# THE DEVELOPMENT OF DUAL BAND CYLINDRICAL DIELECTRIC RESONATOR ANTENNA

By

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for the Degree
Bachelor of Engineering (Hons)
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# CERTIFICATION OF APPROVAL

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Electrical & Electronics Engineering Programme
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Approved:

______________________________

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May 2014

## 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.

______________________________

Khairiah Binti Ramli

# ABSTRACT

Antenna with ability to operate in dual band frequency is among famous research and manufacturing product. It can work efficiently and compatible with current technologies devices. Throughout this paper, a design of cylindrical dielectric resonator antenna (DRA) is produce by manipulating the aperture coupling technique. The aperture coupling technique used is C-shaped slot and the parameter that varies is the position and dimension of the C-shaped slot. The constant parameters in this project is the size and the length of the microstrip feeder line which act as the transmission line for the signals and also the size of cylindrical DRA which function to radiate the signals. The results will be analyzed based on the resonant frequency impedance bandwidth, return loss, and radiation pattern. The desired antenna design must achieve the objective, which is to operate at dual band frequency 3.6 GHz and 5.2 GHz. The effect of tuning the slot positions and dimensions on the resonant frequency are also investigate and discussed.

# ACKNOWLEDGEMENTS

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| CDRA | Cylindrical Dielectric Resonator Array |
| CST | Computer Simulation Technology |
| WLAN | Wireless Local Area Network |
| WiMAX | Worldwide Interoperability for Microwave Access |
| IEEE | Institute of Electrical and Electronics Engineers |
| PCB | Printed Circuit Board |

# CHAPTER 1
# INTRODUCTION

This chapter will brief on the background of study, problem statement, the objectives and the scope of study. Explanation of the importance on designing the antenna will be mention in the background of study. Finally, it will give reader a quick glimpse on how the project will be carried out.

## 1.1 Background of Study

Couple of years back, researcher start to enhance the technology by producing antenna that can work on dual frequency band. The rapid development in miniaturizations technology affects the demand in mini size of device such as mobile phone, gaming console, laptop etc. as well as antenna. Antenna is defined as a means for radiating or receiving radio waves according to IEEE Standard Definitions of Terms. Generally, it can also know as a transducer that receive or transmit signal that propagate in free space [1].

Nowadays, there are many types of antenna in market for example the microstrip patch antenna and Dielectric Resonator Antenna (DRA). The DRA is antenna that available in mini size that made up of ceramics or any dielectric material that work for microwave frequencies. Antenna designers more attracted to DRA as it has none metallic loss, lightweight, and small size. In addition, it is highly efficient because it working at millimeter wave frequency and have suitable scale in microwave band [2-4]. Previous research has developed many technique of coupling the DRA. The purpose of the coupling technique is to excite the DRA and radiates the signal to free space. There are several types of coupling technique such as aperture coupling technique, probe coupling, microstrips coupling and coplanar coupling [5].

## 1.2 Problem Statement

The development in the antenna design is continuing as the demand in market increasing. Existing design have to satisfy the characteristic of low cost, lightweight, and wider in term of bandwidth. In addition, the most important parameter is that it is shrinking in size since the antenna has to fit in smaller devices. Therefore, in this paper, the design of DRA that operates for dual frequency band will overcome the problem and enhance the technology in antenna specifically in wireless communication area.

Antenna that work at two frequencies operation has become an attraction in radio frequency identification systems, wireless communication system, wireless sensor network, microwave energy harvesting systems and many others as it improves the space usage and reduces the numbers of antennas. For example in Worldwide Interoperability for Microwave Access (WiMAX), frequency that are been used is between 3.6-3.8 GHz while in wireless local area connection (WLAN) system, frequency that is widely used is 5.15-5.35 GHz. It is substantial in decreasing the circuit complexity and dimensions [6-7].

## 1.3 Objectives

In this project, the aims are to:

- Design a dual band cylindrical DRA, which operates at 3.6 GHz and 5.2 GHz.
- Study and analyze the effect of aperture coupling technique on resonant frequency.

## 1.4 Scope of Study

This project covers the design and fabrication of the microwave antenna. The preliminary design of the cylindrical dielectric resonator antenna is simulate using CST Microwave Studio. The performance analyses are perform on the resonant frequency impedance bandwidth, return loss, and radiation pattern.

The results of simulation are compared with the measurement. The design utilizes the aperture coupling technique to the cylindrical DRA. The C-shape slot are studied and analysed for tuning the resonant frequency of cylindrical DRA for dual band, operating at 3.6 GHz and 5.2 GHz.

# CHAPTER 2
# LITERATURE REVIEW

Chapter two provides an overview of the DRA. It explains the major characteristics of DRA which generally applicable to most DRAs. A detailed on cylindrical DRA and aperture coupling technique, which is used in this project, is also presented. The theory of antenna also been discussed and lastly, the application of dual band on previous research are reviewed in detail.

## 2.1 Overview of Dielectric Resonator Antenna (DRA)

In 1939, Richtinger had demonstrated the first microwave resonators in non-metallic form of dielectric spheres and solid [8], and in early 1960s, the mode of the antenna was analyzed by Okaya and Barash [9]. During that time, the low loss ceramics resources had widen the used of dielectric resonators to produce filters and oscillators due to the high Q-factor (low loss). Concurrently with the increase in antenna application, the research in the same area had also been rigorously done during 1980s focusing on the characteristics of the dielectric resonators. The analysis of the shapes on the resonant mode, radiation pattern and gain had been investigated [10-12].

Early 1990s, researchers had interested in method to excite the DRAs and relating numerous calculation related to determine Q-factor and input impedance. The planar and linear DRA arrays were given voluminous attention in mid 1990s. After countless research had been done, the needs of designing antenna for wireless applications were emphasized in the same decade. The design of antenna had much focused in the augmentation of bandwidth to meet the requirement for broadband.

## 2.2 Characteristics of DRA

The early investigation had concludes some findings of characteristics which are applicable for most DRAs. The major characteristics are summarized below:

- $\lambda_o/\varepsilon_r$ proportional to the size of the DRA. Where, the $\lambda_o$ is free-space wavelength (at resonant frequency) and $\varepsilon_r$ is the value of dielectric constant.
- Aspect ratio of DRA gives effect to radiation Q-factor and resonant frequency for fixed dielectric constant, which allow flexibility in design.
- Absence of surface waves and slightest conductor losses can retain the high radiation efficiency even at millimeter-wave frequency by choosing dielectric material with low loss characteristics.
- The bandwidth and physical size of DRA can be controlled by wide selections of dielectric constant in the range of 8 to over 100.
- Frequency from as low as 1.3 GHz up to 40 GHz can be designed using DRA.
- As to excite the DRAs efficiently, several feeding mechanism can be used such as coplanar waveguide lines, microstrip lines and slot to develop reconciliation with existing technologies.
- DRA can be excited internally, to achieve broadside or omni-directional radiation pattern for different coverage specifications.

The high degree of versatility and flexibility of DRA is the main advantages consenting the designs to suit a wide range of physical or electrical requirement of numerous communication applications.

## 2.3 Cylindrical Dielectric Resonator Antenna (CDRA)

DRA have gained so much interest for its features such as high radiation efficiency and very high degree in term of versatility and flexibility. Hence, suit the design in very wide range of electrical and physical requirements of communications applications [13-14]. The DRA have three basic shapes that are cylindrical, rectangular and hemispherical.

Compared to other shapes, cylindrical type DRA is the most suitable in order to get the high gain because it is directional and does not have any edge that will affect the operation as shown in figure 2.1 [15-16]. The resonant frequency and Q-factor in antenna is dominance by the ratio of radius/height thus offering the ease in the fabrication. By altering the dimension of DRA, different Q-factors can be acquired. In circuit application, CDRA have been utilizing since it has small-scale size and high in Q-factor, which are perfect for filter and oscillation applications [17].

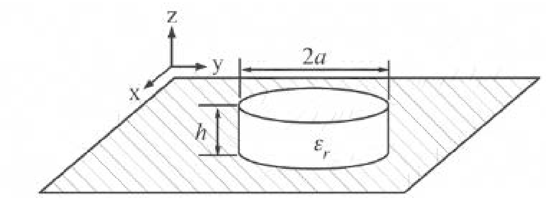



Figure 2.1. Overview of CDRA on ground plane.

In order to design antenna for specific applications, calculations are required to observe the relation between height, radius, and resonant frequency. Based on past research, there are different modes that are categorized for antenna. The resonant frequency can be achieved by substituting the value into one of the equations in table 2.1. Where:

$k_o$ = free space wave number;

$\alpha$ = radius of CDRA;

$h$ = height of CDRA;

c = speed of light;

$\varepsilon_r$ = dielectric constant of CDRA.

Table 2.1. Resonant frequency with different mode calculations

| MODE | EQUATION |
|---|---|
| $HE_{11\delta}$ | $k_o a = \frac{6.324}{\sqrt{\varepsilon_r + 2}}\left[0.27 + 0.36\left(\frac{a}{2h}\right) + 0.02\left(\frac{a}{2h}\right)^2\right]$ (2.1) |
| $TE_{01\delta}$ | $k_o a = \frac{2.327}{\sqrt{\varepsilon_r + 1}}\left[1 + 0.2123\left(\frac{a}{2h}\right) + 0.00898\left(\frac{a}{2h}\right)^2\right]$ (2.2) |
| $TM_{01\delta}$ | $k_o a = \frac{\sqrt{3.83^2 + \frac{\pi a^2}{2h}}}{\sqrt{\varepsilon_r + 2}}$ (2.3) |
| $TE_{011+\delta}$ | $k_o a(\varepsilon_r) = \frac{2.208}{\sqrt{\varepsilon_r + 1}}\left[1 + 0.7013\left(\frac{a}{h}\right) + 0.002713\left(\frac{a}{h}\right)^2\right]$ (2.4) |

Free space wave number, $k_o$ and resonant frequency, $f_o$ can be relate as in equation 2.5:

$$k_o = \frac{2\pi f_o}{c} \tag{2.5}$$

## 2.4 Aperture Coupling Techniques

The most common method used to excite the DRA is an aperture coupling method. To make the DRA radiate, aperture are placed on ground plane where DRA is located. The aperture also known as slot can appear in various shapes like C, E, U, cross-shaped or rectangular shaped. C-shaped slot usually excite the DRA in circular polarization. Figure 2.2 shows the rectangular shaped slot placed on microstrip line and ground plane [18-20].

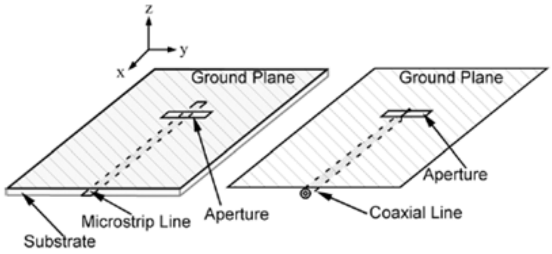



Figure 2.2. Overview of aperture and microstrip line on ground plane.

Alteration on aperture coupling parameters including the shape, length or width thereby perturbing the Q-factor as well as the resonant frequency. To allow efficient energy coupled to DRA, maximum current generated under the aperture slot by using differential signal [21]. Towards obtaining the strongest coupling effect, the position of aperture must be on the center of the DRA as shown in figure 2.3.

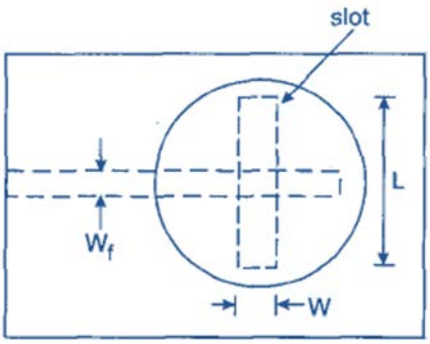



Figure 2.3. Overview of slot and CDRA on ground plane.

## 2.5 Fundamental Theory of Antenna

### *2.5.1 Radiation Pattern*

Energy radiation that distributed by antenna in space is called radiation pattern. It is presented in graph form either in 2-dimensional (2D) or 3-dimensional (3D) graph. Variation of electromagnetic field strength are shown in the graph at all point equidistant from antenna. The radiation pattern shows radiation characteristic of antenna, therefore it is one of important parameters in designing the antenna.

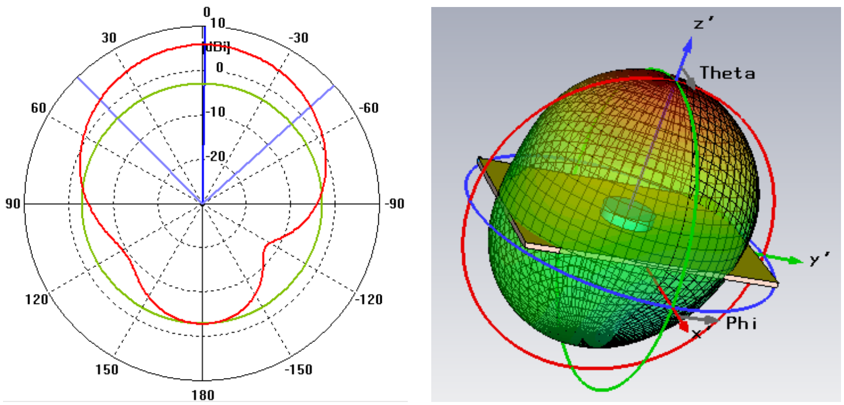



Figure 2.4. 2D radiation pattern (left) and 3D radiation pattern (right)

### *2.5.2 Return Loss*

Return loss shows the relation between input and output port of a devices. Concisely, it shows the power losses in the signal reflected by discontinuity in transmission line. It measure how well a device or lines are match. The value of return loss should be less than -10dB. This is due to the 10% of incident power reflected back towards the sources from the antenna under consideration.

## 2.6 Dual Band Application

Dual band are utilized not only in wireless communication system but also in Radio Frequency Identification (RFID) and Global Positioning Systems (GPS).In RFID, the needs of dual band are resulted from the high demand in the RFID technology. Ultra-High Frequency (UHF) and High Frequency (HF) band often used compared to other frequency band. For instance, the RFID tag is used in warehouse to tagged objects, thus, required high-speed band to operate [22-24].

In the GPS technology, the antenna inside the GPS must capable to operate more than one frequency subsequently. This is to ensure the system navigate on exact location without lagging in time. In favor to deliver velocity, position and timing information, the GPS have to work on more than one frequency [25-26].

## 2.7 WLAN and WiMAX

WiMAX stands for Worldwide Interoperability for Microwave Access which is commercially named based on IEEE 802.16 standards. It is one of the wireless broadband types and can be utilized for many other applications such as cellular backhaul, hotspot, etc. In Malaysia, WiMAX is very well known in the application of Packet One Network (P1) and YES Broadband because it provides 4G type of internet. The frequency band of WiMAX are divided into three types which are high band, middle band and low band. The high band is rated from 5.2 GHz to 5.8 GHz, the middle band are from 3.2 GHz to 3.8 GHz and the low band range from 2.5 GHz to 2.8 GHz.

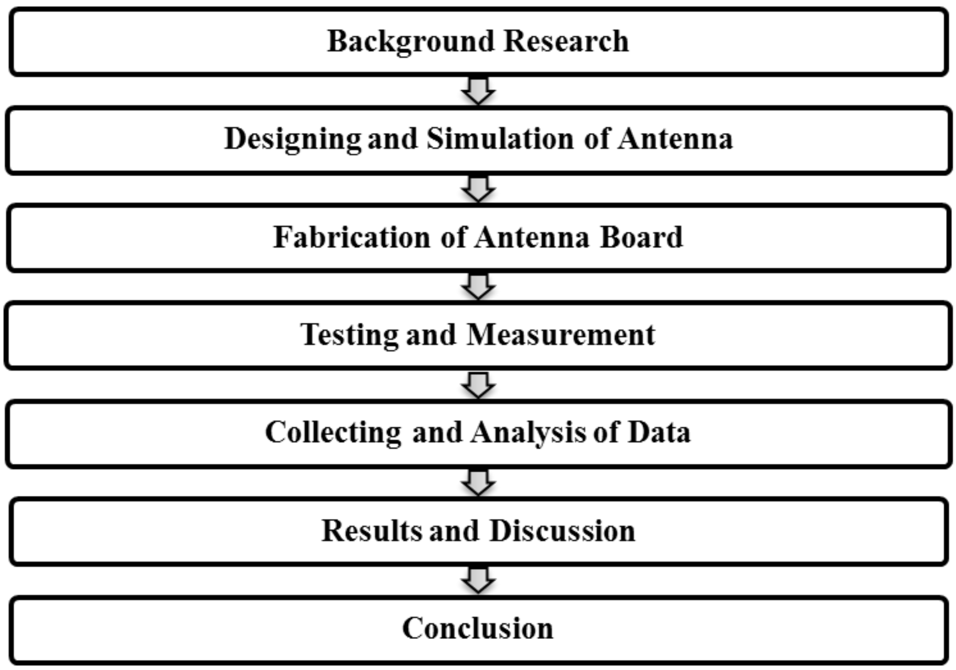
Apart from WiMAX, Wireless Local Area Network (WLAN) is another way to access internet. The WLAN is an extend to the wired of local area network and more convenient in term of connectivity. People tend to choose WLAN rather than LAN as it does not require a device to be connected to a modem in order to access internet. Similar to LAN, WLAN have securities that cannot allowed any random clients to connect using it. Standard used for WLAN is different from WiMAX which is IEEE 802.11. But since WLAN are widely used and popular among the end users, it has many protocol such as IEEE802.11/a, IEEE802.11/b, IEEE802.11/g, etc.

# CHAPTER 3

# METHODOLOGY / PROJECT WORK

This chapter explains the methodology used to develop the CDRA. The initial progress starts with understanding the theory and characteristics of the antenna. It will then continue with the design and simulation, fabrication and lastly the measurement of the antenna. In this chapter, the method to study and analyses the aperture coupling will also be discussed.

## 3.1 Research Methodology




The cluster of this project is based on the wireless communication network. Background studies on previous work of DRA design are reviewed. The literature review are focusing on how antenna are design, the aperture coupled techniques and testing and measurement. One of the objectives is to develop the dual band CDRA. In order to achieve dual band, suitable method needs to comprehend and previous research paper is used to compare the methods.

### *3.1.1 Design and simulation of antenna*

After understanding the concept of antenna and methods to achieve dual band frequency, the design for the simulation is started. Details of the design are explained in chapter results and discussions. The simulation is run in the CST microwave studio software and preliminary design consisting of 12 designs are introduced (aperture slot design). The electromagnetic wave propagation also analyzed using the software. Any modification done is to maximize the performance by adjusting the configuration. The important element in this simulation is CDRA and the C-Shaped slot as these parameters are used to radiate EM wave and control the resonant frequency. The overview of CST microwave studio software presented in figure 3.1.

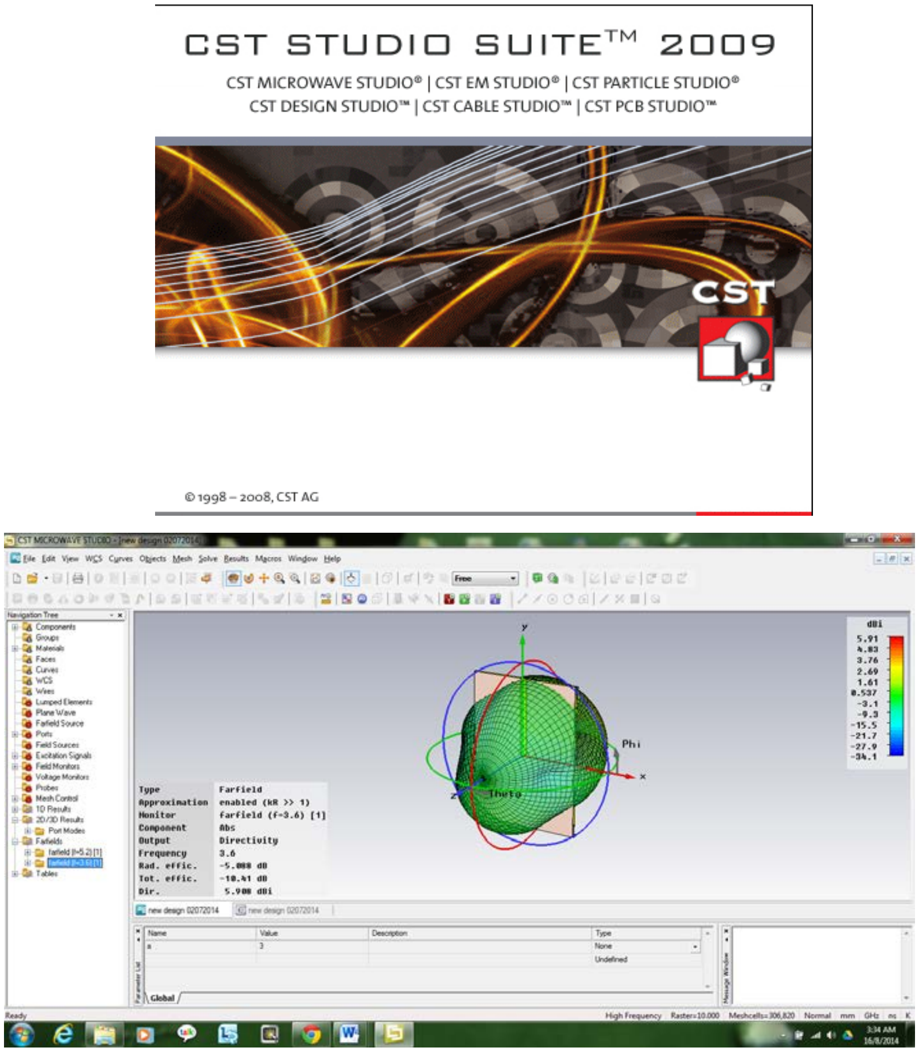



Figure 3.1. Overview of CST microwave studio software.

### *3.1.2 Fabrication of antenna printed circuit board (PCB).*

Succeeding with the design and simulation part, antenna designs are sent to the PCB fabrication lab to fabricate the antenna PCB that located on building 22, Universiti Teknologi PETRONAS. Time taken for the process of fabricating PCB usually takes 2-3 weeks depending on the number of designs sent. All the way through this process, another simulation on the effect of the slot position and slot parameters are prepared to investigate the effect of these changes to the resonant frequency.

### *3.1.3 Testing and Measurement*

Antenna that has fabricated will be check to ensure that the measurements of the fabricated are similar to the simulated designs. Figure 3.2 shows the SMA connector are soldered parallel to the microstrip line of the antenna.

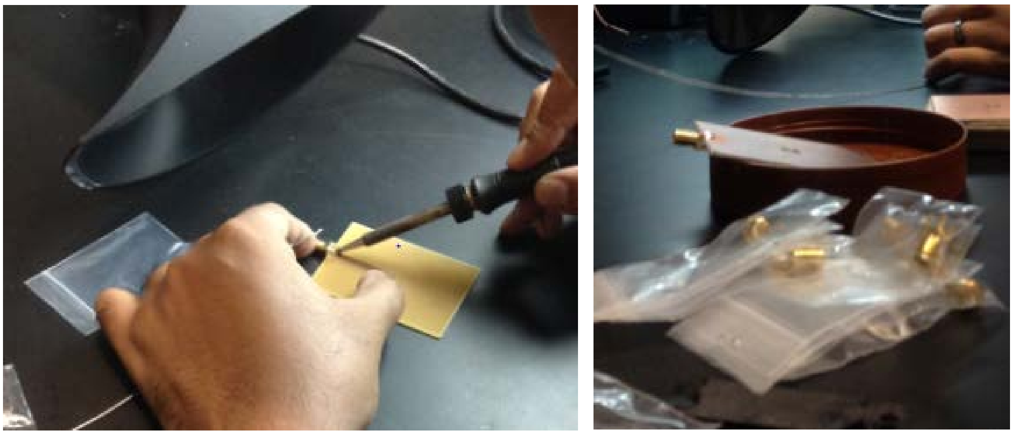


Figure 3.2. Soldering SMA connector to antenna waveguide port.

When the soldering processes finished, the antenna will then tested by using the Field Fox Microwave Analyzer to compare the frequency achieve with the simulated results. The measurement and testing are conducted at Wireless Communication lab, Building 21, Universiti Teknologi PETRONAS. The DRA used in the measurement and simulation are using CCTO ( $CaCu_3\,Ti_4O_{12}$) dielectric material with dielectric constant of 55.

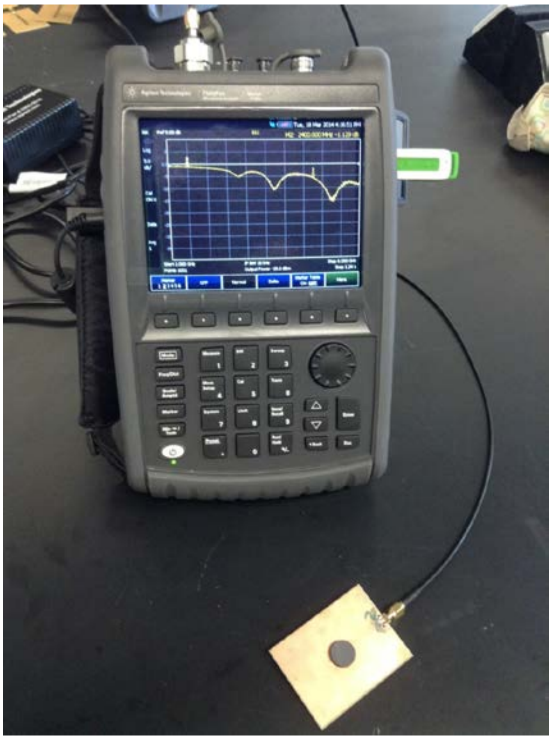


Figure 3.3. Measurement test on antenna using Field Fox microwave analyzer.

Before start conducting the measurement, this tool needs to be calibrate by using the calibrations kit. This is to ensure that the results taken from the analyzer is valid. After calibration process, the cable that has been calibrated cannot be simply taken off. Once the cable is taken off from the analyzer, it need to recalibrate again. To test the antenna, simply connect the cable into the port that had been soldered to the antenna. The graph display on the monitor shows the frequency that works for the antenna. The measured results will then save on the pendrive that attached on the devices as shown in figure 3.3.

### *3.1.4 Collecting and Analysis of Data*

The simulated and measured data are recorded in term of resonant frequency impedance, return loss, and the radiation pattern for the first objective of this project. The second simulation that has been run to study the aperture coupling effect on resonant frequency also recorded and discussed in the next chapter.

### *3.1.5 Results and Discussion*

Finally, the results for both simulated and measured will be relate and analyzed. The design parameters for dual band CDRA will be highlighted. The effect of resonant frequency by the C-Shape slot position and parameters will be described.

## 3.2 Gantt Chart

Table 3.1. FYP 1 Gantt Chart

| PROJECT FLOW / WEEK | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Submission and confirmation of project title | ■ | ■ | | | | | | | | | | | | |
| preliminary research & preparing extended proposal | | ■ | ■ | ■ | ■ | ■ | | | | | | | | |
| submission of extended proposal | | | | | | ■ | | | | | | | | |
| designing antenna and simulation | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |
| proposal defense | | | | | | | | ■ | ■ | | | | | |
| preparing interim report | | | | | | | | | | ■ | ■ | ■ | ■ | |
| submission of interim report | | | | | | | | | | | | | | ■ |

Table 3.2. FYP 2 Gantt Chart

| PROJECT FLOW / WEEK | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soldering the antenna with the port | ■ | | | | | | | | | | | | | |
| Test the antenna using Field Fox Microwave Analyzer | | ■ | ■ | ■ | ■ | | | | | | | | | |
| Examine the findings | | | | | | ■ | ■ | ■ | ■ | ■ | | | | |
| Submission of progress report | | | | | | | | ■ | | | | | | |
| Pre-Sedex (Electrex) presentation | | | | | | | | | | ■ | | | | |
| Preparing final report | | | | | | | | | | ■ | ■ | ■ | ■ | |
| Submission of final report | | | | | | | | | | | | | | ■ |

# CHAPTER 4
# RESULTS AND DISCUSSION

Chapter four presents preliminary designs of the antenna with the results of selected antenna that achieving dual band of 3.6 GHz and 5.2 GHz. the results are presented in form of return loss graph which consist of the gain, resonant frequency and bandwidth together with 2D and 3D radiation pattern graph. In this chapter, the effect of tuning the aperture slot on the resonant frequency will also presented in graph to show the difference in resonant frequency.

## 4.1 Preliminary Design

The preliminary design is conducted using the CST Microwave Design Simulation. This software is a tool that had specialty to design and simulate high frequency components. Other than antenna, it can be used to design high frequency devices such as filters, planar, couplers, etc. Process of designing has been easier since the software provide 3D of design simulation.

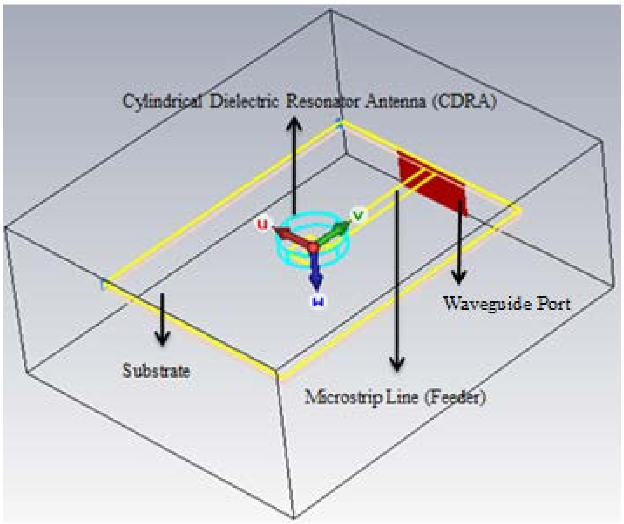



Figure 4.1. Perspective view of design simulation

Figure 4.1 shows the perspective view of the antenna in CST Microwave design simulation. The side that facing upward (front) is the microstrip line also known as feeder. The other side (back) consist of the C-shaped slot that attach together with the CDRA as shown in figure 4.5. The CDRA position is placed at the centre of the substrate and fixed for all designs.

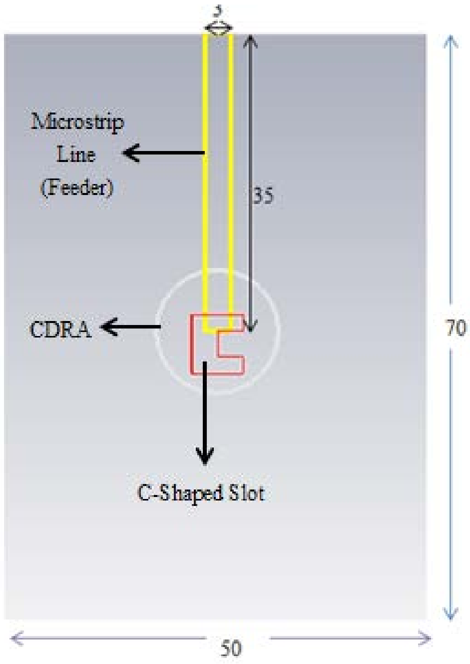



Figure 4.2. Preliminary design of the antenna

Table 4.1. Description of each components

| | |
|---|---|
| Substrate | Length : 70mm ; Width : 50mm ; Thickness : 1.45mm<br>Material = FR4 with dielectric constant 4.9 |
| Microstrip Line (Front) | Length : 35mm ; Width : 3mm : Thickness : 0.016mm<br>Material = Copper |
| Ground Plane (Back) | Length : 70mm ; Width : 50mm ; Thickness : 0.016mm<br>Material = Copper |
| Cylindrical Dielectric Resonator Antenna (CDRA) | Radius : 7.2mm : Thickness : 3mm<br>Material = CCTO ( $CaCu_3\,Ti_4O_{12}$) with dielectric constant 55 |
| C –Shaped Slot | Described in details in table 4.2 |

The substrate made with FR4 material with dielectric constant of 4.9. It has 70mm front side, is made up from copper. The microstrip line has 0.016 thickness, 35mm length and 3mm width. The ground plane on the backside consist of the C-shaped slot which is made from copper and the designs of C-shaped slot are summarized in table 4.2. The CDRA has 7.2mm radius and 3mm thickness which made from CCTO material with 55 dielectric constant with 70mm length x 50mm width with thickness of 1.45mm.

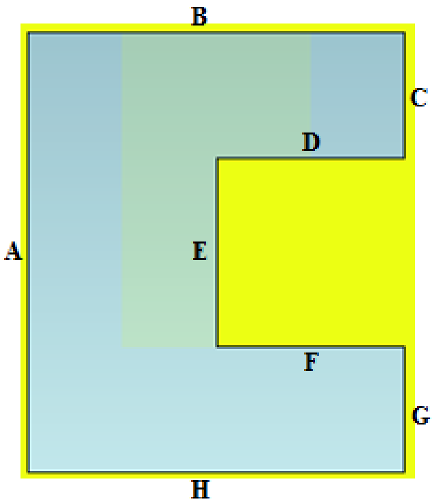



Figure 4.3. Dimension of C-shaped slot

The other designs is done varying by the dimension A, B, C, D, E, F, G, H as shown in the figure 4.3. There are 12 designs including the preliminary design. For the first four design, the dimension of C-Shaped slot is fixed but the position is varies. The position of first design is set 33mm away from the waveguide port and for second, third and fourth design it is placed 30mm, 27mm and 24mm away respectively. While for the remaining 8 designs, the variable is the dimension of C-Shaped slot as shown in table 4.2. For all remaining 8 designs, the positions are set 30mm away from the waveguide port. Design 5, 6, 7 and 8 are varies in dimension of E, C and G. While for the other design which are 9, 10, 11 and 12, the dimension varies are at D and F.

Table 4.2. Summary of dimension of C-shaped slot designs

| Design \ Dimension (in mm) | A | B/H | C | D/F | E | G |
|---|---|---|---|---|---|---|
| 1,2,3,4 (same size) | 7 | 6 | 2 | 3 | 3 | 2 |
| 5 | 7 | 6 | 1 | 3 | 5 | 1 |
| 6 | 7 | 6 | 3 | 3 | 1 | 3 |
| 7 | 7 | 6 | 1 | 3 | 3 | 3 |
| 8 | 7 | 6 | 3 | 3 | 3 | 1 |
| 9 | 7 | 6 | 2 | 5 | 3 | 2 |
| 10 | 7 | 6 | 2 | 4 | 3 | 2 |
| 11 | 7 | 6 | 2 | 2 | 3 | 2 |
| 12 | 7 | 6 | 2 | 1 | 3 | 2 |

## 4.2 Optimal Design

### *4.2.1 Design Verification*

The best design that is selected is design number 2. It has been nominated based on its performance. The antenna is designed and fabricated for WLAN and WiMAX application. The complete dimensions are depicted in table 4.1 and the proposed geometry described in table 4.2. The chosen antenna is presented in figure 4.4. The performances of the antenna are analyzed based on the resonant frequency impedance bandwidth, return loss, and radiation pattern.

Referring to figure 4.4 the C-shaped slot appear on the bottom view while in figure 4.5, the C-shaped slot disappear. This is because the cylindrical DRA is attached to the slot. The cylindrical DRA that is used in this project has the size as small 5-cent coin.

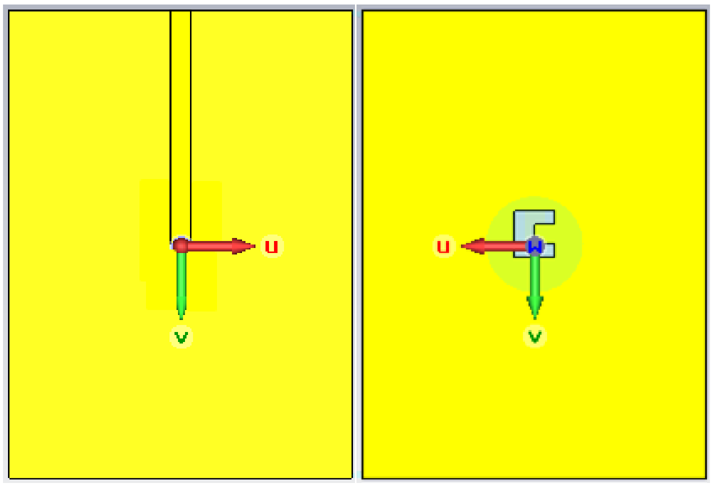



Figure 4.4. The simulated optimal antenna design from top view (left) and bottom view (right)

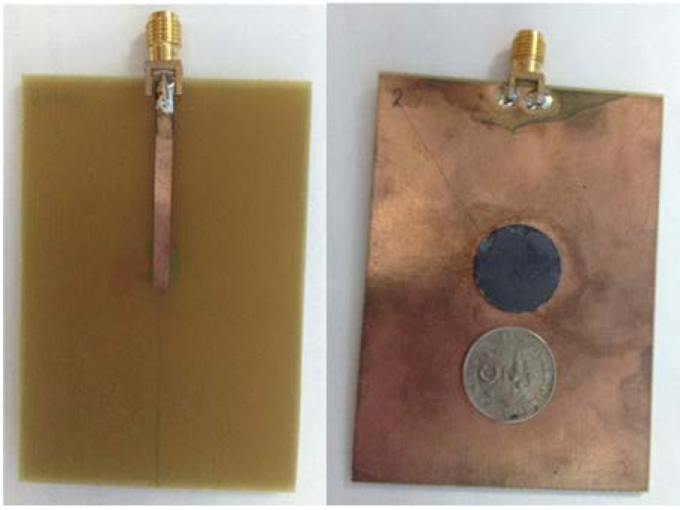


Figure 4.5. The fabricated optimal antenna design from top view (left) and bottom view (right)

From the results obtained through CST, the achieved impedance bandwidths are 0.1596 GHz (3.5448 – 3.7044 GHz) and 0.1456 GHz (4.9588 – 5.1044 GHz). The resonant frequency 3.5791 GHz and 5.0143 GHz with -20.693 dB and -14.1103 dB return losses ($S_{11}$) coefficients respectively.

The antenna then tested using the Field Fox microwave analyzer and achieved the impedance bandwidths of 0.175 GHz (3.836 – 3.661 GHz) and 0.1316 GHz (5.4544 – 5.3228 GHz). The resonant frequency for the simulated are 3.6102 GHz and 5.1932 GHz with return losses ($S_{11}$) coefficients -16.2174 dB and -14.1103 dB.

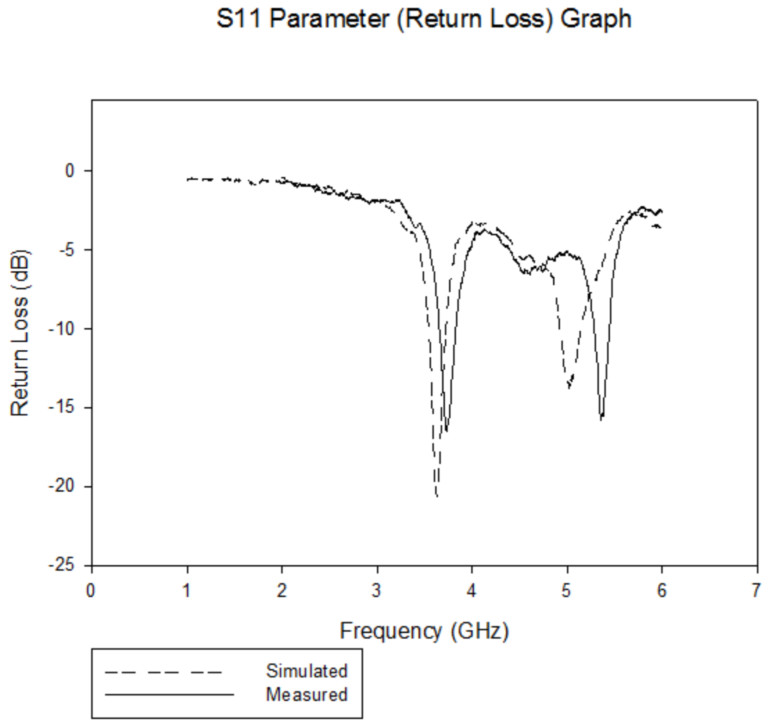



Figure 4.6. Comparison of simulated and measured frequency and return loss $S_{11}$ parameter graph.

### *4.2.2 Radiation Pattern of Antenna*

Antenna radiation pattern are observed at both E-plane (∅= 0°) and H-plane (∅= 90°) for both 3.6 GHz and 5.2 GHz. For f = 3.6 GHz, the H-plane has corresponding directions of main lobes of 2.0° with magnitude 5.9 dB. While for E-plane, the corresponding main lobe magnitude is 1.0° with same magnitude. The side lobe level in H-plane and E-plane are -6.4 dB and -8.8 dB respectively.

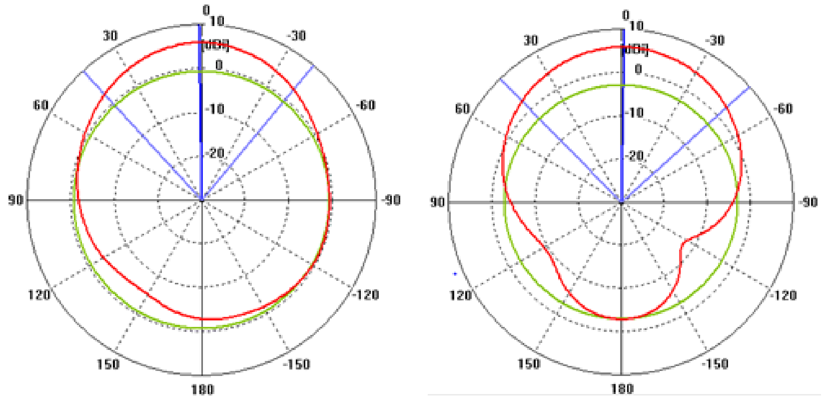


Figure 4.7. The H-plane (left) and E-plane (right) for f = 3.6 GHz.

For f = 5.2 GHz, the H-plane and E-plane has the same corresponding directions of main lobes of 1.0° with magnitude 5.1 dB. Whereas for the side lobe level, H-plane does not shows any value and for E-plane is -8.0 dB. For clear visualization of radiation pattern, figure 4.9 shows the 3D radiation pattern for both 3.6 GHz and 5.2 GHz with the same magnitude and directions of main lobes and side lobes.

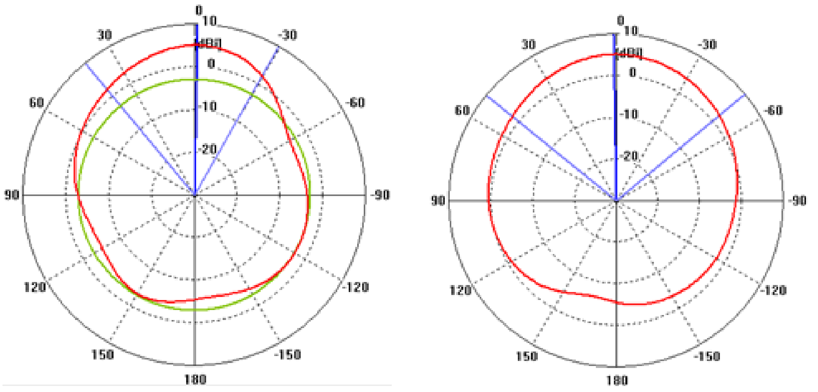



Figure 4.8. The H-plane (left) and E-plane (right) for f = 5.2 GHz.

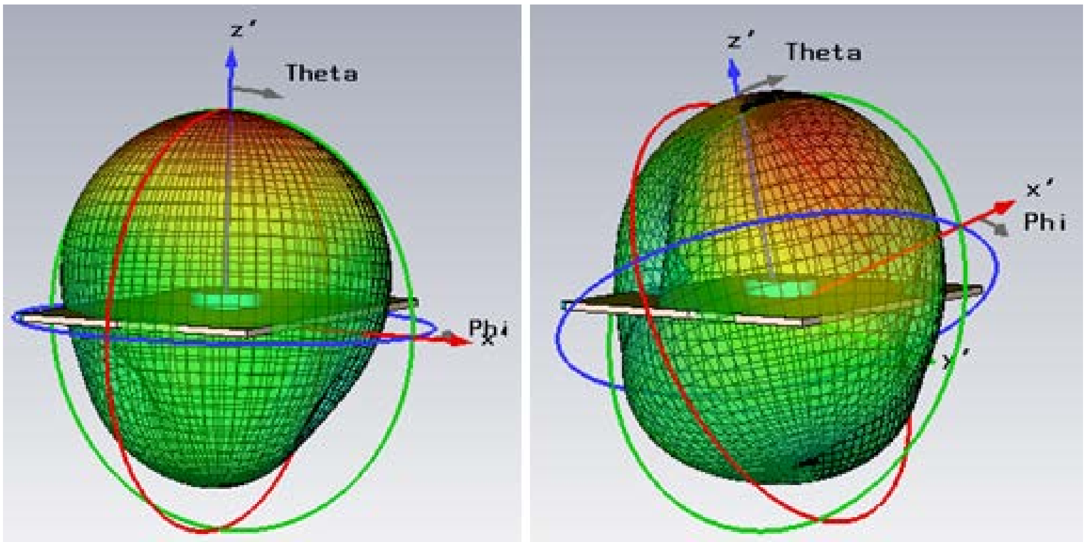



Figure 4.9. 3D radiation pattern for 3.6 GHz (left) and 5.2 GHz (right).

## 4.3 Effect of Tuning the Aperture Slot

The study on tuning the aperture slot has been carried out to determine the effect to the resonant frequency. Three different simulations applying different techniques are explained below. In the study of slot position, the dimension of slot used is fixed though for the study of both dimension effect, the position are fixed which are 30mm from the waveguide port.

### *4.3.1 Effect of slot position on resonant frequency*

The slot positions are placed along the microstrip line. The positions are then varies according to the distance from waveguide port. In the first simulation, the slot has a distance 24mm away from the waveguide port. This variables are continues until 26mm with 0.5mm scales. The simulation results are shown in figure 4.10.

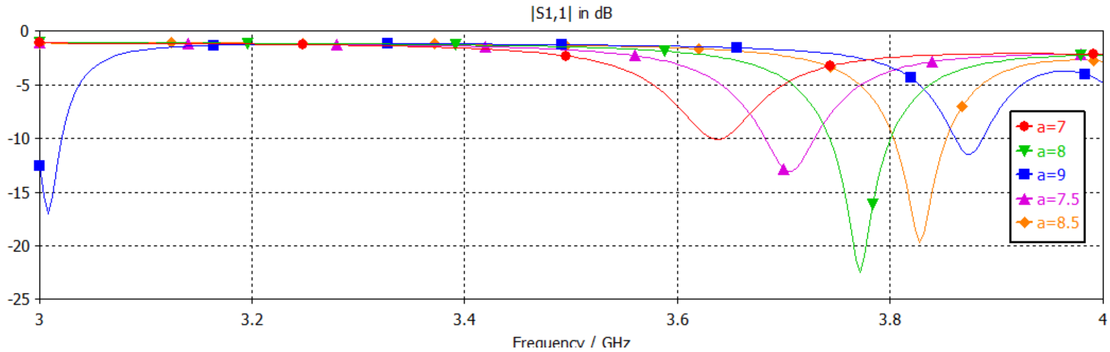



Figure 4.10. Simulations results for different slot position on resonant frequency.

Table 4.3. Summarized results of effect of slot positions on resonant frequency

| Position<br>*distance from waveguide port (mm) | Frequency<br>(GHz) |
|---|---|
| 24 | 3.8760 |
| 24.5 | 3.8280 |
| 25 | 3.7720 |
| 25.5 | 3.7040 |
| 26 | 3.6310 |

The results of the simulation are summarized in table 4.3. Figure 4.11 visualized the relationship between slot position and resonant frequency. As the position of slot away from the waveguide port, the frequency will decrease. With the variance of 0.5mm, the resonant frequency gives approximately 0.05 GHz difference.

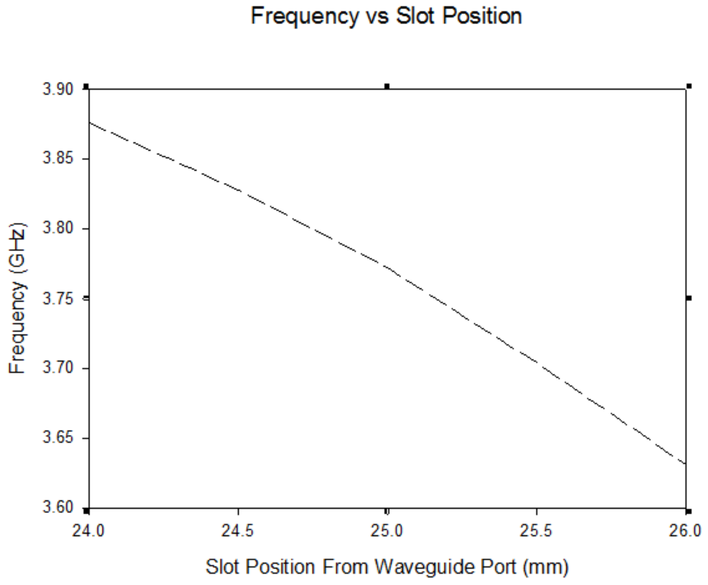



Figure 4.11. Slot position versus resonant frequency graph.

### 4.3.2 *Effect of dimension D and F on resonant frequency*

Early of this chapter has explained how the C-shaped slot is design. In figure 4.3, the dimension of C-shaped slot are shown and so study the effect of tuning the slot, we utilize the same dimension that has been discussed earlier. Figure 4.12 represent the difference of dimension use to patterned the effect of the shape on the resonant frequency. In CST, the design are using coordinates to change the dimensions. In this case, the u-axis (normally use as x-axis) is changing by 0.5mm. Referring to figure 4.12, from left, coordinates at u-axis are -1, -0.5, 0, 0.5, 1, 1.5, 2, and 2.5.

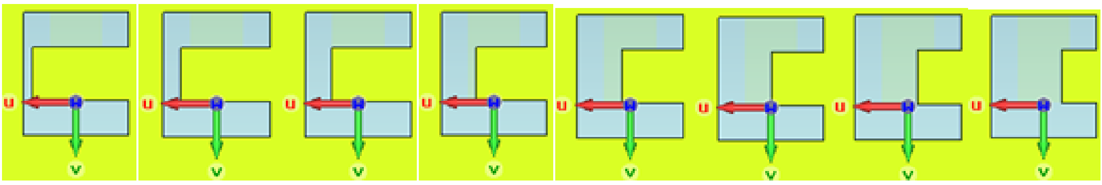


Figure 4.12. Difference in dimension D and F.

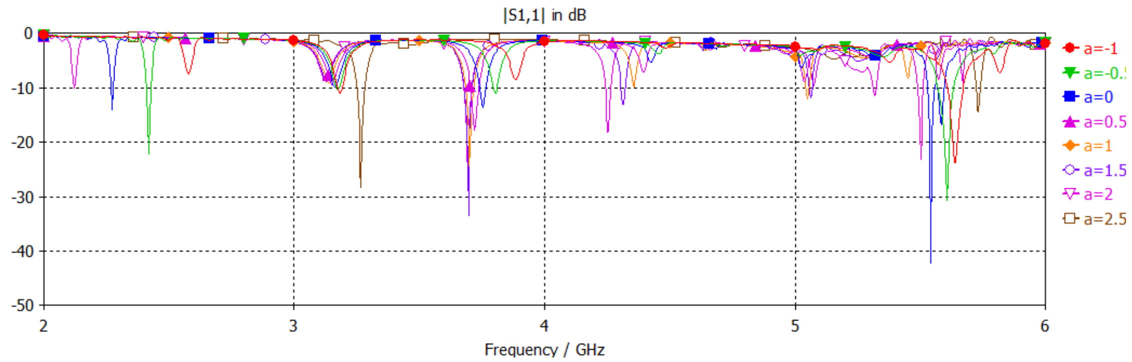



Figure 4.13. Simulation results for different length for D and F dimension.

Table 4.4 Summarized results of effect of difference D and F dimensions on resonant frequency.

| Dimension difference (mm) | Frequency (GHz) |
|---|---|
| -1.0 | NIL |
| -0.5 | 3.8040 |
| 0 | 3.7520 |
| 0.5 | 3.7217 |
| 1.0 | 3.7004 |
| 1.5 | 3.6960 |
| 2.0 | 3.6920 |
| 2.5 | NIL |

In figure 4.13, the simulations are running using parameter sweep so that the graph of different variables can be captured and compared, it then summarized in table 4.4.

The graph of difference of dimension D and F (in mm) against resonant frequency are plotted in figure 4.14. By changing 0.5mm of D and F dimension, the resonant frequency also change by roughly 0.4 GHz. When the width of C-shaped slot is reduce, the resonant frequency achieved is increased.

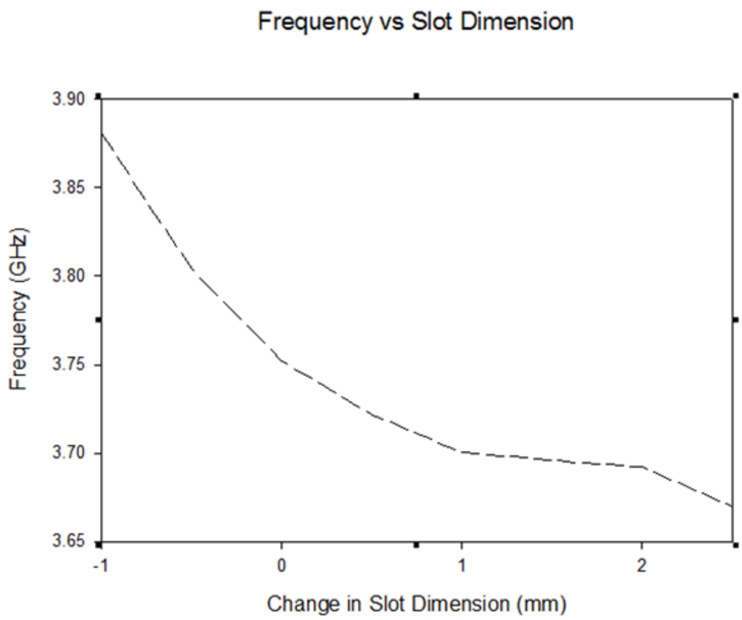



Figure 4.14. Change in slot dimension versus resoannt frequency graph.

### *4.3.3 Effect of dimension C, E and G on resonant frequency*

This study is carry out by varying the C, E and G dimensions of the C-shaped slot. In previous study, the coordinate at u-axis is used to vary the dimensions. In this case, coordinate at v-axis (normally use as y-axis). The coordinate is sweep by scale of 0.5. Referring to figure 4.15, the C-shape has now change at C, E and G. From left, the dimensions are sweep from -1, -0.5, 0, 0.5 and 1.

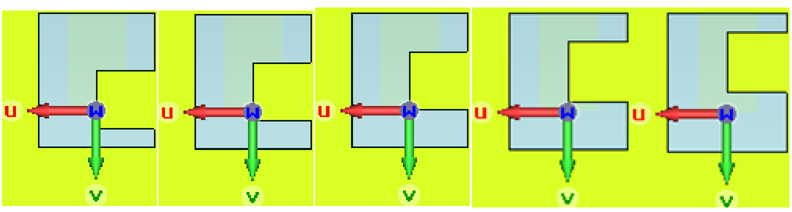


Figure 4.15. Difference in dimension C, E and G.

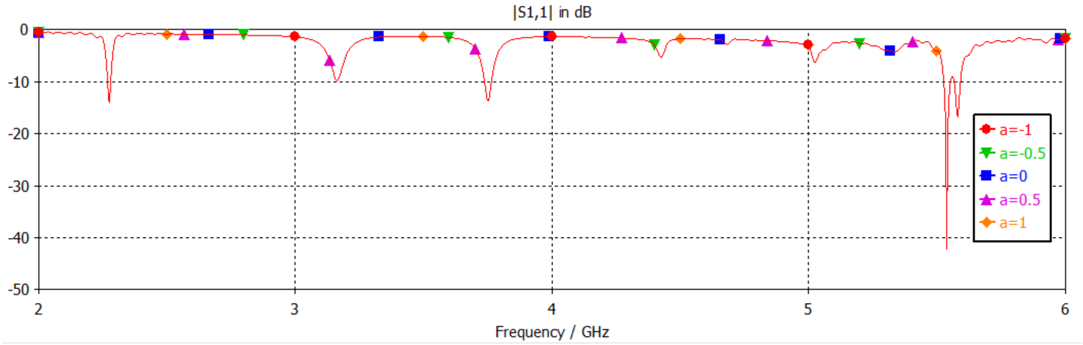



Figure 4.16. Simulation results for different length for C, E and G dimension.

Table 4.5 Summarized results of effect of difference C, E and G dimensions on resonant frequency.

| Dimension difference (mm) | Frequency (GHz) |
|---|---|
| -1.0 | 3.7520 |
| -0.5 | 3.7520 |
| 0 | 3.7520 |
| 0.5 | 3.7520 |
| 1.0 | 3.7520 |

In figure 4.16, the simulations are sweep from -1 to 1. The graph only shows 1 curve because it does not have any differences with each variables. The resonant frequency achieved are the same which is 3.7520 GHz.

## 4.4 Discussion

For the first part, to achieve the dual band antenna, an optimal design has been presented and the performance has discussed. The radiation patterns shown are in omni-directional, which is very good for an antenna because it distribute the radiation evenly. The resonant frequencies achieved are 3.6102 GHz and 5.1932 GHz. These frequencies still fall under the range of WLAN and WiMAX applications. In addition, the bandwidths are 0.175 GHz and 0.1316 GHz, which is favorable because the narrow the bandwidth, the efficiency will increase. The return loss also gives good value the simulated and measured results are in good agreement.

The measured and simulated results are not given the same value due to many factors that should be considered during testing of the antenna. For example, the port that had been attached to the antenna must be soldered just sufficient to ensure no excess lead that can interfere signals transmitted. The other contributed factor is the condition of the DRA. The DRA used in this experiment is not smooth enough and can cause the frequency to vary from the simulation results. In addition, during measurement procedure, any object that can receive or transmit signal should be placed little bit far from the antenna. The unwanted signals will disturbed the measurement results.

In the study of tuning the aperture slot effect, the slot positions give impact to the resonant frequency by changing 0.5mm of distance; the resonant frequency will also change about 0.05 GHz, whereas for tuning the dimension of D and F, changing of 0.5mm will affect about 0.4 GHz on the resonant frequency. However, for the last part, tuning the C, E and G dimensions does not give any effect to the resonant frequency.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

Throughout this paper, study on antenna and aperture coupling technique to the antenna has been done. A dual band antenna with aperture coupling technique that produces use CDRA has been produced. Results show almost similar reading for both simulated and measured. The objective for this project is to produce a design of antenna that can work on dual frequency. The results had proven that final design of the antenna can achieved dual frequency that are 3.6 GHz and 5.2 GHz which cover both for WiMAX and WLAN band. For second objective, which is to study and analyze the effect of aperture coupling technique on resonant frequency, the targeted aim is met. The most influence technique to resonant frequency is by varying the dimension D and F. Nonetheless, changing C, E and G parameter does not affect to neither the resonant frequency nor the return loss.

## 5.2 Recommendation

All the way through the process of developing the antenna, few problems had occurred. During the fabrication of the antenna, the parameter for the antenna had been set, but once the fabrication has been completed, the value of each parameter has been slightly altered due to miscommunication with the PCB technician. since the fabrication take much time, the project is continued by using the fabricated antenna with few changes in the simulation. Luckily, there are few designs that achieving dual band. Instead of getting 2.4 GHz and 5.2 GHz, the project has been changed to aim dual band frequency of 3.6 GHz and 5.2 GHz.

In future, any design that has been sent for fabrication are recommended to be measured manually to ensure that the fabricated is same as the proposed design.

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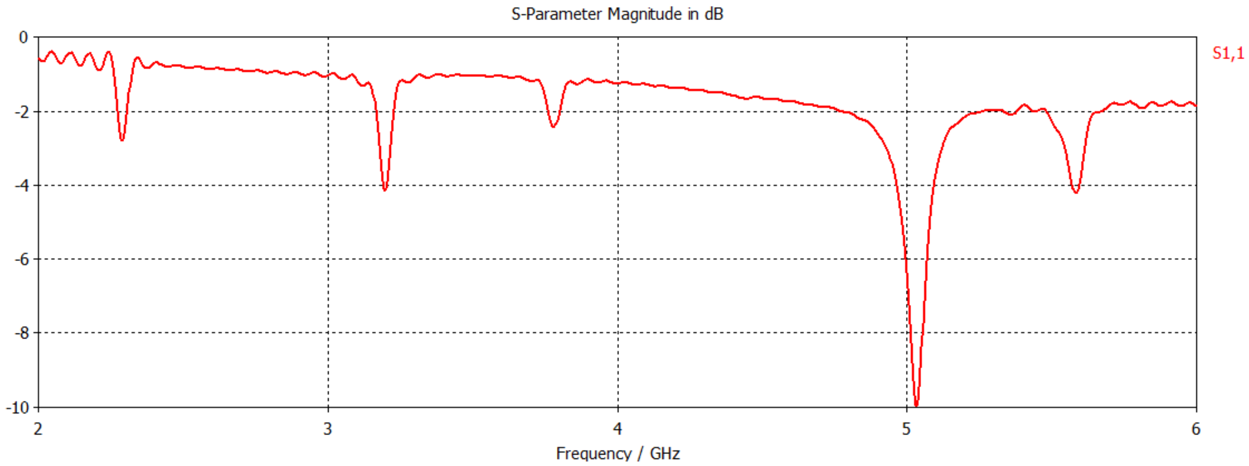
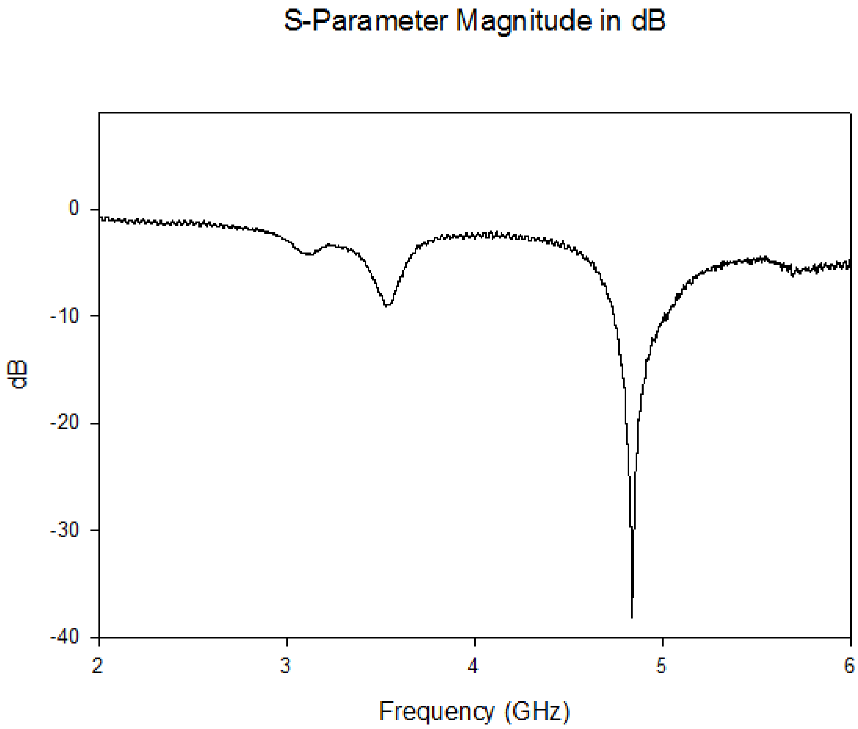
# APPENDICES

# APPENDIX A

## DESIGN 1

* 33mm from waveguide port

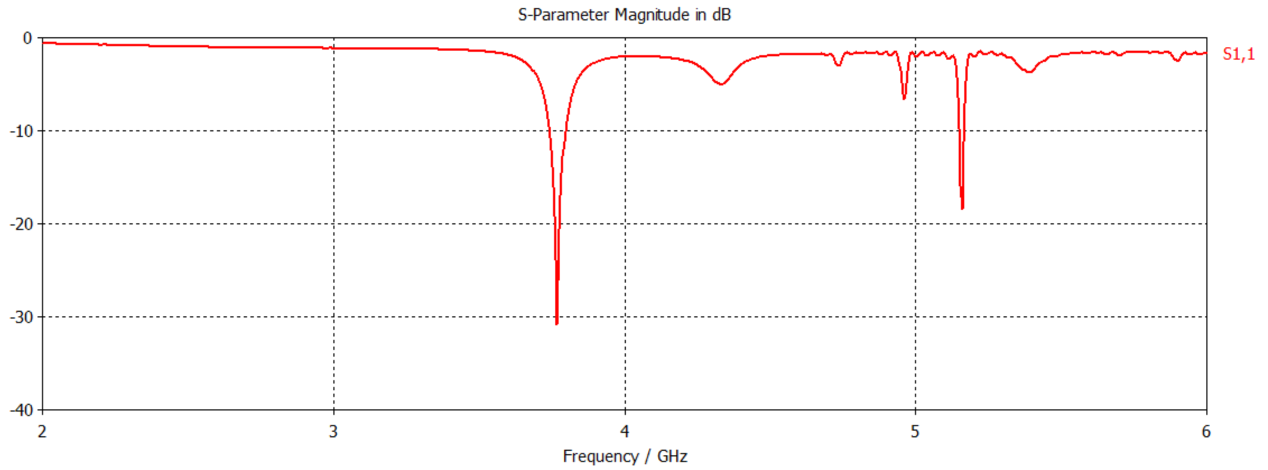


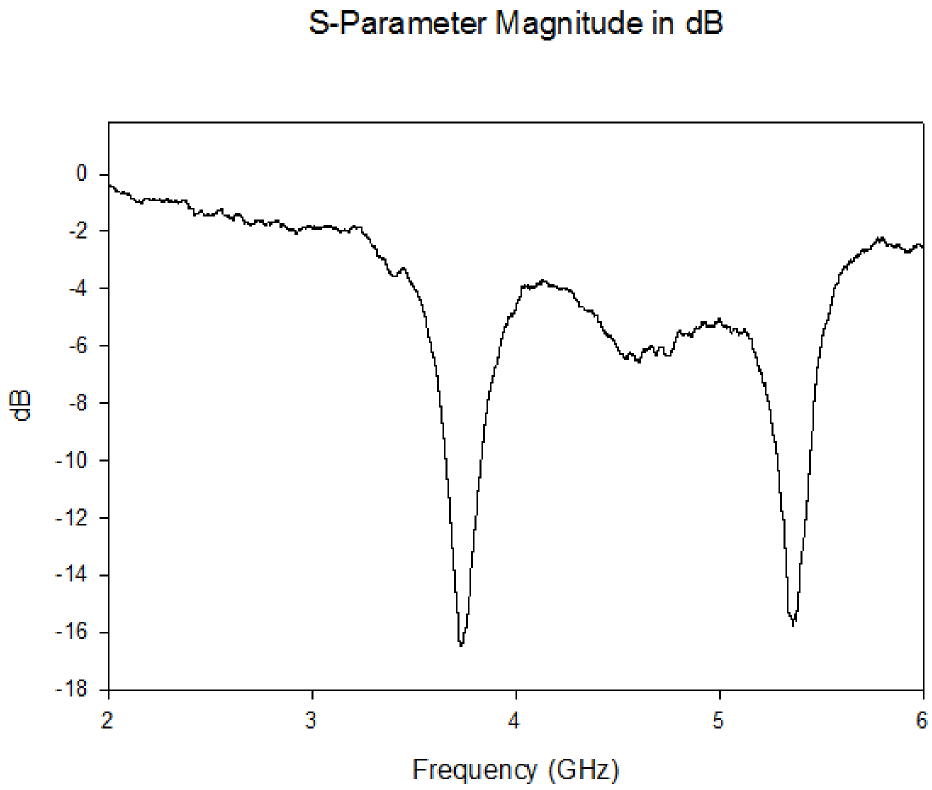



# APPENDIX B

# DESIGN 2

*30mm from waveguide port

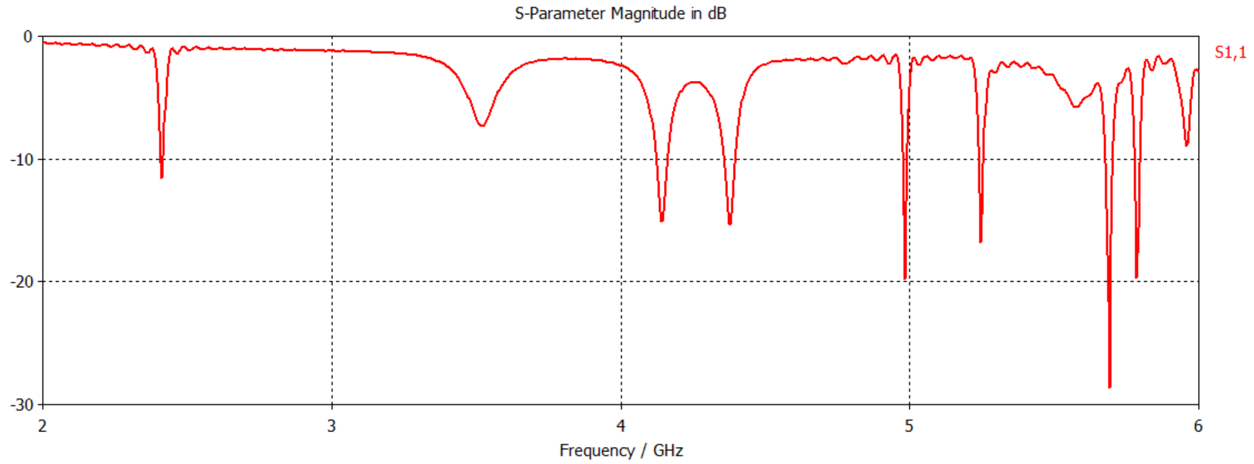


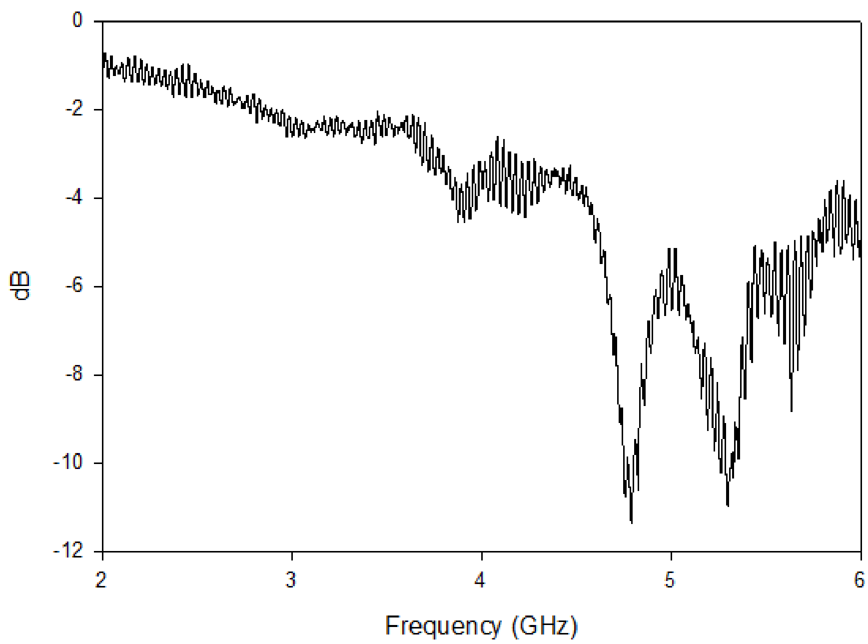
# APPENDIX C

# DESIGN 3

*27mm from waveguide port



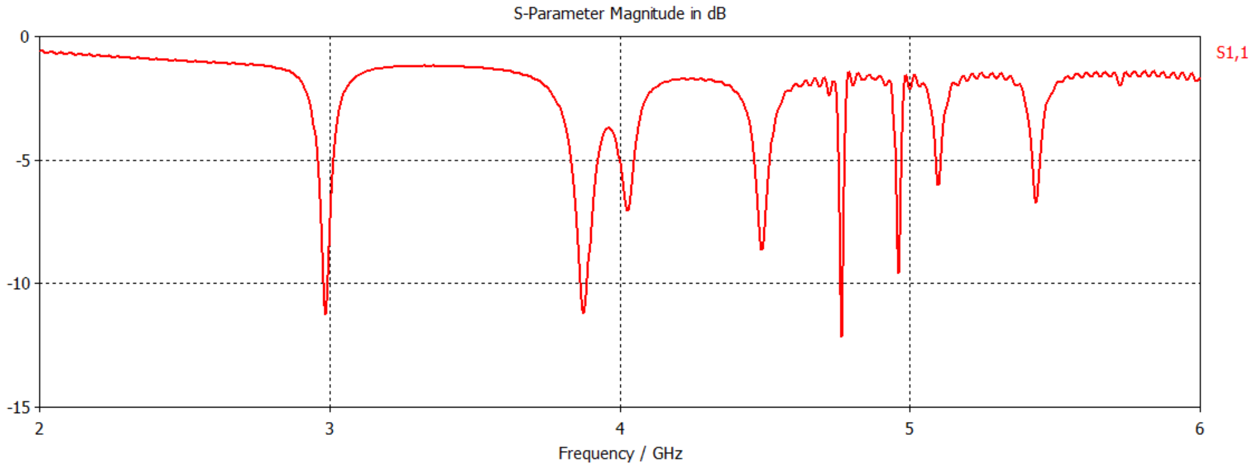

S-Parameter Magnitude in dB

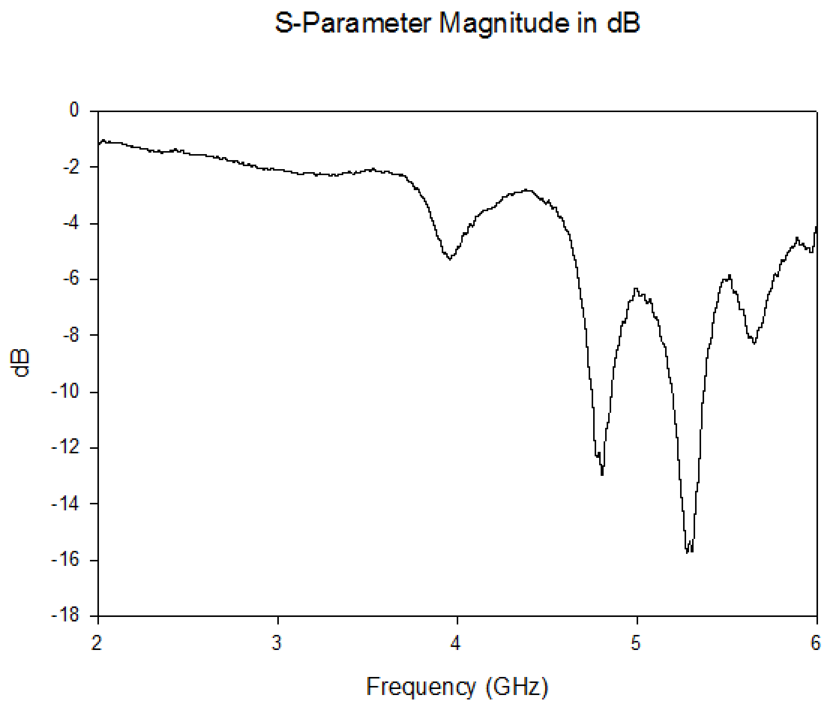


# APPENDIX D

## DESIGN 4

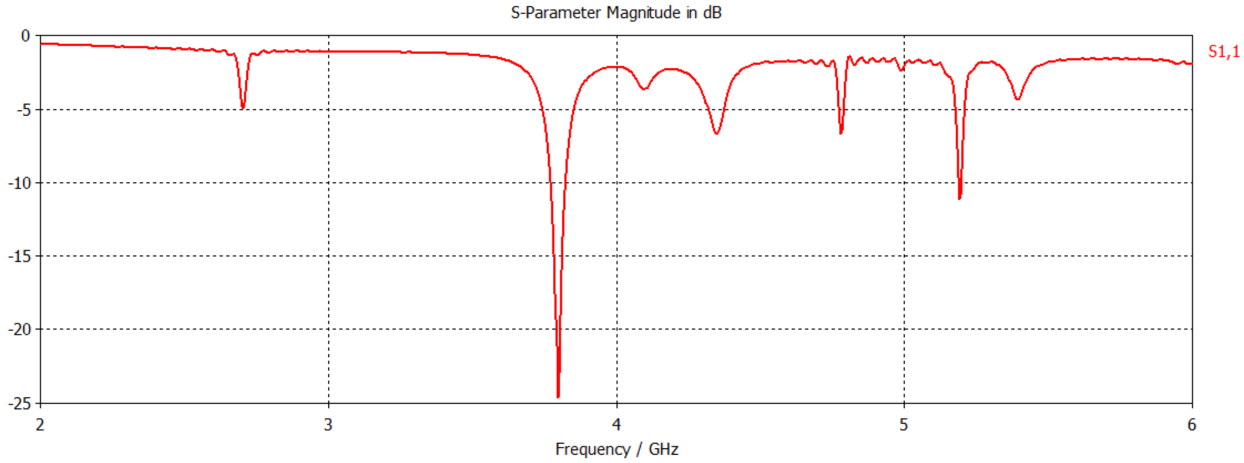
*24mm from waveguide port

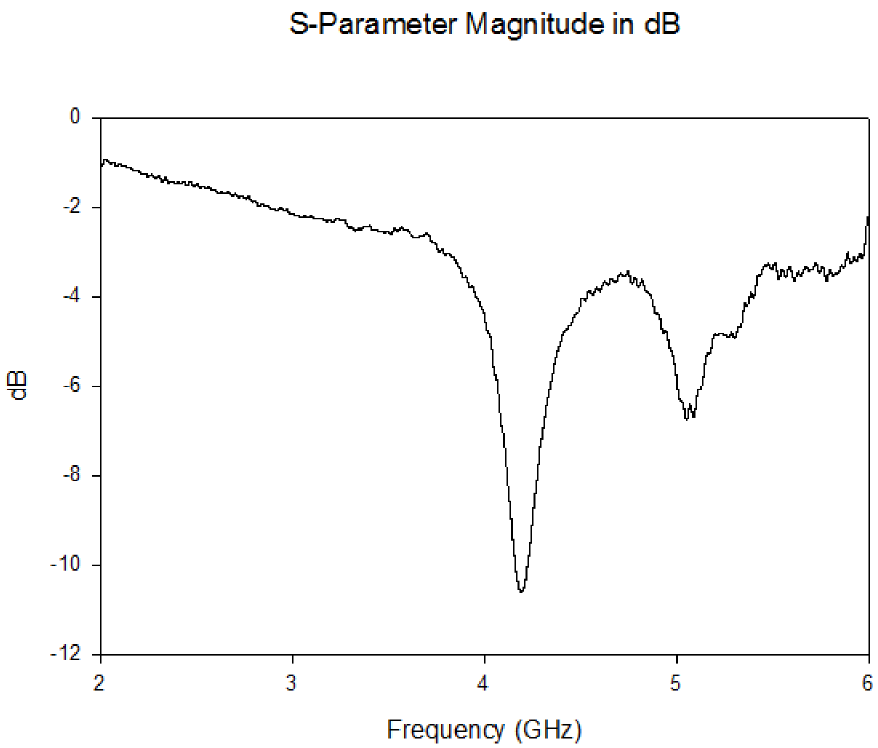


# APPENDIX E

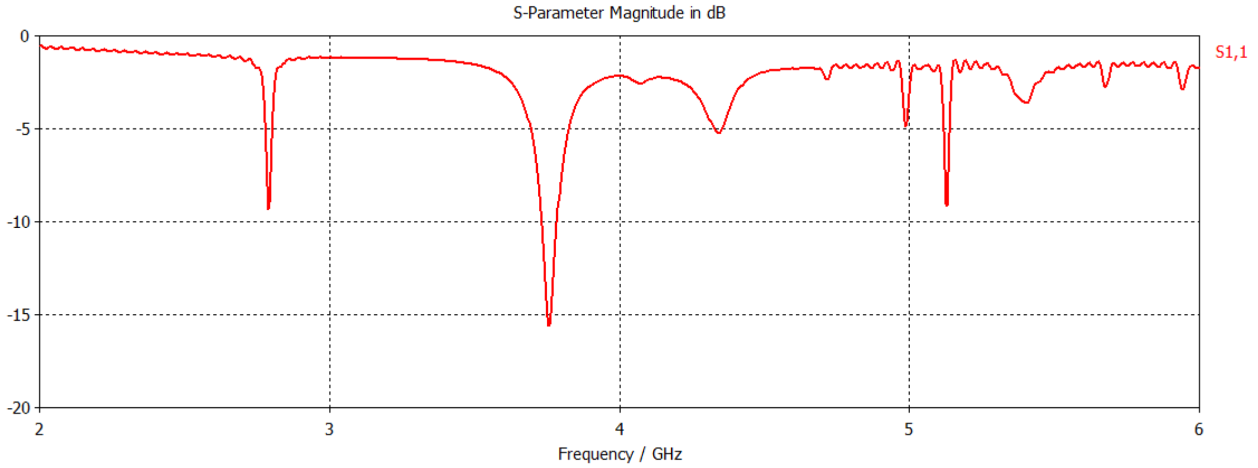
# DESIGN 5

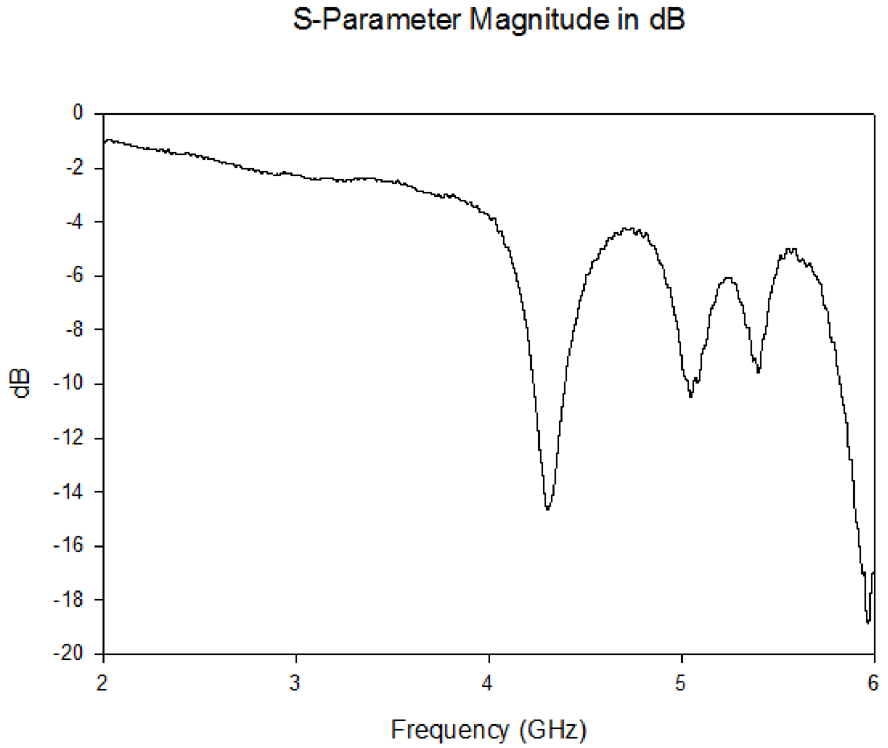


# APPENDIX F

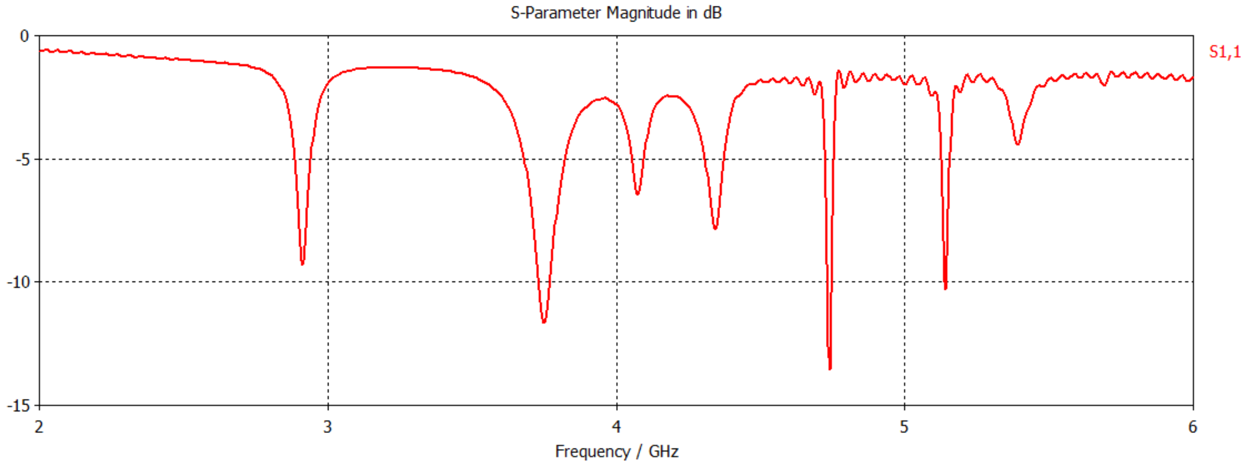
# DESIGN 6

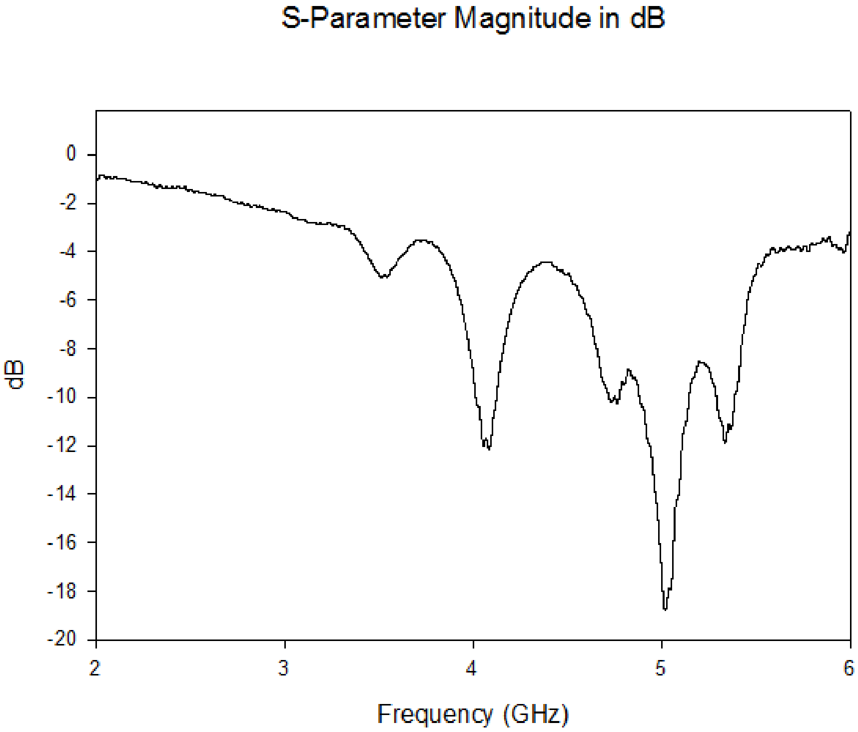


# APPENDIX G

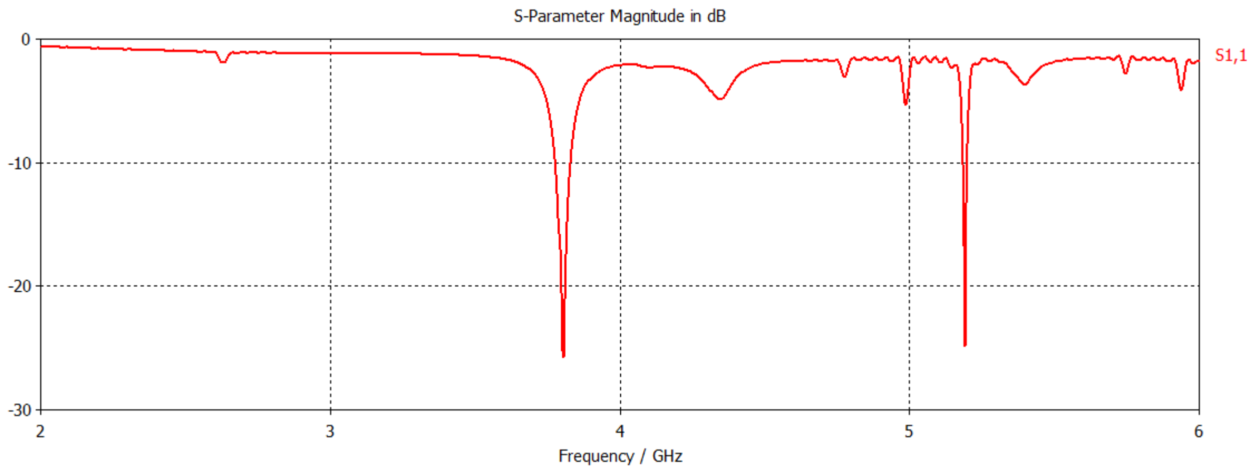
## DESIGN 7

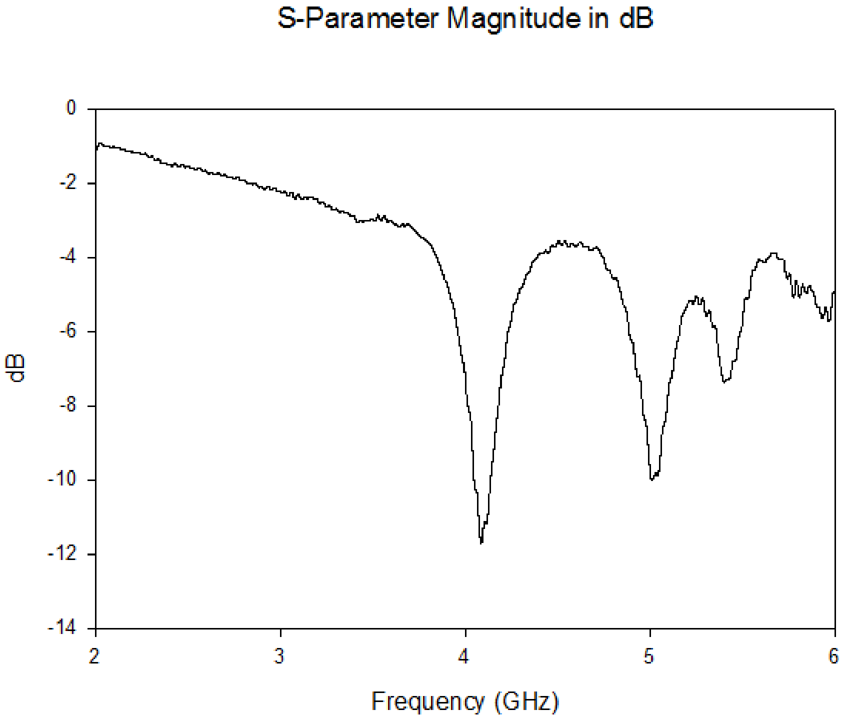


# APPENDIX H

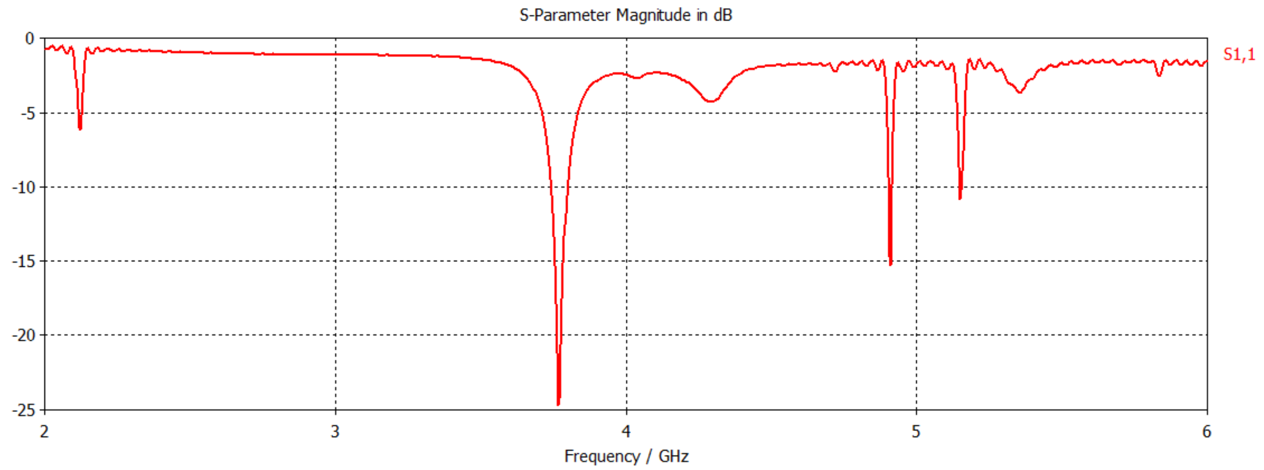
## DESIGN 8

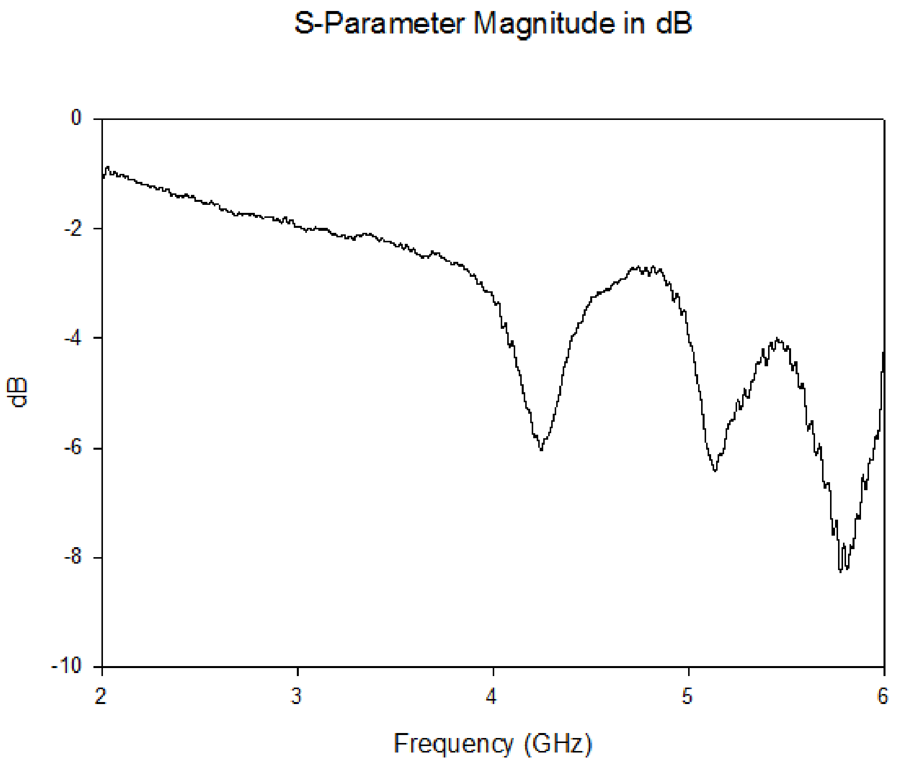


# APPENDIX I

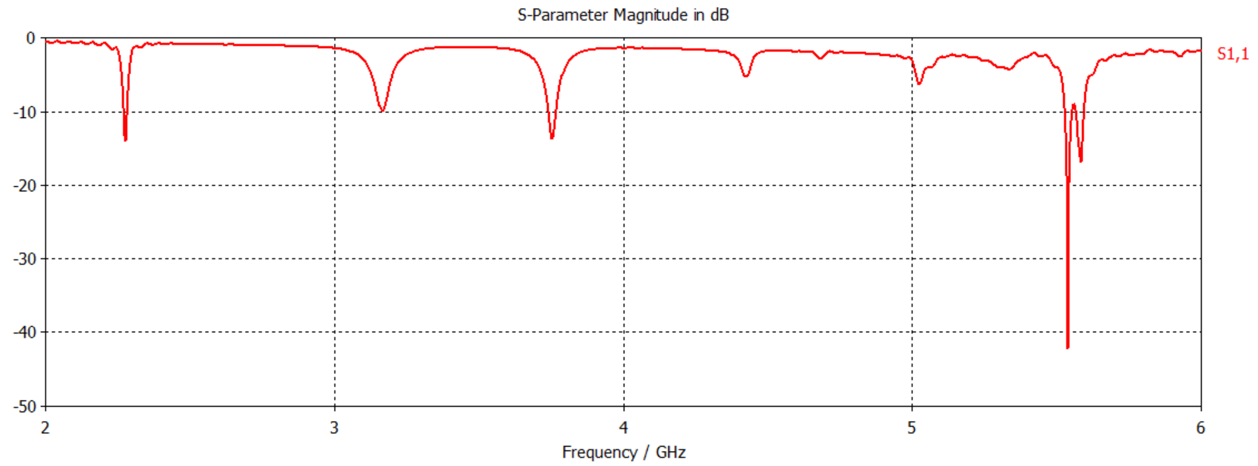
## DESIGN 9



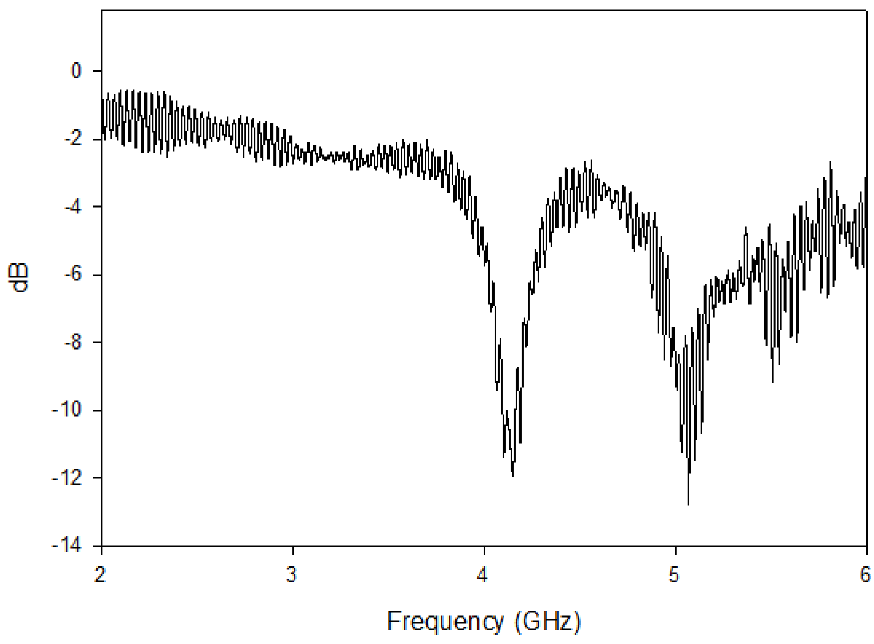



# APPENDIX J

## DESIGN 10

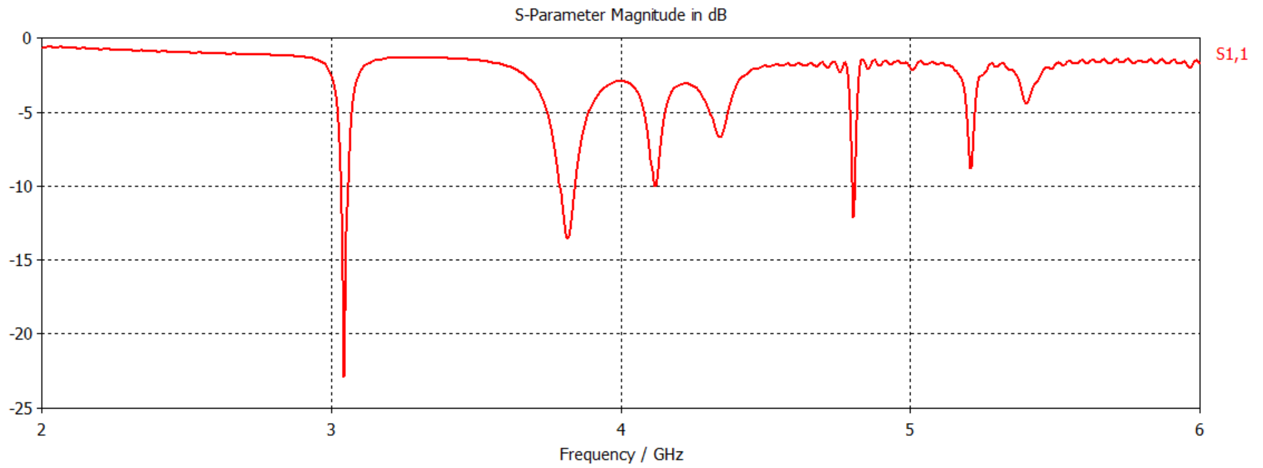



S-Parameter Magnitude in dB

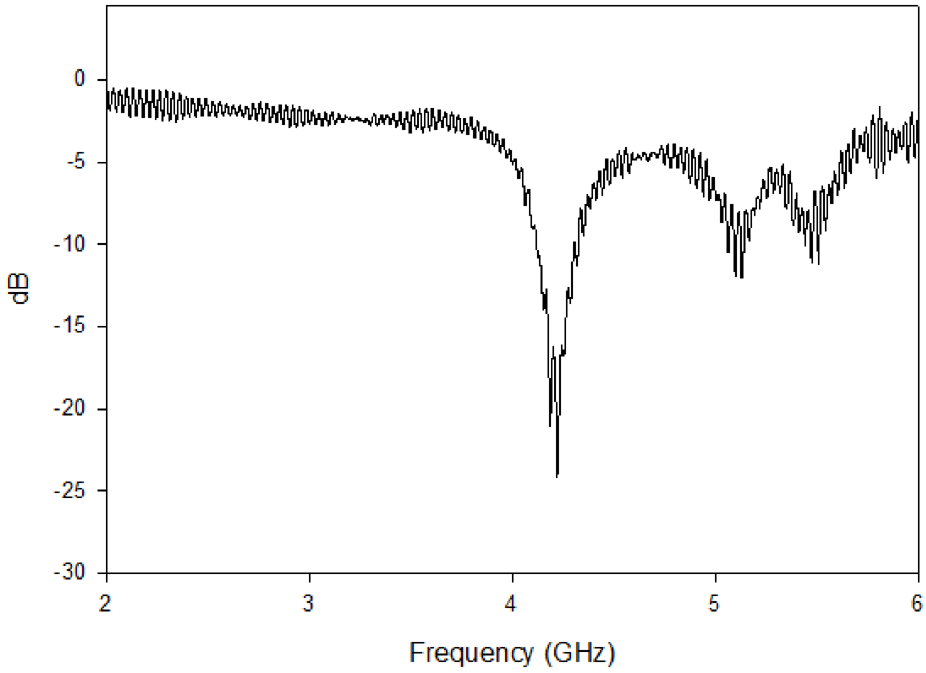


# APPENDIX K

# DESIGN 11




S-Parameter Magnitude in dB



# APPENDIX L

## DESIGN 12