433 MHZ AND 2.4 GHZ DIRECTIONAL AND HIGH GAIN ANTENNAS

NURFARHANA HANIM BINTI RAMLI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

433 MHZ AND 2.4 GHZ DIRECTIONAL AND HIGH GAIN ANTENNAS

NURFARHANA HANIM BINTI RAMLI

This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka

2020

DECLARATION

I declare that this report entitled "433 MHZ AND 2.4 GHZ DIRECTIONAL AND HIGH GAIN ANTENNAS" is the result of my own work except for quotes as cited in the references.

Signature	:	
Author	:	NURFARHANA HANIM BINTI RAMLI
Date	:	26/6/2020

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature	:	....
Supervisor Name	:	Prof. Madya Dr. Maisarah Abu
Date	:	27 June 2020

DEDICATION

I also dedicated to my parent and siblings who has encouraged me all the way and make sure that I able to finish this project. Thanks to them for their moral support and make sure that I never give up to finish this project. Thank you so much for always stays besides me.

ABSTRACT

In recent years, there has been extensively studied on Microstrip Patch Antenna (MPA) because of its lightweight, cheaper and easy to design. Based on the background studies, it is found that in term of gain and return loss, there is still need to improve the antenna. So, in this project, the Rectangular Microstrip Patch Antenna (RMPA) will be proposed on design and analysis with the Defected Ground Structure (DGS). The objective of this project is to design and analysis the RMPA with DGS at frequency band of 433 MHz and 2.4 GHz by using CST Microwave Studio. Besides that, the other objective is to evaluate the simulation antenna with the parameters, comparison of differences length and width of the patch and between RMPA at 433 MHz and 2.4 GHz with and without DGS that will affected the parameters of VSWR, return loss, bandwidth, impedance, resonant frequency, efficiency, gain, realized gain and directivity. In this project, the RMPA with DGS with a frequency band of 433 MHz and 2.4 GHz will be designed and analysed. This planned antenna is designed with the height of the dielectric substrate of FR-4 is 1.6 mm and permittivity of the substrate is equal to 4.3. Furthermore, the design of RMPA with and without DGS also proposed in this project. The DGS that used in this project is in dumbbell form. The dumbbell DGS act as low pass filter. Besides that, Besides, DGS is proposed in

this project because of its low cost and it can enhance the efficiency. As the conclusion, design and analysis of the RMPA with DGS at frequency band of 433 MHz and 2.4 GHz by using CST Microwave Studio and evaluate the simulation antenna with the parameters, comparison between initial (using calculation value) and final design of RMPA and comparison between RMPA with and without DGS at 433 MHz and 2.4 GHz that will affected the parameters of VSWR, return loss, bandwidth, impedance, resonant frequency, efficiency, gain, realized gain and directivity was completed and successful. The final design of RMPA with DGS at 433 MHz and 2.4 GHz have higher percentage of efficiency than the RMPA without DGS and the initial design of RMPA with DGS that is 99.27% and 98.16% respectively. This prove that designing antenna with DGS can improve the efficiency. The S1,1 results for final design of RMPA with DGS at 433 MHz and 2.4 GHz also have some improvement that is from -8.197dB to -35.357dB and from -14.339dB to -20.073dB respectively.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, telah banyak kajian mengenai "Microstrip Patch Antenna (MPA)" kerana profilnya yang rendah, ringan, kos rendah, dan mudah direka bentuk. Berdasarkan kajian tinjauan literatur, didapati bahawa dari segi gandaan dan "return loss", masih ada keperluan untuk penambahbaikan antena. Oleh itu, dalam projek ini, "Rectangular Microstrip Patch Antenna (RMPA)" akan dicadangkan pada reka bentuk dan analisis dengan "Defect Ground Structure (DGS)". Objektif projek ini adalah untuk mereka bentuk dan menganalisis "Rectangular Microstrip Patch Antenna (RMPA)" dengan "Defected Ground Structure (DGS)" pada frekuensi 433 MHz dan 2.4 GHz dengan menggunakan "CST Microwave Studio". Selain itu, objektif lain adalah untuk menilai antena simulasi dengan parameter, perbandingan perbezaan panjang dan lebar tambalan dan antara RMPA pada 433 MHz dan 2.4 GHz dengan dan tanpa DGS yang akan mempengaruhi parameter VSWR, return loss, lebar jalur , impedans, frekuensi salunan, kecekapan, gandaan, "realized gain" dan "directivity". "Rectangular Microstrip Patch Antenna (RMPA)" dengan "Defect Ground Structure (DGS)" pada frekuensi 433 MHz dan 2.4 GHz akan direka bentuk dan dianalisis dalam projek ini. Antena yang dicadangkan ini direka bentuk dengan ketinggian substrat dielektrik FR-

4 adalah 1.6 mm dan pemalar dielektrik substrat sama dengan 4.3. Tambahan pula, reka bentuk RMPA dengan dan tanpa DGS juga dicadangkan dalam projek ini. DGS yang digunakan dalam projek ini adalah dalam bentuk "dumbbell". "DGS dumbbell" bertindak sebagai penapis lulus rendah. Selain itu, Selain itu, DGS dicadangkan dalam projek ini kerana harganya yang rendah dan dapat meningkatkan kecekapan. Sebagai kesimpulan, reka bentuk dan analisis "Rectangular Microstrip Patch Antenna (RMPA) with Defected Ground Structure (DGS)" pada jalur frekuensi 433 MHz dan 2.4 GHz dengan menggunakan "CST Microwave Studio" dan menilai antena simulasi dengan parameter, perbandingan antara awal (menggunakan nilai pengiraan) dan reka bentuk akhir RMPA dan perbandingan antara RMPA dengan dan tanpa DGS pada 433 MHz dan 2.4 GHz yang akan mempengaruhi parameter VSWR, "return loss", lebar jalur , impedans, frekuensi salunan, kecekapan, gandaan, "realized gain" dan "directivity" telah selesai dan berjaya. Reka bentuk akhir RMPA dengan DGS pada 433 MHz dan 2.4 GHz mempunyai peratusan kecekapan yang lebih tinggi daripada RMPA tanpa DGS dan reka bentuk awal RMPA dengan DGS masing-masing adalah 99.27% dan 98.16%. Ini membuktikan bahawa mereka bentuk antena dengan DGS dapat meningkatkan kecekapan. Hasil S1,1 untuk reka bentuk akhir RMPA dengan DGS pada 433 MHz dan 2.4 GHz juga mempunyai beberapa peningkatan yang masing-masing dari -8.197dB hingga -35.357dB dan dari -14.339dB hingga -20.073dB.

ACKNOWLEDGEMENTS

I sincere gratitude to my project supervisor, PM. Dr. Maisarah Binti Abu and my panels, PM. Dr. Azmi Bin Awang Md Isa and Dr. Noor Shahida Binti Mohd Kasim whose contribute and make me motivated by positive criticism to invest the time I have put into this work successfully done. Thanks to them I gain experienced on researches and knowledge about antenna.

My other appreciation is to my parent and siblings who have always give moral support, their prayers and make sure that I can finished this project successful. They also always make me endure the stress and discomfort to make this project done perfectly.

Besides, I also want to thanks to my fellow friends that is Fatihah, Zayanah and others that always give supports and encouraging me to finish my project on time.

Thank you and my love for you all never be quantified.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

MPA	:	Microstrip Patch Antenna
DGS	:	Defected Ground Structure
RMPA	:	Rectangular Microstrip Patch Antenna
MHz	:	Megahertz
GHz	:	Gigahertz
VSWR	:	Voltage Standing Wave Ratio
$\mathcal{E}_r$	:	Dielectric Constant or Relative Permittivity of the Substrate
PCB	:	Printed Circuit Board
ISM	:	Industrial, Scientific, and Medical
EBG	:	Electromagnetic Band Gap
HGA	:	High Gain Antenna
MA	:	Microstrip antennas
FR-4	:	Fire Retardant-4
W	:	Width of the Patch
d	:	Grounded Dielectric Substrate with thickness
RL	:	Return Loss
dB	:	Decibel
Γ	:	Reflection Coefficient
∞	:	Infinity

S_{11}	:	S-parameter
dBi	:	Decibel Isotropic
+	:	Positive
L	:	Length of the Patch
k	:	Free Space
C	:	Speed of Light, $3 \times 10^{8} m/se$
f	:	frequency
π	:	Pi
$Z1$	:	Input Impedance
$Z0$	:	Characteristic Impedance
DMS	:	Defected Microstrip Structure
GPS	:	Global Positioning Systems
CST	:	Computer Simulation Technology
h	:	Height of the Substrate
f_{o}	:	Resonant Frequency
ε_{reff}	:	Effective dielectric constant calculation
L_{eff}	:	Effective Length calculation
ΔL	:	Length extension calculation
L_{g}	:	Length of the Ground and Substrate Plane
W_{g}	:	Width of the Ground and Substrate Plane
Ω	:	Ohms
mm	:	Millimeter
%	:	Percentage
º	:	Degree

IEEE	:	Institute of Electrical and Electronic Engineers
3D	:	Three Dimensional
W	:	Watt
CSRR	:	Complementary Split-Ring Resonator

CHAPTER 1

INTRODUCTION

This chapter will examine the background of project, problem statement, objective, scope of work, and thesis structure of the project. This chapter is a highlight of the project's importance and this thesis arrangement.

1.1 Project Background

Most antenna models have been designed to fit most of the applications. The Microstrip Patch Antenna (MPA) are one of the kinds of antenna. Due to its various advantages such as lightweight, smaller size, integrated circuit suitable, simple to setup on a tough ground and cheap price, MPA are more popularly used for nowadays [1]. The MPA will be designed with dielectric substrate, radiating patch that formed on the top of thin substrate and with ground plane. Nevertheless, there are inherent limitations of MPA, for example limited bandwidth and low gain. The MPA is essentially a narrow-band configuration and a greater thickness of the ground substrate tends to increase the bandwidth [2]. Solving these constraints and enhance the properties of antennas, the researchers used various techniques such as slotting, Defected Ground Structure (DGS), high permittivity dielectric substrates and etc. [3]. DGS is in which the model's ground surface metal is of the MPA is deliberately modified to improve the performance [4]. So, in this project, the MPA will be proposed on design and analysis with the Defected Ground Structure (DGS).

1.2 Problem Statement

In past few years, the Microstrip Patch Antenna (MPA) has been extensively studied despite its low characteristics, compact, low cost and easy to design. Based on the background studies, it is found that in term of gain and return loss, there is still need to improve the antenna. So, the development of the MPA using Defected Ground Structure (DGS) is one of the solutions proposed to improve these two parameters. With the introduction of DGS, the antenna gain can be increased and the return loss will be reduced.

1.3 Objective

This is the objectives of the project:

i. To design and analysis the Rectangular Microstrip Patch Antenna (RMPA) with Defected Ground Structure (DGS) at frequency of 433 MHz and 2.4 GHz by using CST Microwave Studio.

ii. To evaluate the simulation antenna with the parameters, comparison of differences length and width of the patch and between RMPA at 433 MHz and 2.4 GHz with and without DGS that will affected the parameters of VSWR, return loss, bandwidth, impedance, resonant frequency, efficiency, gain, realized gain and directivity.

1.4 Scope of Work

This project will focus on learning and understanding how to use CST Microwave Studio software for antenna design. In addition, the Rectangular Microstrip Patch Antenna (RMPA) with Defected Ground Structure (DGS) at frequency 433 MHz and 2.4 GHz will be designed and analyzed in this project. This proposed antenna is designed with the height of the dielectric substrate of FR-4 with 1.6 mm and dielectric constant of the substrate, $\mathcal{E}_r$ is equal to 4.3. The FR-4 is fire-retardant and it is commonly use in printed circuit board material (PCBs). A copper foil coating is printed on either side of an epoxy FR-4 glass panel, or both. These laminates are usually referred to as laminates clad in copper. Good selection of thermosets for manufactured components for many mechanical and electrical applications due to good dimensional stability, excellent insulation and electrical properties, resistant to moisture and excellent flammability.

In this project, two frequency band have been proposed that is 433 MHz and 2.4 GHz. A frequency band grouped around 433 MHz and 2.4 GHz was already designated as the Industrial, Scientific, and Medical (ISM) radio frequency bands, along with a handful of others. As for the 433 MHz, it is a frequency band commonly used for all types of equipment which requires less power. For example remote controls, infant phone devices, and automatic garage door. The 433 MHz frequency band can transmit for a maximum of two seconds an hour, for a very short transmission periods, how many events that can handle will be limited. The 433 MHz also have short range and the antenna size is bigger. Meanwhile, as for the 2.4 GHz, the system will have longer range and the antenna size will be smaller.

Furthermore, the design of RMPA with and without DGS also proposed in this project. DGS is a band-stop characteristic and can be considered as a simplified from Electromagnetic Band Gap (EBG) structure. DGS is a compress slot of geometry built into the ground plane. The DGS that used in this project is in dumbbell form. The dumbbell DGS act as low pass filter. Besides that, Besides, DGS is proposed in this project because of its low cost and it can enhance the efficiency.

1.5 Thesis Structure

In chapter 1, introduction, project background, problem statement, objectives, scope of work and thesis structure will be briefly explained. In this chapter also will mentioned the information of proposed antenna.

In chapter 2 will be reviewing the literature review of this project. It includes the explanations that related to this project from past work. The past research will be focused on the MPA with DGS.

In chapter 3 will be focused on the methodology of the project. It will explain in detail the methods and procedures for completing and running the project perfectly from the start of the project till the end.

In chapter 4, the data from simulation will presented in tabulated and also the discussion of this project will be included.

In chapter 5, in this last chapter the overall conclusion of this project will be presented and the recommendation for future work also will proposed.

CHAPTER 2

BACKGROUND STUDY

2.1 Introduction

In this chapter, it will be discuss the basic concept and theory of Rectangular Microstrip Patch Antenna (MPA) with Defected Ground Structure (DGS) based on the past research projects. The information that collected in this chapter can be a guideline for the correct design and simulation of the proposed antenna so that it can function perfectly according to the scheme. Most of the past studies discussed nearly the same good Rectangular Microstrip Patch Antenna (RMPA) with Defected Ground Structure (DGS) features that will be achieved in the desired form.

2.2 Directional and High Gain Antenna

Often known as a directional antenna can be a high-gain antenna. A narrow radio beam antenna is a high gain antenna (HGA) which can be used to increase the strength of the signal. The high-directional gain antennas desirable because it makes possible for radios to communicate longer distances at a higher capacity. Directional antennas can increase a wireless network's efficiency by providing a direct path to other nodes with minimal interference. Directional antennas can also significantly raise the possibility for spectrum utilization by focusing energy in the direction intended, and also provide extremely long transmission and reception ranges for the identical amount of electricity. The intensity of the radiated energy in a narrow beam will significantly reduce the detection probability, which may be important for certain applications, for example, using military applications.

2.3 Microstrip Patch Antenna (MPA)

Microstrip Antennas (MA) received considerable attention in the 1970’s, although the first designs and theoretical models appeared in the 1950’s [5]. The fringing fields cause MPA to radiate primarily between the ground plane and the edge of the patch. Figure 2.1 shown that is MPA contains of a patch on one side of a conductivity material on the other side which has a ground plane.

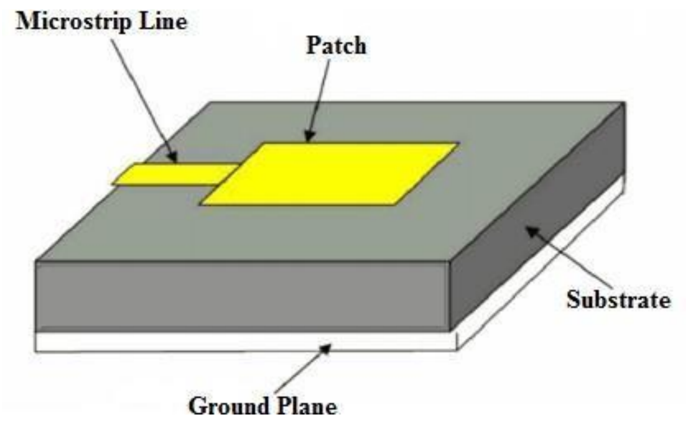

Figure 2.1: Microstrip Patch Antenna (MPA) [6]

The patch is usually made of materials such as gold or copper and also can be any form. Radiating patch is on top of the substrate, which can be any kind of shape, but is usually chosen to be circular or rectangular. In the simulation, usually copper material will be selected for patch plane and ground plane. The substrates material selection for dielectric substrates depends on their relative permittivity range that is $2.2 \leq \varepsilon_r \leq 12$. The substrate and its thickness of the material are crucial. Substrate type has an important role in deciding antenna measurements. The greater permittivity substrate outcomes in a larger antenna size for patches. FR-4 is chosen for the substrate in this project and it has a relative permittivity, $\varepsilon_r = 4.3$. Figure 2.2 shown the patch plane is usually square, circular, triangular, rectangular, and elliptical, or some relevant shape to optimize the prediction of analysis and output. Each shape has its own characteristics, but due to its simpler analysis and production, the most popular designs are square, rectangular and circular.

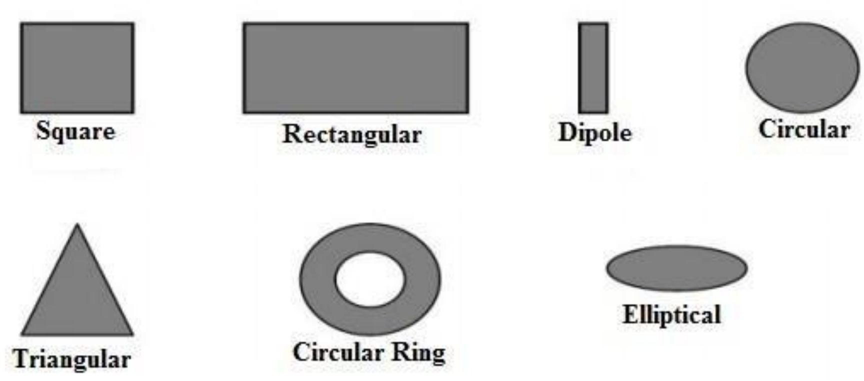

Figure 2.2: Common shape of Microstrip Patch Antenna element [7]

2.4 Advantages and Disadvantages of Microstrip Patch Antenna (MPA)

2.4.1 Advantages of Microstrip Patch Antenna (MPA)

Across modern life, MPA are commonly used in communication because of the following benefits that is small size, integrated circuit compatibility, tough ground simple to setup, cheap price, minimum disturbances, easy to fabrication and highly reliable in hazardous conditions like speed, atmospheric pressure etc. [8-9].

2.4.2 Disvantages of Microstrip Patch Antenna (MPA)

MPA have their limitations over standard antennas. The disadvantages of MPA are followed as low gain, poor efficiency, limited handling capacity, narrow bandwidth, unnecessary feed and intersection radiation, wave propagation excitation, poor radiator and fire radiator except tapered slot antennas [8-9].

2.5 Feeding Technique

The feeding techniques of an antenna usually can be categorized into two kinds of contacts and noncontacts. Coaxial probe, microstrip line, proximity coupling and aperture coupling are the four common feeding methods applied in patch antenna.

2.5.1 Microstrip Line

One of the most popular types of planar transmission lines is the microstrip line, primarily because it can be generated though the optical lithographic processes and can be easily implemented with other passive and active microwave systems. The conductor's width is positioned on a thin, grounded dielectric substrate with depth, d, and dielectric constant, ε_r. The Microstrip line is one of the planar transmission line types that are most common. Microstrip line also incorporates simple fabrication processes and other passive and active microwave products. Figure 2.3 shown as Microstrip Line feed.

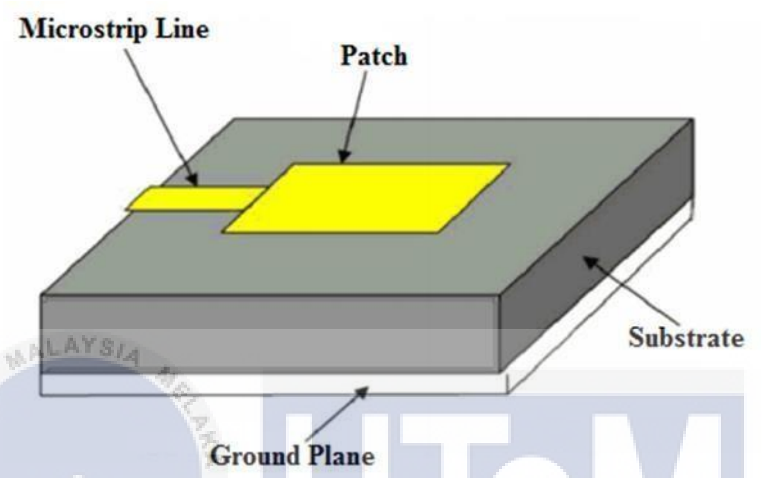

Figure 2.3: Microstrip Line Feed [2]

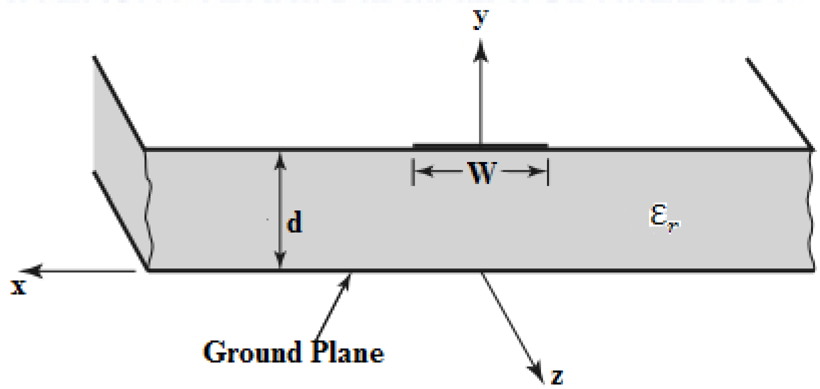

Figure 2.4: The geometry of a Microstrip Line

The figure 2.4 shown the geometry of Microstrip line. W is the width of printed thin conductor, d is the depth of the substrate and ε_r is the relative permittivity of the substrate.

2.5.2 Aperture Coupled Feed

Figure 2.5 shows the coupled aperture feed contains of two distinct substrates segregated by a ground plane. On the bottom side of the lower substrate there is a microstrip feed line, where such energy is combined to the patch by a slot on the ground plane separating two substrates. The structure enables individual layout of the feed mechanism and of the radiating element. The top substratum usually uses a dense low conductivity constant substratum whereas the bottom substratum is the high dielectric substratum. The ground plane in the center distinct the feed from the radiation component and minimizes unwanted interference with radiation for pattern forming and purity of polarization. This is the hardest feeding among all types because it involves multi-layer manufacturing and has limited bandwidth. Two dielectric substrates separate the antenna component in the centre by a ground plane on.

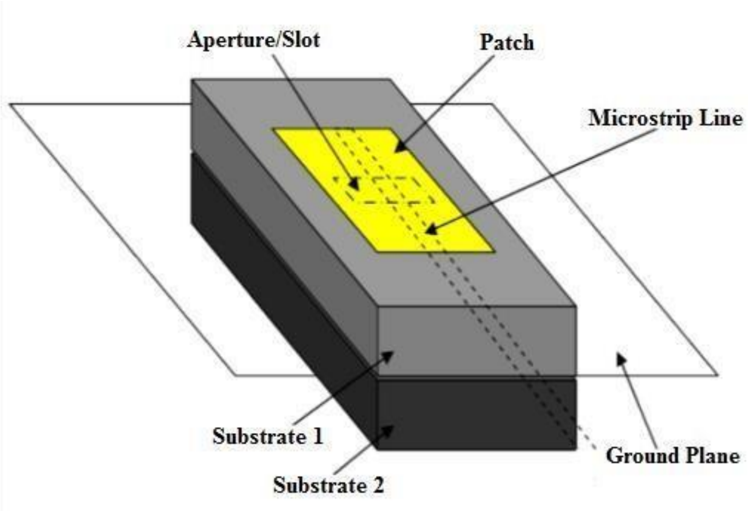

Figure 2.5: Aperture Coupled/Slot Feed

2.5.3 Proximity Coupled Feed

The largest bandwidth and lowest emission are in proximity coupling. It's hard to make, though. The feeding connector length and the patch width to long ratio are used to monitor the match. Its mechanism to coupling is capacitive. The main drawback of this feeding method is a challenging coat requiring proper compatibility, and an increase in the total width of the antenna. Figure 2.6 shown the Proximity Coupled Feed.

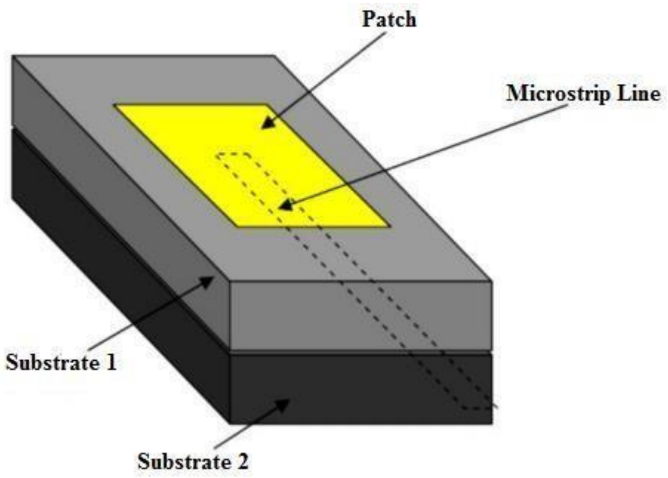

Figure 2.6: Proximity Coupled Feed

2.5.4 Coaxial Feed

The coaxial feed is a rather popular method of feeding patch antennas from Microstrip. The coaxial connector interior conductor, as shown in Figure 2.7 and Figure 2.8 is the Microstrip Patch antenna with Coaxial Feed with top view and side view, Spreads through the dielectric and is welded to the patch plane while connecting the external conductor to the ground plane. The benefit of this feeding approach is that to match the impedance, the connector can put inside the patch at any spot. Besides, it is simple to design and built this feed system and has low emission. There's some limitation, though. The inductance increase could affect the matching issue when working with thicker substrates.

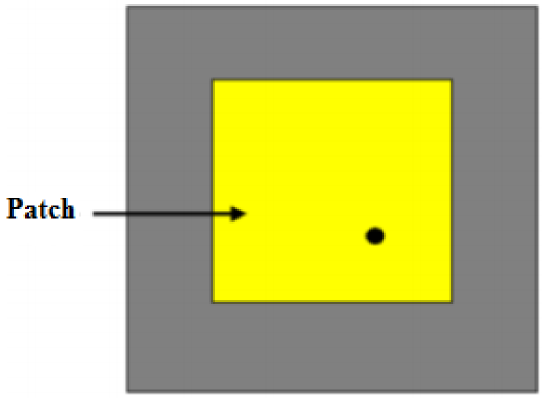

Figure 2.7: Front View of MPA with Coaxial Feed

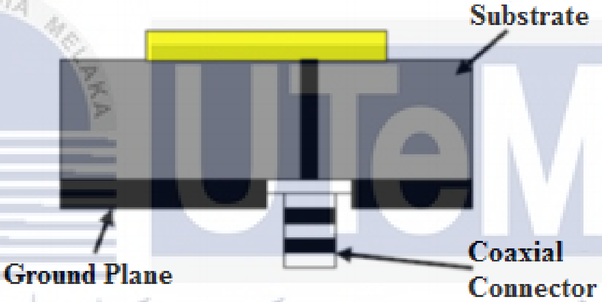

Figure 2.8: Side of MPA with Coaxial Feed

2.6 Important Parameters of Antenna

2.6.1 Return Loss (RL)

RL or S- parameter is a parameter that indicates or assesses impedance match value. If the load is not balanced, all the power is not supplied, there is an energy return, which is called lossess, and this lossess is known as the RL. If the RL indicator is higher than 10 dB, this means the match is good for an ideal match between both the transmitter and the antenna, $\Gamma = 0$ and $RL = \infty$ which means that no energy is reflected, whereas a $\Gamma = 1$ has RL = 0dB. It ensures that all the energy of occurrence is reflected. Reflection coefficient also known as Γ. Here the formula for the RL,

$$\text{Return Loss (RL)} = -20\, log_{10}|\Gamma| \tag{2.1}$$

2.6.2 Voltage Standing Wave Ratio (VSWR)

Voltage Standing Wave Ratio (VSWR) calculates the ratio of the peak standing wave's amplitude to the lowest standing wave. In other words, the impedance matching value for an antenna is an indicator of reliability, the lower the VSWR is and the good the antenna meets the transmission system and provides the antenna with more energy. The VSWR's impedance match value typically desired less or equal to 2. The formula for VSWR is as follows,

$$\text{VSWR} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{2.2}$$

The coefficient of reflection is also known as Return Loss (RL) or S_{11}.

2.6.3 Gain

In directional antenna, the signal strength in some directions at distance, d from the antenna is stronger than other ways. Antenna gain is the proportion of signal stability in the path of the strongest radiation to that of an ideal isotropic antenna, the unit is in dBi. Although a directional antenna can increase the signal stability in one path, the total radiated signal power of any antenna could not exceed that of an ideal isotropic antenna. Consequently, a directional antenna with a positive gain in some paths would typically have a negative gain in certain paths to minimize overall energy produced less than for an optimal isotropic antenna. In receiving and transmitting modes, the antenna gain is the same.

2.6.4 Bandwidth

Bandwidth defines the frequency range in which the antenna will radiate or absorb energy properly. Also, one of the defining criteria used to settle on an antenna is the desired bandwidth. For example, most antennas types have very narrow bandwidths, so the wideband operation could not be used.

2.6.5 Radiation Pattern

The pattern of radiation graph is one of the very beneficial charts to evaluate and compare different antennas. A radiation structure defines the intensity difference that an antenna radiates as a result of the path where the antenna is directed, it provides the strength that the transmitting antenna or the receiving antenna emit or receive. In other words it is a numerical equation or a visual presentation of the radiation characteristics of the antenna, as a function of space coordinates. The radiation pattern is measured somewhere in the-field region, and is interpreted as a property of the directional locations. The normalized pattern of radiation was shown in (2.3). Where W is width of antenna and L is for the length of antenna.

$$E_\theta = \frac{\sin\left(\frac{kW \sin\theta \sin\phi}{2}\right)}{\left(\frac{kW \sin\theta \sin\phi}{2}\right)} cos\left(\frac{kL}{2} \sin\theta \cos\phi\right) \cos\phi \tag{2.3}$$

Where k is the free space and C is for speed of light. The formula for k is,

$$k = \frac{2\pi}{\lambda}$$

$$= \frac{2\pi f}{C} \tag{2.4}$$

2.6.6 Directivity

Directivity is an integral parameter of the antenna. It is the proportion of the frequency of propagation from the antenna to the total intensity of propagation across all paths in a given direction. The typical radiation intensity is comparable to the antenna's total power, which is divided by 4π. n other phrase, energy can be focused in particular path by the antenna.

2.6.7 Input Impedance

Impedance of the input is the impedance indicating an antenna at its terminals, or the voltage-to - current ratio at a pair of terminals. The maximum power transfer will be reached if the input impedance of the transmission line and the antenna is balanced. If not balanced, the overall performance of the process will be reduced. This however at the antenna terminal reflected wave is produced and it will move back to the source of power. To obtain optimal flow of energy across the transmitting system and the patch, the input impedance must suit the impedance behaviour of the transmitting system for this parameter. If the current impedance does not suit, the wave is reflected will be generated at the port of the antenna and travel back to the source of power. Reflexion on energy results in reduction in the total process efficiency. Also in case the antenna is required to transfer or receive power will this failure potential arise. The $Z1$ is the Input Impedance if the patch has been fed to the end, so, the scales of input impedance as,

$$Z1 = Z0\ [\frac{1 + S_{11}}{1 - S_{11}}] \tag{2.5}$$

Where, the $Z0$ is Characteristic Impedance and S_{11} is Return Loss.

2.7 Defected Ground Structure (DGS)

Recently, many approaches have been suggested to use slots, fractal geometry or notches on patch antennas of different shapes, using high permittivity substrates, tuning stub and some other methods such as Defected Microstrip Structure (DMS), and Defected Ground Structure (DGS). DGS is among the ways of reducing the size of the Microstrip antennas, DGS requires of a basic ground level etching, or often a complex design for higher quality. Figure 2.9 shows the examples of Defected Ground Structure (DGS).

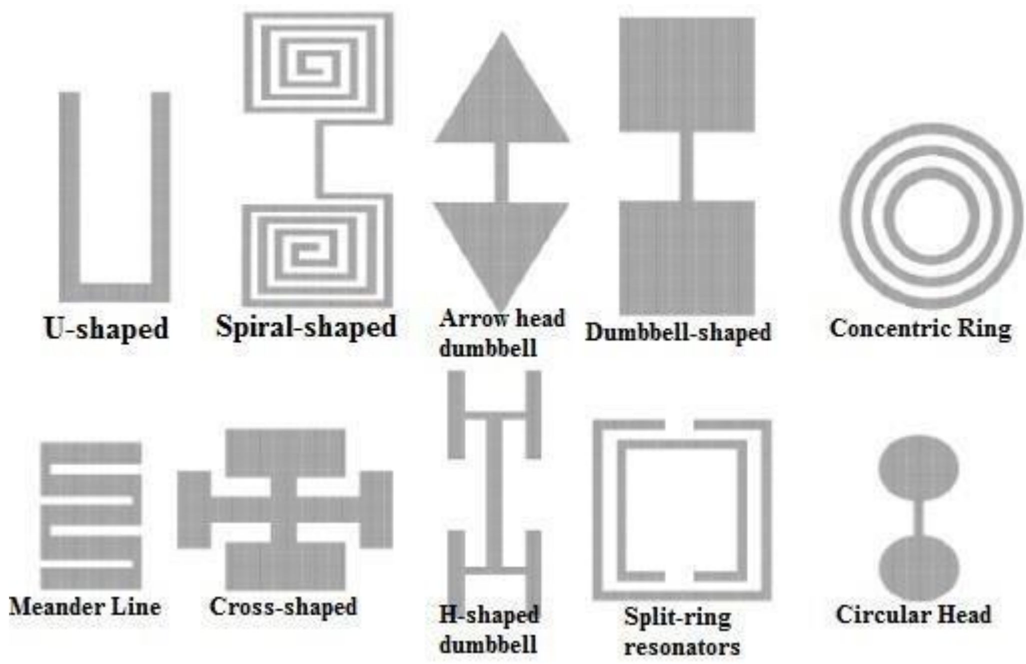

Figure 2.9: Examples shapes of Defected Ground Structure (DGS)

The DGS can be based on a resonator circuit similar to L-C. The value of the inductance and the capacity depends on the area and the size of the shape [10]. The required frequency of resonance can be achieved by differentiating the different dimensions of the etched form.

2.8 Past Work Research

2.8.1 Microstrip Patch Antenna (MPA)

Because of its numerous benefits, such as low density compatibility with integrated circuits, lightweight, ease of installation on a hard surface, cheaper, minimal disturbances, and highly reliable in hazardous conditions such as speed, atmospheric pressure, etc., Microstrip Patch Antennas (MPA) are more common nowadays [1][2][8][11][13].

Besides that, MPA are gradually searching their applications in a wide range of radar, navigation, telemetry, biomedical devices, cellular and satellite communications, military network bomb services, remote sensing global positioning systems (GPS), and so on [1][2][11][12][13].

A Microstrip Patch antenna's standard design contains of a dielectric substrate with a fixed dielectric constant. There is a patch plane on one side of a dielectric substrate and the ground surface on the other side [1][11].

2.8.2 Shape of the Microstrip Patch Antenna (MPA)

The conductive patch shape for MPA can be any geometric form of which the most common are rectangular and circular. The circular and Rectangular MPA is used for comprehensive and demanding applications as simple and easy as it offers flexibility in the feed line, several frequency processing, linear and circular polarization, frequency flexibility, reasonable bandwidth and so on [1][11].

2.8.3 Defected Ground Structure (DGS)

DGS means that some defective structure is implanted in the ground plane of the antenna and the shielded current distribution will be disrupted for better performance liable on the different dimensions, form, and defect’s size. DGS geometry can be one or a few etched structures that are easier to implement and do not require a large area. The word for this approach simply indicates that the ground plane has a "Defect" that has been cut off, which inhibits the movement of the shield current in the ground plane and influences the input impedance and flow of current of the antenna [1][2][8][10][12].

Developing DGS into MPA results in enhanced parameters such as size decrease, bandwidth, other standardized power flow, beam distance, s-parameter, VSWR, gain increasing [1][2][8][10][12].

Defected Ground Structures (DGS) may have various shaped slots that are engraved on the ground plane by Microstrip circuits such as Dumbbell-shaped, Circular head, Split-shaped resonators, H-shaped dumbbell, and Cross-shaped and so on that help to improve resonant bandwidth [2][10].

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will be discussing the methodology, so there will have information on Rectangular Microstrip Patch Antenna (RMPA) with Defected Ground Structure (DGS) for the simulation and fabrication process. In this project, the methodology will start with the studying and understanding of the parameters for designing RMPA. This includes studying the antenna's properties for example frequency, the pattern of radiation, and antenna gain. Reviews of the related background studies are conducted from related journals from IEEE publishes the paper. The simulation process will be carried out by using the Computer Simulation Technology (CST) Microwave Studio. The design is optimized accordingly to meet the theoretical expectations.

3.2 Flow Chart of the Methodology

In this project, design will be implemented by using software. The simulation process will be carried out by using the CST Microwave Studio. Figure 3.1 shown the flow chart of the RMPA with Defected DGS design.

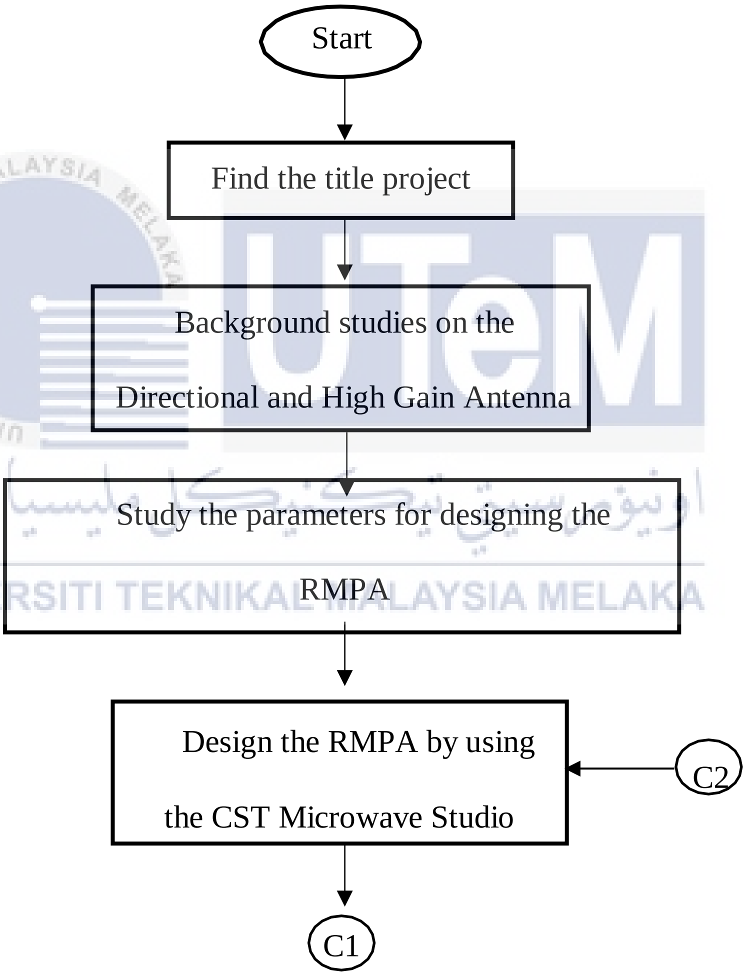

Figure 3.1: Flow Chart of the Rectangular Microstrip Patch Antenna (RMPA) with Defected Ground Structure (DGS) design

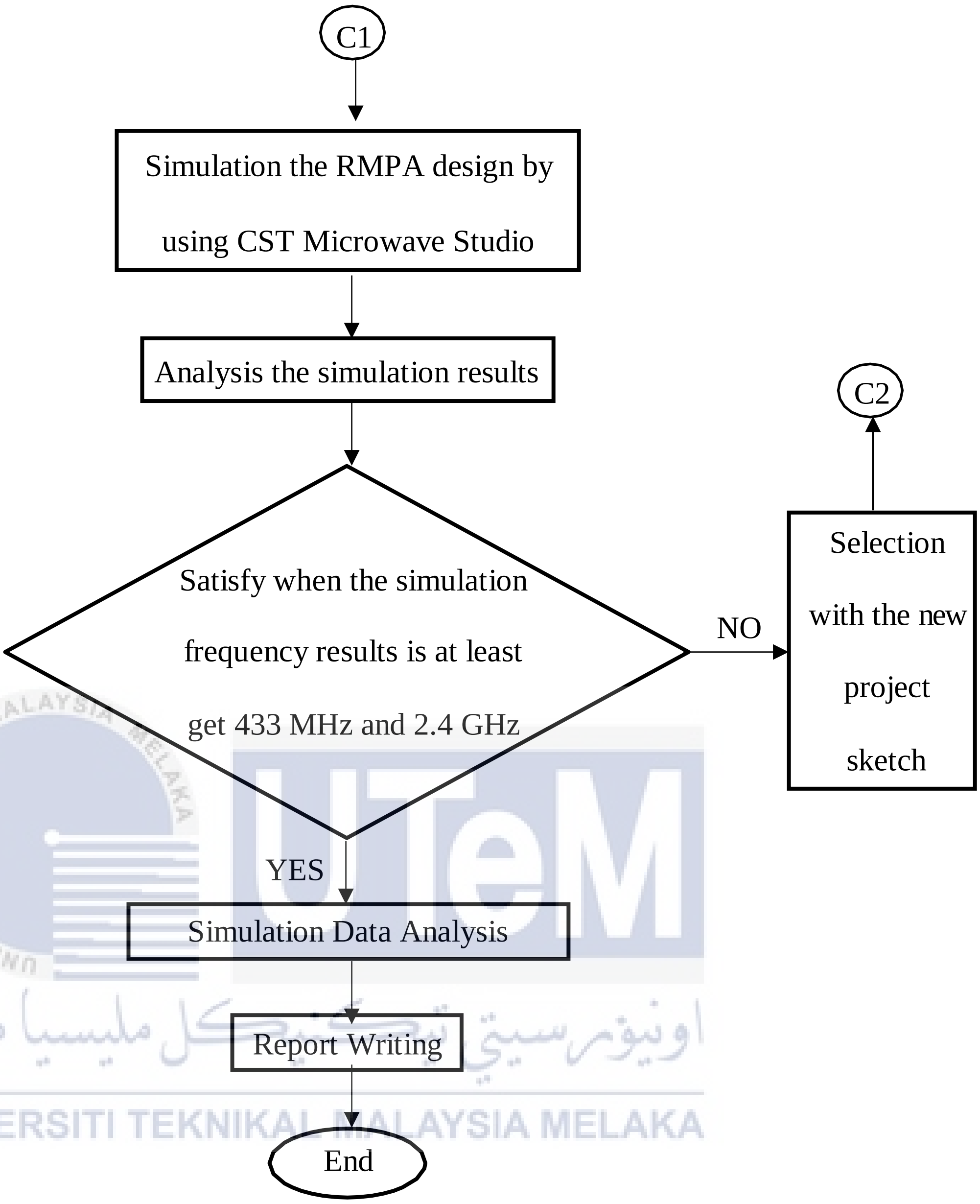

Figure 3.1: Continued

3.3 Calculation and Parameter Study

3.3.1 Characteristic of FR-4 Substrate

In this project, the substrates that will be used is FR-4 that has a permittivity of the substrate, $\varepsilon_r = 4.3$. Furthermore, the height of the substrate is, h = 1.6 mm with the resonant frequency equal to 433 MHz and 2.4 GHz. In Table 3.1, it is shown the characteristic of the substrate (FR-4) at frequency 433 MHz. Meanwhile, Table 3.2 shows the characteristic of the substrate (FR-4) at frequency of 2.4 GHz.

Table 3.1: The Characteristic of the substrate (FR-4) at Frequency of 433 MHz

Characteristic	**Values**
Resonant Frequency, f_o	433 MHz
Substrate	FR-4
Permittivity of The Substrate, ε_r	4.3
Height of The Substrate is, h	1.6 mm

Table 3.2: The Characteristic of the Substrate (FR-4) at Frequency of 2.4 GHz

Characteristic	Values
Resonant Frequency, f_o	2.4 GHz
Substrate	FR-4
Permittivity of The Substrate, ε_r	4.3
Height of The Substrate is, h	1.6 mm

3.3.2 Characteristic of Patch Plane

The calculation from (3.1) until (3.5) were used for scheming the Patch Plane.

i.* Calculation of patch width, *W

$$W = \frac{C}{2f_o\left(\sqrt{\frac{\varepsilon_r + 1}{2}}\right)} \tag{3.1}$$

Where, *C* is equal to $3 \times 10^8\, m/se$ and $\varepsilon_r = 4.3$

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$W = \frac{3 \times 10^8}{2(433M)\left(\sqrt{\frac{4.3+1}{2}}\right)}$ $W = 212.8043\ mm \approx 213\ mm$	$W = \frac{3 \times 10^8}{2(2.4G)\left(\sqrt{\frac{4.3+1}{2}}\right)}$ $W = 38.3934\ mm \approx 39\ mm$

ii. Effective permittivity calculation, ε_{reff}

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3.2)$$

Where, $\varepsilon_r = 4.3$ and $h = 1.6$ mm

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$\varepsilon_{reff} = \frac{4.3+1}{2} + \frac{4.3-1}{2}\left[1 + 12\frac{1.6\ m}{213m}\right]^{-\frac{1}{2}}$ $\varepsilon_{reff} = 4.2303 \approx 4.2$	$\varepsilon_{reff} = \frac{4.3+1}{2} + \frac{4.3-1}{2}\left[1 + 12\frac{1.6\ m}{39m}\right]^{-\frac{1}{2}}$ $\varepsilon_{reff} = 4.0007 \approx 4.0$

iii. Effective Length calculation, L_{eff}

$$L_{eff} = \frac{C}{2f_o\sqrt{\varepsilon_{reff}}} \qquad (3.3)$$

Where, C is equal to $3 \times 10^8\, m/se$

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$L_{eff} = \frac{3 \times 10^8}{2(433M)\sqrt{4.2}}$ $L_{eff} = 169.0358\ mm \approx 169\ mm$	$L_{eff} = \frac{3 \times 10^8}{2(2.4G)\sqrt{4.0}}$ $L_{eff} = 31.25\ mm \approx 31\ mm$

iv. Length extension calculation, ΔL

$$\Delta L = 0.412(h)\,\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (3.4)$$

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$\Delta L = (0.6592\ m)\frac{(4.5)\,(\frac{213\ m}{1.6\ m} + 0.264)}{(3.942)\,(\frac{213\ m}{1.6\ m} + 0.8)}$ $\Delta L = 0.7495\ mm \approx 0.75\ mm$	$\Delta L = (0.6592\ m)\frac{(4.3)\,(\frac{39\ m}{1.6\ m} + 0.264)}{(3.742)\,(\frac{39\ m}{1.6\ m} + 0.8)}$ $\Delta L = 0.7414\ mm \approx 0.74\ mm$

v. Calculation of patch length, *L*

$$L = L_{eff} - 2\Delta L \tag{3.5}$$

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$L = 169\ m - 2(0.75\ m)$ $L = 167.5\ m \approx 168mm$	$L = 31\ m - 2(0.74\ m)$ $L = 29.52\ m \approx 30\ mm$

3.3.3 Characteristic of Ground and Substrate Plane

The calculation from (3.6) and (3.7) can be used for designing the Ground and Substrate Plane.

i. Length of the Ground and Substrate Plane, L_g

$$L_g = 6h + L \tag{3.6}$$

Where, h = 1.6 mm and the value of L will refer in table 3.3.

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$L_g = 6(1.6\ m) + 168\ mm$ $L_g = 177.6\ mm$	$L_g = 6(1.6\ m) + 30\ mm$ $L_g = 39.6\ mm$

ii. Width of the Ground and Substrate Plane, W_g

$$W_g = 6h + W \tag{3.7}$$

Where, h = 1.6 mm and the value of W will refer in table 3.3.

$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
$W_g = 6(1.6\ m) + 213\ mm$ $W_g = 222.6\ mm$	$W_g = 6(1.6\ m) + 39\ mm$ $W_g = 48.6\ mm$

So, Table 3.3 shows all the calculation value for the patch plane, length and width of the ground plane and substrate plane.

Table 3.3: All calculation value for the Patch Plane, Length and Width of the Ground Plane and Substrate Plane.

	$f_o = 433\ MHz$	$f_o = 2.4\ GHz$
Calculation of patch width, W	213 mm	39mm
Effective permittivity calculation, ε_{reff}	4.2	4.0
Effective Length calculation, L_{eff}	169 mm	31 mm
Length extension calculation, ΔL	0.75 mm	0.74 mm
Calculation of patch length, L	168 mm	30 mm
Length of the Ground and Substrate Plane, L_g	177.6 mm	39.6 mm
Ground and Substrate Plane, W_g	222.6 mm	48.6 mm

3.4 Antenna Design

In this antenna design, it will focus on designing the RMPA with DGS at frequency 433 MHz and 2.4 GHz by using CST Microwave Studio software. The planned antenna is designed with the dielectric substrate of FR-4 with 1.6 mm and permittivity of the substrate, ε_r is equal to 4.3. Table 3.5 shows the specification antenna design of RMPA at frequency 433 MHz, meanwhile, on the Table 3.6 shows the specification antenna design of RMPA at frequency of 2.4 GHz.

Table 3.4: The Specification Antenna Design of Rectangular Microstrip Patch Antenna for Resonant Frequency of 433 MHz

Parameters	**Specifications**
Resonant Frequency, f_o	433 MHz
Substrate Material	FR-4
Permittivity of The Substrate, ε_r	4.3
Height of The Substrate is, *h*	1.6 mm
Feeding Technique	Microstrip Feed Line
Impedance	50Ω

Table 3.5: The Specification Antenna Design of Rectangular Microstrip Patch Antenna for Resonant Frequency of 2.4 GHz

Parameters	Specifications
Resonant Frequency, f_o	2.4 GHz
Substrate Material	FR-4
Permittivity of The Substrate, ε_r	4.3
Height of The Substrate is, h	1.6 mm
Feeding Technique	Microstrip Feed Line
Impedance	50Ω

3.4.1 RMPA with DGS

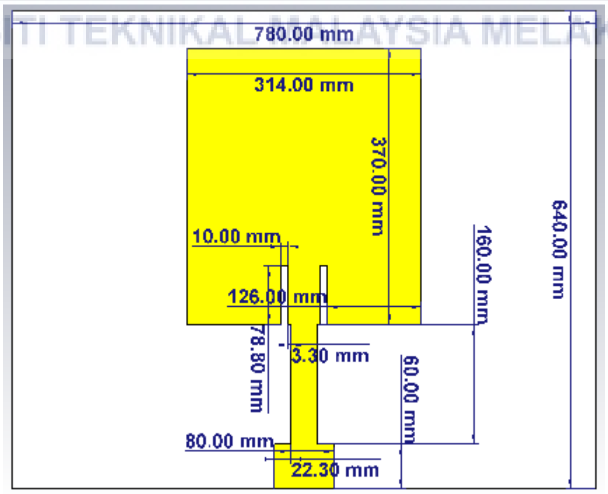

Figure 3.2: Front view dimension (mm) of RMPA with DGS at 433 MHz resonant frequency

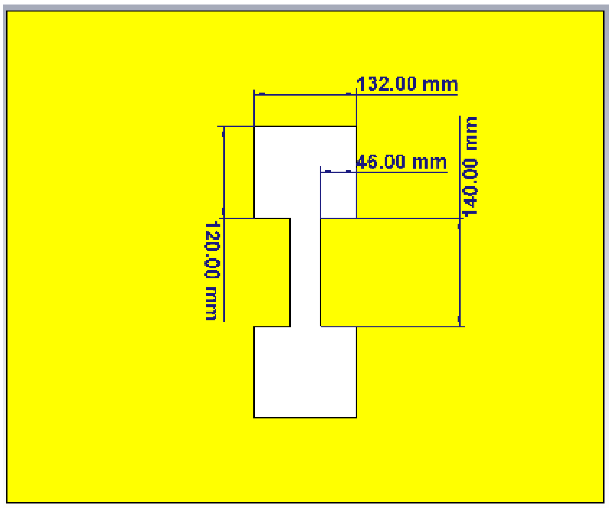

Figure 3.3: Back view dimension (mm) of RMPA with DGS at 433 MHz resonant frequency

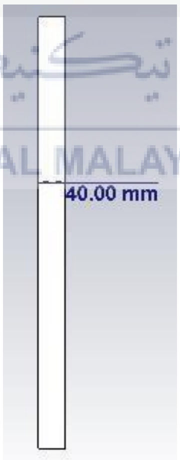

Figure 3.4: Side view of thickness dimension (mm) of RMPA with DGS at 433 MHz resonant frequency

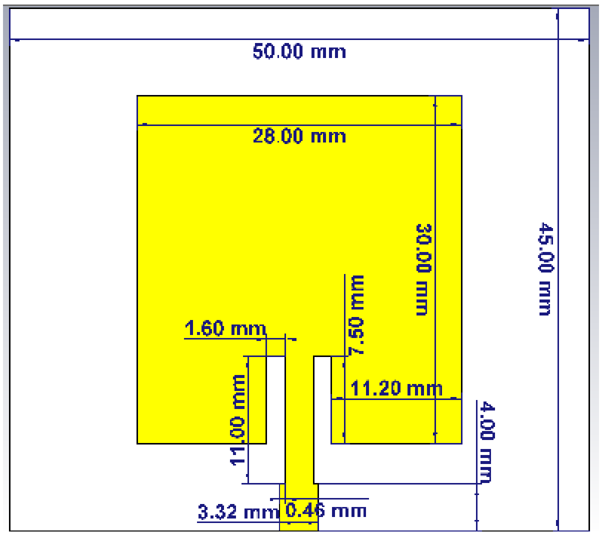

Figure 3.5: Front view dimension (mm) of RMPA with DGS at 2.4 GHz resonant frequency

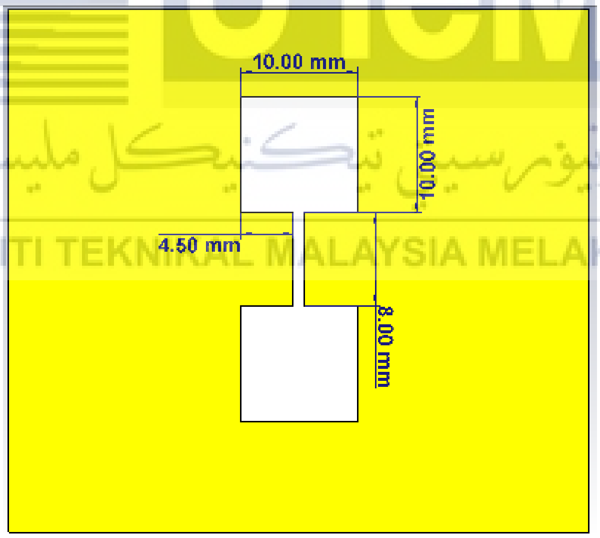

Figure 3.6: Back view dimension (mm) of RMPA with DGS at 2.4 GHz resonant frequency

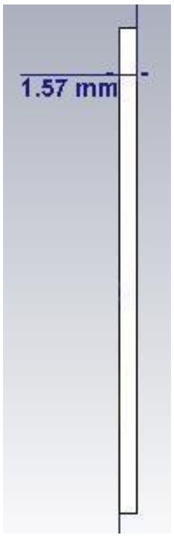

Figure 3.7: Side view of thickness dimension (mm) of RMPA with DGS at 2.4 GHz resonant frequency

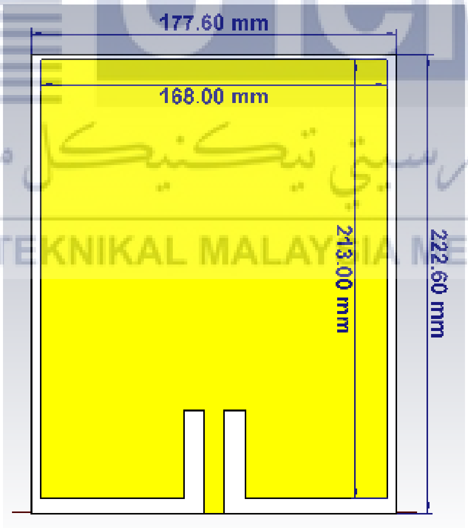

Figure 3.8: Front dimension (mm) of Initial Design Patch of RMPA with DGS at 433 MHz resonant frequency

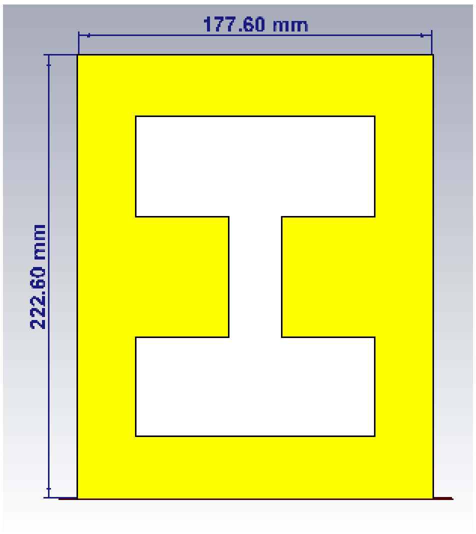

Figure 3.9: Back dimension (mm) of Initial Design Patch of RMPA with DGS at 433 MHz resonant frequency

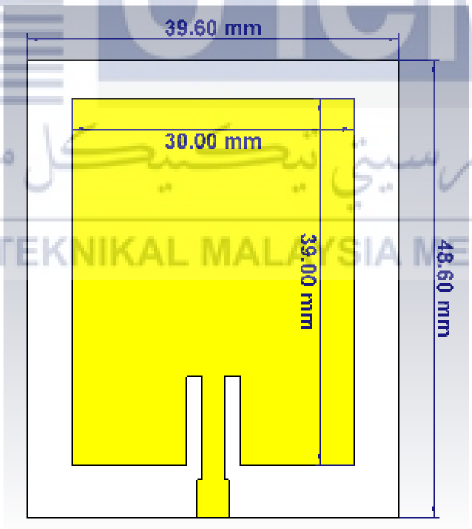

Figure 3.10: Front dimension (mm) of Initial Design Patch of RMPA with DGS at 2.4 GHz resonant frequency

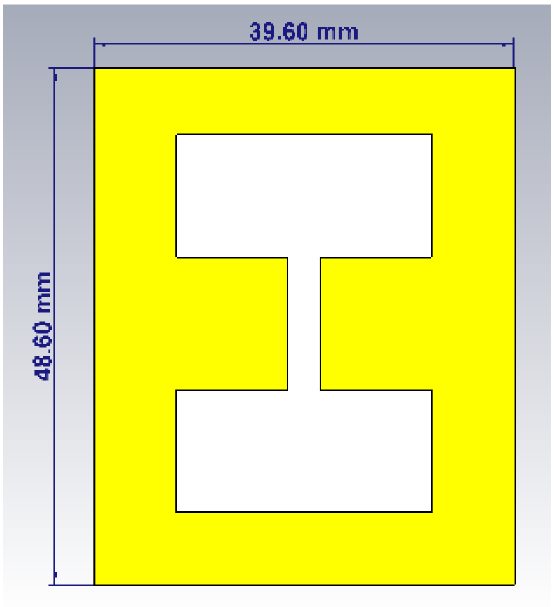

Figure 3.11: Back dimension (mm) of Initial Design Patch of RMPA with DGS at 2.4 GHz resonant frequency

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter focus on the analysis and discussion of S-parameter ($S_{1,1}$) that is also known as return loss, resonant frequency, VSWR, impedance, bandwidth, directivity and polar plot of radiation pattern for RMPA at frequency 433 MHz and 2.4 GHz. All of this comparison simulated results was done and obtain by using the simulation software of CST Microwave Studio.

4.2 Simulation Results

4.2.1 RMPA without DGS

4.2.1.1 RMPA without DGS at 433 MHz

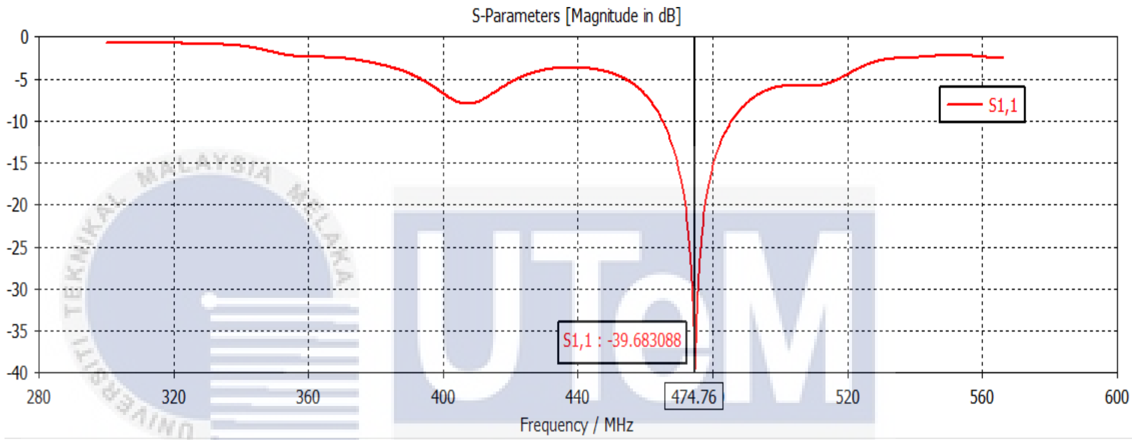

Figure 4.1: S-parameter result of RMPA without DGS at 433 MHz

The figure 4.1 show the result of $S_{1,1}$ is equal to -39.683dB and 474.76 MHz of resonant frequency. From this, RMPA at frequency of 433 MHz is an ideal match between both transmitter and antenna because the $S_{1,1}$ value more than 10dB.

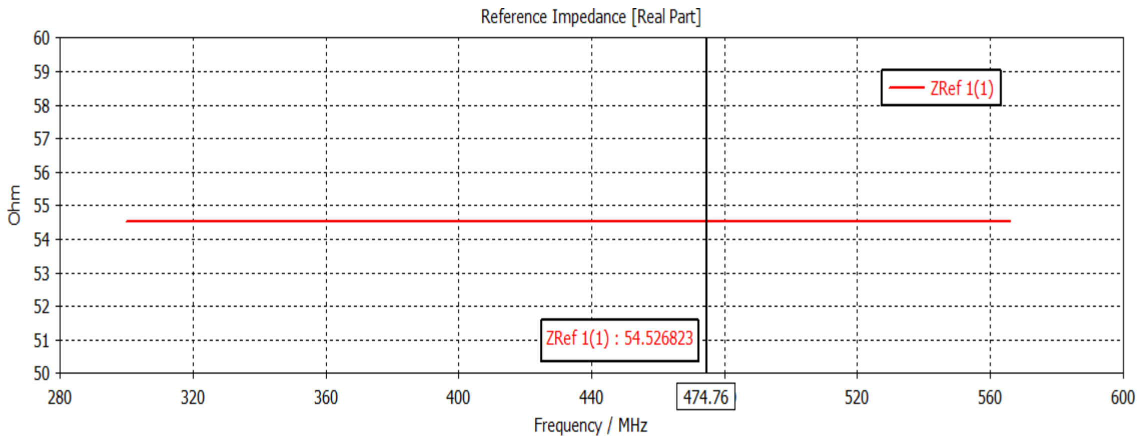

Figure 4.2: Impedance result of RMPA without DGS at 433 MHz

Figure 4.2 here is the impedance result of RMPA without DGS at frequency of 433 MHz is equal to 54.527Ω. The impedance almost have a good impedance matching because it has nearly equal to 50Ω.

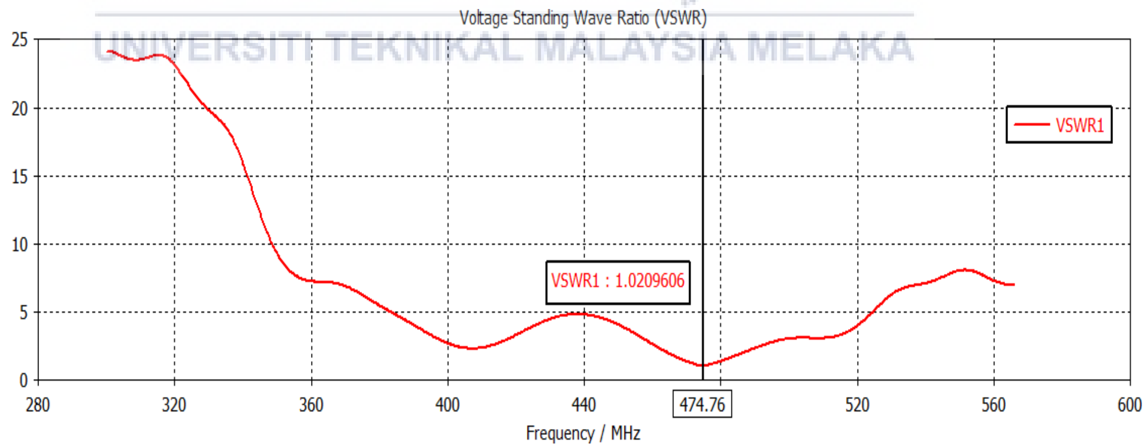

Figure 4.3: VSWR result of RMPA without DGS at 433 MHz

Based on Figure 4.3, it is shown that the result of the voltage standing wave ratio (VSWR) for 433 MHz with 1.021. The RMPA without DGS at frequency of 433 MHz fits the transmission line and provides the antenna more energy because the VSWR results for both antenna is less than or match with 2.

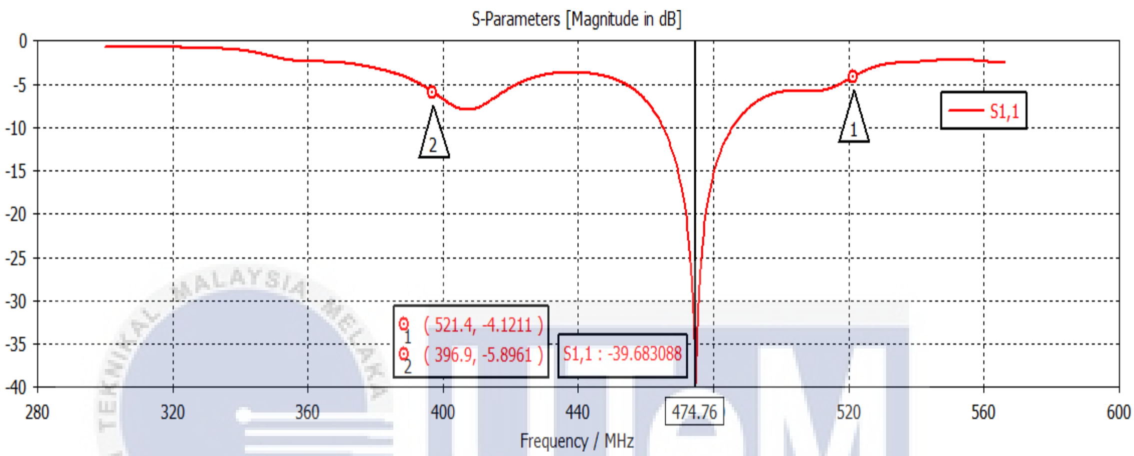

Figure 4.4: Bandwidth result of RMPA without DGS at 433 MHz

The bandwidth result from the Figure 4.4 can be obtain by calculation from 1 minus 2 that is 521.4 MHz – 396.9 MHz = 124.5 MHz for RMPA without DGS at 433 MHz frequency.

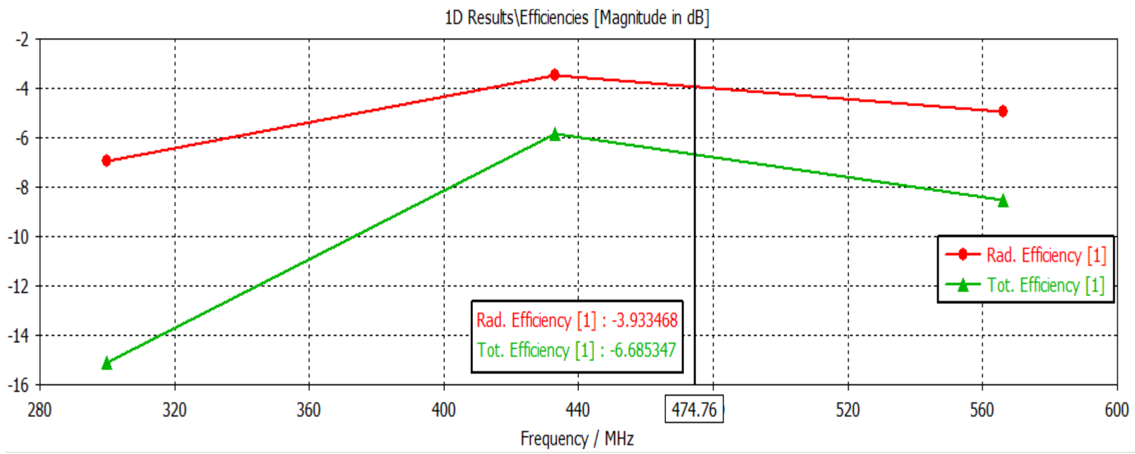

Figure 4.5: Efficiency of RMPA without DGS at 433 MHz

Figure 4.5 shows the efficiency of RMPA without DGS at 433 MHz that is 0.5884dB. The percentage of efficiency is 58.84%.

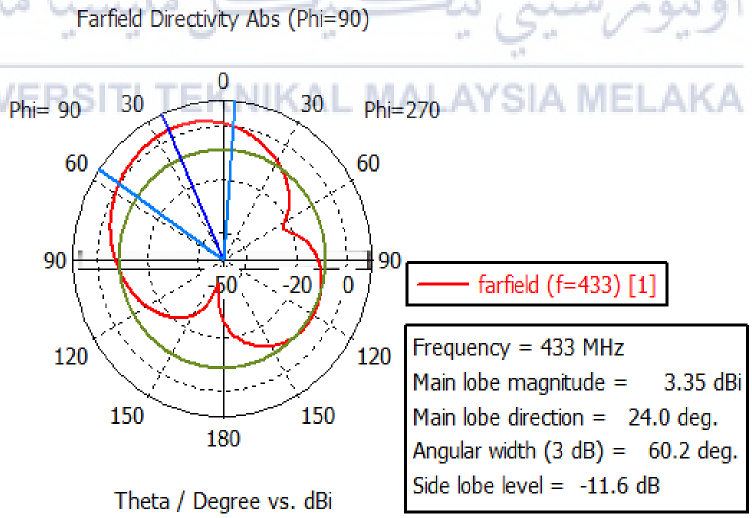

Figure 4.6: Polar Plot of RMPA without DGS at 433 MHz

Figure 4.6 shows the polar plot of RMPA without DGS at 433 MHz. The 3dB angular beamwidth of RMPA with 433 MHz is equal to 60.2º.

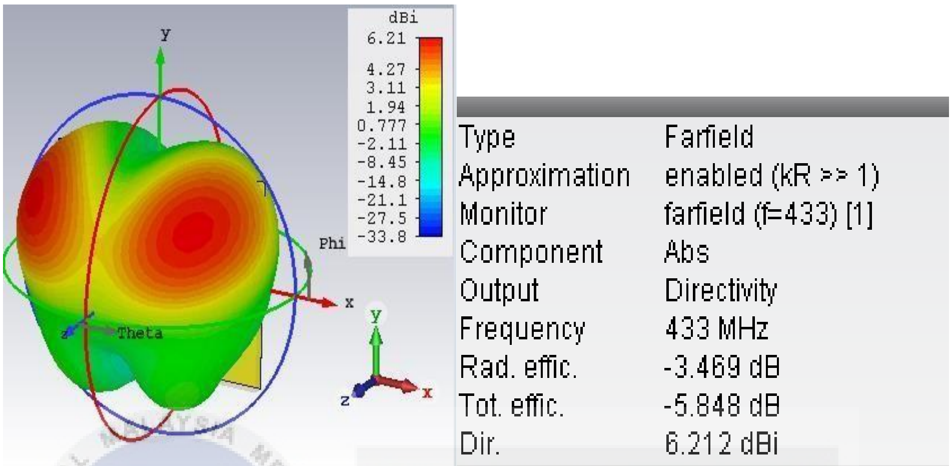

Figure 4.7: Directivity of RMPA without DGS at 433 MHz

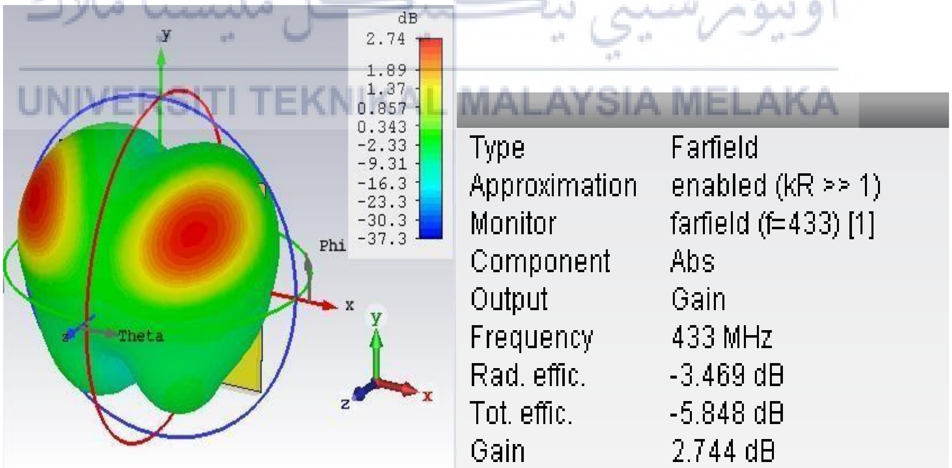

Figure 4.8: Gain (IEEE) of RMPA without DGS at 433 MHz

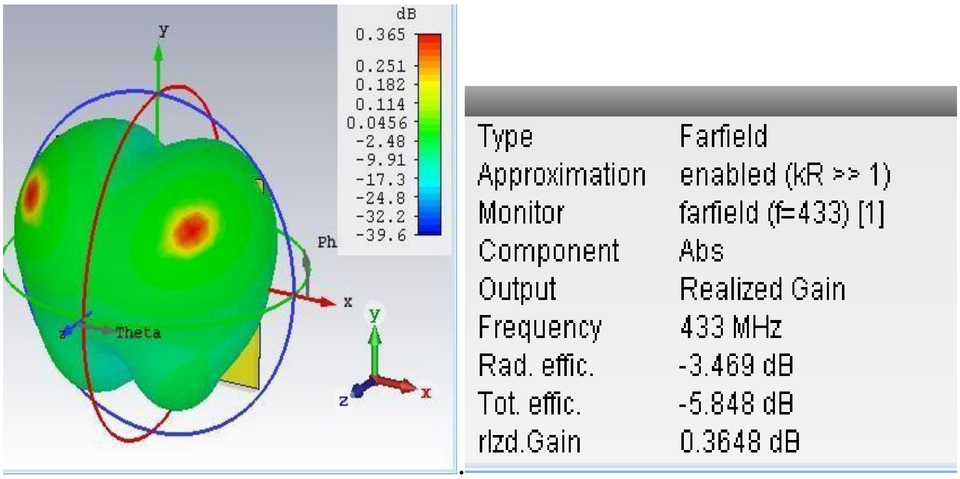

Figure 4.9: Realized Gain of RMPA without DGS at 433 MHz

Figure 4.7, Figure 4.8 and Figure 4.9 shows the directivity, gain (IEEE), and realized gain results of RMPA without DGS at 433 MHz respectively. The directivity is equal to 6.212dBi. The gain (IEEE) is equal to 2.744dB meanwhile realized gain is equal to 0.3648dB. The value of realized gain is lower than the gain (IEEE) because it is consider the losses.

4.2.1.2 RMPA without DGS at 433 MHz

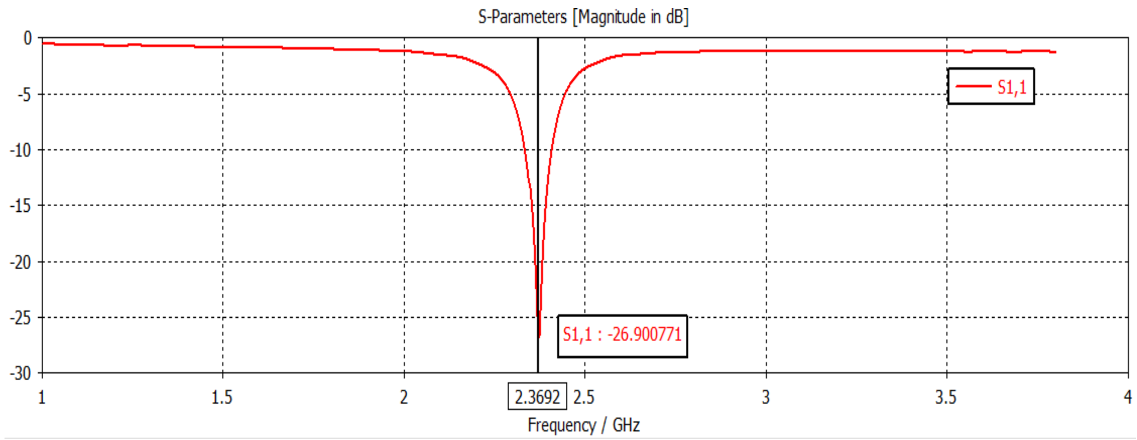

Figure 4.10: S-parameter result of RMPA without DGS at 2.4 GHz

The figure 4.1 show the result of $S_{1,1}$ is equal to -26.901dB and 2.369 GHz of resonant frequency. From this, RMPA at frequency of 2.4 GHz is an ideal match between both transmitter and antenna because the $S_{1,1}$ value more than 10dB.

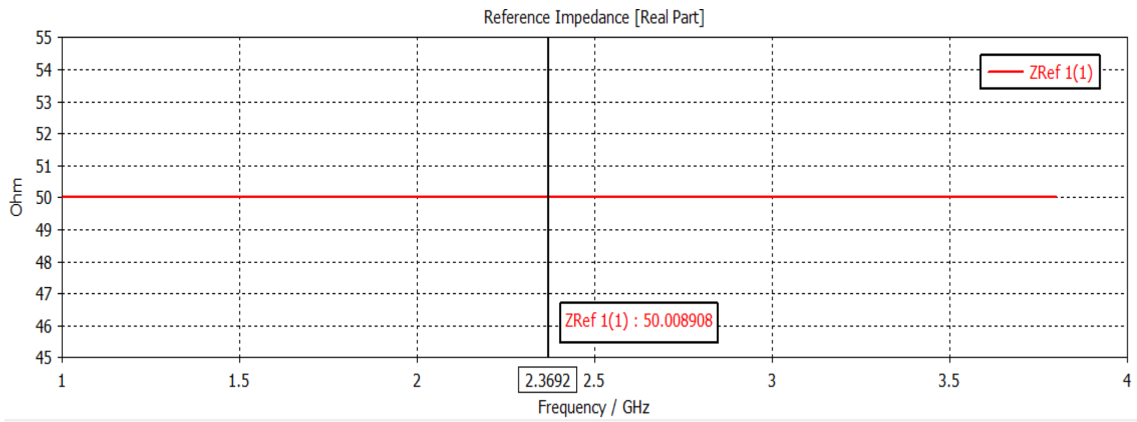

Figure 4.11: Impedance result of RMPA without DGS at 2.4 GHz

Figure 4.11 shows the impedance result of RMPA without DGS at frequency of 2.4 GHz is equal to 50.009Ω. The impedance have a good impedance matching because it has nearly equal to 50Ω.

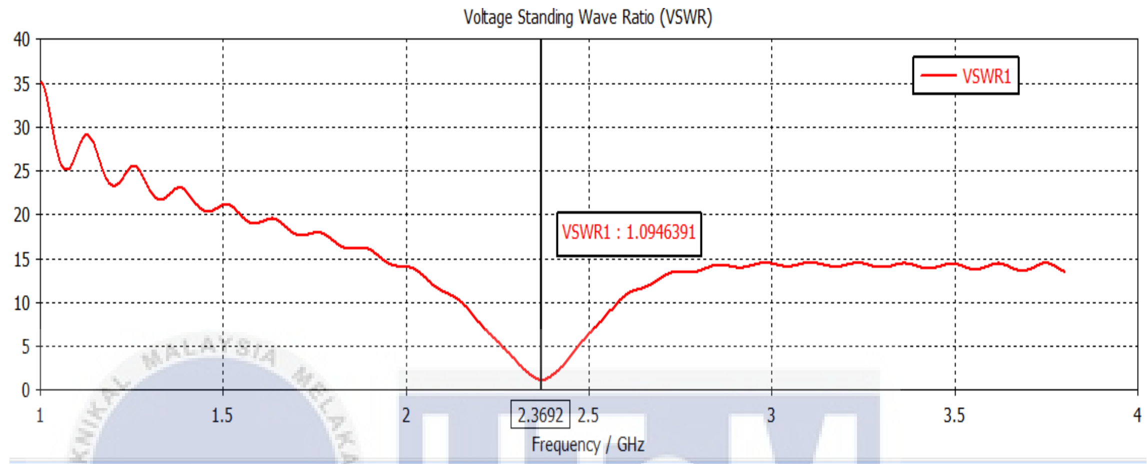

Figure 4.12: VSWR result of RMPA without DGS at 2.4 GHz

Based on Figure 4.12, it is shown that the result of the VSWR for 2.4 GHz with 1.021. The RMPA without DGS at frequency of 2.4 GHz fits the transmission line and provides the antenna more energy because the VSWR results for both antenna is less than 2.

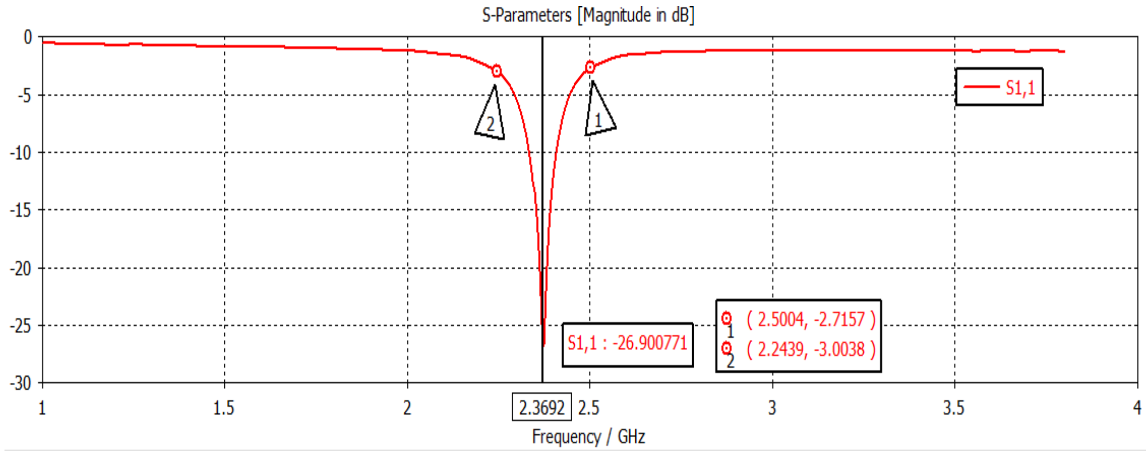

Figure 4.13: Bandwidth result of RMPA without DGS at 2.4 GHz

The bandwidth result from the Figure 4.13 can be obtain by calculation from 1 minus 2 that is 2.5004 GHz − 2.2439 GHz = 256.5 MHz for RMPA without DGS at 2.4 GHz frequency.

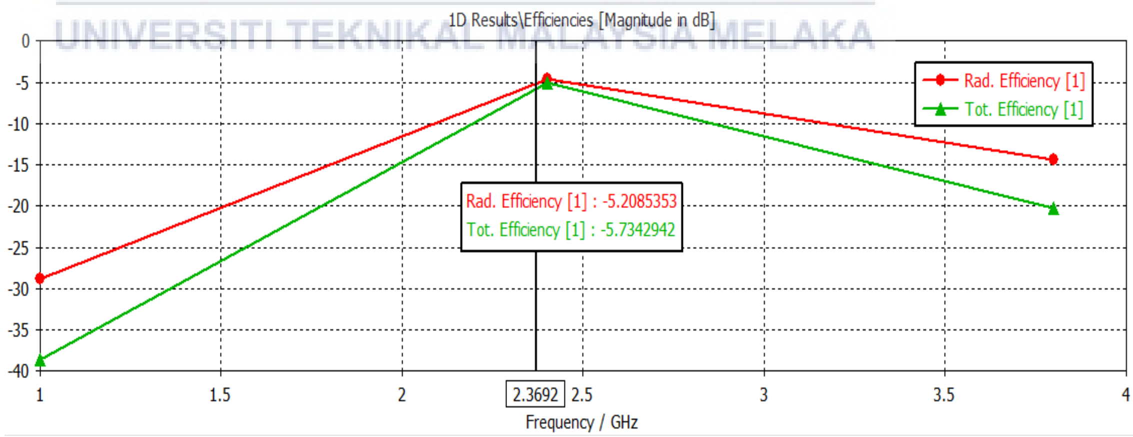

Figure 4.14: Efficiency of RMPA without DGS at 2.4 GHz

Figure 4.14 shows the efficiency result of RMPA without DGS at 2.4 GHz that is 0.9083dB. The percentage of efficiency is 90.83%.

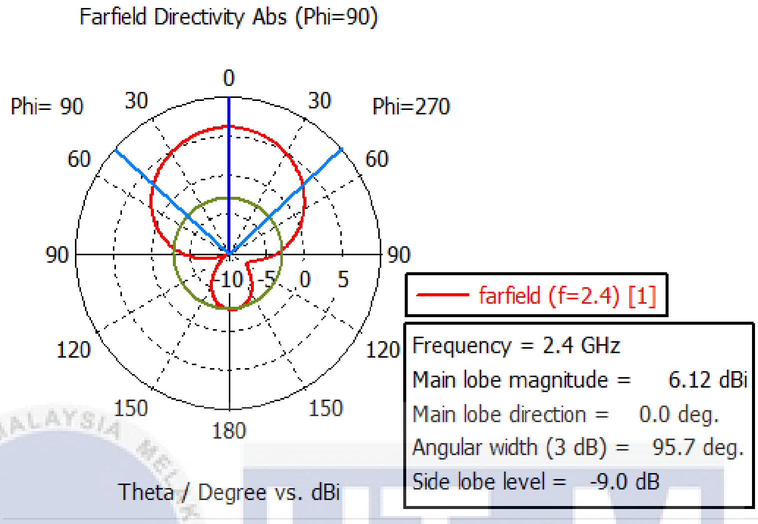

Figure 4.15: Polar Plot of RMPA without DGS at 2.4 GHz

Figure 4.15 shows the polar plot of RMPA without DGS at 2.4 GHz. The 3dB angular beamwidth of RMPA with 2.4 GHz is equal to 95.7º and the radiation pattern is in directional antenna.

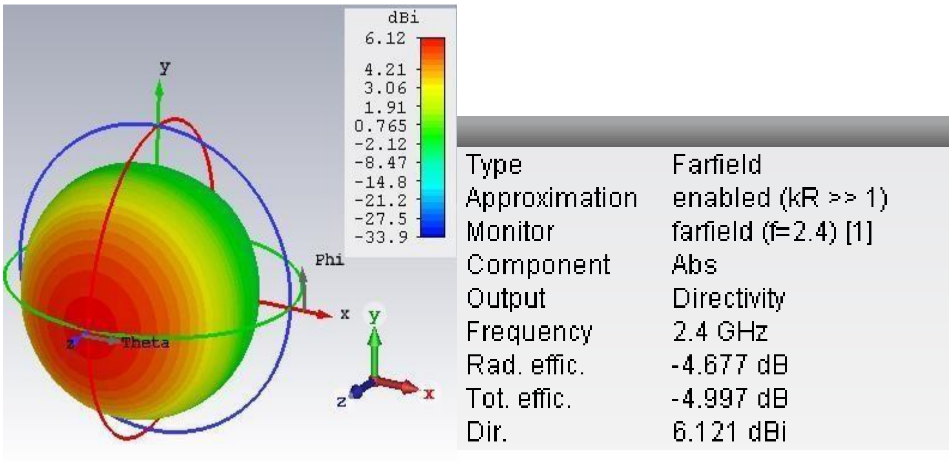

Figure 4.16: Directivity of RMPA without DGS at 2.4 GHz

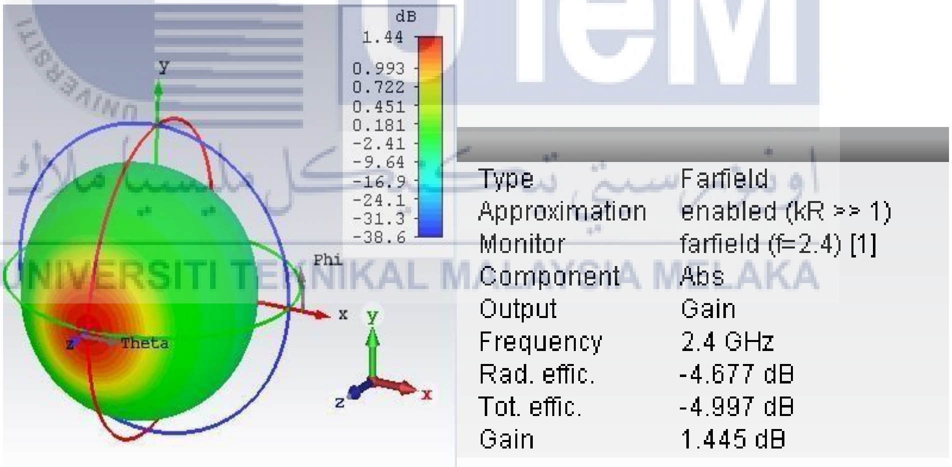

Figure 4.17: Gain (IEEE) of RMPA without DGS at 2.4 GHz

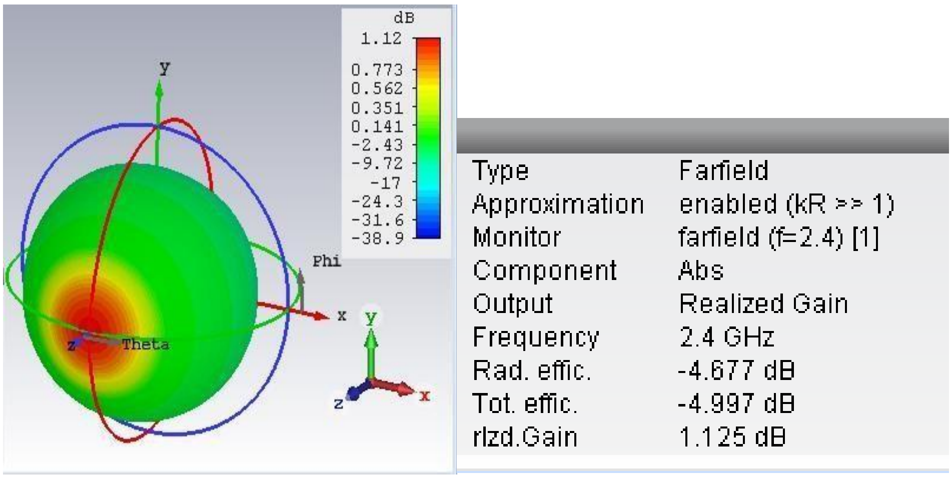

Figure 4.18: Realized Gain of RMPA without DGS at 2.4 GHz

Figure 4.16, Figure 4.17 and Figure 4.18 shows the directivity, gain (IEEE), and realized gain of RMPA without DGS at 2.4 GHz respectively. The directivity is equal to 6.121dBi. The gain (IEEE) is equal to 1.445dB meanwhile realized gain is equal to 1.125dB. The value of realized gain is lower than the gain (IEEE) because it is consider the losses.

4.2.2 RMPA with DGS

4.2.2.1 RMPA with DGS at 433 MHz

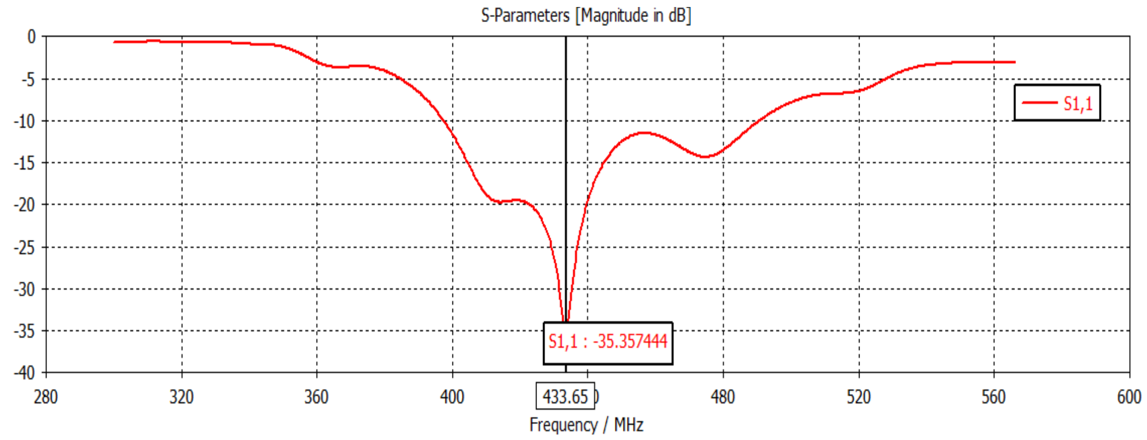

Figure 4.19: S-parameter result of RMPA with DGS at 433 MHz

The figure 4.19 show the result of $S_{1,1}$ is equal to -35.357dB and 433.65 MHz of resonant frequency. From this, RMPA at frequency of 433 MHz is an ideal match between both transmitter and antenna because the $S_{1,1}$ value more than 10dB.

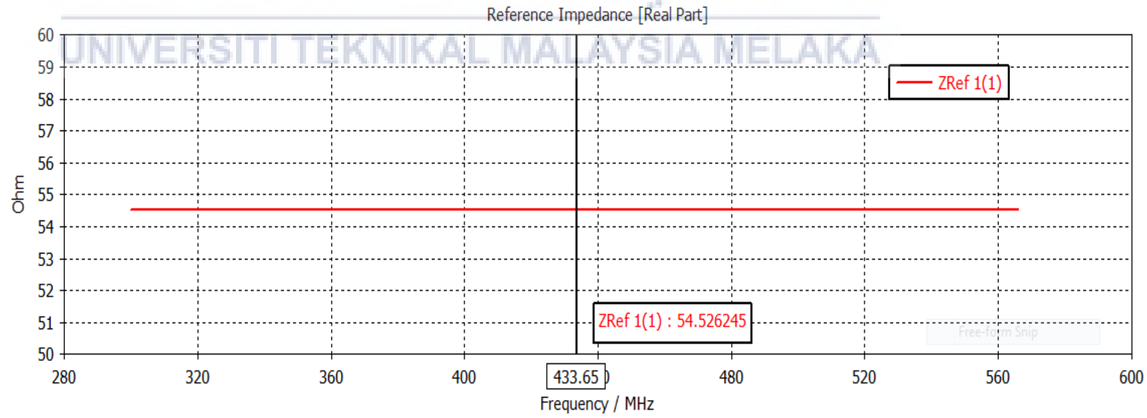

Figure 4.20: Impedance result of RMPA with DGS at 433 MHz

Figure 4.20 here is the impedance result of RMPA with DGS at frequency of 433 MHz is equal to 54.526Ω. The impedance almost have a good impedance matching because it has nearly equal to 50Ω.

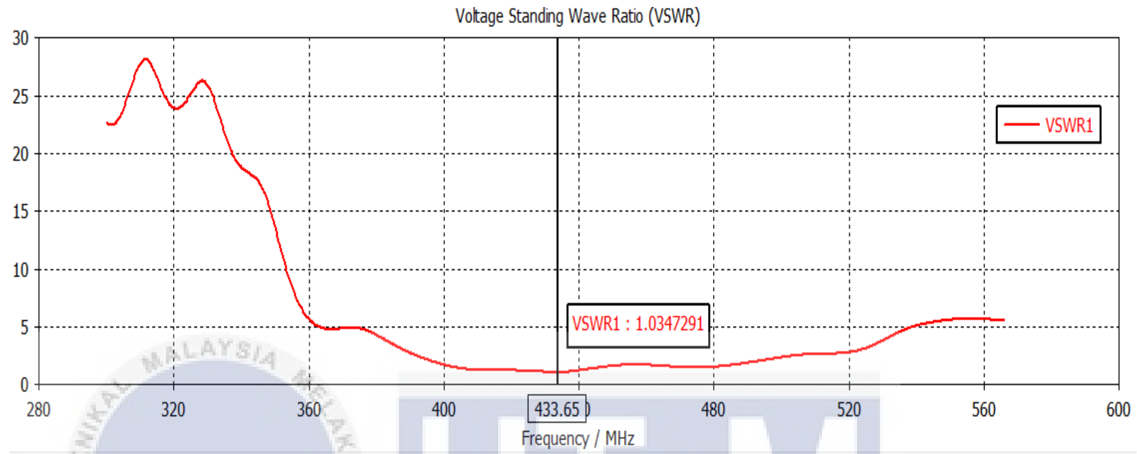

Figure 4.21: VSWR result of RMPA with DGS at 433 MHz

Based on Figure 4.21, it is shown that the result of the voltage standing wave ratio (VSWR) for 433 MHz with 1.035. The RMPA with DGS at frequency of 433 MHz fits the transmission line and provides the antenna more energy because the VSWR results for both antenna is less than or match with 2.

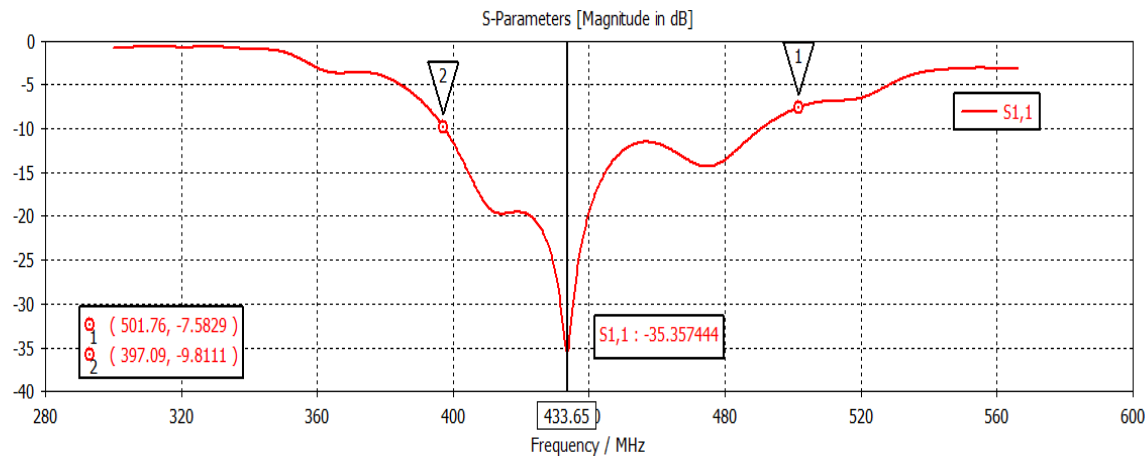

Figure 4.22: Bandwidth result of RMPA with DGS at 433 MHz

The bandwidth result from the Figure 4.22 can be obtain by calculation from 1 minus 2 that is 501.76 MHz − 397.09 MHz = 104.67 MHz for RMPA with DGS at 433 MHz frequency.

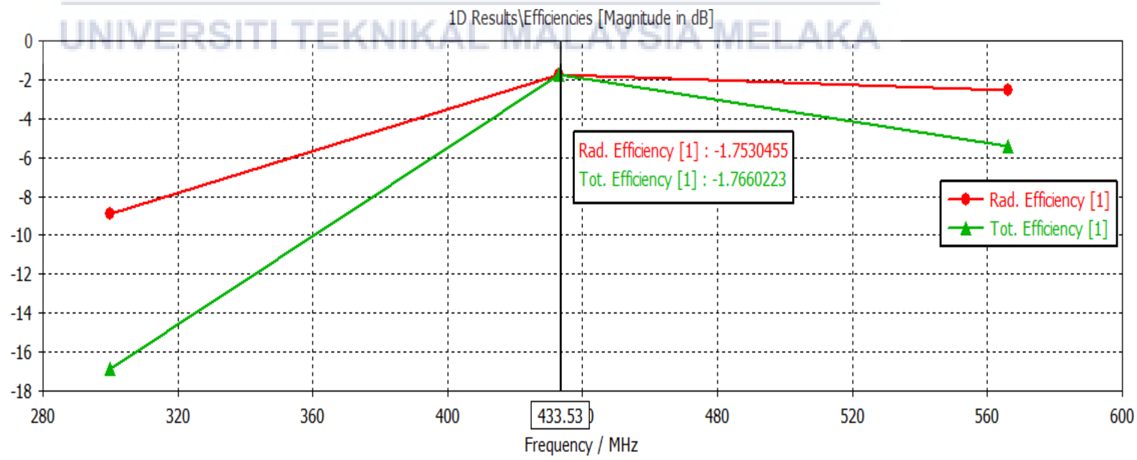

Figure 4.23: Efficiency result of RMPA with DGS at 433 MHz

Figure 4.23 shows the efficiency result of RMPA with DGS at 433 MHz that is 0.9927dB. The percentage of efficiency is 99.27%.

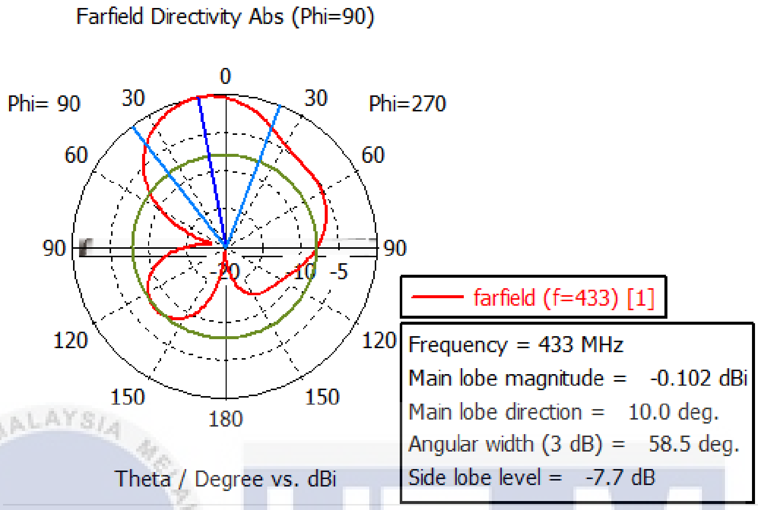

Figure 4.24: Polar Plot of RMPA with DGS at 433 MHz

Figure 4.24 shows the polar plot of RMPA with DGS at 433 MHz. The 3dB angular beamwidth of RMPA with 433 MHz is equal to 58.5º and the radiation pattern is in directional antenna.

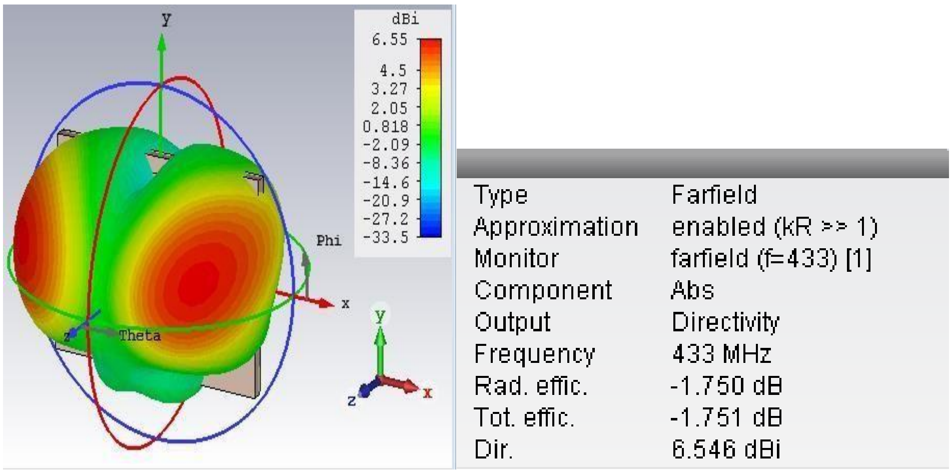

Figure 4.25: Directivity of RMPA with DGS at 433 MHz

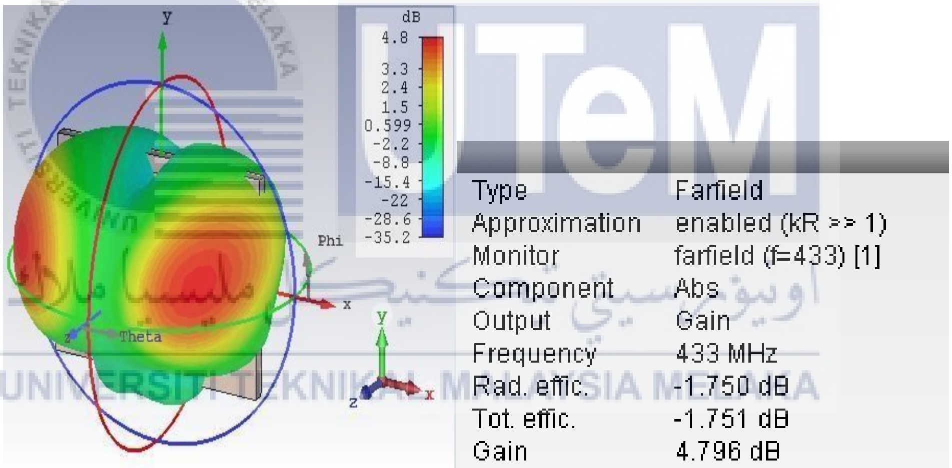

Figure 4.26: Gain (IEEE) of RMPA with DGS at 433 MHz

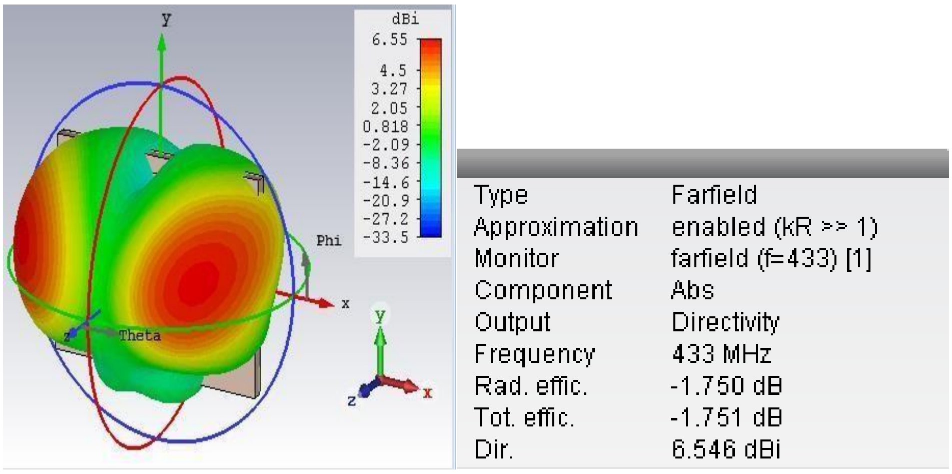

Figure 4.27: Realized Gain of RMPA with DGS at 433 MHz

Figure 4.25, Figure 4.26 and Figure 4.27 shows the directivity, gain (IEEE), and realized gain of RMPA with DGS at 433 MHz respectively. The directivity is equal to 6.546dBi. The gain (IEEE) is equal to 4.976dB meanwhile realized gain is equal to 4.974dB. The value of realized gain is lower than the gain (IEEE) because it is consider the losses.

4.2.2.2 RMPA with DGS at 2.4 GHz

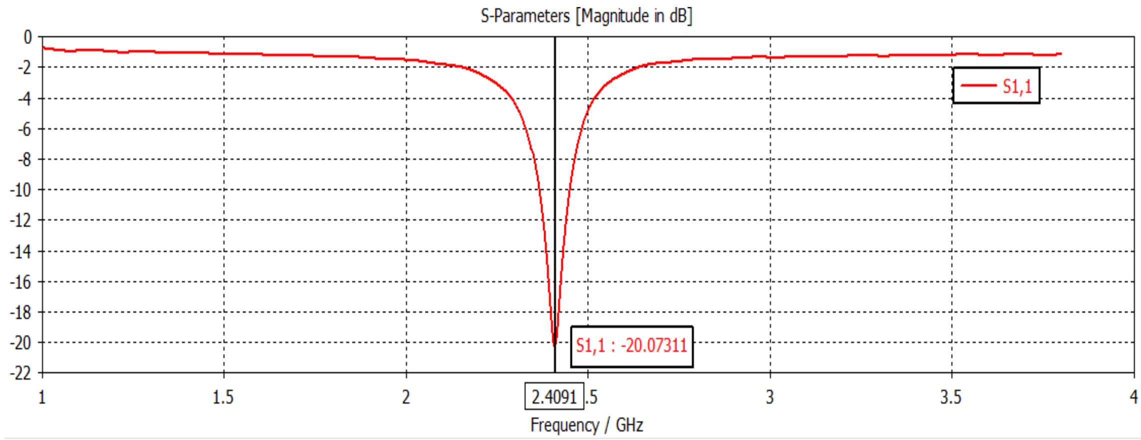

Figure 4.28: S-parameter result of RMPA with DGS at 2.4 GHz

The figure 4.28 show the result of $S_{1,1}$ is equal to -20.073dB and 2.409 GHz of resonant frequency. From this, RMPA at frequency of 2.4 GHz is an ideal match between both transmitter and antenna because the $S_{1,1}$ value more than 10dB.

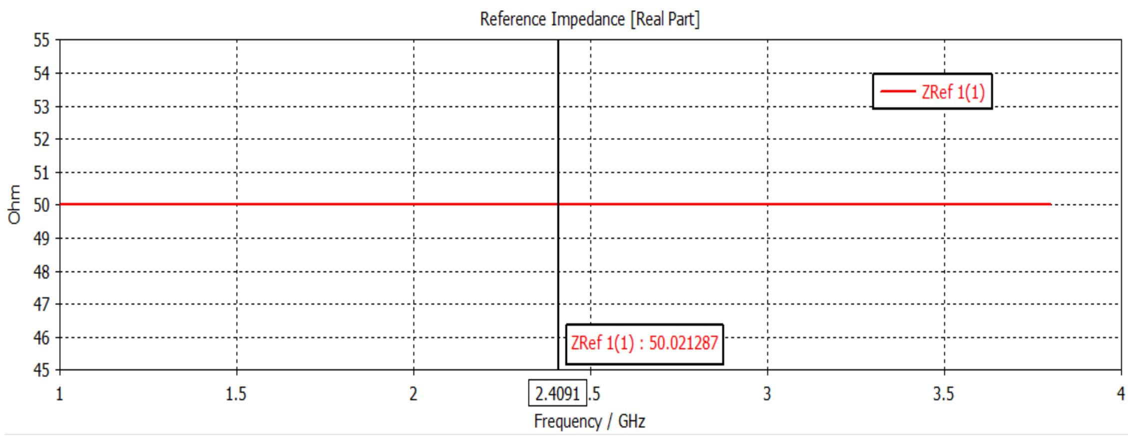

Figure 4.29: Impedance result of RMPA with DGS at 2.4 GHz

Figure 4.29 shows the impedance result of RMPA with DGS at frequency of 2.4 GHz is equal to 50.021Ω. The impedance have a good impedance matching because it has nearly equal to 50Ω.

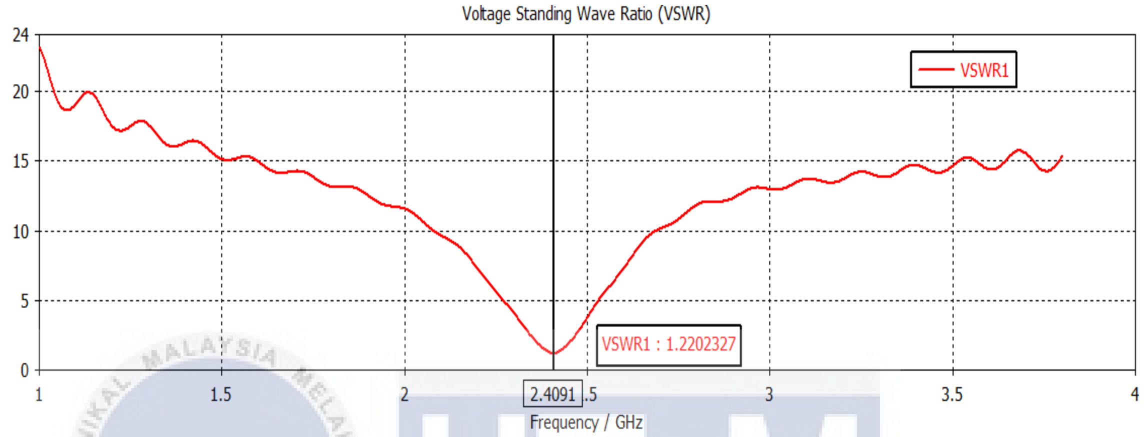

Figure 4.30: VSWR result of RMPA with DGS at 2.4 GHz

Based on Figure 4.30, it is shown that the result of the VSWR for 2.4 GHz with 1.220. The RMPA with DGS at frequency of 2.4 GHz fits the transmission line and provides the antenna more energy because the VSWR results for both antenna is less than 2.

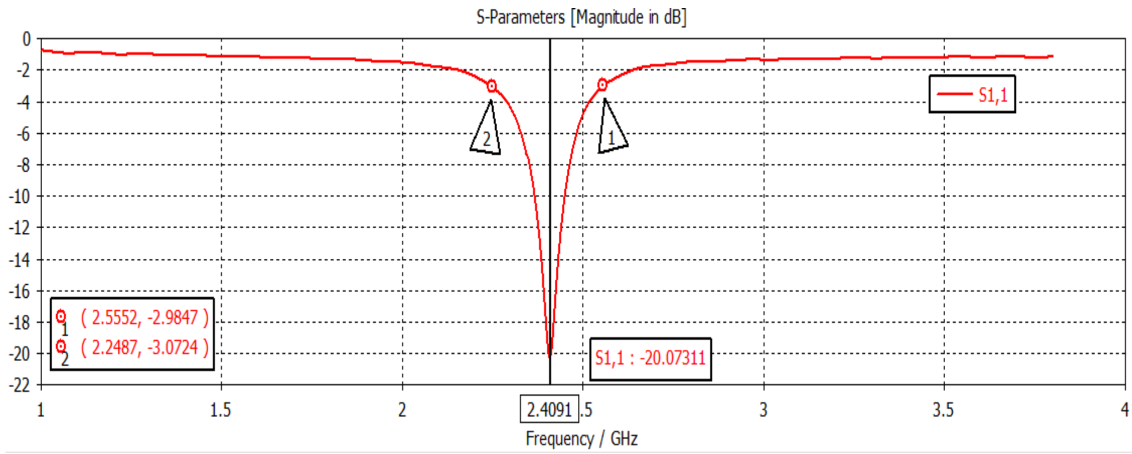

Figure 4.31: Bandwidth result of RMPA with DGS at 2.4 GHz

The bandwidth result from the Figure 4.31 can be obtain by calculation from 1 minus 2 that is 2.5552 GHz – 2.2487 GHz = 306.5 MHz for RMPA with DGS at 2.4 GHz frequency.

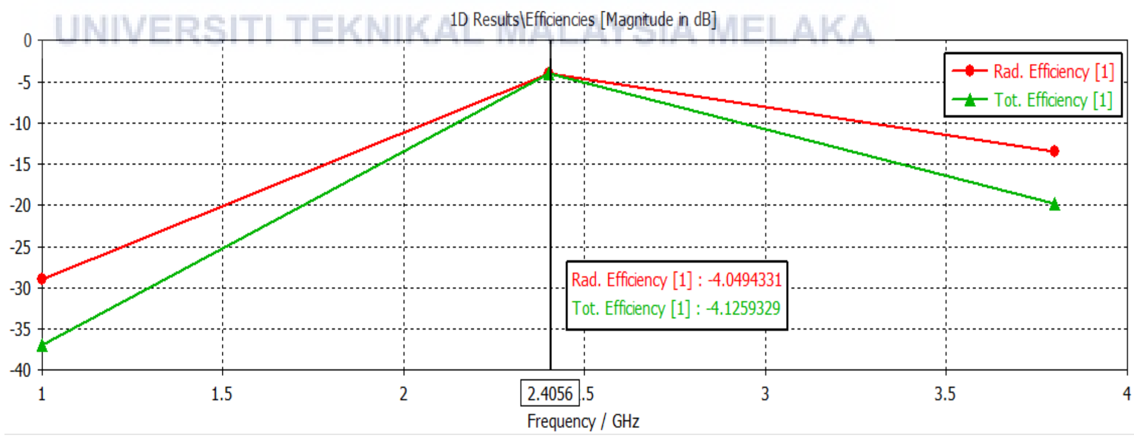

Figure 4.32: Efficiency result of RMPA with DGS at 2.4 GHz

Figure 4.32 shows the efficiency result of RMPA with DGS at 2.4 GHz that is 0.9816dB. The percentage of efficiency is 98.16%.

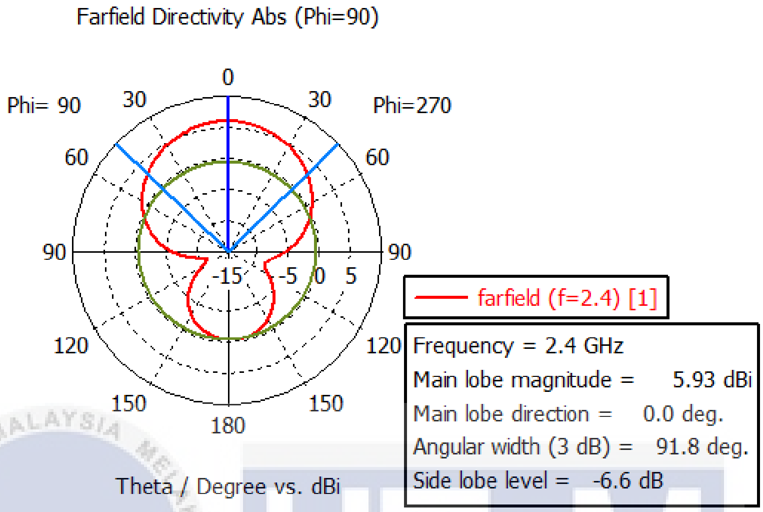

Figure 4.33: Polar Plot of RMPA with DGS at 2.4 GHz

Figure 4.33 shows the polar plot of RMPA with DGS at 2.4 GHz. The 3dB angular beamwidth of RMPA with 2.4 GHz is equal to 91.8º and the radiation pattern is in directional antenna.

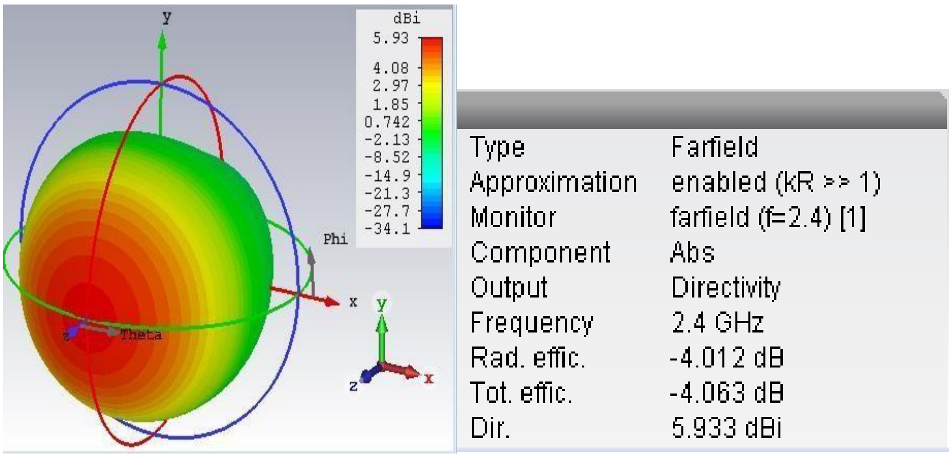

Figure 4.34: Directivity of RMPA with DGS at 2.4 GHz

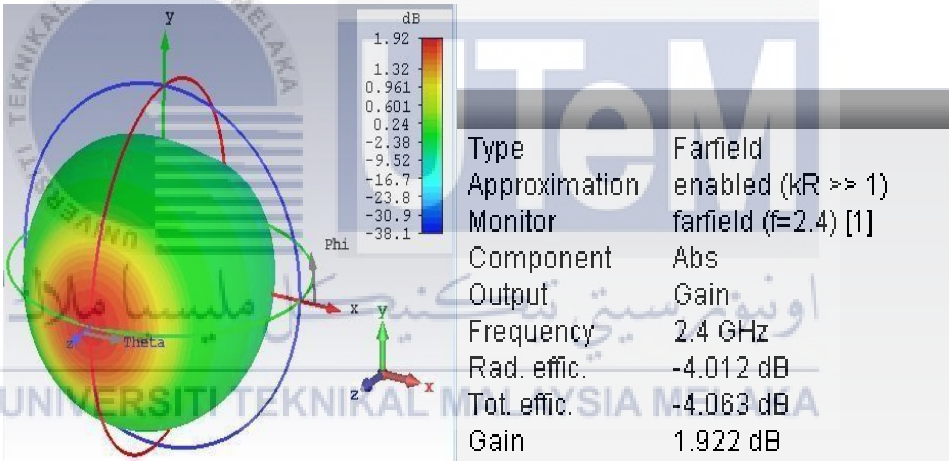

Figure 4.35: Gain (IEEE) of RMPA with DGS at 2.4 GHz

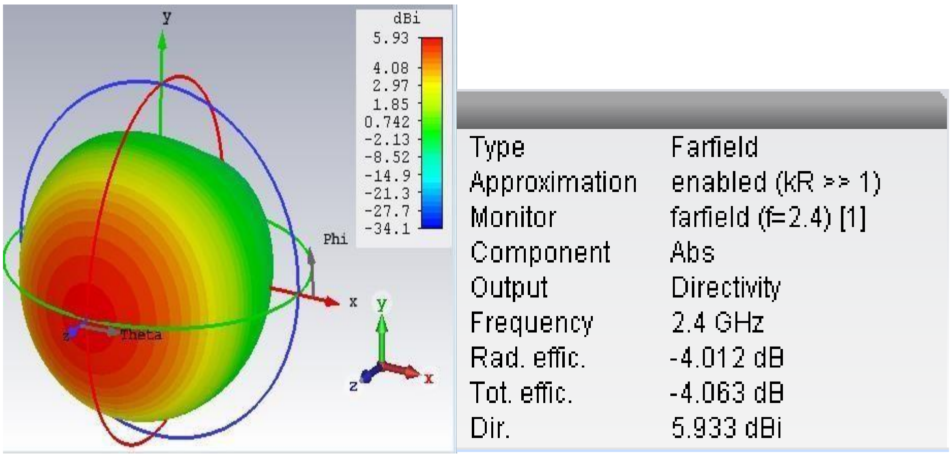

Figure 4.36: Realized Gain of RMPA with DGS at 2.4 GHz

Figure 4.34, Figure 4.35 and Figure 4.36 shows the directivity, gain (IEEE), and realized gain of RMPA with DGS at 2.4 GHz respectively. The directivity is equal to 5.933dBi. The gain (IEEE) is equal to 1.922dB meanwhile realized gain is equal to 1.870dB. The value of realized gain is lower than the gain (IEEE) because it is consider the losses.

Table 4.1: Comparison of parameters between RMPA without and with DGS

Parameter	433 MHz		2.4 GHz	
	Without DGS	**With DGS**	**Without DGS**	**With DGS**
$S_{1,1}$	-39.683dB	-35.357dB	-26.901dB	-20.073dB
Resonant Frequency	474.47 MHz	433.65 MHz	2.369 GHz	2.409 GHz
Impedance	54.527Ω	54.526Ω	50.009Ω	50.021Ω
VSWR	1.021	1.035	1.095	1.220
Bandwidth	124.5 MHz	104.67 MHz	256.5 MHz	306.5 MHz
Efficiency	0.5884dB 58.84% 1.1451W	0.9927dB 99.27% 1.2568W	0.9083dB 90.83% 1.2326W	0.9816dB 98.16% 1.2536W
Gain	2.744dB	4.796dB	1.445dB	1.922dB
Directivity	6.212dBi	6.546dBi	6.121dBi	5.933dBi
Realize Gain	0.3648dB	4.794dB	1.125dB	1.870dB

Table 4.1 shows the comparison of parameters between RMPA without and with DGS at 433 MHz and 2.4 GHz frequency. The RMPA with DGS at 433 MHz and 2.4 GHz have higher percentage of efficiency than the RMPA without DGS that is 99.27% and

98.16% respectively. This prove that designing antenna with DGS can improve the efficiency.

4.2.3 Initial Design of RMPA with DGS

4.2.3.1 Initial Design of RMPA with DGS at 433 MHz

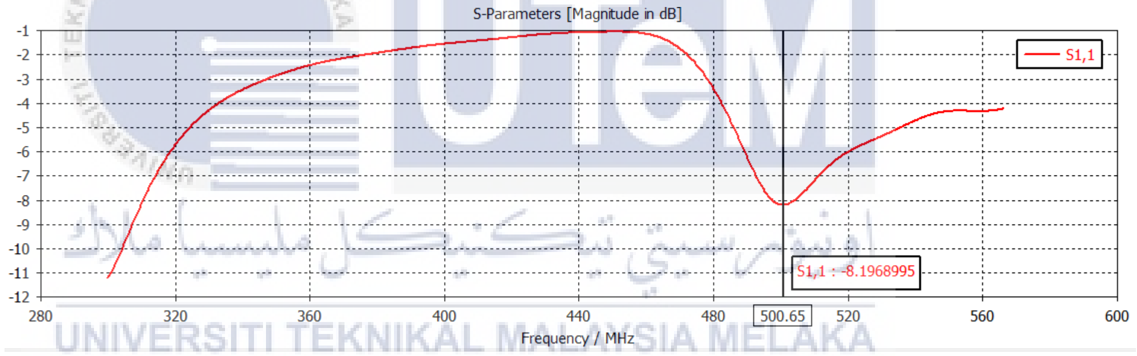

Figure 4.37: S-parameter of Initial Design of RMPA with DGS at 433 MHz

The figure 4.37 show the result of $S_{1,1}$ is equal to -8.197dB and 500.65 MHz of resonant frequency. From this, RMPA at frequency of 433 MHz is not ideal match between both transmitter and antenna because the $S_{1,1}$ value less than 10dB.

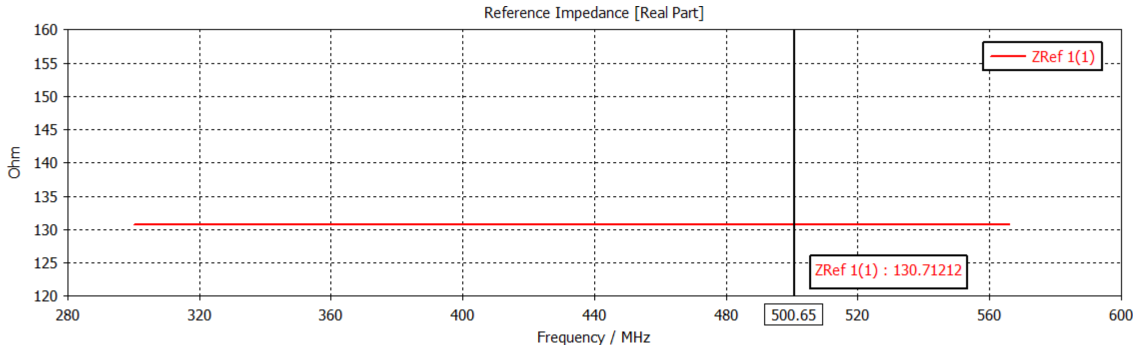

Figure 4.38: Impedance of Initial Design of RMPA with DGS at 433 MHz

Figure 4.38 here is the impedance result of Initial Design of RMPA with DGS at frequency of 433 MHz is equal to 130.712Ω. The impedance is not a good impedance matching because it's not nearly equal to 50Ω.

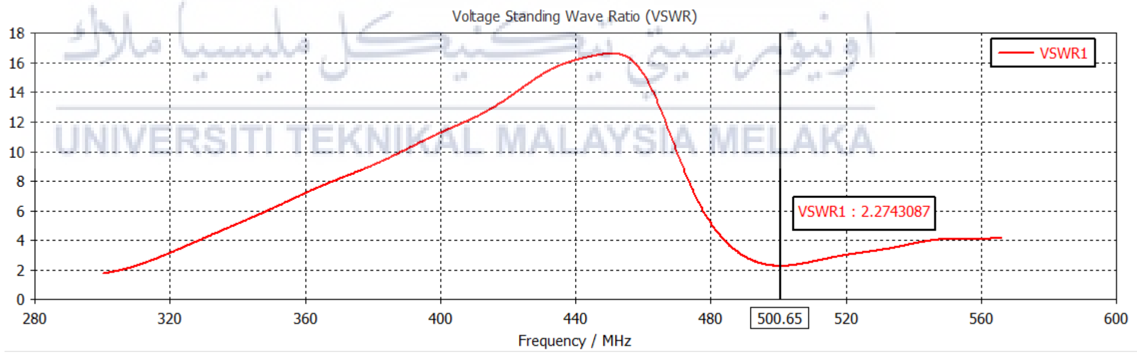

Figure 4.39: VSWR of Initial Design of RMPA with DGS at 433 MHz

Based on Figure 4.39, it is shown that the result of the voltage standing wave ratio (VSWR) for 433 MHz with 2.274. The Initial Design of RMPA with DGS at frequency of 433 MHz not fits the transmission line and provides the antenna more energy because the VSWR results is more than 2.

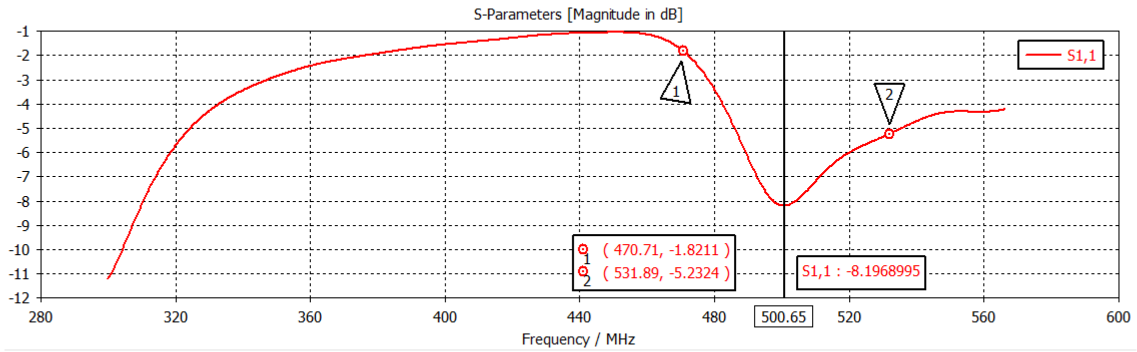

Figure 4.40: Bandwidth of Initial Design of RMPA with DGS at 433 MHz

The bandwidth result from the Figure 4.40 can be obtain by calculation from 2 minus 1 that is 531.89 MHz − 470.71 MHz = 61.18 MHz for RMPA with DGS at 433 MHz frequency.

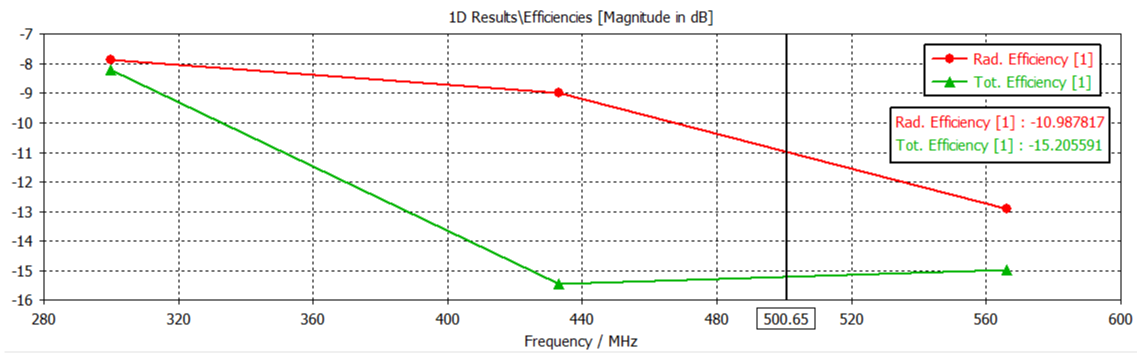

Figure 4.41: Efficiency of Initial Design of RMPA with DGS at 433 MHz

Figure 4.41 shows the efficiency result of Initial Design of RMPA with DGS at 433 MHz that is 0.7226dB. The percentage of efficiency is 72.26%.

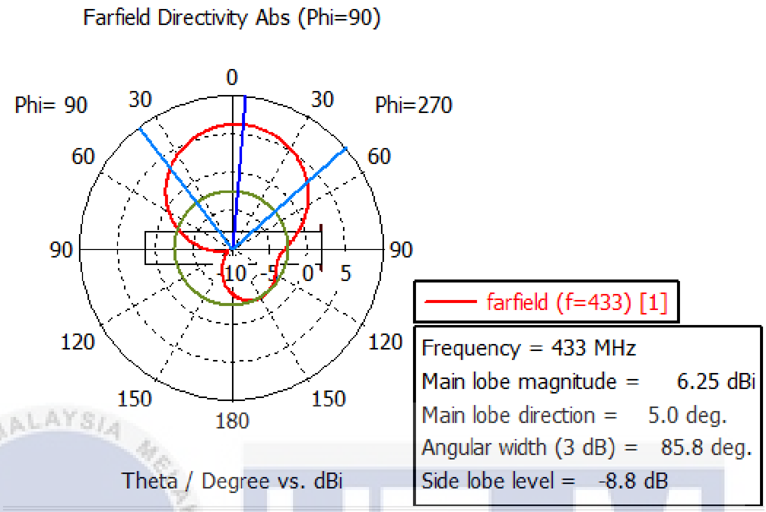

Figure 4.42: Polar Plot of Initial Design of RMPA with DGS at 433 MHz

Figure 4.42 shows the polar plot of Initial Design of RMPA with DGS at 433 MHz frequency. The 3dB angular beamwidth of RMPA with 433 MHz is equal to 85.8° and the radiation pattern is in directional antenna.

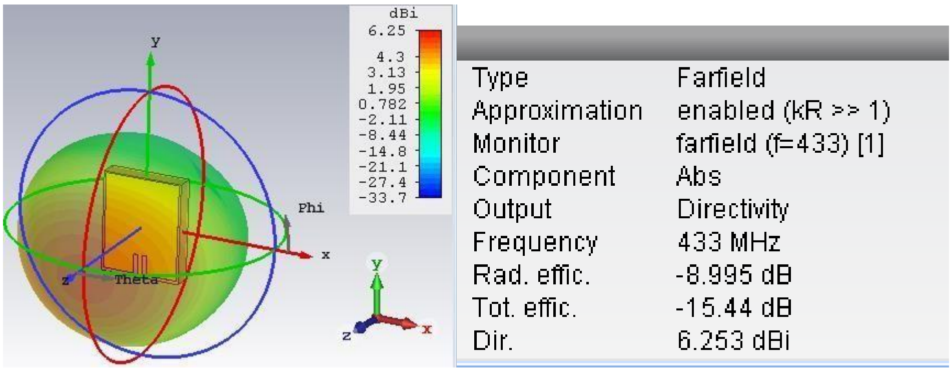

Figure 4.43: Directivity of Initial Design of RMPA with DGS at 433 MHz

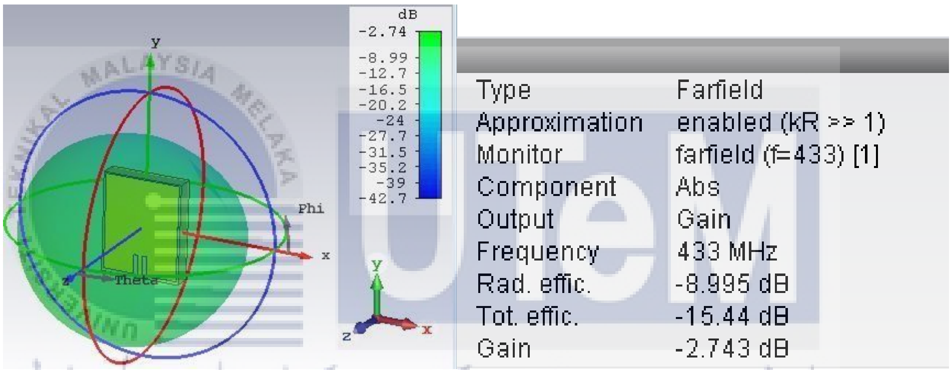

Figure 4.44: Gain (IEEE) of Initial Design of RMPA with DGS at 433 MHz

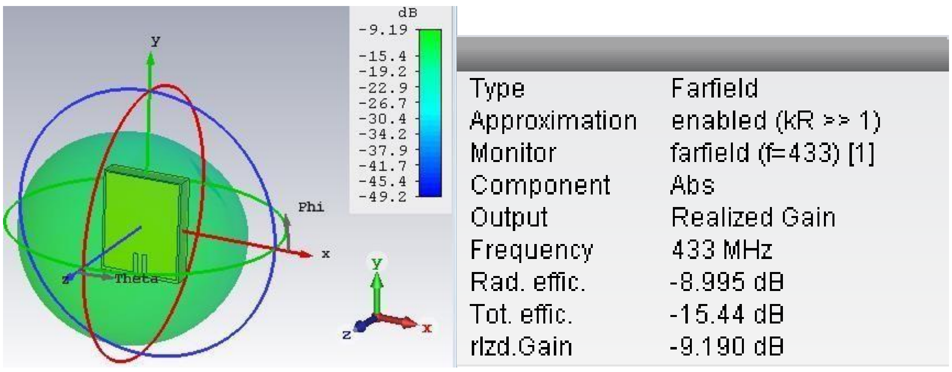

Figure 4.45: Realized Gain of Initial Design of RMPA with DGS at 433 MHz

Figure 4.43, Figure 4.44 and Figure 4.45 shows the directivity, gain (IEEE), and realized gain of Initial Design of RMPA with DGS at 433 MHz respectively. The directivity is equal to 6.253dBi. The gain (IEEE) is equal to -2.743dB meanwhile realized gain is equal to -9.190dB.

4.2.3.2 Initial Design of RMPA with DGS at 2.4 GHz

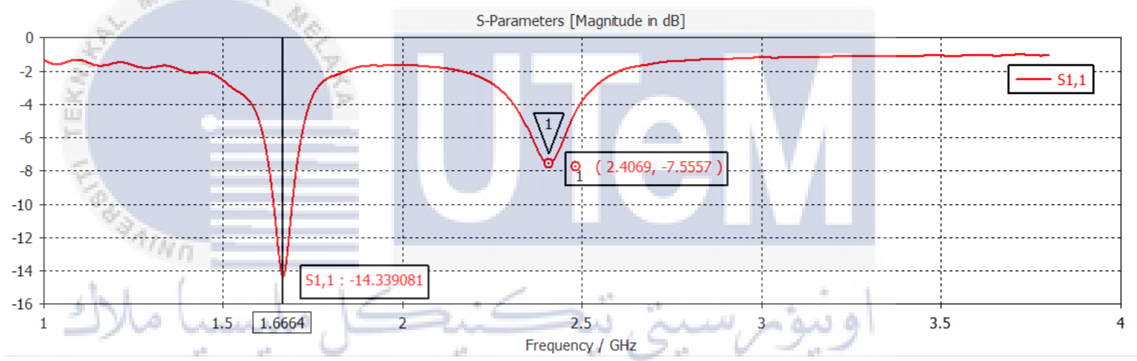

Figure 4.46: S-parameter of Initial Design of RMPA with DGS at 2.4 GHz

The figure 4.46 show the result of $S_{1,1}$ is equal to -14.339dB and 1.666 GHz of resonant frequency. From this, RMPA at frequency of 2.4 GHz is an ideal match between both transmitter and antenna because the $S_{1,1}$ have two resonant frequency.

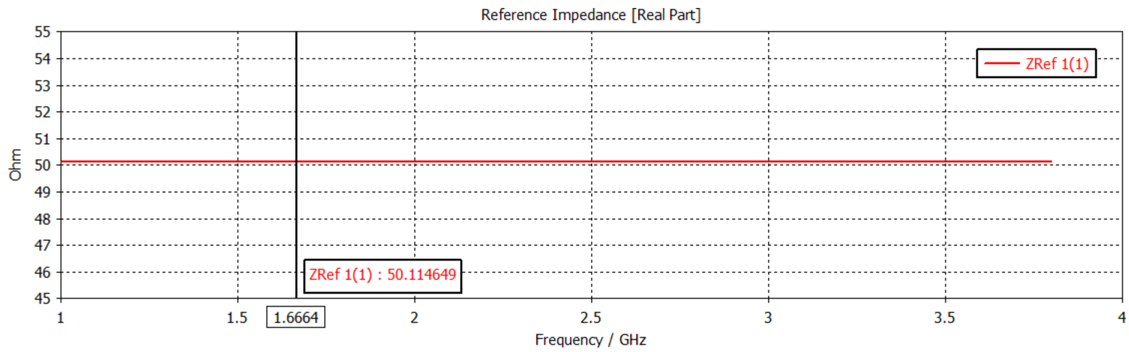

Figure 4.47: Impedance of Initial Design of RMPA with DGS at 2.4 GHz

Figure 4.47 shows the impedance result of Initial Design of RMPA with DGS at frequency of 2.4 GHz is equal to 50.115Ω. The impedance have a good impedance matching because it has nearly equal to 50Ω.

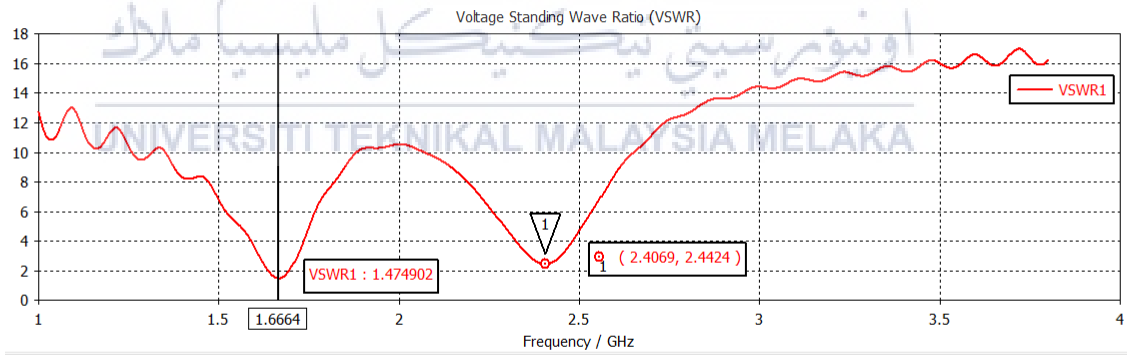

Figure 4.48: VSWR of Initial Design of RMPA with DGS at 2.4 GHz

Based on Figure 4.48, it is shown that the result of the VSWR for 2.4 GHz with 1.475. The Initial Design of RMPA with DGS at frequency of 2.4 GHz fits the transmission line and provides the antenna more energy because the VSWR results is less than 2.

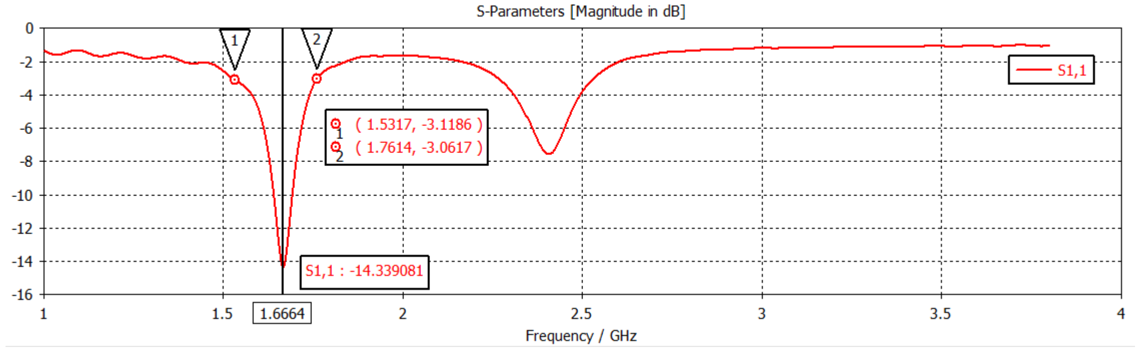

Figure 4.49: Bandwidth of Initial Design of RMPA with DGS at 2.4 GHz

The bandwidth result from the Figure 4.49 can be obtain by calculation from 2 minus 1 that is $1.7614\ \text{GHz} - 1.5317\ \text{GHz} = 229.7\ \text{MHz}$ for Initial Design of RMPA with DGS at 2.4 GHz frequency.

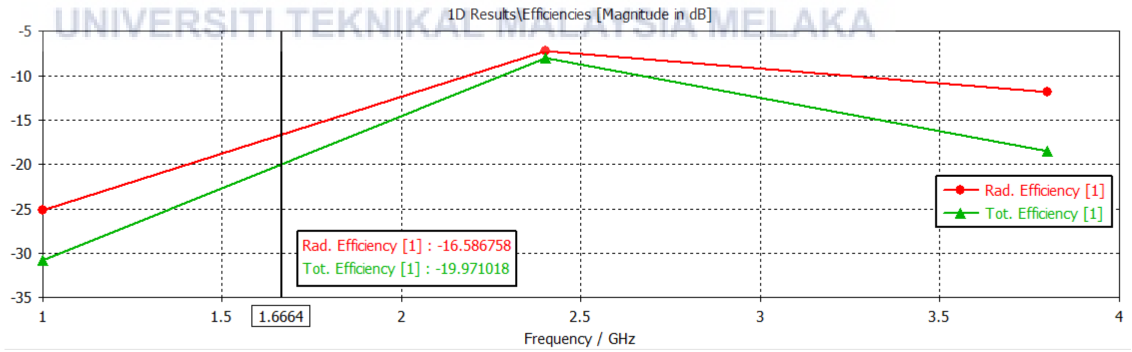

Figure 4.50: Efficiency of Initial Design of RMPA with DGS at 2.4 GHz

Figure 4.50 shows the efficiency result of Initial Design of RMPA with DGS at 2.4 GHz that is 0.8305dB. The percentage of efficiency is 83.05%.

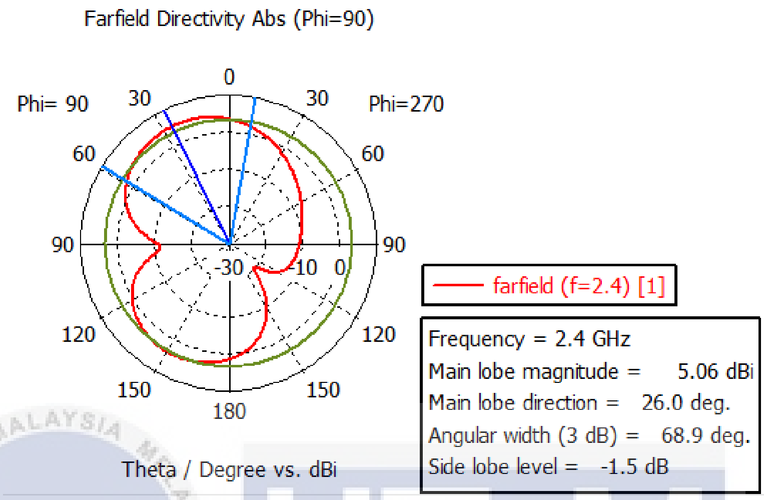

Figure 4.51: Polar Plot of Initial Design of RMPA with DGS at 2.4 GHz

Figure 4.51 shows the polar plot of Initial Design of RMPA with DGS at 2.4 GHz. The 3dB angular beamwidth of RMPA with 2.4 GHz is equal to 68.9º and the radiation pattern is in directional antenna.

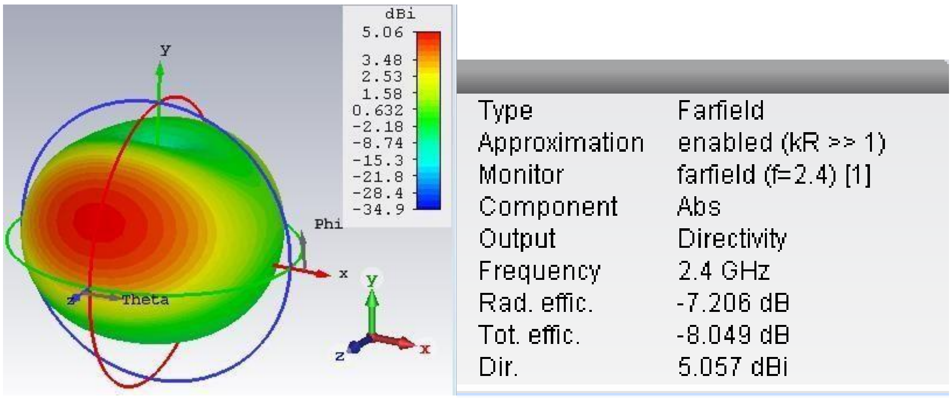

Figure 4.52: Directivity of Initial Design of RMPA with DGS at 2.4 GHz

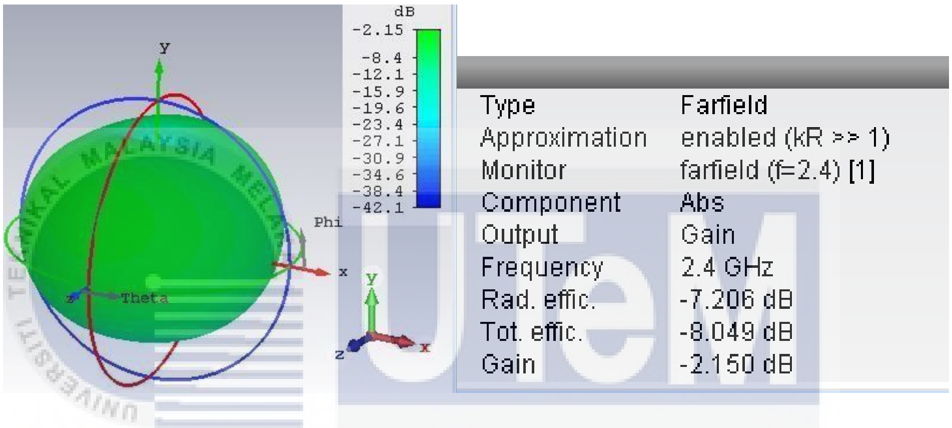

Figure 4.53: Gain (IEEE) of Initial Design of RMPA with DGS at 2.4 GHz

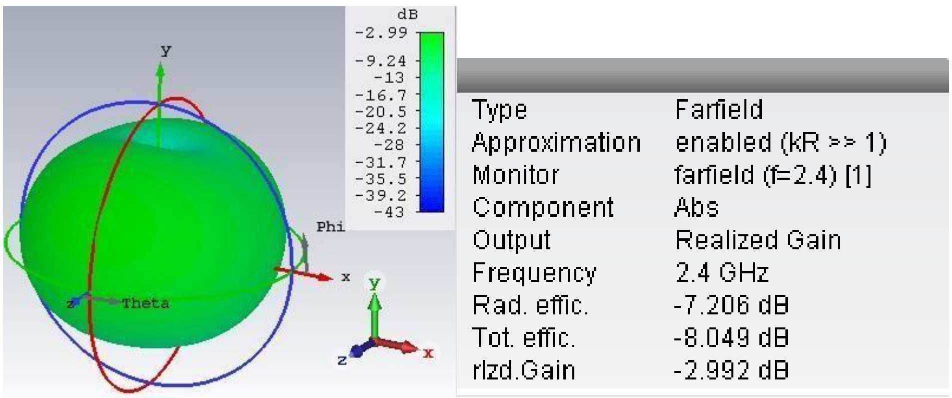

Figure 4.54: Realized Gain of Initial Design of RMPA with DGS at 2.4 GHz

Figure 4.52, Figure 4.53 and Figure 4.54 shows the directivity, gain (IEEE), and realized gain of Initial Design of RMPA with DGS at 2.4 GHz respectively. The directivity is equal to 5.057dBi. The gain (IEEE) is equal to -2.150dB meanwhile realized gain is equal to -2.992dB.

Table 4.2: Comparison between Length and Width of Patch, Substrate and Ground Plane for Initial and Final Design of RMPA with DGS

Parameter	433 MHz		2.4 GHz	
	Initial Design (Calculation Value)	Final Design	Initial Design (Calculation Value)	Final Design
Actual width of patch calculation, *W*	213 mm	370mm	39mm	30mm
Actual length of patch calculation, *L*	168 mm	314mm	30 mm	28mm
Width of the Ground and Substrate Plane, W_g	222.6 mm	640mm	48.6 mm	45mm
Length of the Ground and Substrate Plane, L_g	177.6 mm	780mm	39.6 mm	50mm

Table 4.2 shows the comparison between length and width of patch, substrate and ground plane for Initial and Final Design of RMPA with DGS at frequency 433 MHz and 2.4 GHz. The initial design represented from the theoretical calculation value meanwhile the final design is represented from simulation value. The percentage of differences between simulation and theoretical calculation in terms of patch width for the 433 MHz frequency is increased by 73.71% while for the 2.4 GHz frequency is decreased by 23.08%. Furthermore, the percentage of differences between simulation and theoretical calculation in terms of length of patch for the 433 MHz frequency is increased by 86.90% while the 2.4 GHz frequency is decreased by 6.67%. The percentage of differences between simulation and theoretical calculation in terms of width of ground and substrate plane for the 433 MHz frequency is increased by 187.51% while the 2.4 GHz frequency is decreased by 7.41%. In addition, the percentage of differences between simulation and theoretical calculation in terms of length of ground and substrate plane for the 433 MHz frequency is increased by 339.19% meanwhile for the 2.4 GHz frequency is increased by 26.26%.

Table 4.3: Comparison of parameters between Initial and Final Design of RMPA with DGS

Parameter	433 MHz		2.4 GHz	
	Initial Design (Calculation Value)	**Final Design**	**Initial Design (Calculation Value)**	**Final Design**
$S_{1,1}$	$-8.197dB$	$-35.357dB$	$-14.339dB$	$-20.073dB$
Resonant Frequency	500.65 MHz	433.65 MHz	1.666 GHz	2.409 GHz
Impedance	130.712Ω	54.526Ω	50.115Ω	50.021Ω
VSWR	2.274	1.035	1.475	1.220
Bandwidth	61.18 MHz	104.67 MHz	229.7 MHz	306.5 MHz
Efficiency	0.7226dB 72.26% 1.1810W	0.9927dB 99.27% 1.2568W	0.8305dB 83.05% 1.2107W	0.9816dB 98.16% 1.2536W
Gain	$-2.743dB$	4.796dB	$-2.150dB$	1.922dB
Directivity	6.253dBi	6.546dBi	5.057dBi	5.933dBi
Realize Gain	$-9.190dB$	4.794dB	$-2.992dB$	1.870dB

Table 4.3 shows the comparison of parameters among Initial and Final Design of RMPA with DGS at 433 MHz and 2.4 GHz frequency. The initial design represented from the results of theoretical calculation value meanwhile the final design is represented from results of simulation value. The Final Design of RMPA with DGS at 433 MHz and 2.4 GHz have higher percentage of efficiency than the Initial Design of RMPA with DGS that is 99.27% and 98.16% respectively. This prove that designing antenna with DGS can improve the efficiency. The percentage differences among simulation and theoretical outcomes in terms of the efficiency for the 433 MHz frequency is increased by 37.38% while the 2.4 GHz frequency is increased by 18.19%. The $S_{1,1}$ results for Final Design of RMPA with DGS at 433 MHz and 2.4 GHz also have some improvement that is from -8.197dB to -35.357dB and from -14.339dB to -20.073dB respectively. The percentage differences between simulation and theoretical results for the S-parameter at 433 MHz frequency increased by 331.34% while for the 2.4 GHz frequency is increased by 39.99%.

Table 4.4: Comparison of parameters between Reference and Final Design of RMPA at 433 MHz and 2.4 GHz

Parameter	433 MHz		2.4 GHz	
	Reference Design [25]	Final Design	Reference Design [1]	Final Design
$S_{1,1}$	−18.7dB	−35.357dB	−28.76dB	−20.073dB
Resonant Frequency	433. 83 MHz	433.65 MHz	2.4 GHz	2.4091 GHz
Impedance	50.00Ω	54.526Ω	50.05Ω	50.021Ω
VSWR	−	1.035	1.10535	1.220
Bandwidth	4.5 MHz	104.67 MHz	78.8438 MHz	306.5 MHz
Efficiency	−	0.9927dB 99.27% 1.2568W	−	0.9816dB 98.16% 1.2536W
Gain	−	4.796dB	3.049dB	1.922dB
Directivity	−	6.546dBi	−	5.933dBi
Realize Gain	−	4.794dB	−	1.870dB

Table 4.4 shows the comparison of parameters between Reference [1, 25] and Final Design of RMPA at 433 MHz and 2.4 GHz frequency. The Final Design of RMPA with DGS at 433 MHz and 2.4 GHz have higher percentage of efficiency than the Initial Design of RMPA with DGS that is 99.27% and 98.16% respectively.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion and Future Work

In this thesis, this whole project focus on learning and understanding how to use CST Microwave Studio software for antenna design.

In this thesis, chapter 1 focus on the introduction, project background, problem statement, objectives, scope of work and thesis structure was briefly explained in this chapter. The information of proposed antenna is also mentioned in this chapter.

In the chapter 2 is about reviewing the background studies of this project. It includes the explanations that related to this project from past work. The past research will be focused on the MPA with DGS.

In the chapter 3, this thesis focus on designing and analysis the RMPA without and with DGS at the frequency band of 433 MHz and 2.4 GHz by using CST Microwave Studio. Besides, in this chapter also design and analysis the Initial Design (using calculation value) of RMPA with DGS at the frequency band of 433 MHz and 2.4 GHz by using CST Microwave Studio.

Moreover, in chapter 4 this thesis focus on evaluate the simulation antenna with the parameters of VSWR, return loss, bandwidth, impedance, resonant frequency and directivity and evaluate the comparison of differences length and width of the patch will affected the S-parameter, resonant frequency, VSWR, and impedance.

As the conclusion, design and analysis of the RMPA with DGS at frequency band of 433 MHz and 2.4 GHz by using CST Microwave Studio and evaluate the simulation antenna with the parameters, comparison between initial (using calculation value) and final design of RMPA and comparison between RMPA with and without DGS at 433 MHz and 2.4 GHz that will affected the parameters of VSWR, return loss, bandwidth, impedance, resonant frequency, efficiency, gain, realized gain and directivity was completed and successful.

The final design of RMPA with DGS at 433 MHz and 2.4 GHz have higher percentage of efficiency than the RMPA without DGS and the initial design of RMPA with DGS that is 99.27% and 98.16% respectively. This prove that designing antenna with DGS can improve the efficiency. The $S_{1,1}$ results for final design of RMPA with DGS at 433 MHz and 2.4 GHz also have some improvement that is from -8.197dB to -35.357dB and from -14.339dB to -20.073dB respectively.

The suggestion for future work is another size reduction idea with the use of complementary split-ring resonator (CSRR) for 433 MHz antenna design would improve the size. This design, packed with various tunable elements, would allow a tunable ground plane, shift the impedance, and change the pattern of radiation, frequency, or bandwidth.

REFERENCES

[1] P. A. Nawale1, and Prof. R. G. Zope: "Rectangular Microstrip Patch Antenna for 2.4 GHz Communication Using Defected Ground Structure", *International Journal of Advance Foundation and Research in Computer (IJAFRC)*, Volume 2, Issue 1, pp 1 – 11, January 2015.

[2] Gurpreet, S., Rajni, and Anupma M.: "Design of G-Shaped Defected Ground Structure for Bandwidth Enhancement", *International Journal of Computer Applications*, Volume 75, No. 9, pp 7 – 11, August 2013.

[3] Terry, K. L. and Yeongming, H.: "Microstrip antannas of very high permittivity for personal communications", *Proceedings of 1997 Asia-Pacific Microwave Conference*, Kowloon, Hong Kong, pp. 253 – 256, August 2002.

[4] Liu, H., Li, Z., and Sun, X.: "Compact defected ground structure in microstrip technology", *Electronics Letters*, Volume 41, Issue 3, pp.132-134, February 2005.

[5] Simon, R. S. and Alejandro, A. Z.: "Antennas and Propagation for Wireless Communication Systems": '*Antennas and Propagation for Wireless*

Communication Systems' (John Wiley & Sons Ltd., 2007, 2nd Edition) pp. 1 – 511, 2007.

[6] Vijay, R. G., Suma, B., Venkatalakshmi, M., Ramalaxmi, M.V.V.S, Rajeswari, D., and Derendra, K. K.: "Design of microstrip patch antenna for smart antenna applications", *International Research Journal of Engineering and Technology (IRJET)*, Volume 05, Issue 3, pp 3159 – 3163, March 2018.

[7] Navpreet, K., Narinder, S., and Navdeep, S., "A Study of Different Feeding Mechanisms in Microstrip Patch Antenna", *International Journal of Microwaves Applications*, Volume 6, No. 1, pp 5 – 9, February 2017.

[8] Snehi S. and Neelesh A.: "Improvement of the Performance of Microstrip Patch Antenna", *International Journal of Computer Applications*, Volume 148, No. 10, pp 25 – 34, August 2016.

[9] Anindya, G. and Prof. (Dr.) Malay, G.: "Bandwidth Optimization of Microstrip Patch Antenna - A Basic Overview", *International Journal on Recent and Innovation Trends in Computing and Communication*, Volume 6, Issue 2, pp 133 – 143, February 2018.

[10] Er-rebyiy, R., Zbitou, J., Tajmouati, A., Latrach, M., Errkik, A., and Abdellaoui, L. E.: "A New Design of a Miniature Microstrip Patch Antenna Using Defected Ground Structure DGS", *2017 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, Fez, Morocco, pp. 1 – 4, May 2017.

[11] Tahsin, F. A. N. and Baki, A. K. M.: "Comparative Study of Rectangular

and Circular Microstrip Patch Antennas in X Band", *2014 International Conference on Electrical Engineering and Information & Communication Technology*, Dhaka, Bangladesh, pp. 1 – 5, October 2014.

[12] Gurpreet, S., Rajni, and Ranjit, S. M.: "Microstrip Patch Antenna with Defected Ground Structure for Bandwidth Enhancement", *International Journal of Computer Applications*, Volume 73, No.9, pp 14 – 18, July 2013.

[13] Deepika, S. and Sonam, R.: "Bandwidth Enhancement of Rectangular Shaped DGS Strip Antenna for 5.8GHz Communication", *International Journal for Innovative Research in Science & Technology*, Volume 2, Issue 09, pp 12 – 17, February 2016.

[14] Eyshika, A., Ayushi, S., Nitin, T., and Sumit, S.: "Design and Analysis of Rectangular Patch Microstrip Antenna with Defected Ground Plane for WiMax Applications", *Proceedings of DIGNATE 2014*, pp 30 – 34, 2014.

[15] Ning, D. H., Wing, N. K., Minglu, L. and You, W. M.: "An overview of using directional antennas in wireless networks", *International Journal of Communication Systems*, Volume 26, Issue 4, pp 413 – 448, April 2013.

[16] Hansen, W. W. and Woodyard, J. R.: "A New Principle in Directional Antenna Design", *Proceedings of the Institute of Radio Engineers*, Volume 26, No. 3, pp 333 – 345, March 1938.

[17] Sean, W.: "*Angle of Arrival Estimation using Received Signal Strength with Directional Antennas*", Degree Bachelor thesis, The Ohio State University, 2007.

[18] Evangelos, K., Danny, K., and Eric, W.: "Directional Versus Omnidirectional Antennas for Energy Consumption and k-Connectivity of Networks of Sensors", *International Conference on Principles of Distributed Systems*, Volume 3544, pp. 357 – 368, August 2005.

[19] Ramanathan, R., Jason, R., Santivanez, C., David, W., and Stephen, P.: "Ad Hoc Networking With Directional Antennas: A Complete System Solution", *IEEE Journal on Selected Areas in Communications*, Volume 23, No. 3, pp 496 – 506, March 2005.

[20] Spyropoulos, A. and Raghavendra, C.S.: "Energy Efficient Communications in Ad Hoc Networks Using Directional Antennas", *Proceedings.Twenty-First Annual Joint Conference of the IEEE Computer and Communications Societies*, New York, USA, pp. 220 – 228, November 2002.

[21] Marcelo, B. P., Roberio, D. P. de A., and Carlos, A. F. S.: "Unmanned Aerial Vehicle Propagation Datalink Tool Based on a Hybrid Multiscale Modeling", *Journal of Aerospace Technology and Management*, Volume 10, pp 1– 11, 2018.

[22] Sourabh, B., Shweta, S., Dr. Prakash, V., and Bhaskar, N.: "Study The Various Feeding Techniques of Microstrip Antenna Using Design and Simulation Using CST Microwave Studio.", *International Journal of Emerging Technology and Advanced Engineering*, Volume 4, Issue 9, pp 318 – 324, September 2014.

[23] Raithatha, U. and Sreenath, K. S.: "Microstrip Patch Antenna Parameters, Feeding Techniques & Shapes of the Patch – A Survey", *International Journal of Scientific & Engineering Research*, Volume 6, Issue 4, pp 981 – 984, April

2015.

[24] Rahul, V., Nitin, V., Rahul, R., Kaushik, V., and Arya, A. K.: "Design Study of Microstrip Antenna with Various Feeding Techniques: A Review", *International Journal of Engineering Research & Technology*, Volume 3, Issue 5, pp 619 – 622, May 2014.

[25] Buckley, J., Gaetano, D., McCarthy, K.G., Loizou, L., O'Flynn, B. and O'Mathuna, C.: "Compact 433 MHz antenna for wireless smart system applications" *ELECTRONICS LETTERS*, Vol. 50, No. 8 pp. 572–574, April 2014.