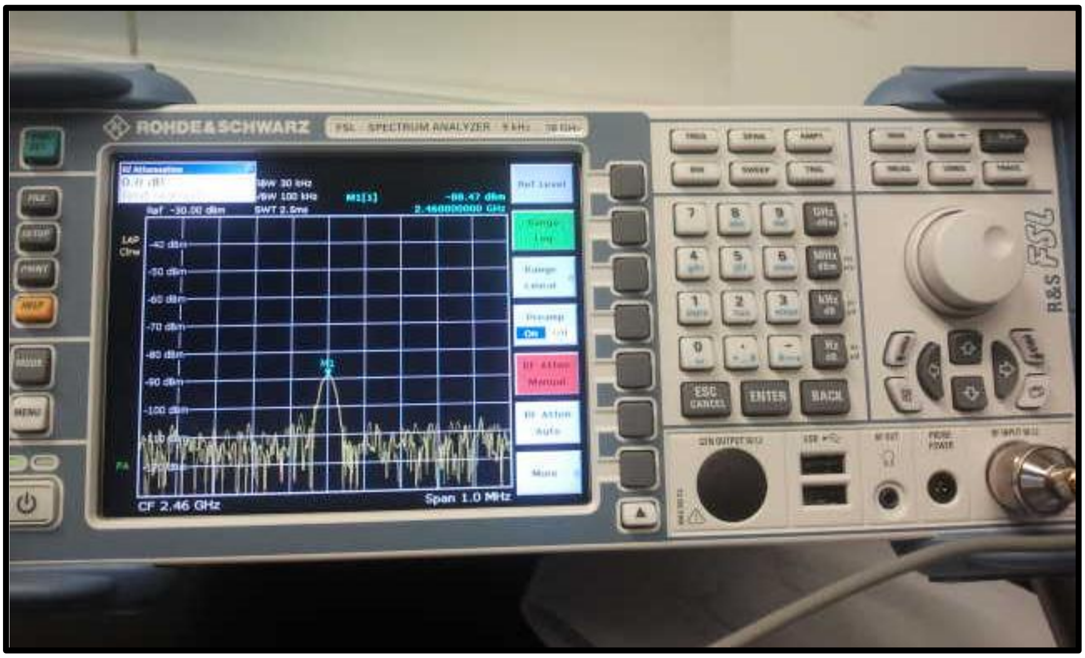


Figure 13: Spectrum Analyzer

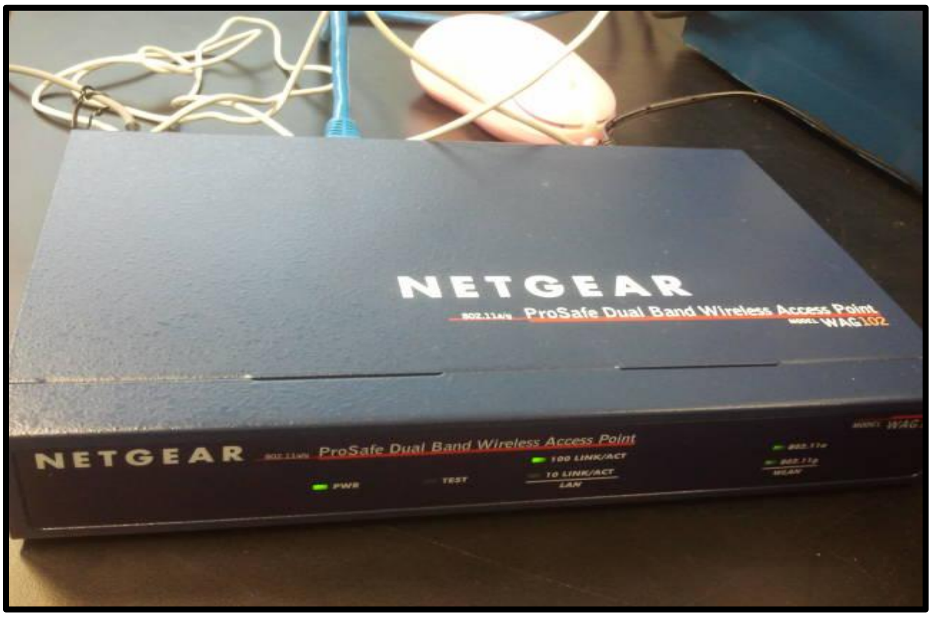


Figure 14: Transceiver Modem

3.3.1 Printed Circuit Board (PCB)

PCB is used as the most crucial part of the antenna. As mentioned earlier, FR4-Lossy with dielectric constant of 55 has been chosen as the material for substrate whereas copper will be used for the back side of the PCB. PCB is commonly used due to its several advantages such as ease of manufacture, better reliability for long life cycle, low cost and also its compact size [23].

3.3.2 Cylindrical DRA

Three cylindrical DRA [24] with the same dimension will be used for the antenna array. These three cylindrical DRA will be arrayed in a vertical position with specified distance between each other. A dielectric constant of 55 is used for the material of the DRA [29].

3.3.3 Spectrum Analyzer

A spectrum analyzer is basically used in wide area of applications throughout the industry. Its main function is to measure the power of the spectrum. In this case, spectrum analyzer is used to calculate the amount of power received for every change in the position of the antenna [25-26]. As the antenna is being rotated from an angle to another angle, the power reading will be recorded to measure the ratio of power transmitted and power received. Through here, the amount of power loss dissipation can also be calculated.

3.3.4 Transceiver Modem

Transceiver is a device or tool that can be used to transmit and receive the signal. The primarily use of transceiver is intended for communication systems where it can provide an interface or medium between the protocol controller and the physical bus in a network [27].

3.4 Project Schedule and Milestone

The Gantt Chart of Final Year Project I is shown as follows:

Table 3: Gantt Chart of Final Year Project I

ACTIVITIES	FINAL YEAR PROJECT I													
	WEEK NO.													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research on literature review of DRA with Array														
Study on CST software														
Designing DRA with Array using CST														
Report Writing														

The expected Milestone of Final Year Project I is shown as follows:

Table 4: Milestone of Final Year Project I

NO	**ACTIVITIES**	**DATE**
1.	Completion of literature review and	Week #7
2.	Completion of study on CST software	Week #9
3.	Completion of design DRA with Array using CST	Week #14
4.	Completion of documentation	Week #14

The Gantt Chart of Final Year Project II is shown as follows:

Table 5: Gantt Chart of Final Year Project II

ACTIVITIES	**FINAL YEAR PROJECT II**												
	WEEK NO.												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Fabrication of the proposed design													
Testing and simulation of the constructed design													
Evaluation and analyze the performance of the constructed design													
Documentation													

The expected Milestone of Final Year Project II is shown as follows

Table 6: Milestone of Final Year Project 2

NO	ACTIVITIES	DATE
1.	Completion of fabrication of the proposed design	Week #5
2.	Completion of testing and simulation of the constructed design	Week #10
3.	Completion of evaluation and analyze the performance of the constructed design.	Week #12
4.	Completion of documentation	Week #13

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Antenna Design

Throughout FYP 1, focus was emphasized on mastering the basic skills of CST before starting to create the finalized design for fabrication. Many designs has been constructed and simulated through trial and error processes to get familiar with the skills in antenna design. Figure 15 shows the finalized design of DRA with array. This linear array consists of 3 cylindrical dielectric resonator antennas (CDRAs) arranged in an array to acquire higher gain.

The design is started by creating a brick with a length (*L*) of 101 mm, width (*w*) of 75 mm, and height (*h*) of 1.6 mm as the substrate. FR4-Lossy is the material that is used for the substrate. This is followed by the ground plane which is placed behind the substrate. The ground plane will be fabricated using copper material with a length (*L*) of 101 mm, width (*w*) of 75 mm, and height (*h*) of 0.016 mm. This usage of copper and lossy material has its own advantage of minimizing power loss dissipation and higher reliability. The microstrip line is placed at the front side of the antenna with the same dimensions as the substrate and ground.

Each of the CDRA has a diameter of 7.65 mm and height of 2 mm using FR4 Lossy with a dielectric constant of 55 as the material. These 3 elements CDRAs is arrayed and separated from each other with a distance of 16 mm from the top of the cylinder. Three rectangular aperture slots with length (L) of 14 mm and width (w) of 4 mm are used to excite the three CDRAs. These three CDRAs are located at the back side of the board. The distance between each rectangular slot is 13.6 mm and the first slot is located at a distance of 22 mm from the top of the board.

The design with the specific dimensions was constructed in CST Software. Port is added to the design and frequency range is set. The simulation will usually takes a few minutes before the S11 Parameter and Farfield is created. Field monitors were set to several different frequencies thus making it easier for comparison of S11 Parameter and directivity for each frequency. Only then, we will be able to determine the best resonance frequency that has return loss below -10 dB.

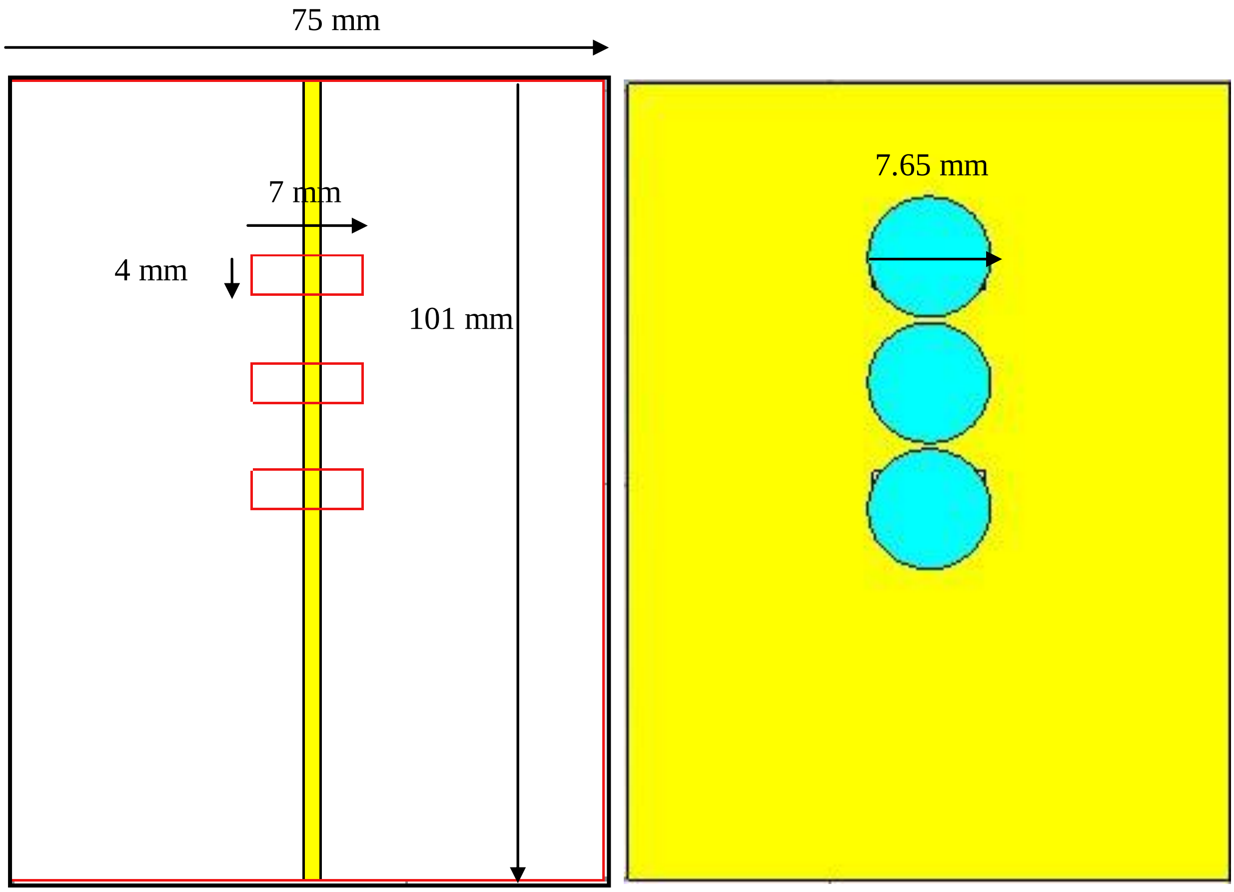


Figure 15: The dimension of antenna

4.2 Fabrication

Earlier this semester, in Week 2, the designs that need to be fabricated were sent to the PCB Lab in Block 22 under the supervision of Mr. Hasrul, the technician in charge. Approval from the supervisor and lab executive is acquired before sending in the design for fabrication process. The materials for the board were also identified and determined. FR4- Lossy is used as the materials for substrate and copper for the ground. Periods of 2 weeks were needed to complete the fabrication process.

Before submitting the design, I needed to convert the design from CST Software into Geber File form. Holes were added into the design as a requirement for Geber File format. It is very crucial to ensure the dimensions in Geber File is the most accurate one since Geber File is the main reference that will be used by the technicians in charge to fabricate the board.

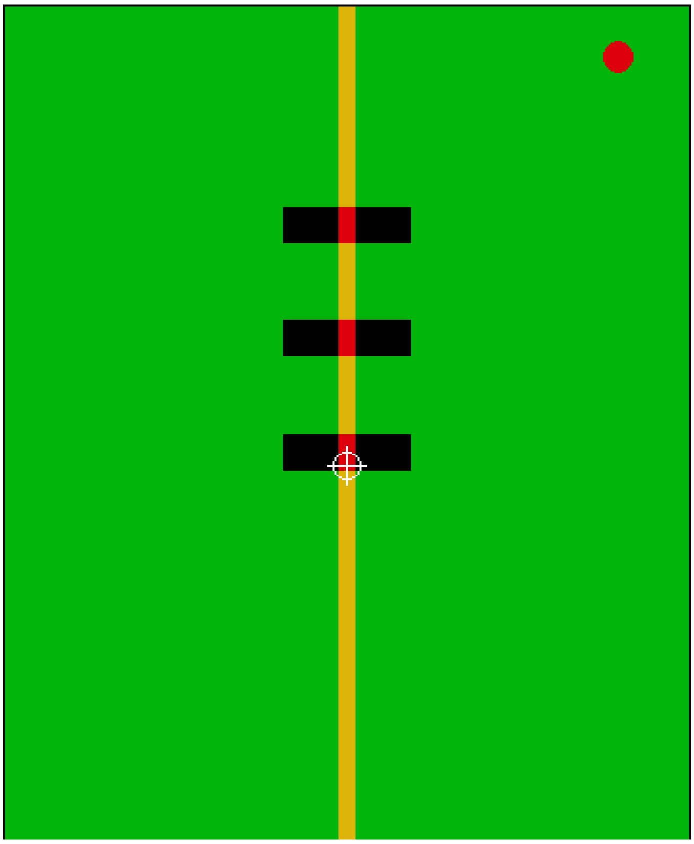


Figure 16: The antenna in Geber File form

After two weeks, the fabricated board was ready for collection.

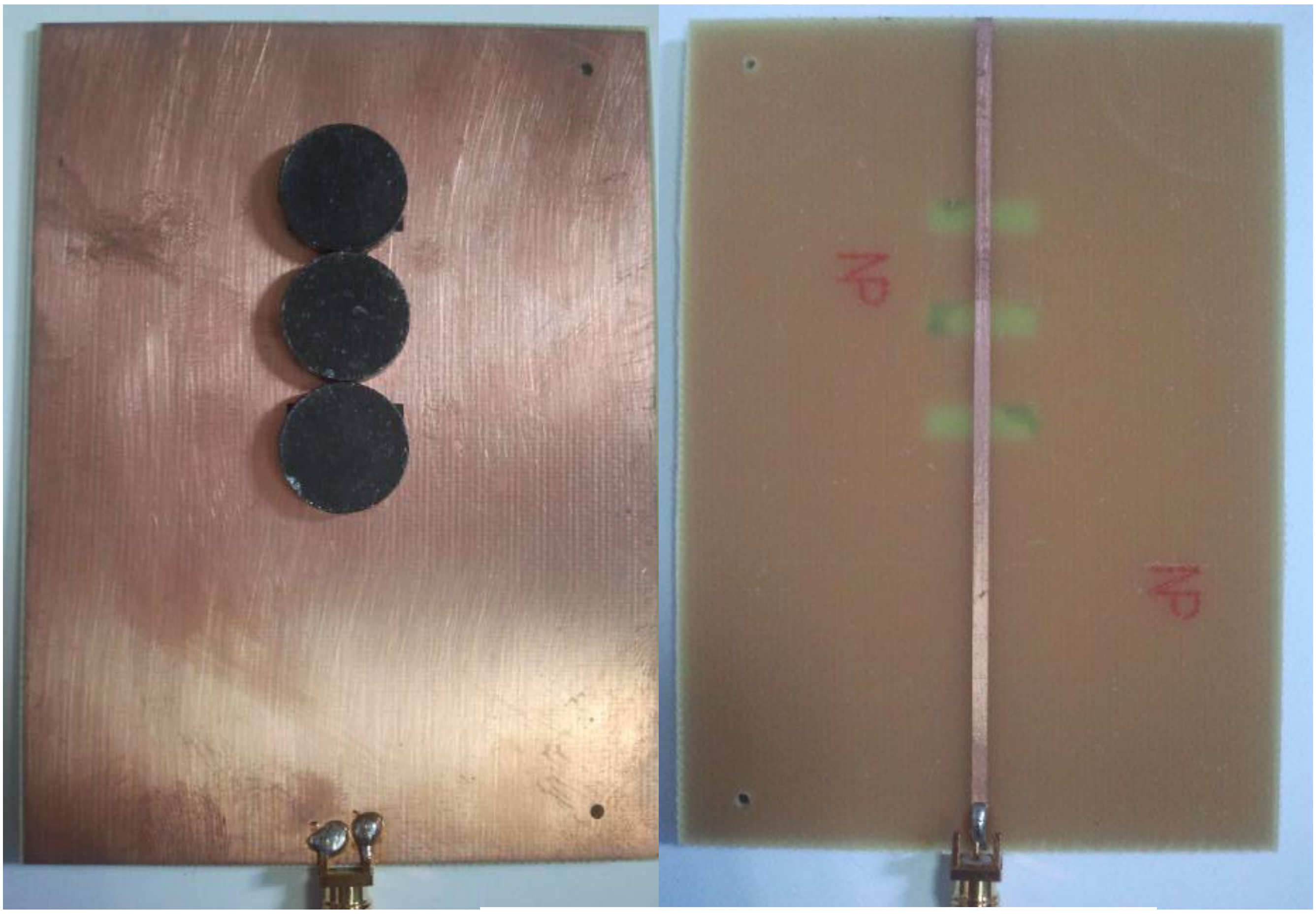


Figure 17: The fabricated antenna

4.3 Testing and Simulation Process

4.3.1 Network Analyzer Testing

The testing and simulation of the constructed design were started during Week 7. Network analyzer is designed to measure the s-parameters of electrical networks. In this case specifically, network analyzer is utilized to measure the S11 Parameter of the constructed antenna. A resonant frequency of 5.24 GHz was obtained after several trials.

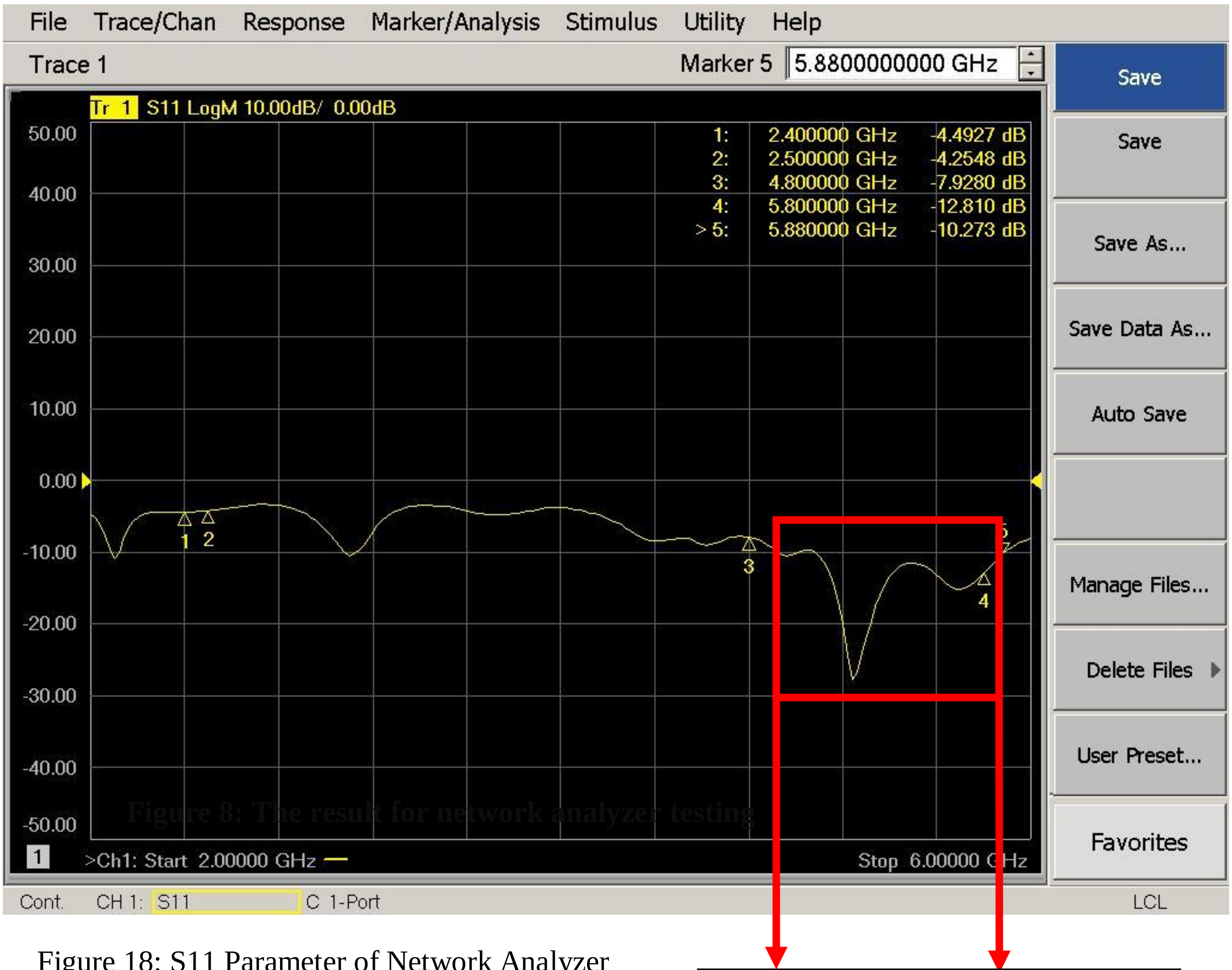


Figure 18: S11 Parameter of Network Analyzer

Bandwidth for Network Analyzer:

5.88 GHz – 5.14 GHz = **0.74 GHz**

4.3.2 Bandwidth

As mentioned earlier in this report, the main objective of the antenna is to produce a wide bandwidth antenna to suit the necessity of high data rates. An antenna is considered as a wideband antenna if the message bandwidth is larger than the channel's coherence bandwidth. Thus, it is desirable to obtain a large bandwidth when the antenna is tested using network analyzer as above. Bandwidth is calculated as the range of frequencies that has a return loss of below -10 dB.

4.3.3 Return Loss

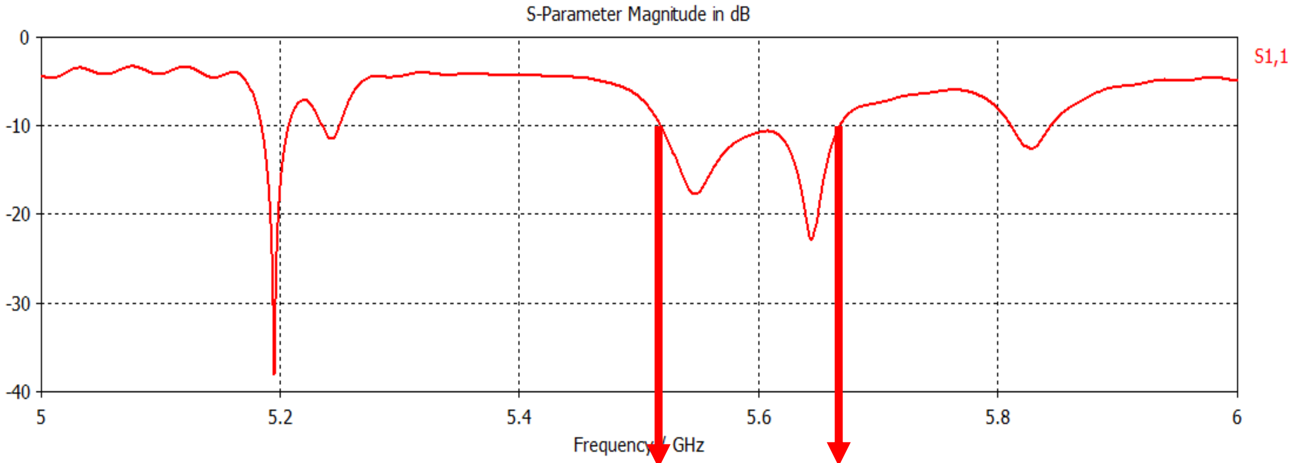
Return loss is the measurement of the ability of the receiving end to absorb the transmitted signal. Some of the signal will be reflected back where this signal will create interference that leads to error in measurement. The S-parameter (scatter matrix) will be used to calculate the magnitude of the loss signal where the x-axis shows the frequency when the highest magnitude of the loss signal occurred. This result gave the highest return loss in dB of -27.7264 dB at 5.24 GHz. The simulated value is still acceptable because it is still lower than -10dB which is the reference value for an antenna to start transmitting signal.

Freq(Hz)	S11(DB)
5.14E+09	-12.594075
5.24E+09	-27.726381
5.34E+09	-17.681082
5.44E+09	-12.149169
5.54E+09	-11.850219
5.64E+09	-14.489126
5.74E+09	-14.756117
5.84E+09	-11.485115
5.86E+09	-10.86223
5.88E+09	-10.320196

Figure 19: S11 Parameter Measurement

4.4 Simulation Result for S11 Parameter

The simulation result is compared as below:



Bandwidth in CST Simulation:

5.697 GHz – 5.495 GHz = **0.148 GHz**

Figure 20: The Simulation Result for S11

4.4.1 Comparison between Simulation and Measurement

From the graph obtained using simulation in CST Software, we found out that the bandwidth is 0.21 GHz and the maximum return loss for simulation is -26.2033 GHz at 5.34 GHz which is quite similar with the network analyzer measurement. However, there exist some differences between the reading obtained during simulation in CST Software and measurement processes using Network Analyzer. This comparison is shown in Figure 22 below. The differences between the bandwidth of network analyzer and the bandwidth of CST Simulation are depicted as below:

Bandwidth in CST Simulation:

5.697 GHz – 5.495 GHz = **0.148 GHz**

Bandwidth for Network Analyzer:

5.88 GHz – 5.14 GHz = **0.74 GHz**

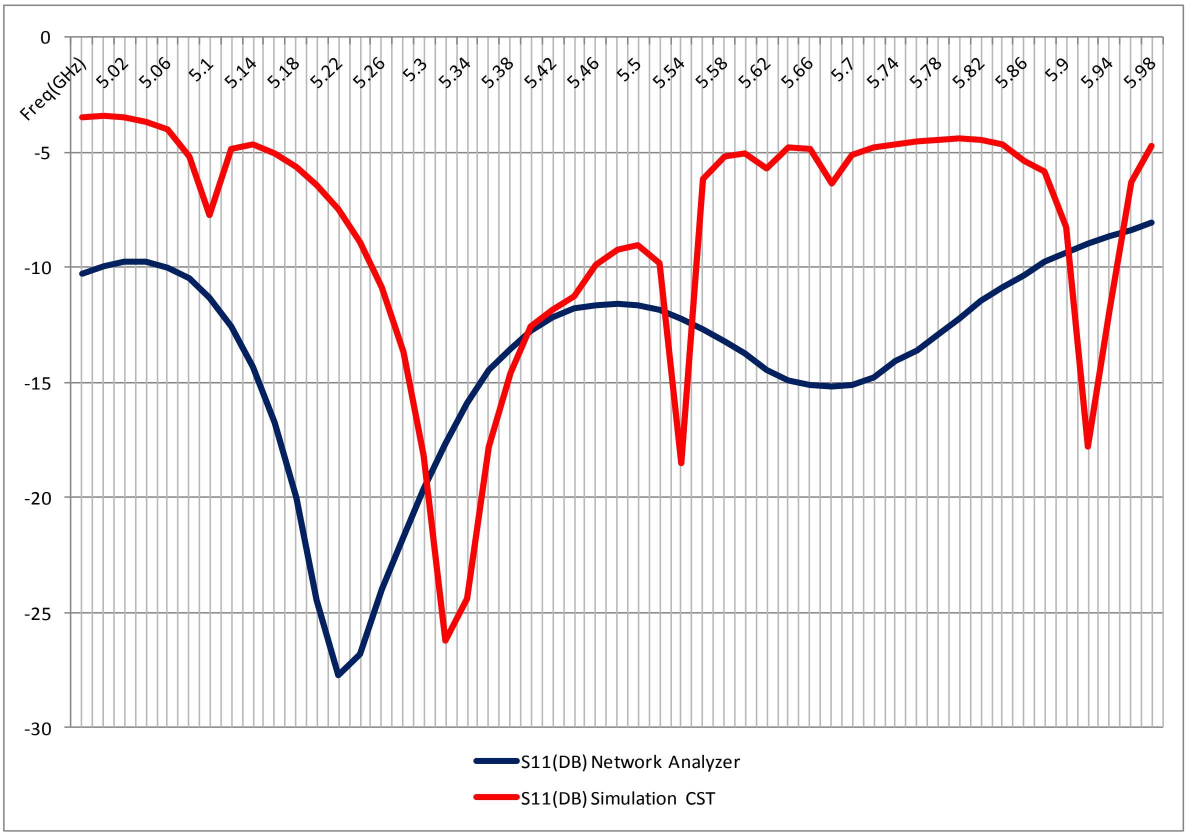


Figure 19: Comparison between the S11 of Network Analyzer and S11 of CST Simulation

There exist differences of about 0.5 GHz between the bandwidth measured using network analyzer and bandwidth in CST Simulation. There are some losses that occurs between fabrication and simulation. Return loss for both simulation and fabrication is below -10 dB but there are some fabrication losses that have caused some ripples above -10 dB. Error such as the unequal surface of DRA might leads to air gap that might interfere the results. Further studies will be conducted to clarify the differences between the two readings.

4.5 Spectrum Analyzer Testing

Moving on to the next stage, testing using spectrum analyzer was conducted to obtain the radiation pattern in both E-Field and H-Field. This is determined through radiation pattern obtained using spectrum analyzer. It will consists of several lobes that represents the main lobe, side lobe and back lobe.

These procedures are done by securing the antenna on a tripod with adjusted height and distance from another tripod that is used to hold the transceiver modem as shown in the picture below. The antenna is rotated using the antenna's positioning system. In obtaining the radiation pattern, spherical coordinates is used as the coordinate system of choice where the antenna's angle is adjusted from 0 to 360 degree and the reading for every position is recorded.

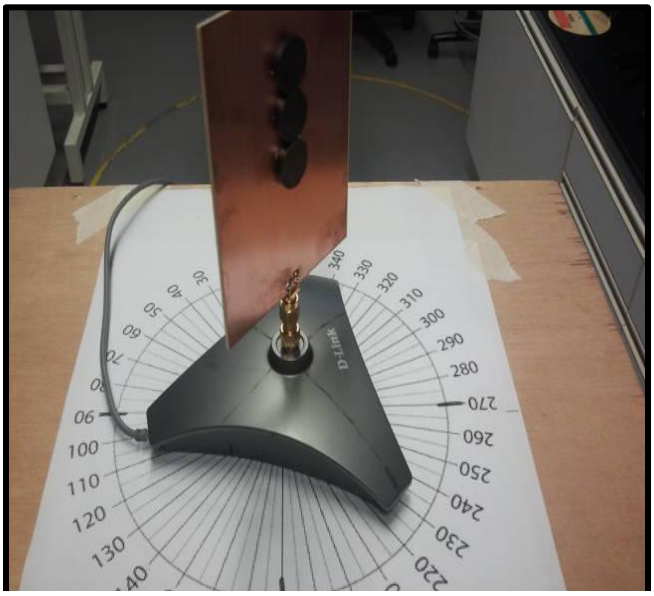


Figure 20: The Antenna which is Rotated Using Spherical Coordinates from 0 to 360 Degree

Figure 21: The Antenna is Placed On Top of A Tripod.

4.6 Result for E-Field and H-Field

In simulation result, farfield is used to produce the radiation pattern at several frequencies. Since the DRA is directional, the maximum radiation should be directed at one lobe. Meanwhile, backlobe will contain the lowest radiation. The side that is in the same direction with the antenna's directivity will create the maximum radiation strength. By setting field monitors from 5 GHz to 6 GHz, the radiation pattern for each frequencies can be seen. For example, as the figure shows, in this simulation several frequencies were set to observe the radiation pattern.

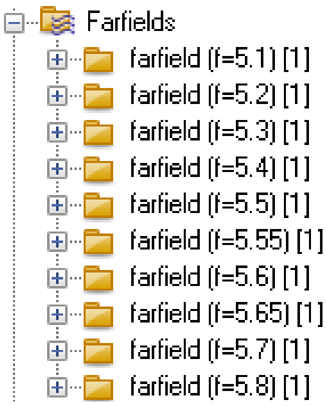


Figure 22: Farfield Range Frequencies.

For E-Field, the main lobe magnitude is 8.73 dBi.

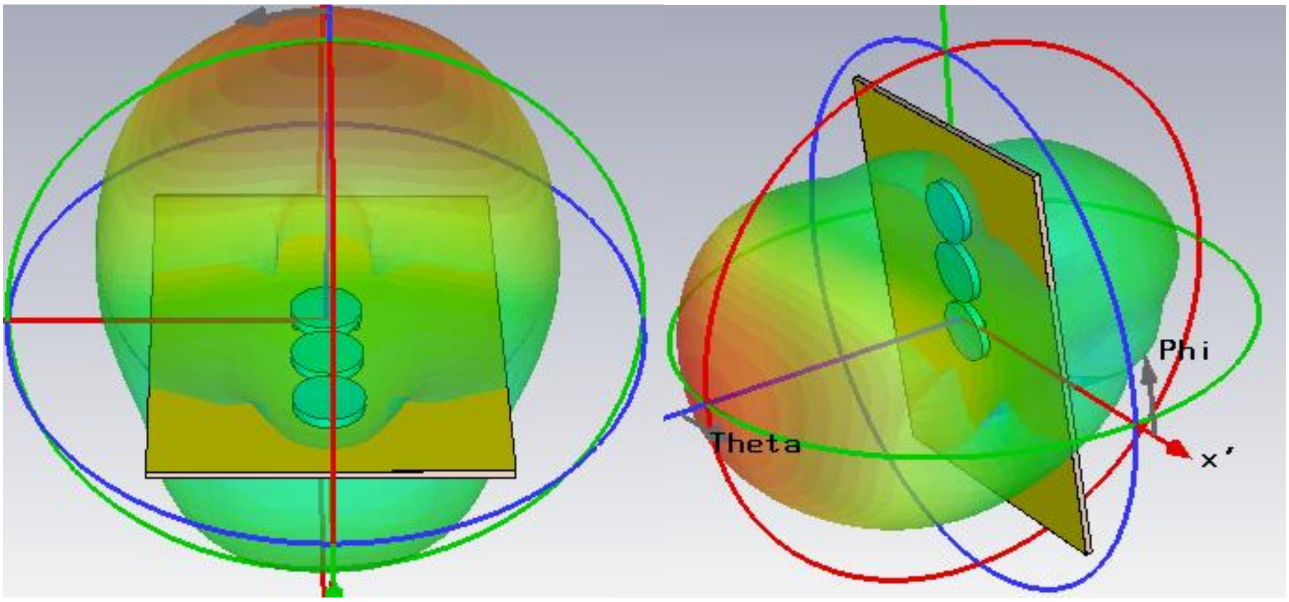
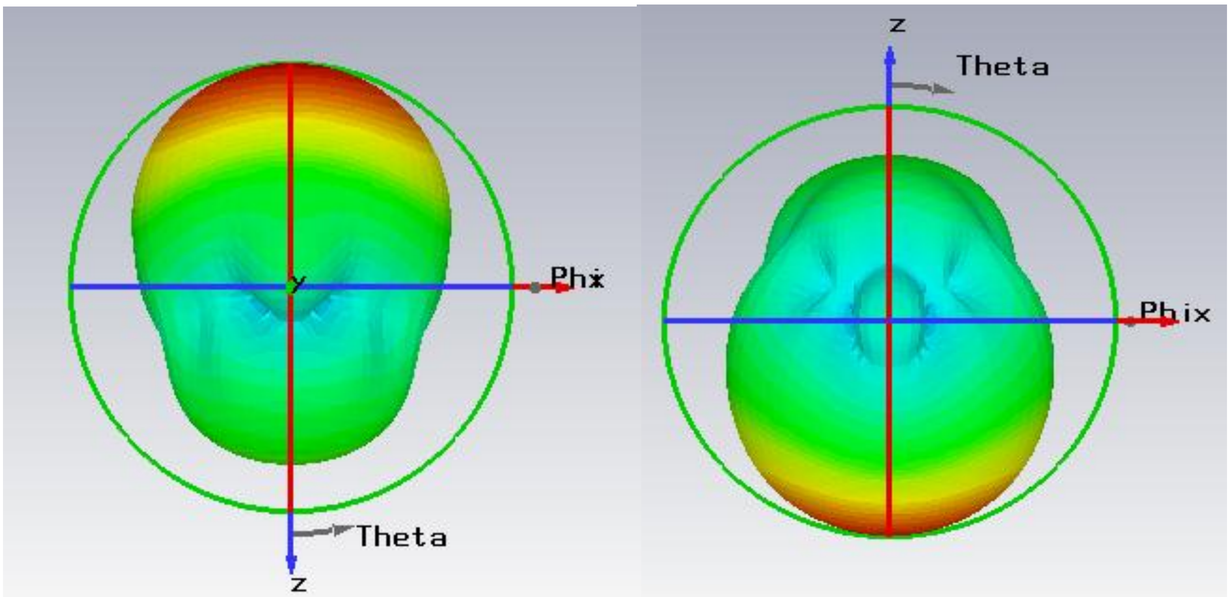
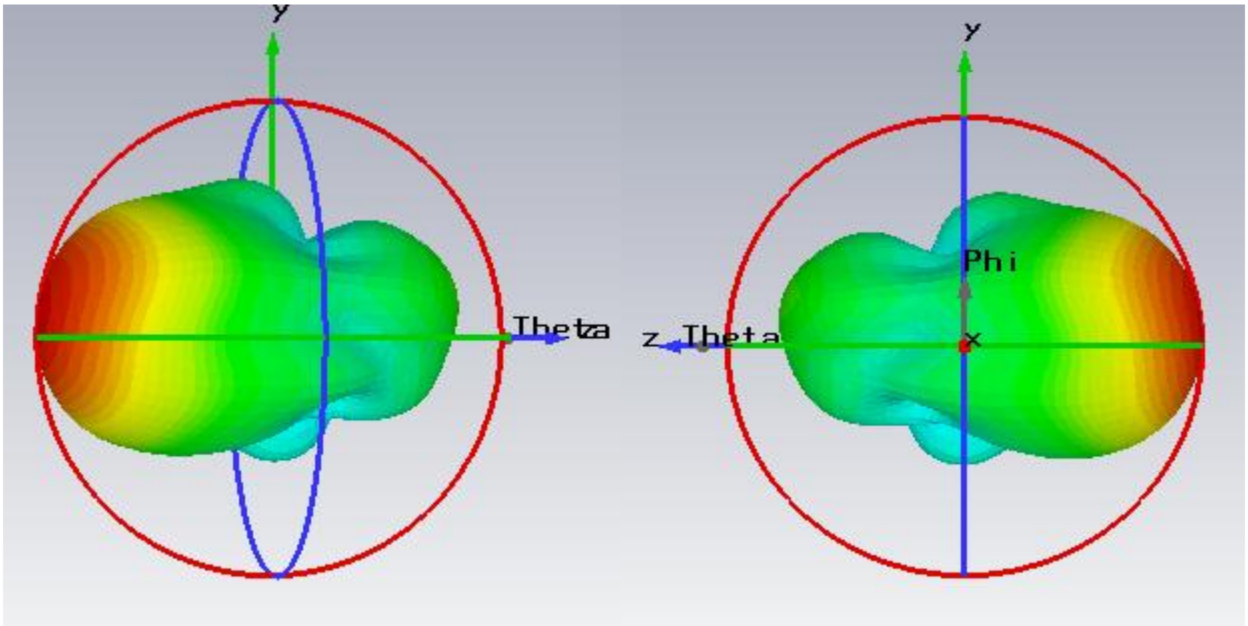


Figure 22: The Radiation Pattern of E-Field 3D (Top and Side View)

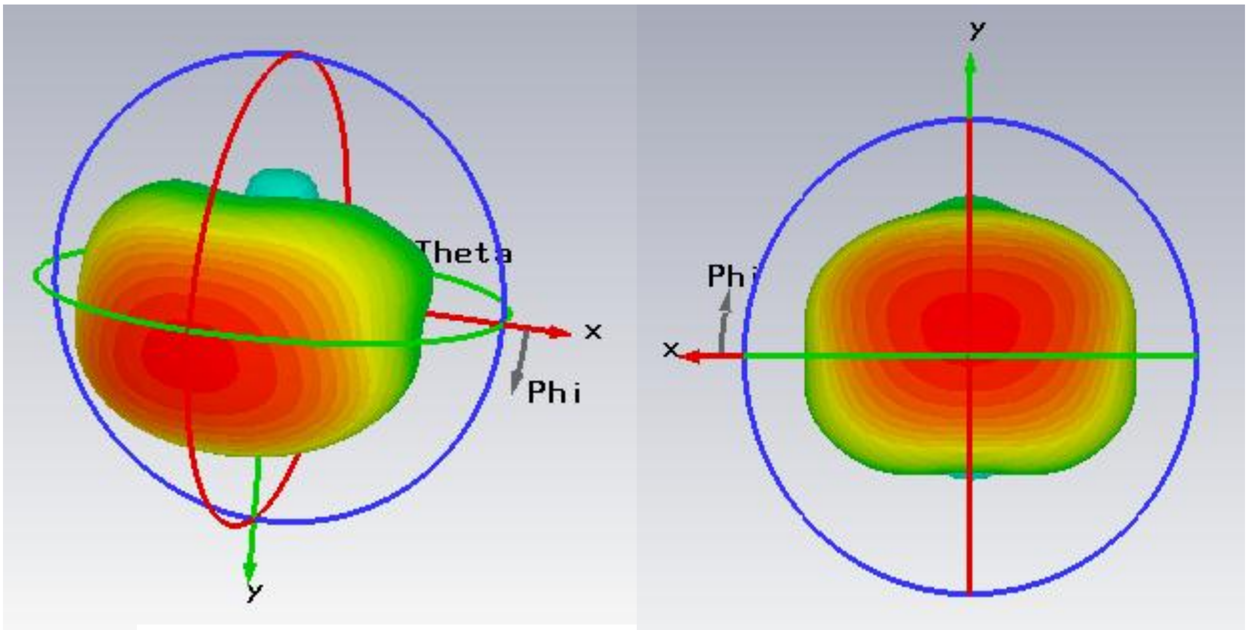
To make it clearer, Figure 24 below shows that the red region area has the strongest radiation indicating a main lobe in one direction. This clearly shows that this antenna is a directional antenna with main lobe and another side lobe.



(a)



(b)



(c)

Figure 23: Radiation Pattern in E-Field Result (a) Top and Bottom View, (b) Right and Left View, (c) Clearer View

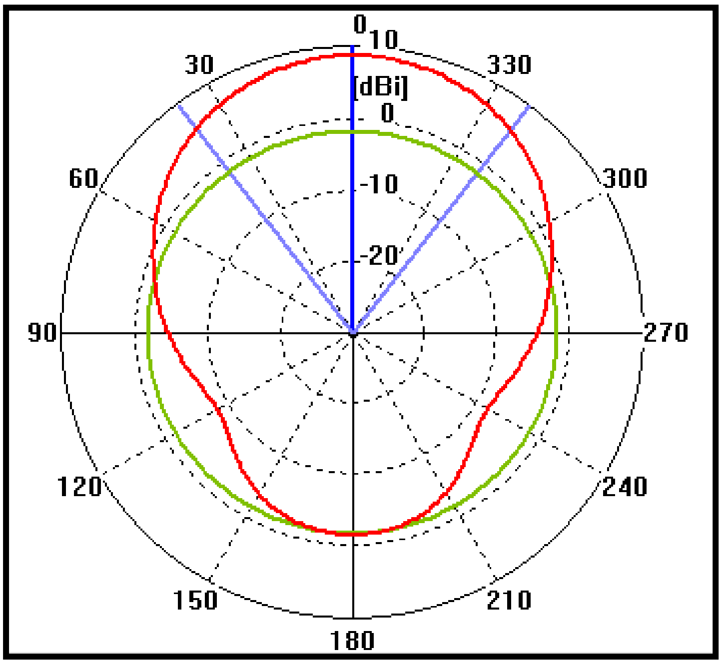


Figure 24: Radiation Pattern in E-Field Result

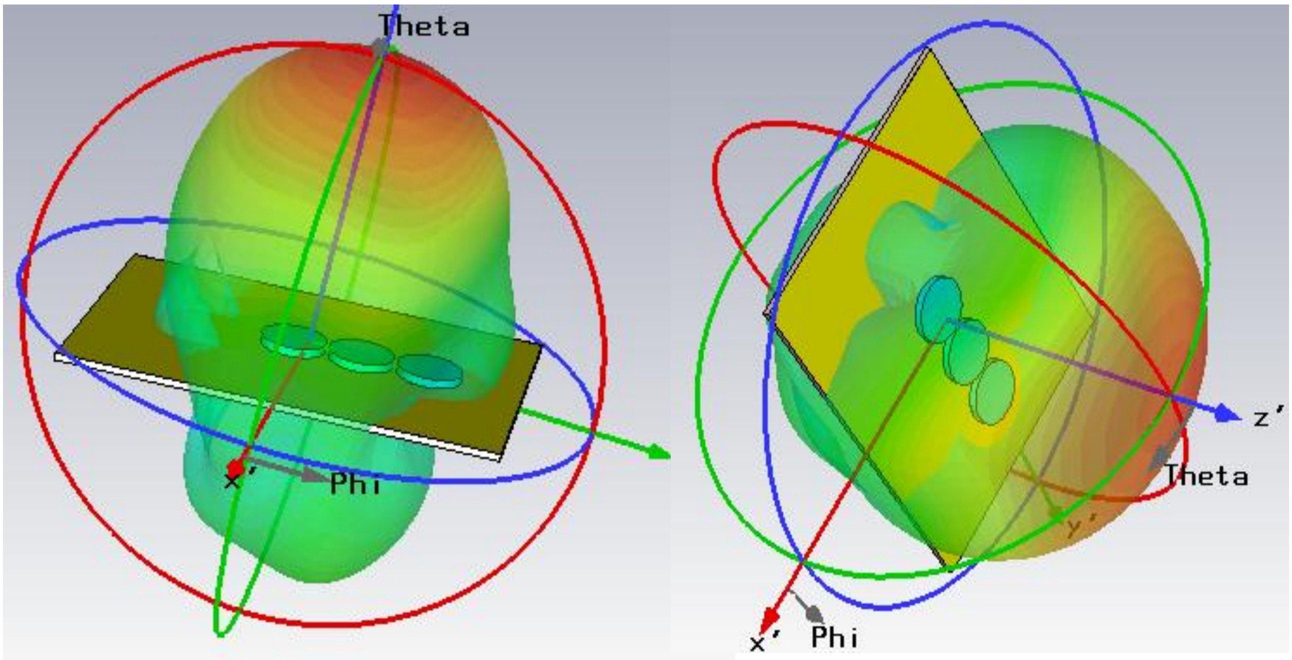


Figure 25: Radiation Pattern in H-Field 3D Result (Top and Side View)

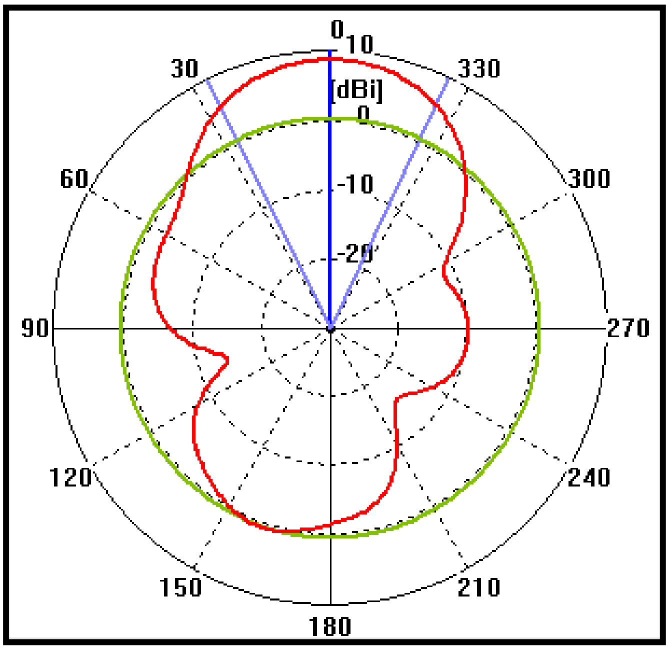


Figure 27: Radiation Pattern in H-Field Result

From here, we can observe that the signal strength is at its highest point when the DRA is facing the antenna. E-Field is defined as the direction in which the antenna radiates its highest power. During simulation, several frequencies have been set and the radiation pattern of E-Field and H-Field at each frequency is observed. Figure below shows the best radiation pattern from the range of frequencies that has been tested. The red region area signifies the region which has the maximum radiation. Since this is a directional antenna, it contains one main lobe and a few sidelobes as shown in the figure. This main lobe is in the same direction as the antenna's directivity while the side lobe is due to the slots radiation in the opposite direction.

4.7 Discussion

Throughout the process of completing the project, many trials and error processes has been done. In order to get the best dimensions for every layer and structure in the antenna, analysis on the factors that affect the performance of antenna ahs to be studied thoroughly. For example, there are several aspect that needs to be looked into in determining the most ideal slot length *(L)* and width *(w)* to be used in this design.

The length of the slots should be suitable to produce a sufficient amount of coupling between the DRA and feed line whereas the width should be narrow enough to reduce the size of back lobe in the antenna performance. The length l_s and width w_s are both determined using these two equations:

$$l_s = \frac{0.4\ \lambda_o}{\sqrt{\varepsilon_e}}$$

$$w_s = 0.2\ l_s$$

Other than that, comparison on the slots position and distance between slots must also be taken into consideration. Several comparisons of slots size and S11 Parameter is shown below. Based on the comparison that has been conducted, it is observed that there are significant differences when different parameters are used for slot length, position and distance between slots. After several trials, 7 mm and 4 mm has emerged as the best slots dimension that provide the widest bandwidth of 0.202 GHz.

For slots with length *(L)* = 8 mm and width (*w*) = 5 mm,

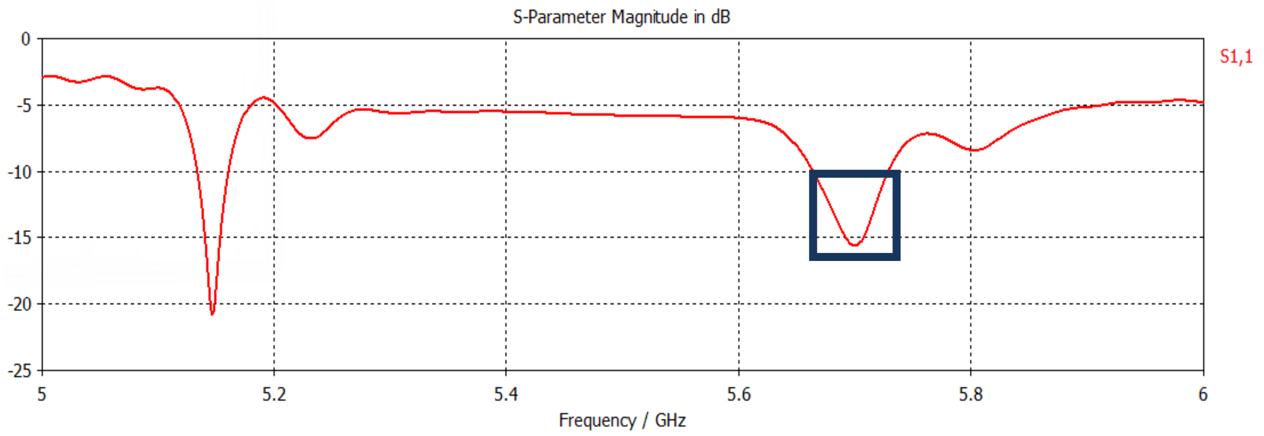


Figure 28: S11 Parameter for Length (L) = 8mm and Width (w) = 5 mm

For slots with length *(L)* = 9 mm and width (*w*) = 5 mm,

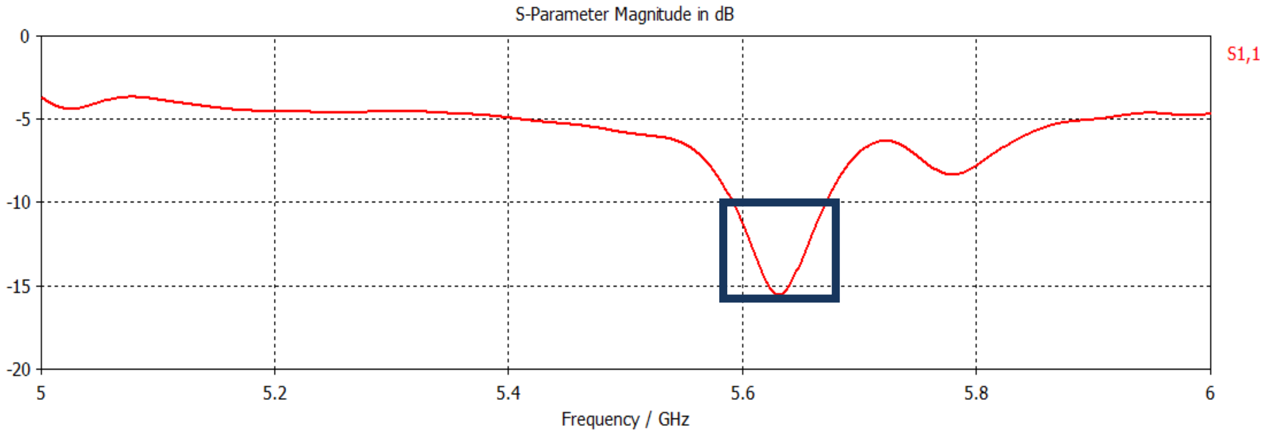


Figure 29: S11 Parameter for Length (L) = 9 mm and Width (w) = 5 mm

For slots with length *(L)* = 10 mm and width (*w*) = 5 mm,

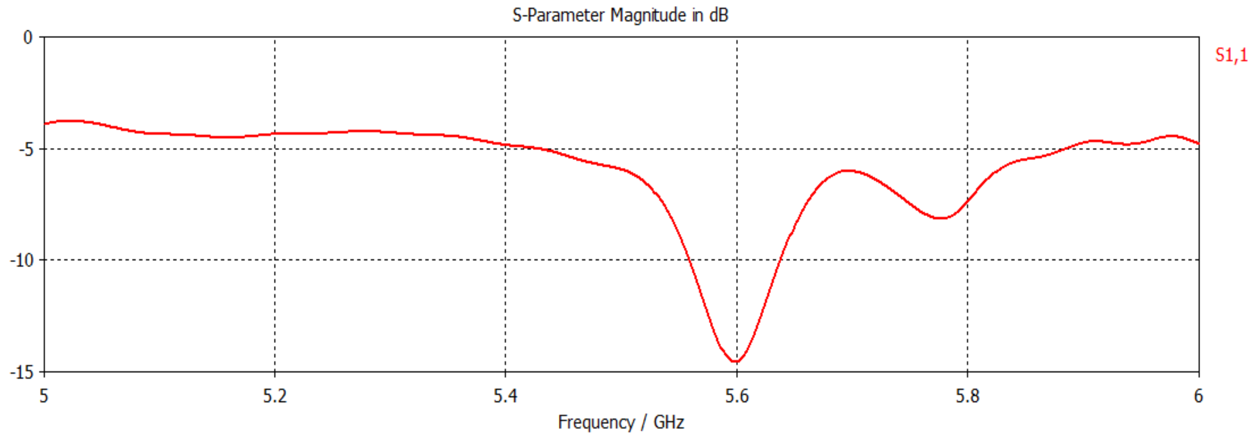


Figure 260: S11 Parameter for Length (L) = 10mm and Width (w) = 5 mm

The result is summarized in the following table which indicates length of 7 mm and width of 4 mm is the most ideal dimension.

Length (*l*) of Slots (mm)	**Width (w) of Slots (mm)**	**Bandwidth (GHz)**
7	4	0.148
8	5	0.063
9	5	0.078
10	5	0.078

Table 6: Results for Several Distances from Top of Substrate

From here, we can see that different parameters in every single aspect will lead to different result. Thus, it is crucial to get the best parameters before start fabricating the antenna. Using this value, observation on distance of slots from the top of substrate is conducted and it is found out that a distance of 22 mm exhibits the widest bandwidth as compared to 24 mm and 26 mm. Other than that, distance between slots is the most ideal at a distance of 13.6 mm. therefore, this dimension of 7 and 4 mm at a position of 22 mm from the top of substrate with 13.6 mm distance between slots is used in this article for the fabrication process.

Distance from Top of Substrate (mm)	Bandwidth (GHz)
22	0.148
24	0.089
26	0.008

Table 7: Results for Several Distances from Top of Substrate

Distance between Slots (mm)	Bandwidth (GHz)
12.6	0.057
13.6	0.148
14.6	0.114
15.6	0.03

Table 8: Results for Several Distances between Slots

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

In order to design a perfect antenna, every single details of measurement have to be calculated in details. This is crucial in order to produce an idea antenna that can be fully utilized in wireless application for the market. In this project, the antenna has managed to achieve resonance frequency of up to 5.34 GHz with directivity of 8.8 dBi. However, there are several differences between the results from the measurement process and also from the simulation process. This might be caused by the power loss that might have occurred during the fabrication process. Some error that occurs might also lead to these differences. Further analysis should be done in future to enhance the parameter of the antenna to obtain a better performance antenna.

RECOMMENDATIONS

There are some recommendations to this project that need to be highlighted so that the project can be completed successfully. For the project improvement, the recommendations are:

- During measurement using spectrum analyzer, some difficulities occurs because there are quite a lot of interfering signals in the lab. Thus, the necessity of having a wide area room that can absorb the signal with minimize interference is very important for the measurement process to run smoothly.
- Students have to rotate the antenna array manually from every degree to another degree. This might pose some risks of inaccuracy since the angle might be slightly adjusted. therefore, it would be very helpful to have an automatic device that can rotate the antenna for every degree precisely. This is important so that the most accurate result can be obtained.

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