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DESIGN OF MICROSTRIP PATCH ANTENNA FOR AIRCRAFT APPLICATION

Muhammad Aliff Naqiuddin Bin Mohd Nordin

Thesis submitted in partial fulfilment of the requirements

for the award of the degree of

Bachelor of Engineering Technology in Electrical with Honours.

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UNIVERSITI MALAYSIA PAHANG

JANUARY 2021

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ABSTRACT

In this project, a new noble design of single patch microstrip patch antenna with defected ground structure is presented for aircraft applications. The operational frequency for this new patch antenna is 5GHz. The size of the new patch antenna is only 27mm x 21.5mm, making it small and compact. The substrate that is used for the antenna construction is RT/Duroid 5880 and thickness of only 1.6mm, making it parallel with the concept of small and compact. The new patch is designed using High Frequency Structure Simulator (HFSS) software. Not only the software can be used to design, HFSS can also be used to simulate the newly design patch antenna where users can see their design's return loss, radiation pattern, gain and many more required variables.

ABSTRAK

Dalam projek ini, reka bentuk *patch* tunggal jalur mikro *patch* antena yang tersendiri dengan struktur tanah yang rosak dipersembahkan untuk aplikasi pesawat. Frekuensi operasi bagi *patch* antena ini adalah 5GHz. Saiz *patch* antena baru ini hanya 27mm x 21.5mm, menjadikannya kecil dan padat. Substrat yang digunakan untuk pembinaan antenna adalah RT/Duroid 5880 dan ketebalan hanya 1.6mm, menjadikannya selari dengan konsep kecil dan padat. *Patch* baru direka menggunakan perisian *High Frequency Structure Simulator* (HFSS). Bukan hanya perisian ini dapat digunakan untuk melakar, HFSS juga boleh digunakan untuk mensimulasikan *patch* antenna yang baru direka di mana pengguna dapat melihat *return loss*, corak radiasi, *gain* dan banyak lagi pemboleh ubah yang diperlukan.

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LIST OF SYMBOLS

GHz	Giga-Hertz
εr	Dielectric constant
W	Width
C	Speed of light
Fr	Operational frequency
εeff	Effective dielectric constant
h	Height
ΔL	Extension length
$Leff$	Efficient length
L	Length
mm	Millimetre
dB	Decibel

LIST OF ABBREVIATIONS

HFSS	High Frequency Structure Simulator
PCB	Printed Circuit Board
RFID	Radio-frequency Identification
GPS	Global Positioning System
PTFE	Polytetrafluoroethylene
3D	3-dimensional
2D	2-dimensional
GUI	Graphic User Interface
DGS	Defected Ground Structure

LIST OF APPENDICES

CHAPTER 1
INTRODUCTION

1.1 Project Background

As the 21st century progresses, the world is moving forward towards the advancement of science and technology. This advancement also includes the world of communication system and for this project, the main focus is on aircraft communication technology. An aircraft uses a specific range of radio frequency to communicate with air traffic control and others in order to navigate to its destination safely. This communication can be achieved with the help of various type of antennas that is on board the aircraft, one of it is a patch antenna.

The history of patch antenna goes back to the 1950s but the application of the idea had to wait for 2 decades after the development of printed circuit board (PCB). This type of antenna is one of the most common type of antenna as it is lightweight, low profile, low cost, easy of conformal and many other advantages of patch antenna. Since the application of the patch antenna in the 1970's, it had been implemented into various system such as in mobile phones, radio-frequency identification (RFID), global positioning system (GPS), satellite communications, radar systems, and even missile guidance system. Not to mention, this type of antenna is also being use as one of the antenna in aircraft communication system.

Each antenna that is on board the aircraft have its very own unique design, features, functions and location on the aircraft. For this project, the operating frequency for the antenna is 5GHz which is in the C-band, where the C-band is a designation for microwave frequency ranging from 4GHz to 8GHz. Higher frequencies have higher tendencies to be interrupted by weather such as water absorption, which can cause an interruption in the transmission process.

1.2 Problem Statement

Generally, one of the characteristics of patch antenna is that the patch antenna has low gain and high harmonics. These characteristics could affect the communication, thus preventing a clear transmission of information. With that, a communication error might occur which can lead to accident or any unwanted incidents. Therefore, a new design of patch antenna is needed to be constructed in order to get a good gain for communication and no other high harmonics or noise that may interrupt the communication.

With the new idea of proposing a new design, comes many other variables that needed to be consider in order to get a new patch antenna that have a good gain and little to no noise. One of the variables that need to take into consideration is that the design of the new patch must be suitable for 5GHz frequency band for aircraft application. The next variable that need to be taken into consideration is the material for the antenna substrate. Not only the substrate need to have a good and suitable dielectric constant, the substrate also need to be able to withstand extreme weather as is it going to be mounted on an aircraft body, have excellent chemical resistance and isotropic, which mean the substrate need to have identical values of a certain properties on every direction.

1.3 Objectives

The target for this project is to accomplish the following objectives:

1. To design a new 5GHz microstrip patch antenna for aircraft applications.
2. To develop a new microstrip patch antenna integrated filter for aircraft application.
3. To evaluate the performance of the newly design structure using simulation software.

1.4 Project Scope

The scope for this project is to develop a new microstrip patch antenna design for aircraft applications. To come up with a new patch antenna design, firstly need to ensure the draft design has not been done by other researcher and able to work with an operating frequency of 5GHz. After ensure the draft is noble, proceed with full design of the patch antenna together with its substrate material and all other dimensions. The main rule of designing the new patch antenna is to ensure the total size of the patch antenna is small and compact as possible.

The next part is to achieve the second objective are design the integrated filter for the patch antenna. After that, finalizing the dimensions of the filter which is length, width and thickness. Lastly, the design filter must be able to receive only 5GHz signal and filter out any other noise that is presence at other frequencies.

After finishing the design, proceed with the performance evaluation of the new microstrip patch antenna. Evaluate the return loss of the antenna and ensure the return loss frequency is at 5GHz only. Then proceed with the evaluation of the antenna's radiation pattern as well as the total gain of the antenna.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed on the literature review for the topic of design of integrated patch antenna for aircraft applications. Firstly, the basics of the patch antenna is discussed in this chapter. Then, the various type of antenna feeding technique which is microstrip line, coaxial probe and many more. Next is the substrate and dielectric material for the patch antenna.

2.2 PATCH ANTENNA

Patch antenna is one of many types of radio antenna which can be used to transmit and receive information. Nowadays, there are many ways in designing a patch antenna which can make it smaller in size and more compact. The antenna usually can be mounted on a smooth flat or curved surface. In designing a patch antenna, there are a few things that are needed in order for the antenna able to work and function properly. First, is the operating frequency of the antenna as well as the application of the antenna. Next, the type of substrate that is suitable considering the application and requirements. Some calculation is required before proceeding to design the antenna using the variables that had been acquired such as the operating frequency, dielectric constant (εr) and thickness of substrate. The calculation will spill out the value for width and length of the patch antenna that can be used as the basic understanding for designing the patch antenna. Then, proceed with designing the patch antenna using including the substrate that had been selected and the type of feeding for the antenna. Figure 2.1 shows a simple basic square design of a patch antenna.

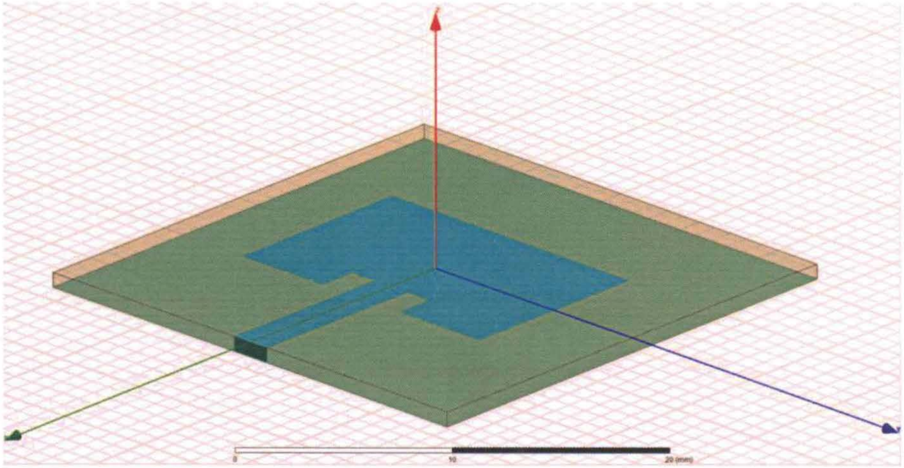

Figure 2.1: Basic design of patch antenna

A patch antenna is so small in size which makes it very light weight and very thin. Besides that, the manufacturing of a patch antenna is very cheap that manufacturer able to make it in mass production as it can be printed directly onto a circuit board that operates on microwave frequency (Waterhouse, R. B. 2003).

2.3 ANTENNA FEEDING

There are a few techniques that can be used to feed or supply the patch antenna with an electromagnetic energy for the antenna to radiate. The types of feeding technique play a major role in case of efficiency and matching input impedance. The types of antenna feeding techniques are shown and discuss as follows.

2.3.1 MICROSTRIP FEED LINE

The microstrip feed line technique is one of commonly use feeding technique to feed the patch antenna. The patch itself is connected directly with a conducting strip that the edge of the antenna as shown in Figure 2.1. The conducting feed is placed on the same substrate surface with the patch antenna and some design may include an inset cut before attaching the feed line to the patch antenna. The size on inset cut and the feed line may affect the patch antenna, so a proper adjustment and experimentation is needed to achieve the target for the patch antenna. This type of feeding is commonly used because of it is easy and simple to fabricate.

2.3.2 COAXIAL PROBE

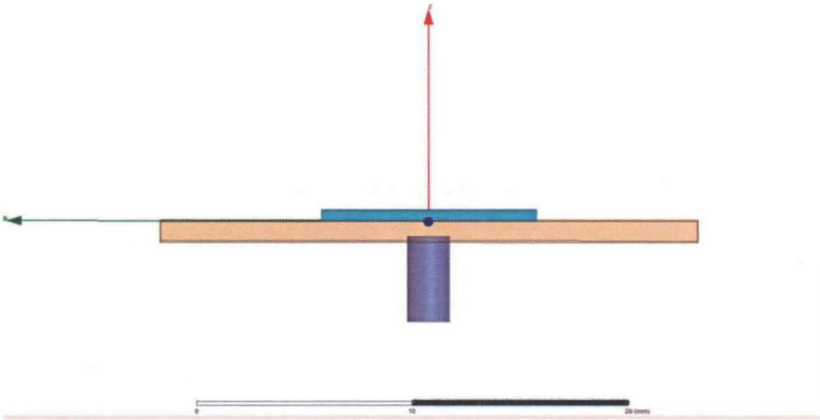

Figure 2.2: Coaxial probe feed

The coaxial probe feeding is also one of the common technique used to feed a patch antenna. As shown in Figure 2.2, the probe is connected inside of the substrate and the bottom conductor is connected to the ground plane. This method is also easy to fabricate as the substrate only needed to be drilled to make a hole to connect the coaxial probe, but it is not suitable for thick substrates.

2.3.3 APERTURE COUPLED FEED

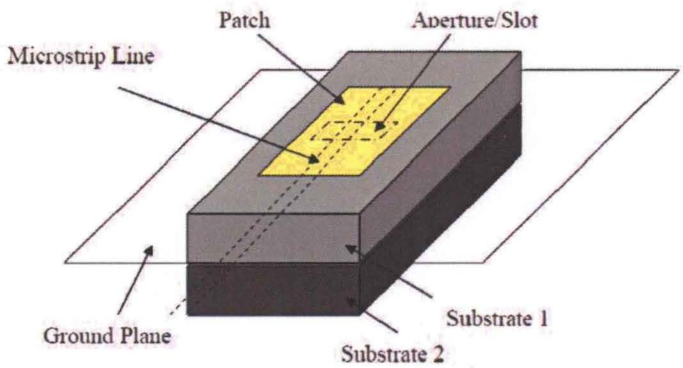

Figure 2.3: Aperture coupled feed

This feeding technique is quite different from the other technique. As Figure 2.3 shows, the patch antenna and the feed line are separated on two different substrates divided by a ground plane. The feed line is connected to the patch through a slot or an aperture on the ground plane. This feeding method is quite difficult to fabricate as it requires two substrates and a conducting ground plane to separate the two substrates. The top substrate is usually thinner and low dielectric constant compare to the bottom substrate which is usually thick and high dielectric constant

2.4 SUBSTRATE & DIELECTRIC MATERIAL

Substrate is another one of the major component for this project because the patch itself is going to be fabricated on top of the substrate's surface. Besides that, the type of material that is chosen to be a substrate can also affect the functionality and performance of the patch antenna. The substrate act as a separation barrier between the patch and ground plane that will also produce an electric field between them.

For this project, Rogers RT Duroid 5880 has been selected as the material for the substrate. This material is a glass microfiber reinforced PTFE (polytetrafluoroethylene) composite that are designed for exacting stripline and microstrip circuit applications. Dielectric constant (ε_r) is the ratio of electrical permeability of a substance to the electrical permeability of free space. The dielectric constant for Rogers RT Duroid 5880 is 2.20. We choose this material because of the ease to fabricate the designed patch and the ground plane on to the substrate. Apart from that, the selected is also resistant to all liquids or chemicals, whether hot or cold, which is suitable for aircraft application (Rogers Corp, 2018).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

A patch antenna normally can be constructed by using its own formula and calculation that have been found by past researcher. But nowadays, the advancement of computer and technology helped in the development of patch antenna development. A single-patch microstrip patch antenna can be constructed by using a simulation software. The values from the calculation can be used into the software to generate a desired patch antenna with its own specifications and requirements.

This chapter will explain about the work flow and methods that is being used in the development of a microstrip patch antenna for aircraft application.

3.2 FLOWCHART

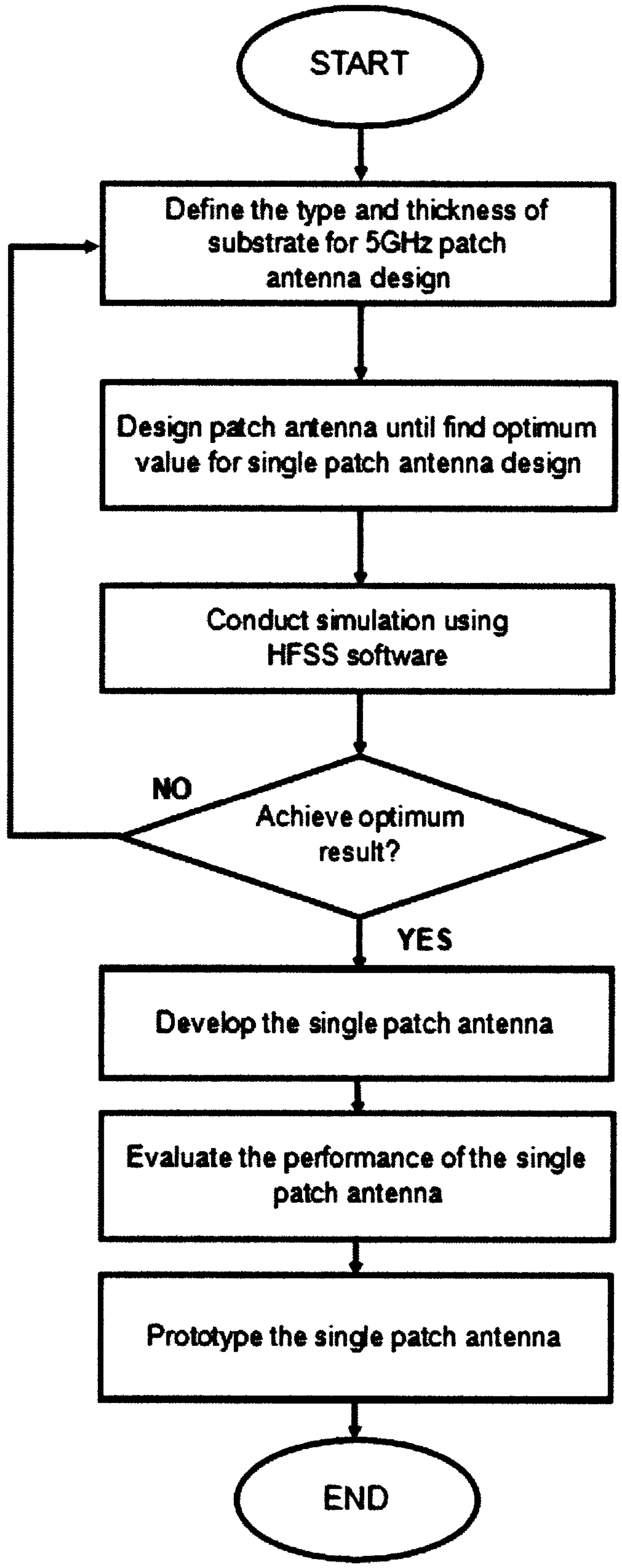

Figure 3.1: Flow Chart of Single Patch Microstrip Patch Antenna

3.3 PATCH ANTENNA FORMULA

To construct a patch antenna, there are a few things and steps needed to be taken before begin to design the antenna. First, we need to determine what is the operational frequency (Fr) that we wanted to apply to the antenna. For this application we choose 5GHz for the operational frequency for our antenna.

Next, we need to select the material for the substrate of the patch antenna. Each substrate material has a different dielectric constant (εr) which can affect the functionality of the patch antenna. RT/duroid 5880 is the type of substrate that we choose for our substrate material with a dielectric constant of 2.20 with height (h) of 1.5748mm.

After determine the operational frequency of the antenna and material for the substrate, we proceed with the calculation for the size of patch whereby the formula is as given;

$$W = \frac{C}{2Fr}\sqrt{\frac{2}{\varepsilon r + 1}} \tag{1}$$

where W is the width of the patch antenna, C is the speed of light ($3x10^8$m/s), Fr is the operational frequency that we had determined and εr is the dielectric constant of the substrate.

$$\varepsilon eff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1/2} \tag{2}$$

εeff is the effective dielectric constant of the antenna which will be used in the next formula to calculate the length of the antenna.

$$\Delta L = h(0.412)\left[\frac{\varepsilon eff + 0.3}{\varepsilon eff - 0.258}\right]\left[\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right] \tag{3}$$

$$Leff = \frac{C}{2Fr\sqrt{\varepsilon eff}} \tag{4}$$

$$L = Leff - 2\Delta L \tag{5}$$

ΔL is the calculation of extension length while $Leff$ is the efficient length. To get the actual length (L), the formula stated that $2\Delta L$ is subtracted from $Leff$. With all that, we can get the actual width and length of the patch antenna.

3.4 PATCH ANTENNA CALCULATION

Based on the formula given, we manage to calculate and get the value for the width and length of the patch antenna. The variables and calculations are as follows;

Fr = 5GHz $\qquad \varepsilon r = 2.20$ $\qquad$ *h* = 1.5748mm (0.0015748m)

Width of patch antenna, *W;*

$$W = \frac{C}{2Fr}\sqrt{\frac{2}{\varepsilon r + 1}}$$

$$W = \frac{3x10^8}{2(5x10^9)}\sqrt{\frac{2}{2.20 + 1}}$$

$$W = 0.023718m \tag{6}$$

εeff

$$\varepsilon eff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + 12\left(\frac{h}{W}\right)\right]^{-1/2}$$

$$\varepsilon eff = \frac{2.20 + 1}{2} + \frac{2.20 - 1}{2}\left[1 + 12\left(\frac{0.0015748}{0.023718}\right)\right]^{-1/2}$$

$$\varepsilon eff = 2.0476 \tag{7}$$

ΔL

$$\Delta L = h(0.412)\left[\frac{\varepsilon eff + 0.3}{\varepsilon eff - 0.258}\right]\left[\frac{\frac{W}{h} + 0.264}{\frac{W}{h} + 0.8}\right]$$

$$\Delta L = 0.0015748(0.412)\left[\frac{2.0476 + 0.3}{2.0476 - 0.258}\right]\left[\frac{\frac{0.023718}{0.0015748} + 0.264}{\frac{0.023718}{0.0015748} + 0.8}\right]$$

$$\Delta L = 0.0008223m \tag{8}$$

$Leff$

$$Leff = \frac{C}{2Fr\sqrt{\varepsilon eff}}$$

$$Leff = \frac{3x10^8}{2(5x10^9)\sqrt{2.0476}}$$

$$Leff = 0.02096m \tag{9}$$

Length of patch antenna, *L;*

$$L = Leff - 2\Delta L$$

$$L = 0.02096m - 2(0.0008223m)$$

$$L = 0.0193154m \tag{10}$$

From the calculation that have been done, the dimension for the patch antenna is acquired and can be used as the basic understanding for designing the patch antenna.

3.5 SIMULATION SOFTWARE

After obtaining the dimensions of the patch antenna from the calculation, to start designing the patch antenna, a software can be used to design and simulate the created patch antenna. The simulation software is High Frequency Structure Simulator (HFSS).

HFSS is one of the software that can be used for 3D and 2D design of antennas, antenna arrays, filters and other complex electronic circuit that uses the application of radio frequency or electromagnetic wave. This software can also be used to simulate the designed antenna or filters using the variables that had been decided such as operating frequency, substrate type and thickness, and many more. From the simulator, researchers can obtain the results that they required such as the return loss, gain, radiation pattern and many other parameters. Figure 3.2 is the graphical user interface (GUI) of HFSS.

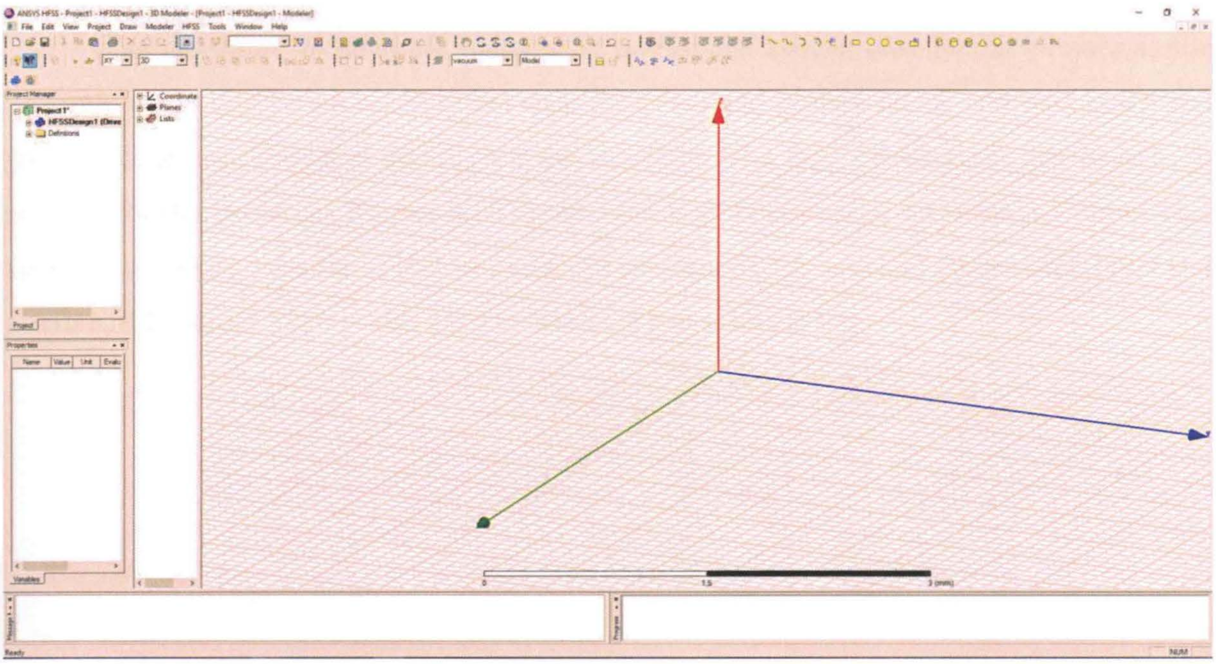

Figure 3.2: GUI of HFSS

3.6 DESIGN OF PATCH ANTENNA

The target for this project is to design a patch antenna that can function at 5GHz and it is for aircraft application. Microstrip patch antenna is chosen because of its small size, compact very lightweight. There are a few things that needed to be consider before designing a microstrip patch antenna which are the shape of the patch itself, material of substrate and the ground plane. Both patch and ground plane are design on the substrate, whereby the patch is on top of the substrate and the ground plane is at the bottom part. The antenna functions by the interaction between the patch and ground place through the dielectric constant of the substrate by forming an electromagnetic field in between them.

3.6.1 SUBSTRATE

The selection of substrate material is one of the crucial part in this project as the substrate is the interaction medium between the patch and ground plane, and both patch and ground plane are fabricated directly on the substrate. The type of substrate that have been selected for this project is Rogers RT/Duroid 5880 with thickness of substrate is 1.6mm. This substrate is chosen because of its low dielectric constant of 2.2, low loss tangent of 0.0009 and flexible. RT/Duroid 5880 is also easy to fabricate and stable to use.

3.6.2 PATCH ANTENNA DESIGN

The design of the patch antenna is going to work at an operational frequency of 5GHz to receive and transmit signal. Figure 3.3 shows the design of the single patch antenna.

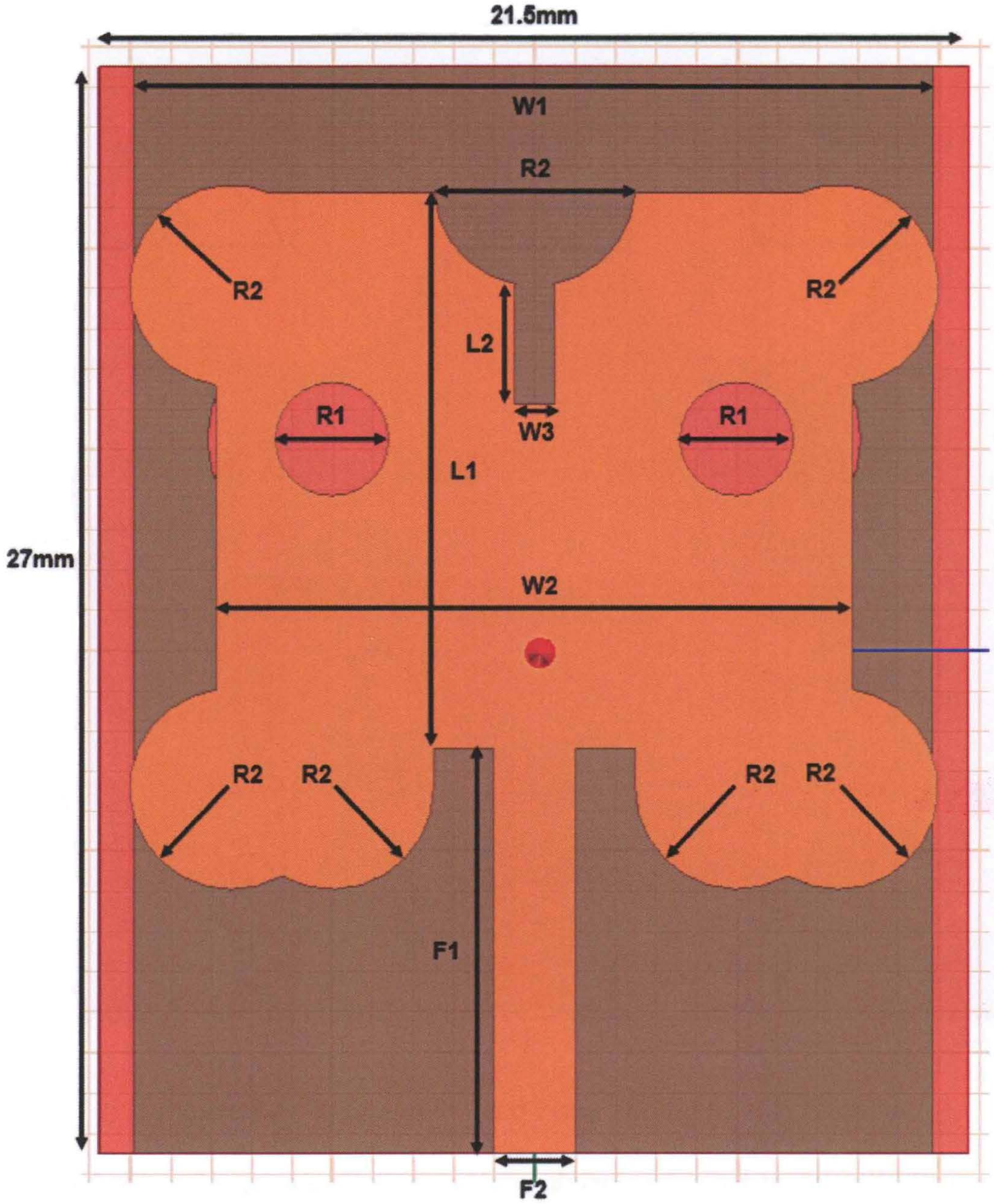

Figure 3.3: Design of Single Patch Antenna

As shown in the figure above, the orange colour is the designed patch antenna, the light red plane is the substrate and the light brown section is the ground plane of the patch antenna. The size of the substrate is 27mm x 21.5mm, which shows the patch antenna is small and compact in size. Figure 3.4 shows the ground plane of the patch antenna.

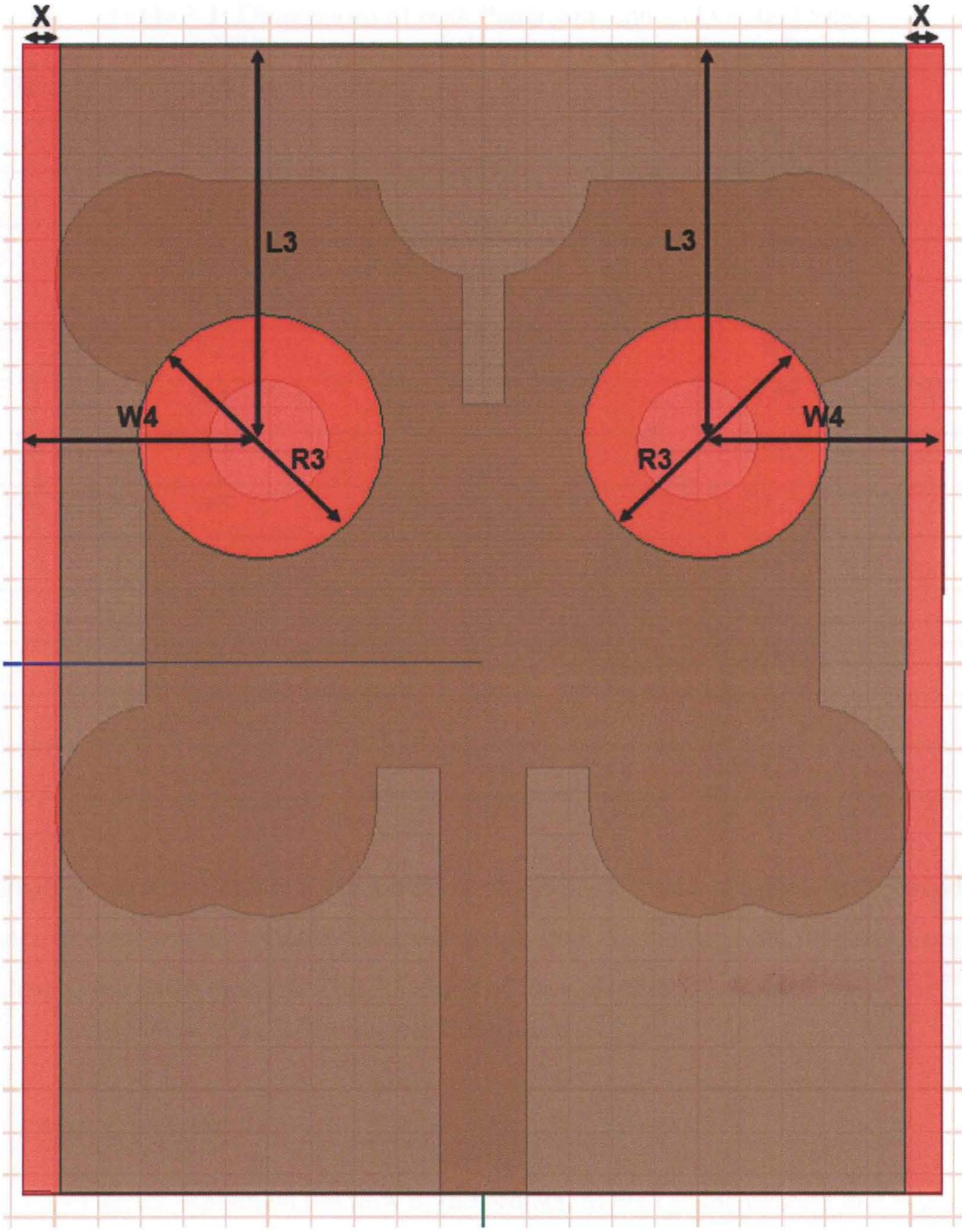

Figure 3.4: Design of Ground Plane of Single Patch Antenna

The ground plane design uses the principle of defected ground system (DGS) whereby the ground plane of the patch antenna does not fully cover the substrate. As shown in figure above, the width of the ground plane is smaller than the substrate and there are two holes behind the 'eye' of the patch antenna. Table 3.1 shows the dimension of both single patch antenna and ground plane.

Table 3.1: Dimensions of both Patch Antenna and Ground Plane

Parts of Microstrip Patch Antenna	Dimensions (mm)
L1	17
L2	3
L3	5.25
F1	10.555
F2	2
W1	19.75
W2	15.8
W3	1
W4	5.55
R1	2.8
R2	2.5
R3	2.875
X	0.875

A microstrip patch antenna is a combination of the patch itself, substrate and ground plane. The patch interact with the ground plane will produce an electromagnetic field that have a good return loss to the patch antenna. The thickness of the substrate is 1.6mm.

3.7 CONCLUSION

This chapter explain on the flow of the project, as well as the method that is used in the designing of the single patch microstrip patch antenna.

CHAPTER 4

RESULTS & DISCUSSION

4.1 INTRODUCTION

High Frequency Structure Simulator (HFSS) not only can be used to design the microstrip patch antenna, it also can function as a simulator whereby the user need to key in a few variables and the software will give out the result. The software can simulate the design and shows the result of the antenna's return loss, radiation pattern, gain and many other parameters that the user requires. In this project, the performance and results of the microstrip patch in the most important thing.

This chapter will explain and show the results of the newly designed microstrip patch antenna.

4.2 RESULT OF THE RETURN LOSS OF SINGLE PATCH MICROSTRIP PATCH ANTENNA

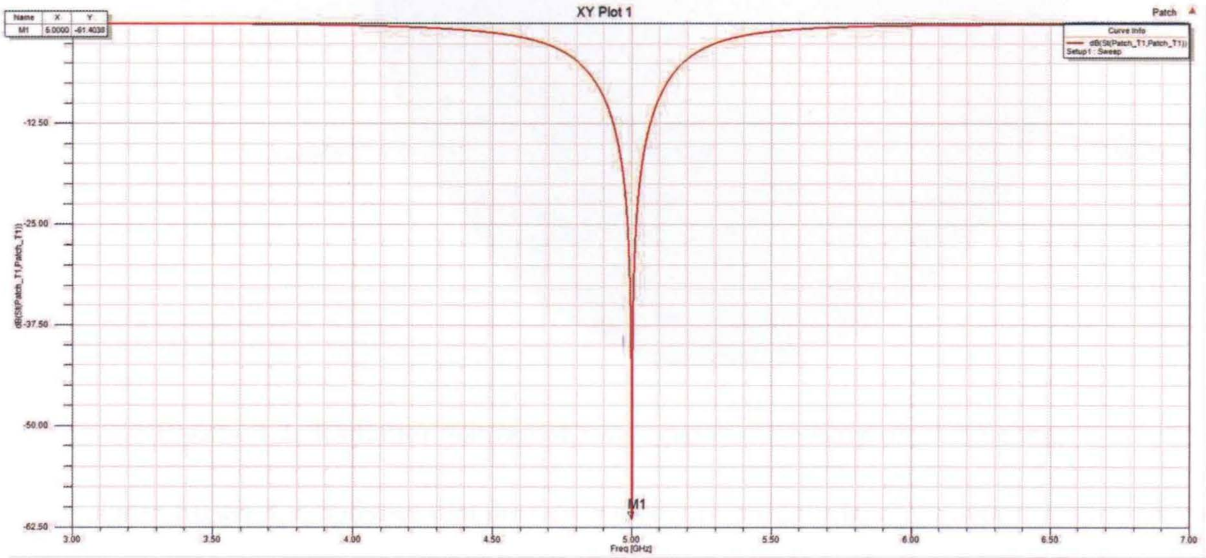

Figure 4.1: Return loss of single patch microstrip patch antenna

From Figure 4.1, it shows that the newly designed patch antenna return loss where the frequency is directly on 5GHz at -61.4038dB. Theoretically when the return loss of an antenna is more that -10dB at a certain frequency, the antenna is able to receive the signal at that frequency and if the return loss is more than -20dB, the signal that is received is purer. For this case, the 5GHz signal that is being transmitted or received by the antenna is a pure signal.

Besides that, the result shows that the signal is purely on 5GHz and there is no noise present at any other frequency either less than or more than 5GHz.

4.3 RESULT OF THE RADIATION PATTERN OF SINGLE PATCH MICROSTRIP PATCH ANTENNA

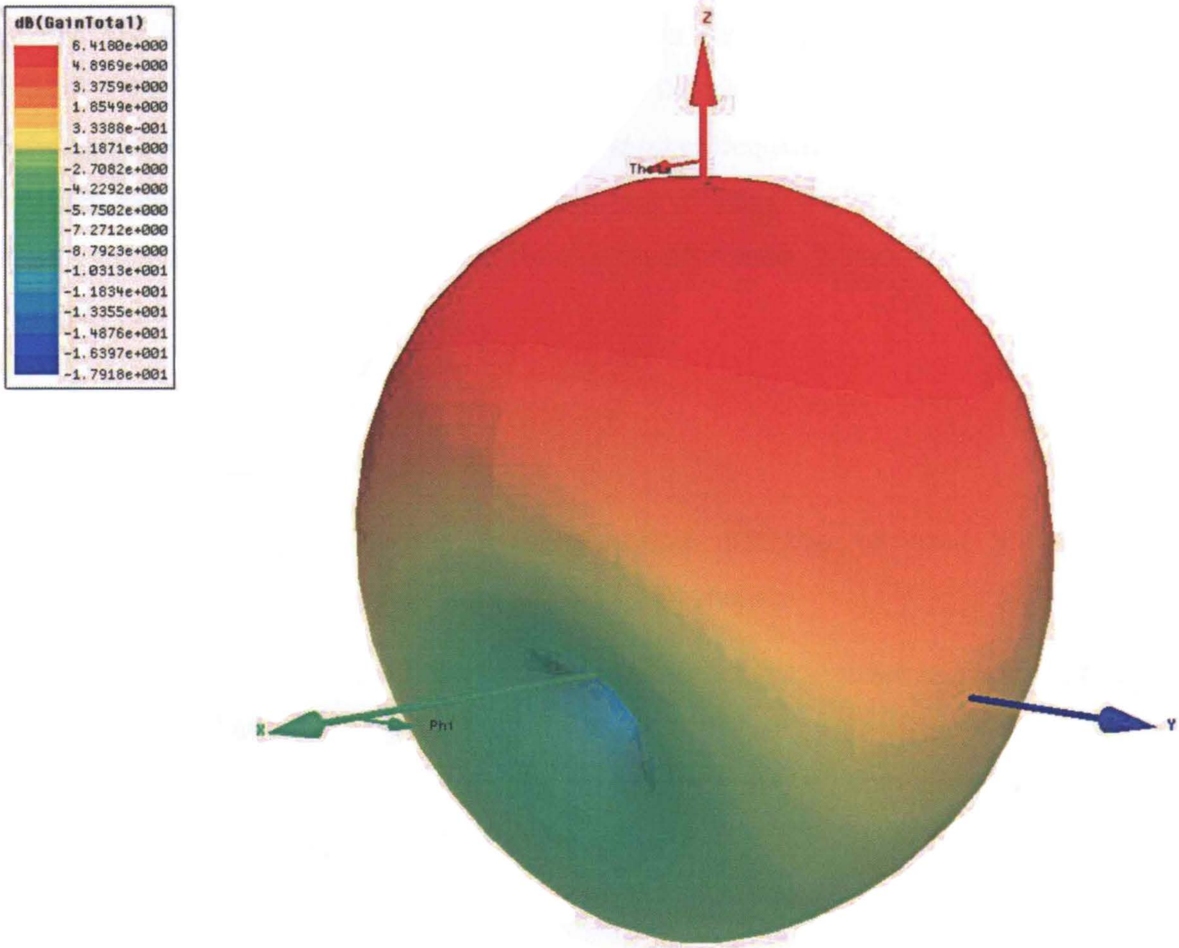

Figure 4.2: Radiation pattern of single patch microstrip patch antenna

From Figure 4.2, it shows that the newly designed patch antenna radiation pattern where the antenna radiates at frequency of 5GHz. The shape of the radiation pattern is in omni-directional but with a heavier concentration on the top area. This mean the antenna able to radiates power on all direction and the top area has the highest power compare to other regions.

4.4 CONCLUSION

In this chapter, the author has explained on the newly designed single patch microstrip patch antenna's results of return loss and radiation pattern.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 CONCLUSION OF PROJECT

The purpose of this thesis was to design a new 5GHz single patch microstrip patch antenna for aircraft applications. The antenna was designed and simulated using HFSS software. The results in previous chapter shows that the patch antenna gives an excellent return loss graph of -61.4038dB at 5GHz with no noise at other frequencies. The patch antenna design was very compact where the substrate size was only 27mm (L) x 21.5mm (W) and thickness of only 1.6mm. Overall, the design and simulated performance is good for fabrication for the prototype phase.

5.2 RECOMMENDATION

The following list is the recommendation that can be used for any future implementation of the patch antenna for aircraft applications:

1. Improve the design of the patch antenna as change the substrate material, thickness as well as the dimension.
2. The bandwidth of the return loss still can be improved and widen by changing the feeding technique for the patch antenna.

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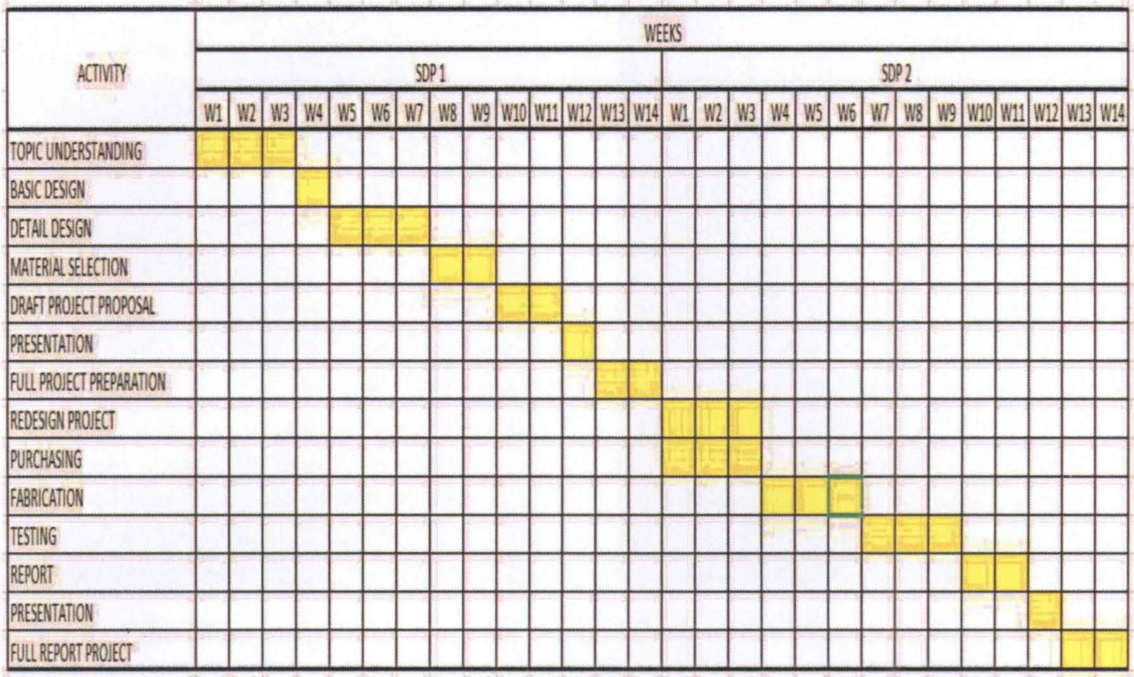
APPENDICES

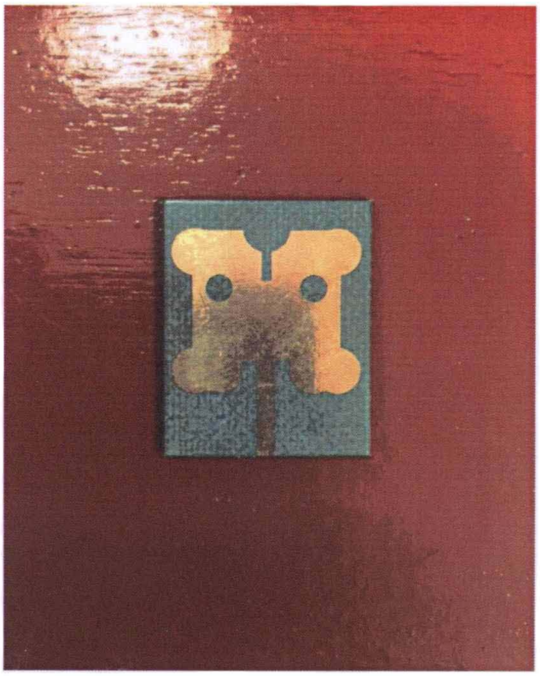
APPENDIX A

Project Gantt chart



APPENDIX B

Prototype of single patch microstrip patch antenna



Front of the Microstrip Patch Antenna

Back of the Microstrip Patch Antenna

APPENDIX C

Prototype of single patch microstrip patch antenna with integrated filter