DESIGN AND DEVELOPMENT OF AN ADHESIVE ANTENNA

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Honours) Electronic Engineering

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DESIGN AND DEVELOPMENT OF AN ADHESIVE ANTENNA"** was prepared by **EILEEN TAN MEI FOONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

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Date : _________________________

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ABSTRACT

Due to the advancement of technology, the quality of life of mankind has been improving. One of the most essential factors which mediate a better and more comfortable living standard is the rapid development of wireless communication. Wireless communications have contributed significantly in the technological advancement in the healthcare and medical fields. This project presents the design of a 24 mm × 24 mm × 1 mm adhesive antenna which is used specifically for biotelemetry. The antenna is fabricated on a Rogers RT/duroid 5880 dielectric substrate. The antenna is designed using High Frequency Structure Simulator (HFSS). The antenna acts as a gateway between implantable medical devices and the external base station. It allows the implanted devices to communicate with the base station via the Wireless Body Area Networks (WBANs). The proposed planar monopole adhesive antenna is capable of operating in three resonant bands. The adhesive antenna resonates at the ISM (2.4 – 2.5 GHz), WBAN (3.1 – 10.6 GHz) and WLAN (5.15 -5.725 GHz) bands. The designed antenna is simulated using HFSS and the fabricated antenna is experimentally verified by attaching it onto a human's skin. Furthermore, the gain of the antenna is above -13.57 dBi, whereas the average SAR values at 2.41 GHz, 3.27 GHz and 5.06 GHz are respectively, below 3.217 μW/kg, 7.035 μW/kg and 27.85 μW/kg. Average SAR is known as Specific Absorption Rate to measure the rate of energy absorbed by the human body when exposed to an electromagnetic field of radio frequency. The designed antenna is safe to be used by the users as the average SAR values for the antenna are below the limits set by the IEEE C95.1-1999 and IEEE C95.1-2005 standards. The antenna's simulation and measurement performances confirm its omnidirectional radiation patterns and good tri-band operations with high reflection coefficient.

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CHAPTER 1

INTRODUCTION

1.1 Background

An antenna is a conductor that can transmit and receive signal such as radio, microwave or satellite signals. In telecommunication, a planar antenna is known as an antenna fabricated on a printed circuit board. It contains of a metallic patch attached on dielectric materials and supported by the ground plane. Very often, the planar antenna operates at the microwave frequency range. Planar antenna has a lot of advantages such as low profile, lightweight, small volume, and comfortable to planar and nonplanar surfaces. Besides, it is also simple and inexpensive. These factors reduce the cost of the design. A planar antenna particularly a microstrip antenna is inconstant in term of resonant frequency, pattern, polarization, and impedance when it comes to patch pattern and mode selected (Balanis,2015).

Digital health care systems are used to monitor chronic diseases such as heart disease, diabetics, and stroke. Due to budget cuts and the shortage of physicians, health systems are struggling to care for patients, especially those with chronic illness, which will get worse as people live longer. This issue can be managed by creating models of care that incorporate existing technologies. (Wood, 2004) Nowadays, people are already using medical devices to check blood pressure, pulse rate and monitor physical activity. Thus, in this study, adhesive antenna is designed to be applied onto the human's skin for healthcare purposes. This antenna is intended to serve as a gateway to amplify the electromagnetic wave radiated from the implantable medical device (Shrourou, 2019).

Nowadays, a lot of people have started to rely on implantable medical devices. The main goal of these implantable devices is to ease their health care monitoring or inspect various diseases in the body and transmit this to the base station. An antenna is an essential component of data transmission from implants to the external environment via wireless links known as biotelemetry. Therefore, the size of the conventional antennas is much bigger than the implantable antenna used for general wireless application. Thus, the implantable antenna needs to be small in order to place into the human body. However, the efficiency of the implanted antenna will be poor as the implanted antenna will be placed within a complex lossy environment (Kumar and Shanmuganantham, 2017). This is due to the high-water content in the biological tissues. Thus, the electromagnetic waves are weak in transmitting the signal from the body to the outside base. Besides, batteries are generally one of the bulkiest electronic components in implantable medical devices (Felicio, Costa & Fernandes, 2018). Hence, the size of the antenna has to be minimized so that larger space could be apportioned for installing batteries.

In this study, a planar monopole adhesive antenna which is applied onto the skin surface is designed. The design is be printed on a flexible Rogers RT/duroid 5880 epoxy substrate and connected via on SMA connector. High permittivity dielectric substrate materials are used in the design to reduce the antenna size. Human's skin has been used as the adhesive antenna medium. By using High Frequency Structure Simulator software (HFSS) the adhesive antenna was designed. This designed antenna is used to amplify the signal transmitted between the implanted devices and external base station. As the antenna enhance the signals, the electromagnetic waves can be transmitted farther away.

1.2 Problem Statements

Implantable antennas embedded within the human body is extremely inefficient. This is because the human body has high conductivity and permittivity and is therefore lossy and frequency dependent. The lossy environment may impair the off-body communication between the implantable devices and the base station which is located some distance away from the human body. To overcome this limitation, an adhesive antenna is designed to be placed onto the skin surface. The adhesive antenna acts like a repeater. It enhances the signal transmitted by the implantable antenna so that it could be effectively sent to the base station.

1.3 Aims and Objectives

This are the objectives of the thesis:

i) To design and develop an adhesive antenna.
ii) To validate the performance of the adhesive antenna.
iii) To ensure that the adhesive antenna is suitable to be applied onto human's skin.

CHAPTER 2

LITERATURE REVIEW

2.1 Ansys High Frequency Structure Simulator Software (HFSS)

ANSYS High Frequency Structure Simulator software (HFSS) is the manufacturing standard for simulating 3D full-wave electromagnetic fields and designing electronic products. The products include antenna, a printed circuit board (PCB), IC packages and radio frequency or microwave components. ANSYS HFSS is mainly used for the design of high frequency, high-speed electronics found in communication systems, radar systems, satellites, and other high-frequency RF and digital devices such as smartphones and tablet by the worldwide engineers.

HFSS can help antenna designers who are constantly facing difficulty with applying designs across ever-increasing frequency bands inside a smaller and smaller footprint with many simulation technologies and powerful automated adaptive mesh refinement that delivers best quality level precision. Additionally, this software utilizes versatile solvers and an intuitive GUI to give unparalleled execution in addition to significant knowledge into all 3D EM issues. HFSS gives an amazing and comprehensive Multiphysics analysis of electronic items to ensure thermal and structural reliability by integrating with ANSYS thermal, structural and fluid dynamics tools with ANSYS.

Furthermore, HFSS becomes the ultimate tool of choice for antenna simulation because it delivers precise, automatic, and effective solution to overcome the difficulties. These challenges are reduction size of the antenna, restricted of channel bandwidth, reduction of design time, and antenna communication with different components. HFSS also can analyse the basic performance characterization such as gain, return loss, input impedance, directivity, and a variety of polarization characteristic. Engineers can decide the parts of the geometry applicable to the antenna's performance because the HFSS could give conception of electric and magnetic field together in far -field and near -field. In summary, HFSS is better than the other electromagnetic simulators which require manual control by user and multiple ways to confirm the appropriate and precise mesh generation (Ansys.com, 2019).

2.2 Rogers RT/ duroid 5880 Circuit Materials

RT/duroid® 5870 and 5880 glass microfiber reinforced Polytetrafluroethylene (PTFE) composites are designed for the demanding application strip lines and microstrip. Glass reinforcing microfibers are randomly oriented to maximize fibre reinforcement benefits for circuit manufacturers in the most valuable direction and in the final application of the circuit (Hofmannlp.de, 2019).

In this project, Rogers RT/duroid 5880 is selected for designing the adhesive antenna. The dielectric constant for RT/duroid 5880 substrate is 2.2 and its dissipation factor is 0.0009. Its dielectric constant is consistent across a wide frequency range from panel to panel. Rogers RT/duroid 5880 was selected as the substrate of the adhesive antenna rather than another type of PCB material such as FR-4. The FR-4 materials provide a highly effective balance between cost, production capacity, electrical properties, durability, and performance. However, the Roger RT/duroid 5880 is an ideal material for electrical features and advanced performance to the design. It is ideal because RT/duroid 5880 can provide less dielectric loss, low loss of electrical signal, low cost of circuit manufacturing, low range of dielectric constant, and low outgassing for space applications (Raypcb.com, 2019).

Next, RT/duroid 5880 provides low moisture absorption, has uniform electrical properties over frequency and excellent in chemical resistance whether hot or cold. It is also easy to cut, sheared, and machined to be shape. Furthermore, RT/duroid 5880 supports broadband applications at microwave frequencies in the millimetre range, where dispersion and circuit losses must be minimized, due to its low dielectric constant (Hofmannlp.de, 2018).

Table 2.1: Properties of RT/duroid 5880 Series Circuit Materials

(Available at: https://www.rogerscorp.com/documents/1100/acs/RT-duroid-5880LZ-High-Frequency-Laminates.pdf)

Property	Typical value RT/duroid 5880	Direction	units	conditions
Dielectric Constant Process	2.00 ± 0.04	Z		10GHz /23 °C
Dielectric Constant design	2.00	Z		8GHz – 40GHz
Dissipation Factors, tan	Typ: 0.0021 Max: 0.0027	Z		10GHz/23°C
Thermal Coefficient of Dielectric Constant	+20	Z	ppm/°C	-50°C to 150°C 10GHz
Volume Resistivity	1.74 ×10^7		Mohm·cm	C-96/35/90
Surface Resistivity	2.08 × 10^6		Mohm	C-96/35/90
Electrical Strength	40		kV	D48/50
Dimensional Stability	-0.38	X,Y	%	
Moisture Absorption	0.31		%	24 hours/23°C
Thermal Conductivity	0.33	Z	W/m°K	80°C
Coefficient of Thermal Expansion	54,47,40	X,Y,Z	ppm / °C	0 to 150°C

2.3 Industrial, Scientific and Medical (ISM) Band

Generally, ISM bands are open frequency bands which vary by region and permits. Most common daily utilization at the ISM bands are low-power, short range communications such as WiFi, Bluetooth, wireless phones, and RFID. Several in the United States are acquainted with the 2.4 GHz ISM band, as most WiFi and Bluetooth communications work in these bands, although 5 GHz WiFi systems have become more obtainable in recent years (McNeil, 2018). Furthermore, almost all electronic gadgets such as printers, tablet computers, laptops, and cell phones are currently utilizing the 2.4 GHz and 5.7 GHz ISM bands to have 802.11 wireless modems. As for lower frequencies of 13 MHz and 27 MHz ISM bands are used by near field communication devices such as proximity cards and contactless smart cards.

2.4 Wireless Body Area Network (WBAN)

Wireless Body Area Network (WBAN) is a wireless medical sensor system that can be installed on or within the human body to monitor and control various medical conditions. In this advance technology, the integrated circuit and wireless communication enable to build a smart device that are miniature, lightweight, and ultra-low-powered to be built (Yang, Hu and Liu, 2018).

WBAN antenna will consists of sensor nodes and a Gateway node to transmit signal to the external database server. The Gateway node can be used to connect signals received by the sensor node to a range of telecommunication network either through a standard telephone network, mobile phone, hospital network or using WiFi (Jamil and Mehmet,2010). Since WBAN is dedicated for medical devices, it can be used to transmit body signals such as pulse rate, blood pressure, body temperature, and electrocardiography (ECG) by applying on the body. The Wireless WBANs can easily place or take away from the body and could provide sufficient convenience to the patients. Therefore, the patient’s health condition can be monitored anytime and anywhere with the wireless medical devices for prevention and early risk detection.

Adhesive antennas which operates in the WBAN range can transmit data to an external server for analysis and storage. Since the antenna can be placed onto a human body, the antenna design should think about the wearer’s impact on the transient characteristic. Because of the human body is a lossy medium, the propagating wave experiences attenuation. Thus, when designing adhesive antennas, the loss of the antenna is to be minimised.

2.5 Wireless Local Area Network (WLAN)

Wireless Local Area Network (WLAN) consists of network adapters which is a wireless network that convey high frequency radio signals instead of sending information to other computers or devices on a network using wires or cables. The standard WLAN frequency range is 5.150 GHz to 5.725 GHz. The applications of WLAN are becoming more extensive due to the expansion of wireless communication technology and use of the frequency bands without the need for agreement. The growth of the WLAN communication technology will be improved by the antenna. WLAN communication system generally require fast, high-efficiency and reliable sending and receiving of data that is reflected in the antenna subsystem. In the wireless system, the antenna is an important part. (Yang et al., 2016).

2.6 Basic Definition of The Antenna Parameters

An antenna is a device that enables electromagnetic radio waves to be sent and/or received. The techniques of antenna measurement refer to antenna testing to ensure that the antenna meets specifications. Gain, radiation pattern, bandwidth, input impedance, and return loss are typically antenna parameters.

2.6.1 Gain

Gain is known as how well the antenna converts input power into the direction of radio waves or vice versa. It also refers to how well the antenna is capable of receiving or transmitting a signal. It accounts for the antenna's efficiency of directional capabilities. The intensity ratio is defined in a given direction by gaining the antenna to the radiation intensity that would be obtained if power accepted by the antenna isotropically radiated. Besides, relative gain is also defined as the ration of power gain in a given way to reference antenna's power gain in its referenced direction.

2.6.2 Radiation pattern

The antenna's radiation pattern defines the power variation that an antenna radiates as a function of the direction away from the antenna. The radiation pattern is generally determined in the far-field region and is represented by the directional coordinates. The radiation efficiency represented by the radiation pattern representing the relative field strength transmitted from or received by the antenna in a graphically depicts. Two-dimensional patterns can be obtained by dividing them into horizontal and vertical planes from three-dimensional patterns. These resulting patterns are respectively referred to as horizontal pattern and vertical pattern which also known as E and H-planes (www.tutorialspoint.com, 2019).

2.6.3 Bandwidth

Bandwidth is defined as a wavelength frequency band, specified for the communication. It is also described as the frequency range that antenna can radiate or receive energy properly. An important antenna parameter of antenna bandwidth over frequency range is that the desired antenna characteristic, such as impedance, gain or VSWR, fulfils. The impedance bandwidth is the frequency range that perfectly matches the antenna's input impedance with the characteristic impedance of the feeding transmission line. The fractional bandwidth at a 10dB point is the utmost mutual form of antenna bandwidth used in antenna. Proper impedance matching is required to maximize the impedance bandwidth (Mishra, 2015).

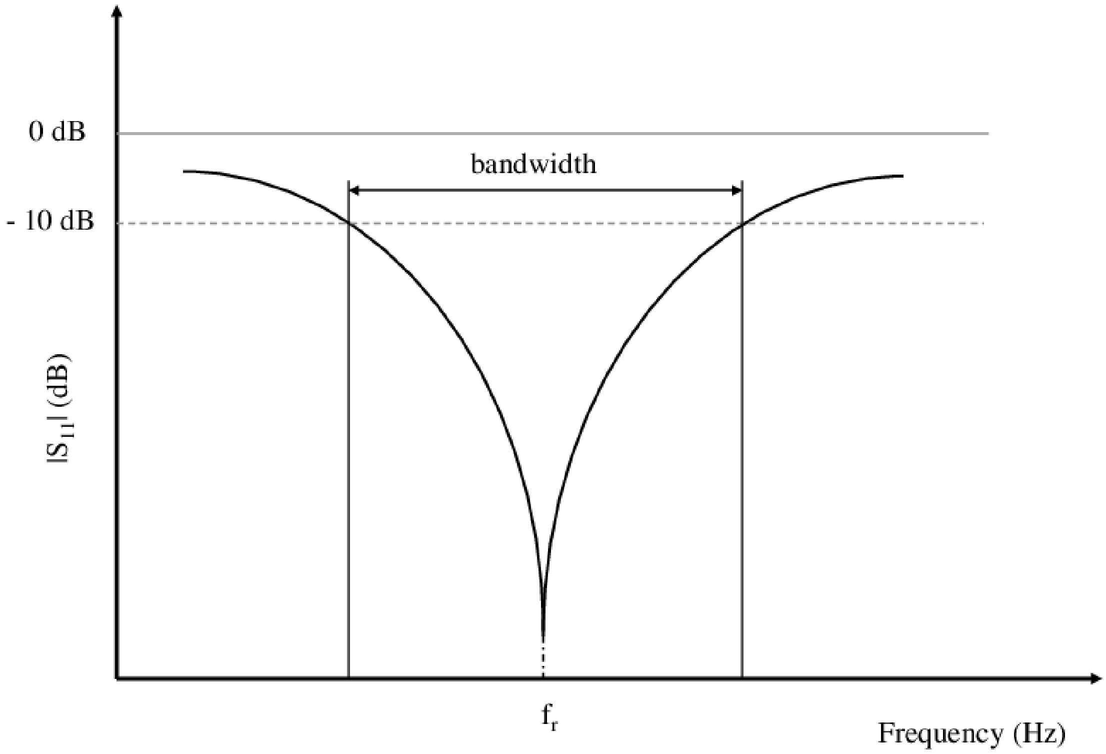

Figure 2.1: Example of Antenna Bandwidth Versus Frequency

2.6.4 Input Impedance

Antenna impedance at the input to the antenna relates the voltage to the current. To archive the high energy transfer efficiency, the impedance of the transmission cable attaches the radio to the antenna must be the same. Generally, the feed of the driving point of the antenna will be needed at 50 Ohms. If there is a case where the antenna has an impedance different from 50 Ohms, then the antenna is mismatched.

2.6.5 Reflection Coefficient

Reflection coefficient is defined as the figure quantifying the amount of the electromagnetic wave reflected by the impedance discontinuity in the transmission medium. The reflection coefficient is equal to the amplitude ratio of the wave reflected to the incident wave. Reducing the reflection coefficient value (S11) is the way to improve antenna mismatch. The shape of the various antenna affects a loss of return (S11).

2.6.6 Specific Absorption Rate (SAR)

Specific Absorption Rate is a tool that measures the rate at which human tissues absorbs energy when exposed to an electromagnetic field of radio frequency (RF). In order to limits exposure of radio frequency for user's safety, there are two different main authorities been established. The IEEE C95.1 – 1999 standard limits the average SAR in the form of a cube to less than 1.6 W/kg over any 1 g of tissue. On the other hand, the IEEE C95.1 -2005 standard limits the average SAR in the form of a cube to less than 2 W/kg over any 10 g of tissue. The antenna's maximum input power should meet these limitation (Alrawashdeh, 2005).

2.7 Planar Monopole Antenna Design Challenge

The adhesive antenna can work as a gateway between the implantable device and base station for the medication purpose. The size of the adhesive antenna should be small to increase the patient's mobility and flexibility. However, the design of the antenna is challenging to be small in size. A low dielectric constant antenna with high substrate thickness could have better gain, radiation and efficiency. Nevertheless, the result of configuration is a large antenna size. A trade-off between the dimensions and dielectric constant is therefore to be taken. Besides, three resonant frequency bands which can operate in adhesive antenna designed, i.e. the

ISM, WBAN and WLAN are also rather challenging. The resonant frequency might affect by the changes of the patch's dimension.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The adhesive antenna is to operate at three resonant bands, i.e. in the range of 2.4 - 2.45GHz, 3.1-10.6GHz, and 5.150 -5.725 GHz. These three frequency bands coincide with the Industrial, Scientific and Medical (ISM), Wireless Body Area Network (WBAN), and Wireless Local Area Network (WLAN) bands respectively. By using Ansoft High-Frequency Structure Simulator (HFSS), a combination of rectangle and U-shapes of the planar monopole antenna is designed and simulated. The volume of the proposed antenna is 24mm × 24mm × 1mm and Rogers RT/duroid 5880 is used as the substrate of antenna.

3.2 Human Body Model

In this project, a planar monopole adhesive antenna design is proposed. The antenna is to be attached onto the human’s skin. As can been seen in Figure 3.1, the human body model used in the design consists of a layer of skin, fat and muscle. A reliable of the human body tissues body must be used because it will affect the antenna efficiency. The properties of the human body model are summarized in Table 3.1.

All the described layers have different dielectric loss having to their difference in thicknesses and electrical properties. Skin is a planar external organ that protects the organism from the environment around it. The skin thickness ranges from 0.4mm to 4mm. Next, fat is an energy and heat insulator reservoir, and everyone has a unique thickness layer anatomy. The muscles are elastic tissues that can relax and contract. The muscle layer has different thicknesses, depending on the type of muscle and body location (Vladimír, 2012). As the thickness of the skin, fat, and muscle need in this study are smaller. So, the application of the antenna is targeted to be applied on the hand wrist which usually has thinner layers as these three tissues.

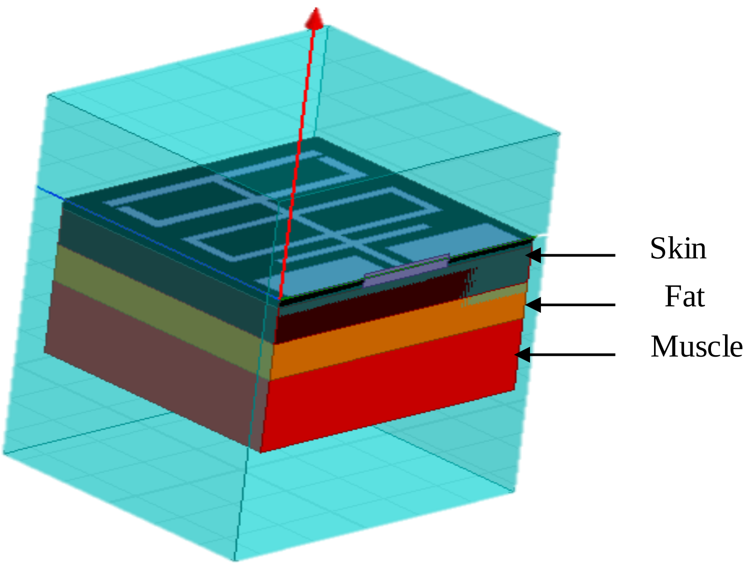

Figure 3.1 : Designed Antenna Attached With Skin, Fat and Muscle

Table 3.1: Electrical Properties and Thickness for Human Skin, Fat and Muscle

Tissues	**Thickness (mm)**	**Relative Permittivity ($\in_r$)**	**Electrical Conductivity (σ)**
Skin	4	38	1.46
Fat	4	5.28	0.10
Muscle	8	52.7	1.73

3.3 Antenna Design

The adhesive antenna is printed on an RT/duroid 5880 substrate with thickness Hs=1mm. The dielectric constant of RT/duroid 5880 is, $\varepsilon_r = 2.2$. The antenna has a size of 24mm × 24mm × 1mm of. As shown In Figure 3.1, the antenna is attached on the skin, fat and muscle layers of human skin model during design stage. The design is simulated with the High Frequency Structure Simulator (HFSS) to obtain the reflection losses. The growth of the designed adhesive antenna and the comparable reflection coefficient are shown in figures below. The resonant frequencies of designed planar monopole adhesive antenna are set within the ISM, WBAN and WLAN bands.

In the initial design, a single strip which resonates at a single band is designed. As shown in Figure 3.3, the initial antenna resonates at 4 GHz and has -11.0057 dB of reflection coefficient. Since, the first band needs to be resonated at the ISM band, a rectangular-shaped strip was added into the original design as shown in Figure 3.4. By varying the size of the rectangular strip, the inductances in the antenna can be adjusted. By selecting the appropriate size, the resonant frequency is subsequently shifted to a lower frequency. As can be observed from Figure 3.5, the resonant frequency falls approximately near the ISM band. In order to generate the second resonant band, a second rectangular strip was appended to the first one, as shown in Figure 3.6. As can be seen in Figure 3.7, two resonant bands are generated. It is to be noted however that the gap between both bands are relatively far apart. To reduce the gap (so that the bands fall into the ISM and WLAN range), a horizontal strip was added in the bottom of the design. Finally, the third band was generated by disrupting the inductance loop at the upper rectangular strip. This was achieved by leaving a pair of narrow gaps at the edge of the upper rectangular strip. The final antenna design and its simulated reflection coefficient are shown in Figures 3.10 and 3.11, respectively.

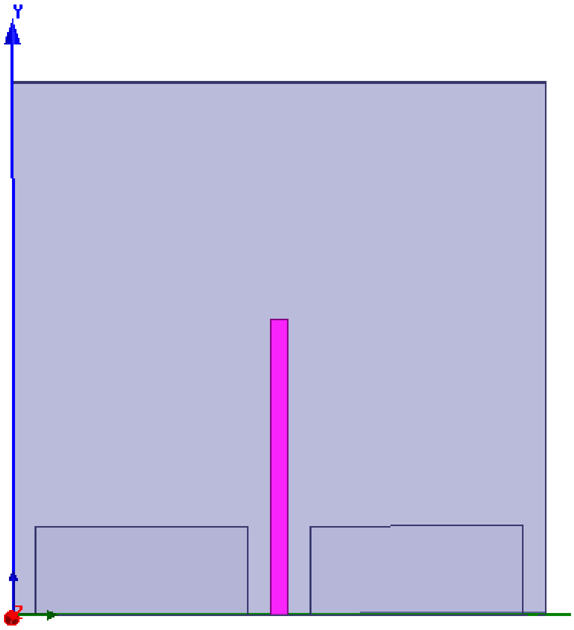

Figure 3.2 : Adhesive Antenna Design with Strip Line

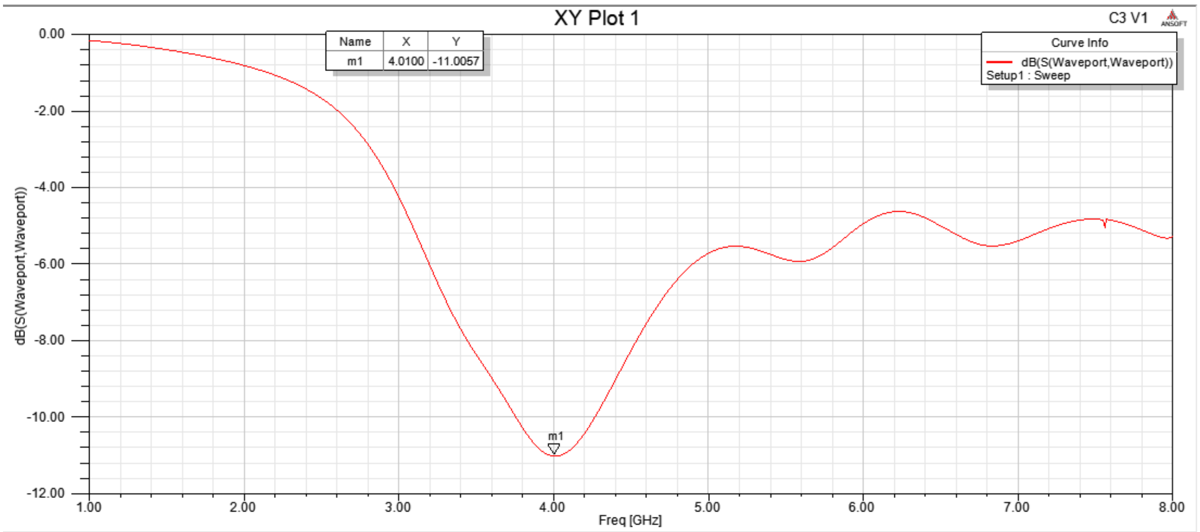

Figure 3.3 : Reflection Loss For Strip Line

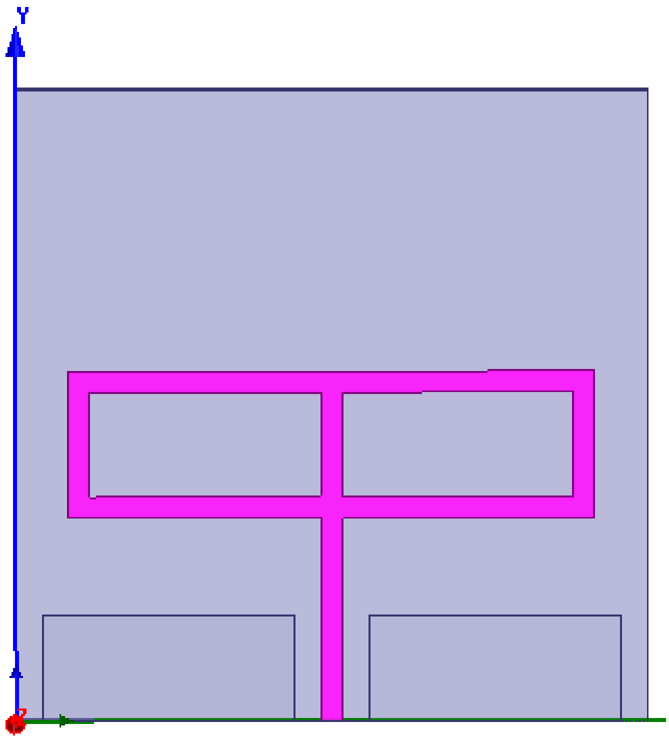

Figure 3.4: Creation of Rectangle Geometry in the Design

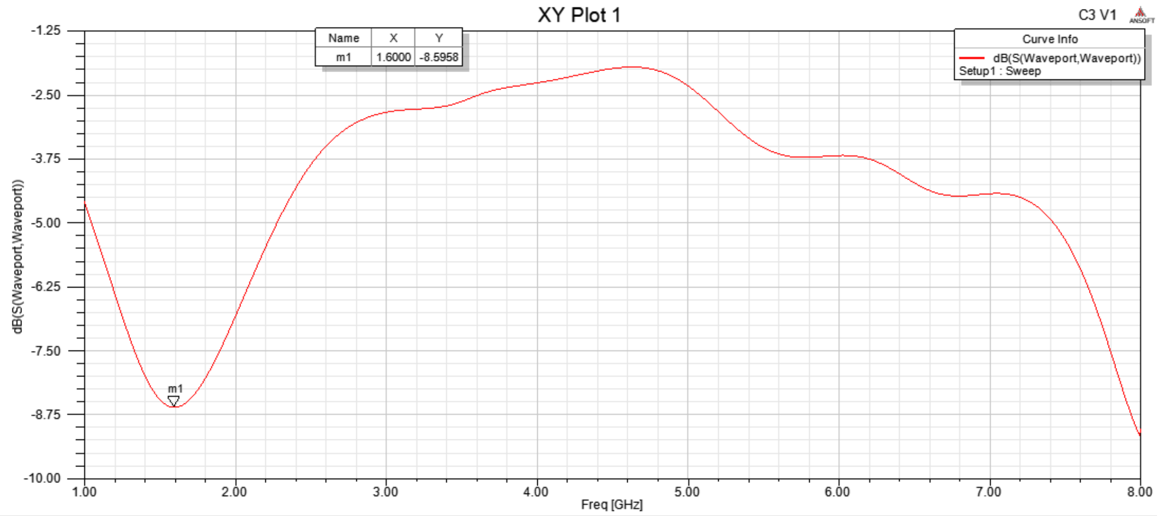

Figure 3.5 : Reflection Coefficient of the added Rectangular Geometry

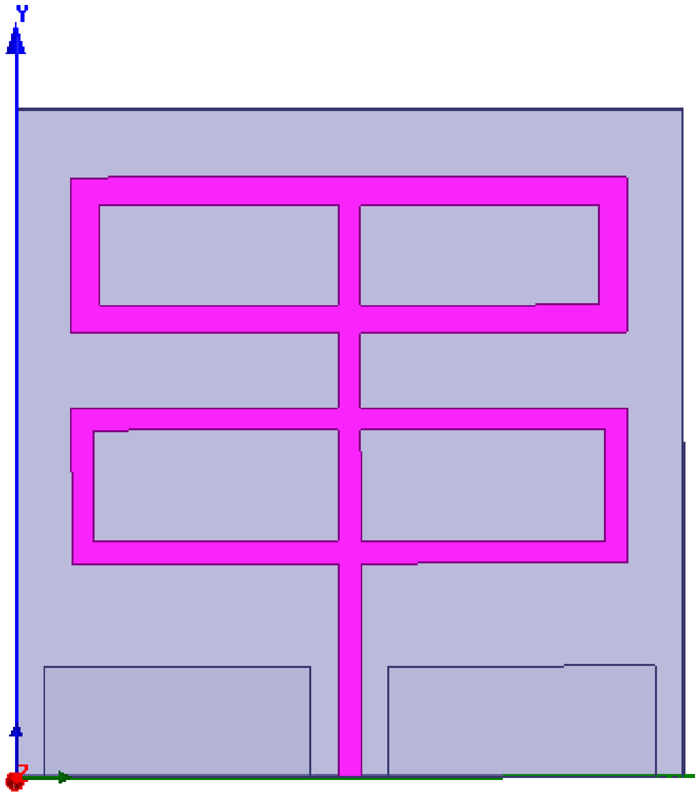

Figure 3.6 : Additional Creation of Rectangle Geometry in the Design

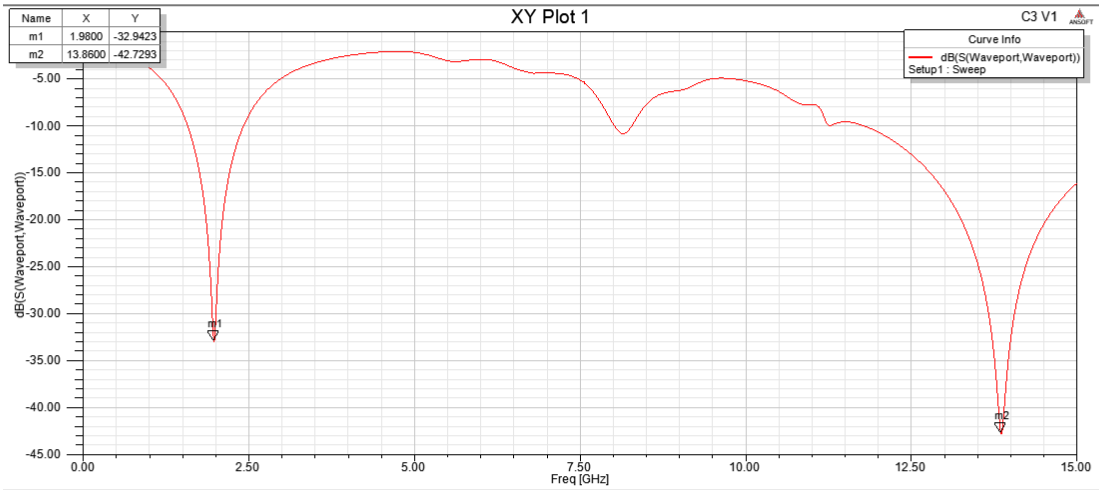

Figure 3.7 : Reflection Coefficient of Additional Creation of Rectangle Geometry in the Design

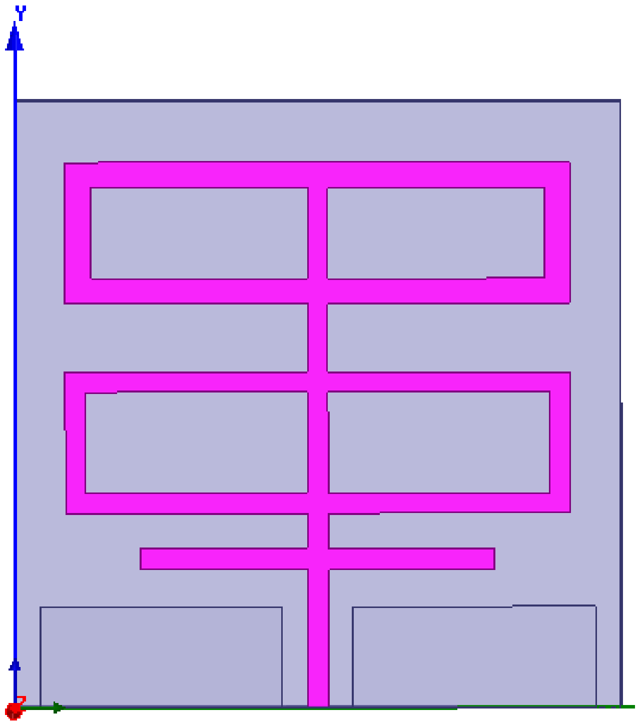

Figure 3.8 : Designed of ISM and WLAN Bands

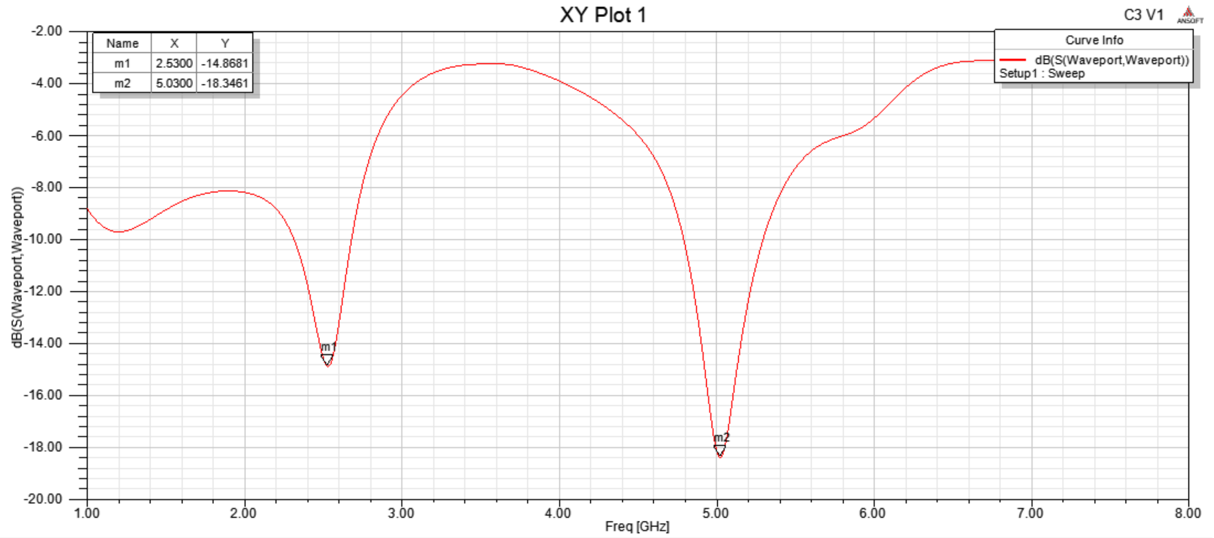

Figure 3.9 : Reflection Coefficient for ISM and WLAN Bands

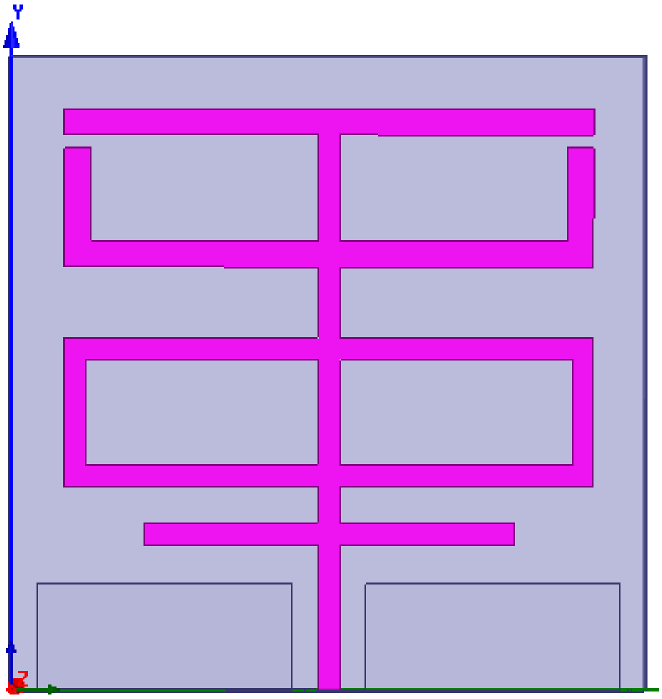

Figure 3.10 : Completed Design of Planar Monopole Adhesive Antenna

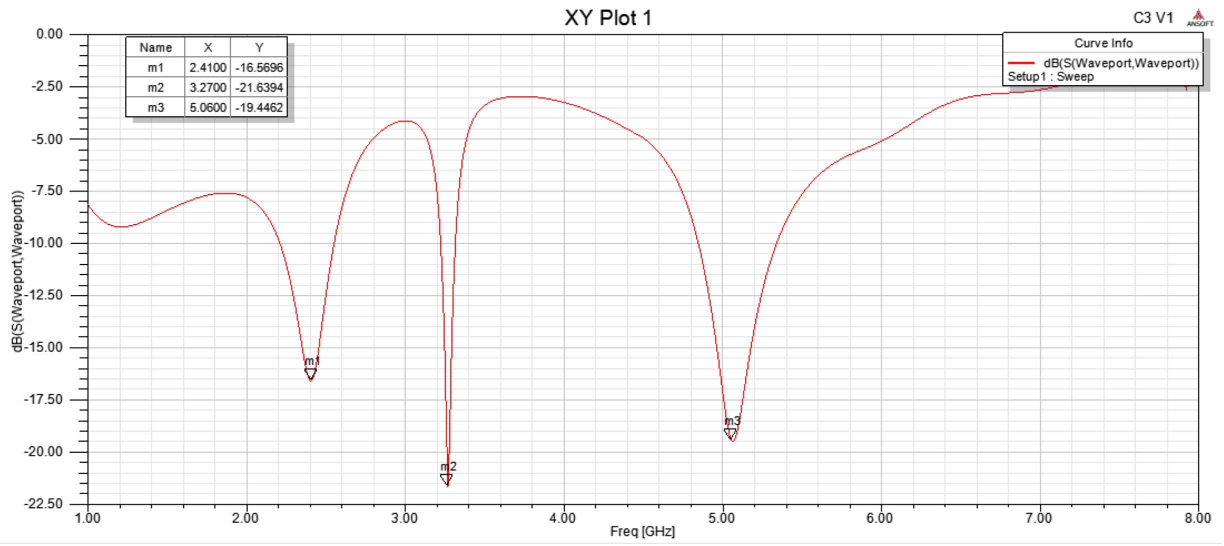

Figure 3.11: Reflection Coefficient for Completed Design of Planar Monopole Adhesive Antenna with ISM, WBAN and WLAN Bands

3.4 Radiation Pattern

In HFSS, the simulation also can generate the radiation pattern report. Firstly, right-click “Radiation” and select “Insert Far Field Setup” and then click “Infinite sphere” to have the setup as shown in Figure 3.12. Next, change the value of Phi and Theta in the Far Field Radiation Sphere Setup to get the E and H-plane result. Therefore, change the values of phi as Start from 0 degree, Stop at 90 degree, and step size will be 90 degree as well. For theta, Start will be at 0 degree, Stop at 360 degree, and step size at 10 degree. After that, to get the radiation pattern, right click “Result” and select “Create Far Field Report” and then choose “Radiation Pattern”. Then create new report for the radiation pattern and change the parameters as Figure 3.15. Set each frequencies of ISM, WBAN, and WLAN bands at the “families” setup for the radiation patterns.

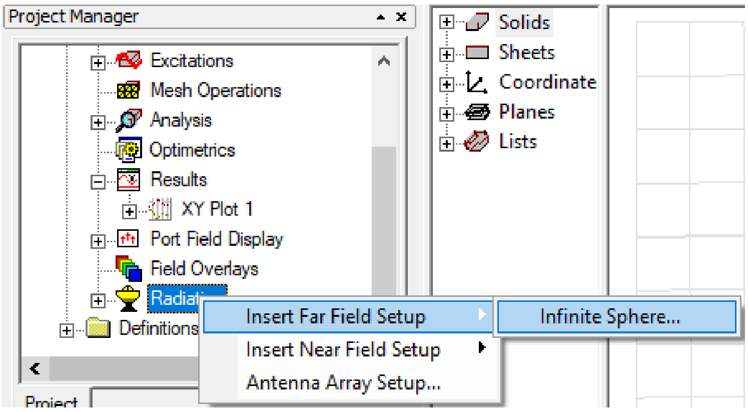

Figure 3.12: Selecting Far Field Setup

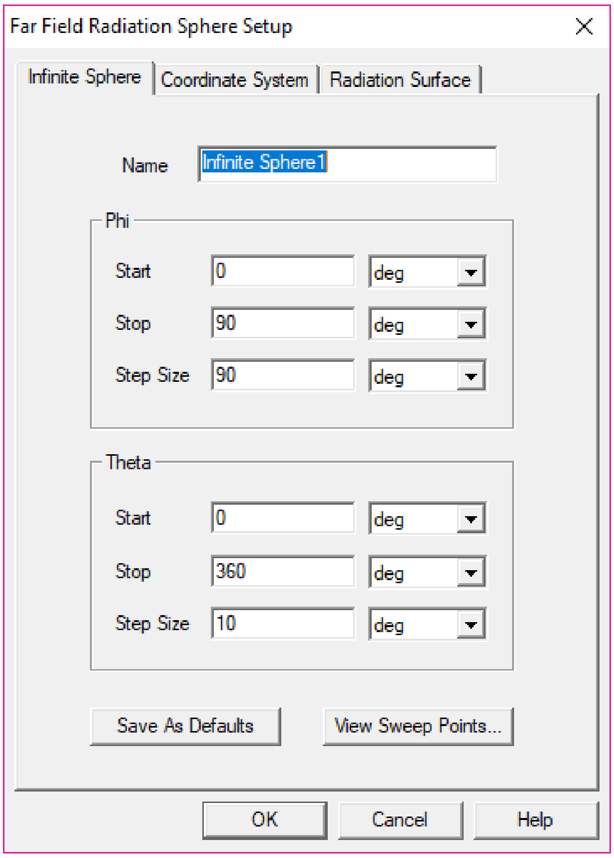

Figure 3.13: Setting for E and H – plane parameters

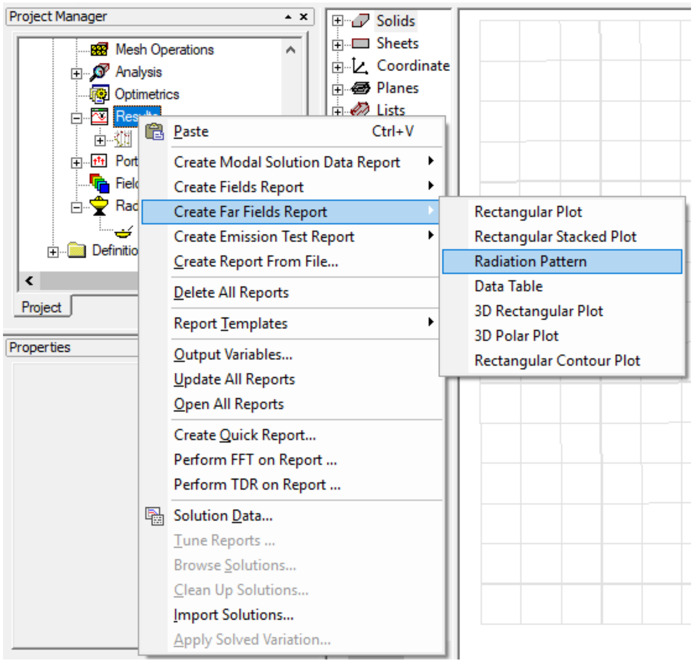

Figure 3.14: Generate Radiation Pattern

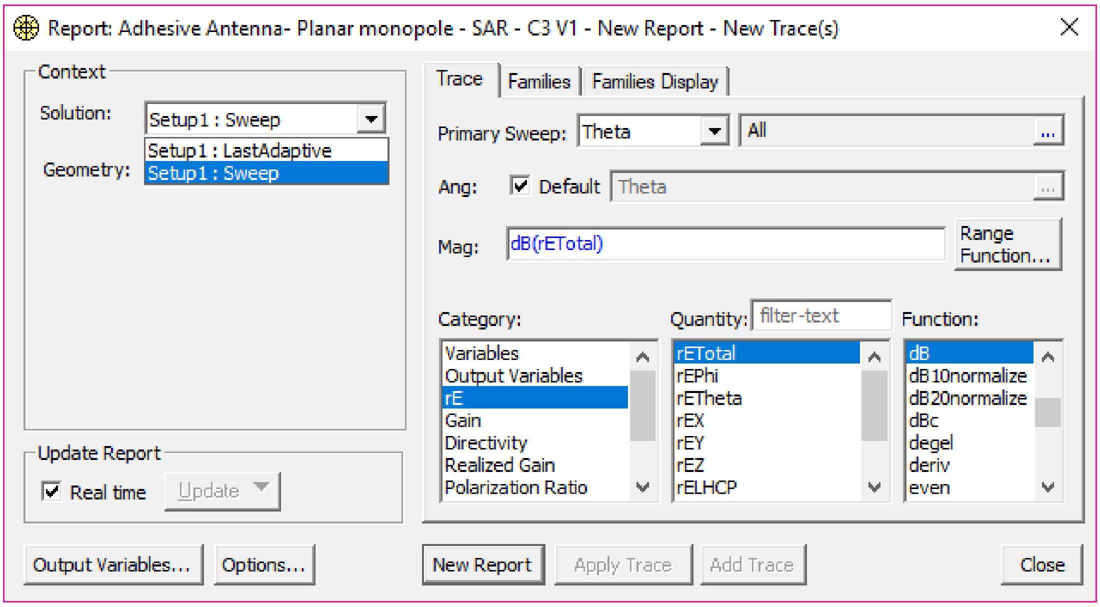

Figure 3.15: Create New Report for Radiation Pattern

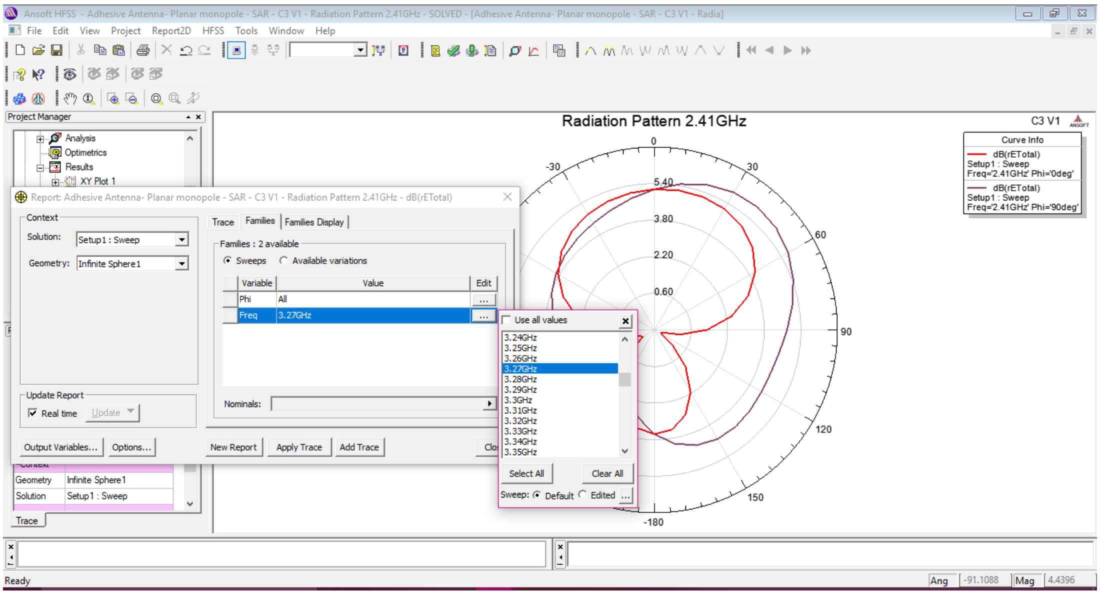

Figure 3.16: Selecting Each Frequency for ISM, WBAN and WLAN Frequencies at Families Setup

3.5 Current Distribution

To obtain the current distribution, right-click on the patch and choose “plot field”, “J”, and select “Mag_Jsuf”. Then, change the solution to Setup1: Sweep in order to select the frequency from the “Intrinsic Variables”. Change the frequency to the

2.41GHz for ISM band, 3.27GHz for WBAN, and 5.06GHz for WLAN at "Intrinsic Variables" to get the current distribution for each frequency. All the steps are shown in figures below.

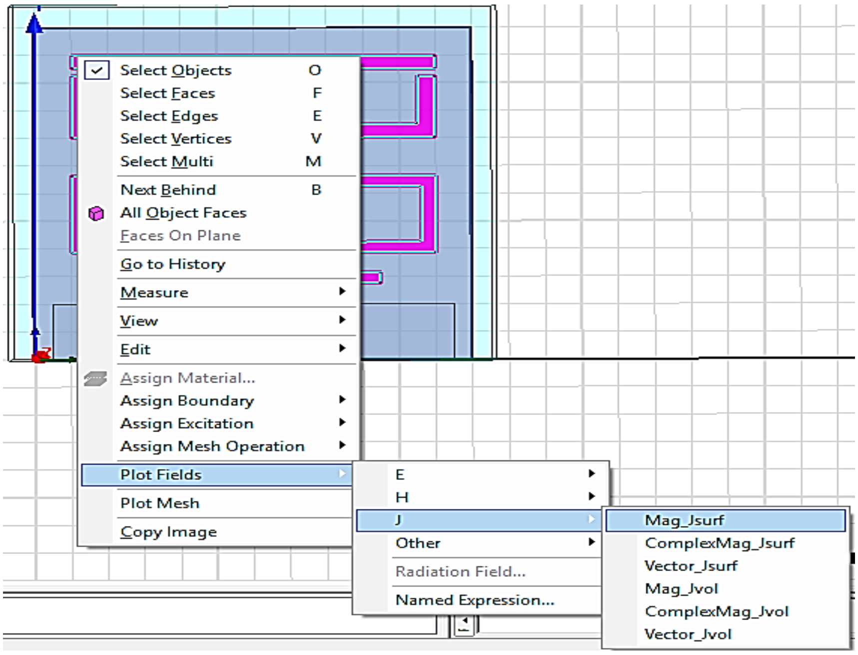

Figure 3.17: Plotting Mag_Jsurf (current distribution)

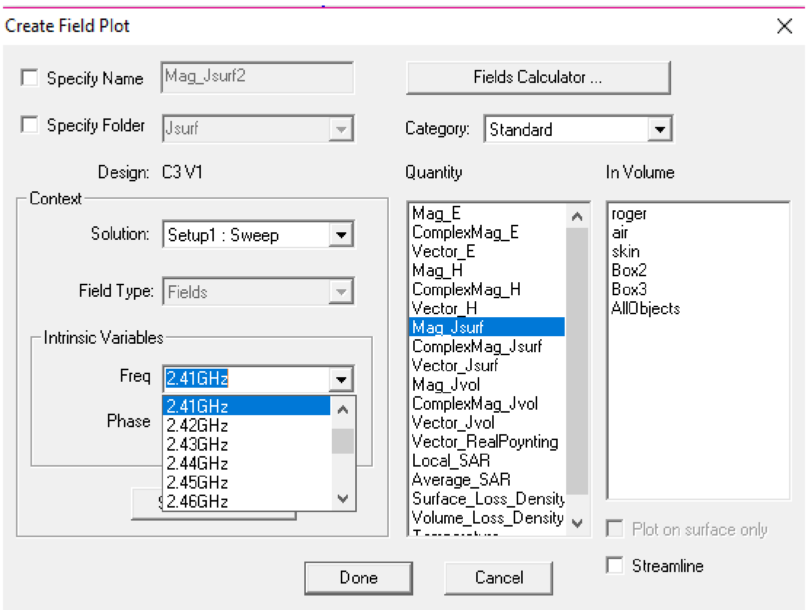

Figure 3.18: Setting Frequency for each ISM, WBAN and WLAN

3.6 Average SAR

In order to view the average SAR, right-click at the antenna designed and select “Plot Field”, “Other” and then “Average SAR”. Then, select “Analysis” and right-click at “Setup 1” to change the solution frequencies for each ISM band, WBAN and WLAN. Next, from the create field plot window, select the required frequencies for the antenna which are 2.41GHz, 3.27GHz and 5.06 GHz at the Intrinsic Variables. After the SAR result was display at designed antenna, the scales of SAR can be adjusted at the SAR field by right clicked and select “Modify”. The SAR report then can be modified to set minimum and maximum value of SAR. The SAR report can be observed in Chapter 4.

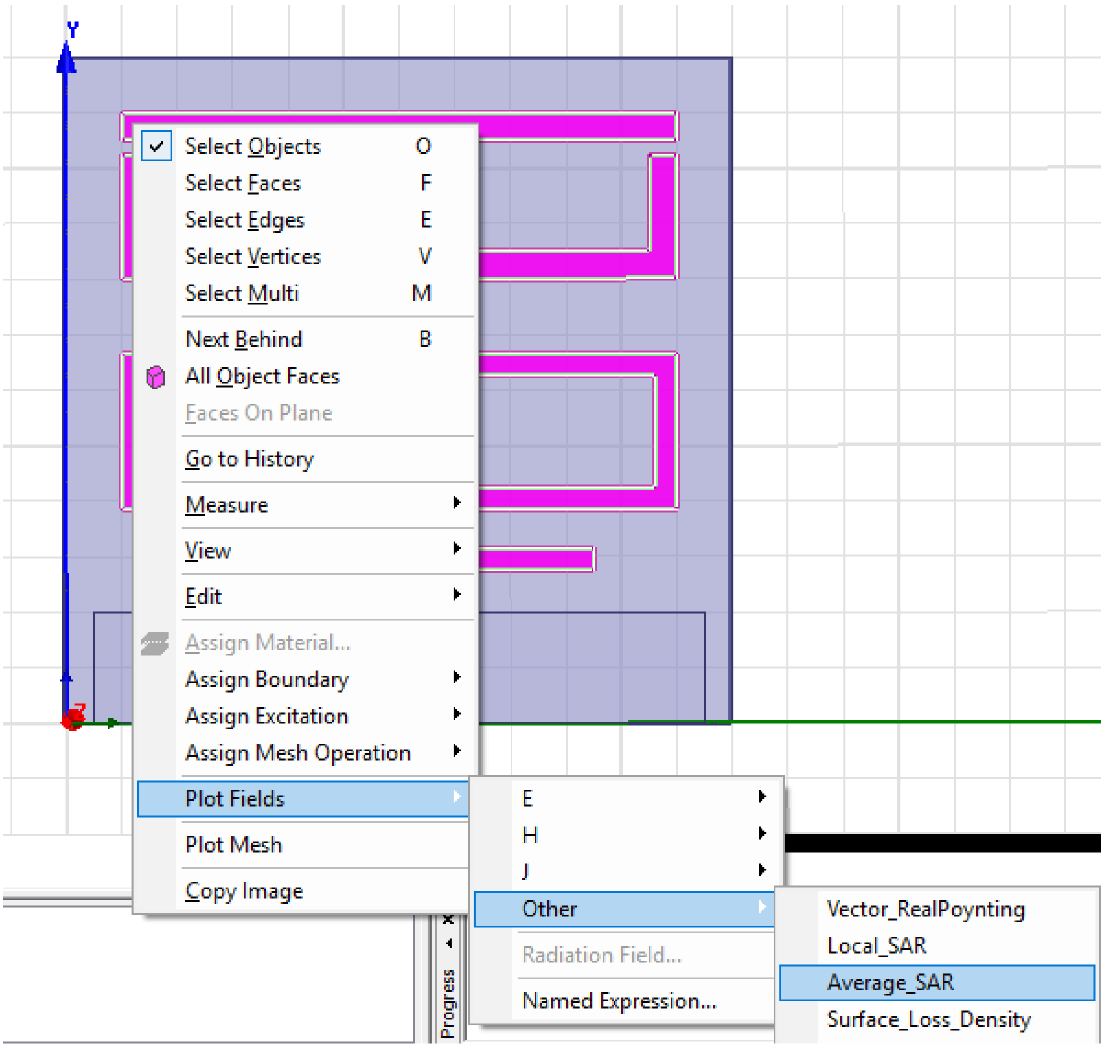

Figure 3.19: Plotting Average SAR

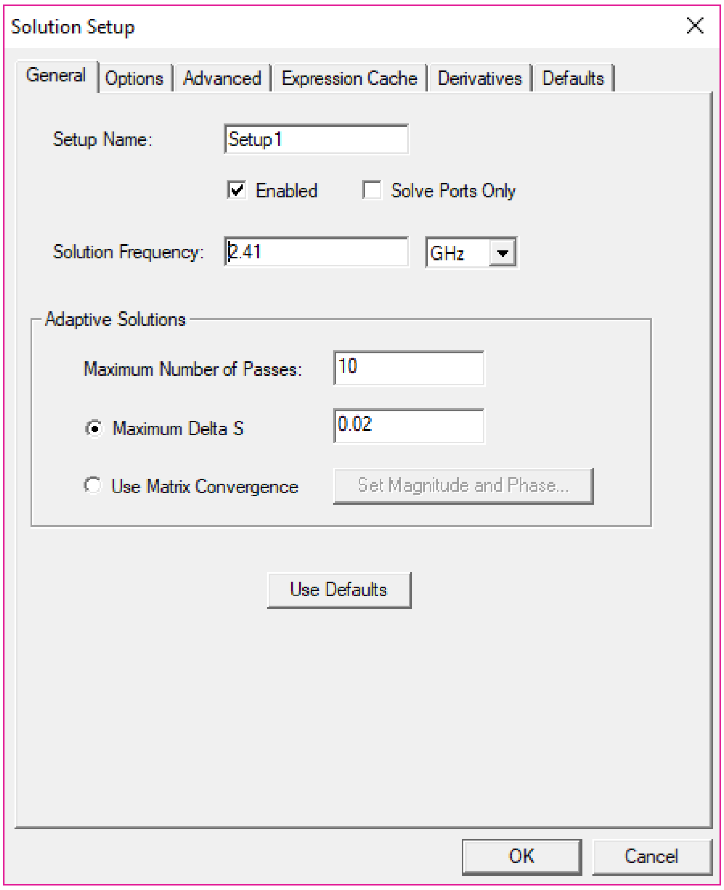

Figure 3.20: Change the Solution Frequncy for Each Resonance Frequencies

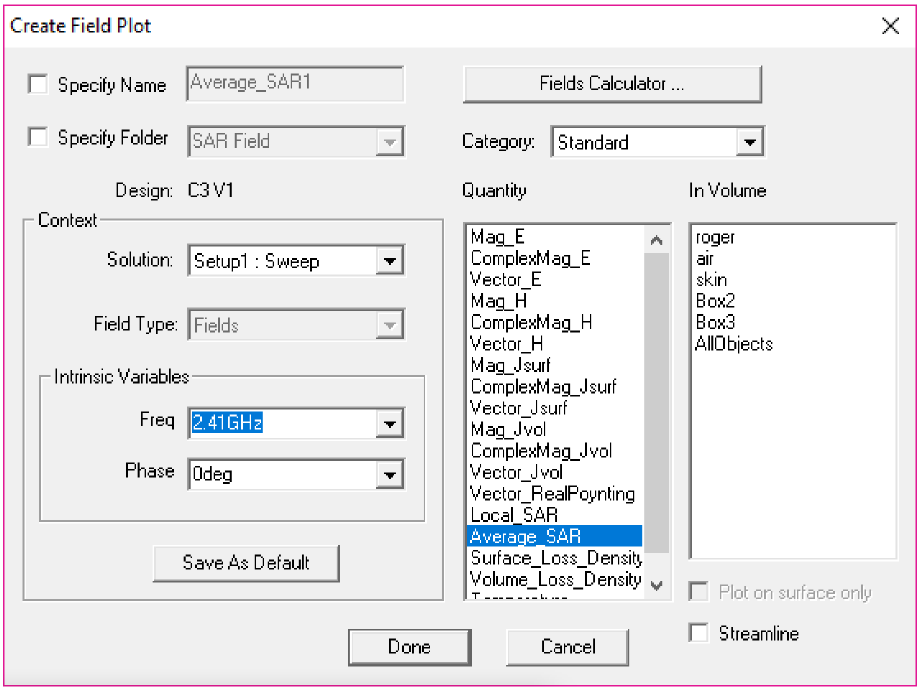

Figure 3.21: Setting Parameters Average SAR Report for Rach Resonant Frequency

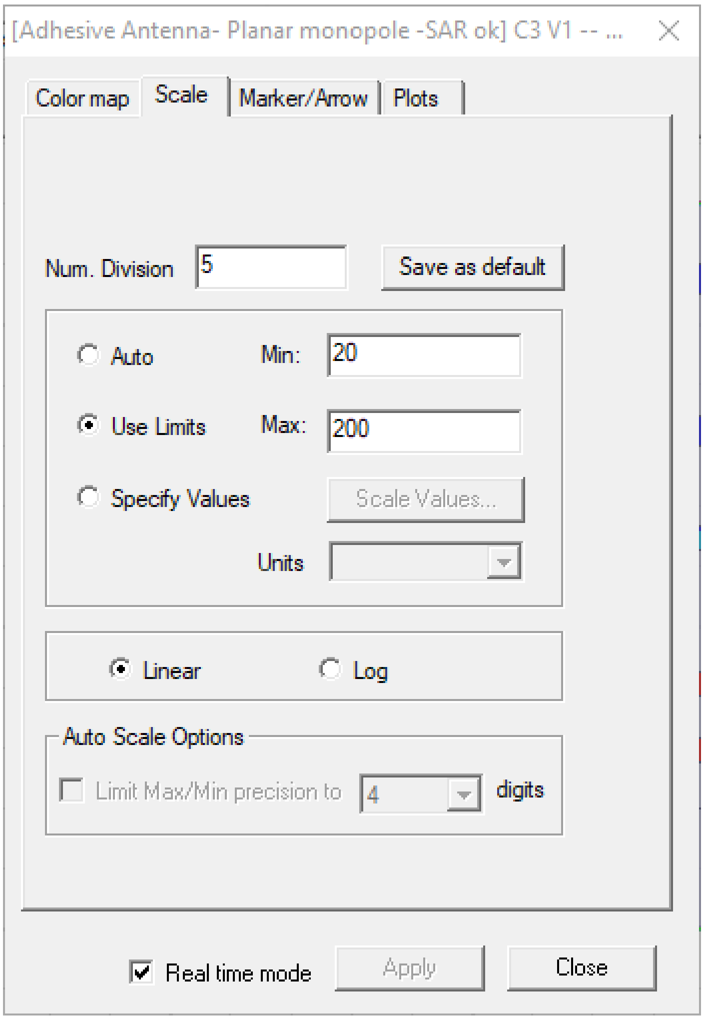

Figure 3.22: Setting Maximum and Minimum Range of SAR

3.7 Gain

The report of the gain also can be obtained in the HFSS. Firstly, right-click at the "result" in the Project Manager. Then, choose "Create Far Fields Report" and "Rectangular Plot" to generate a new report for the gain. After that, change the "Primary Sweep" of "Theta" to "Frequency" to obtain the gain report in frequency as Figure 3.23. Figure 3.24 shows the parameters for Phi and Theta in the families setting in order to choose a specific value.

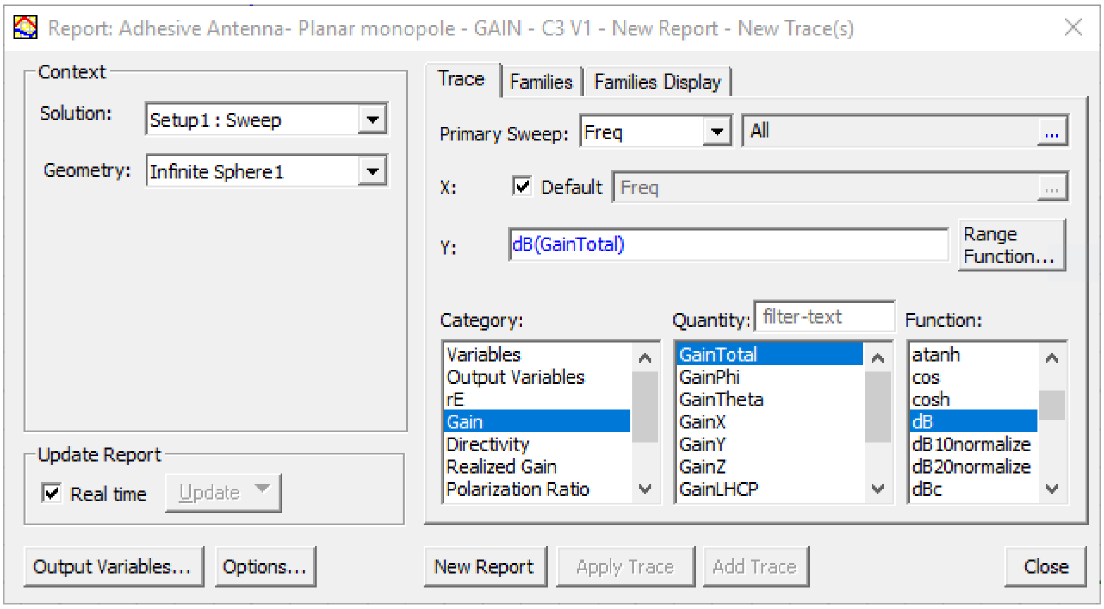

Figure 3.23: Create New Report for Gain

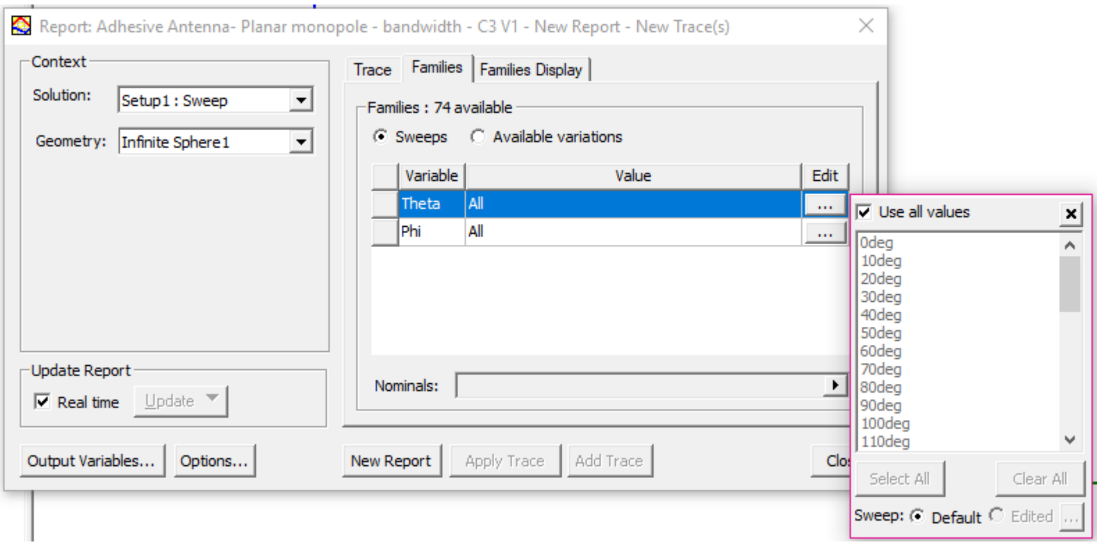

Figure 3.24: Changing Parameters of Phi and Theta at the Families Setting

3.8 Antenna Fabrication

After the design is confirmed and verified in HFSS, the antenna can then be fabricated for further measurement. The design in HFSS needs to be exported and save as Parasolid text file format (.X_T). After that, open the Parasolid text file format saved earlier by using SolidWorks 2013.

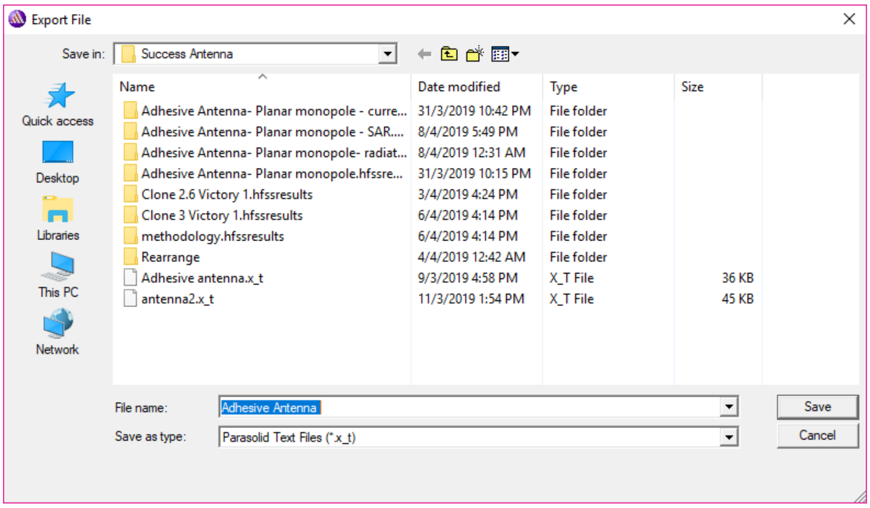

Figure 3.25: Export File and Save As Parasolid Text Files (.X_T) Format

3.8.1 Procedures in SolidWorks 2013 software

1. The designed antenna will be shown in 3D solid structure as depicted in Figure 3.26.
2. Change the designed antenna into transparent form and viewpoint face to the patch of design as depicted in Figure 3.27.
3. Save it into DWG file format and click all the edges of the lines of the designed for the DWG output at faces/loops/edges as depicted in Figure 3.30.
4. Figure 3.31 shows the designed lines have been clicked and finally pressed save.

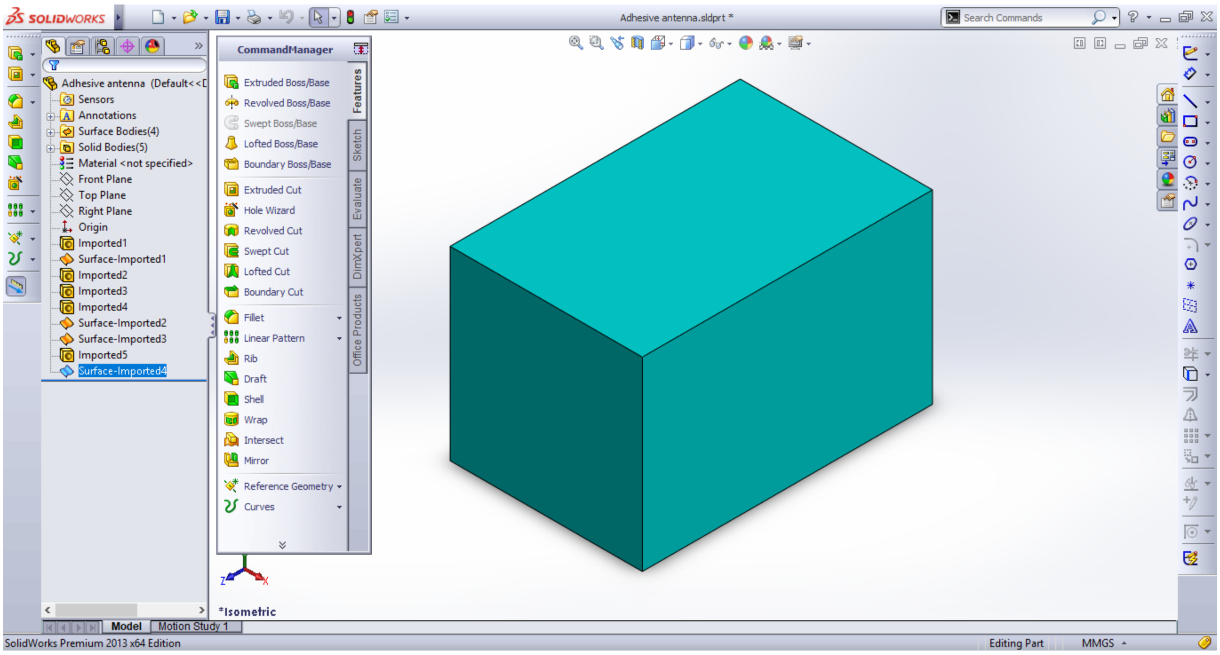

Figure3.26: Three Dimension of Solid Structure in SolidWorks 2013

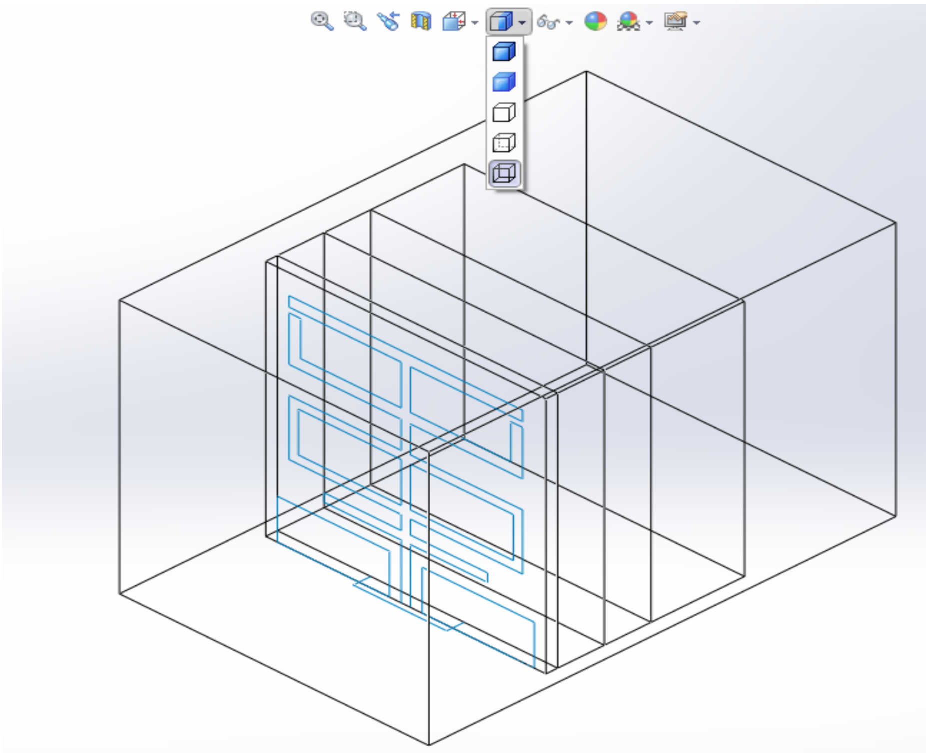

Figure 3.27: Change the Display View to Transparent Type

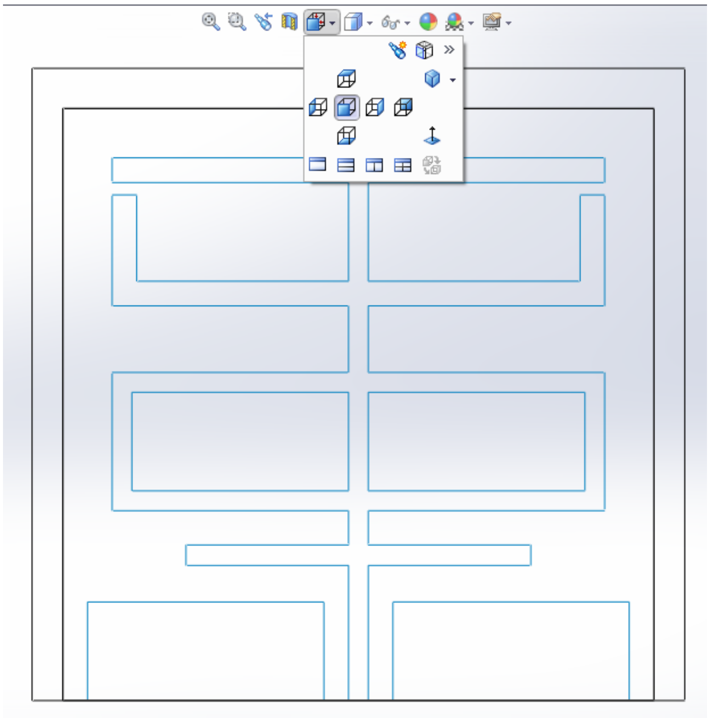

Figure 3.28: Change the View Point to Designed Surface

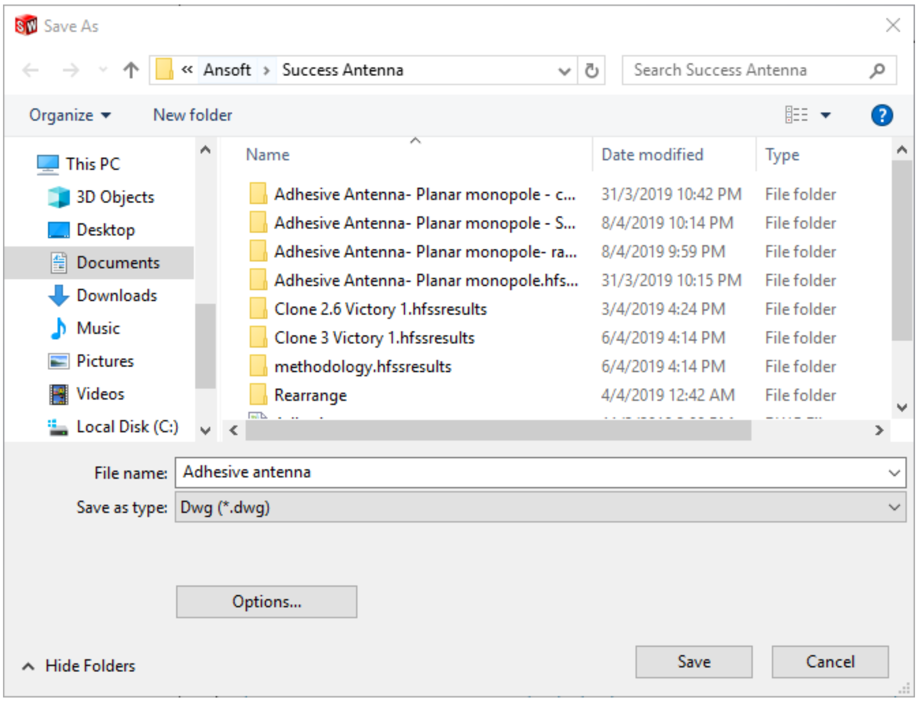

Figure 3.29: Saving the File as DWG File Type

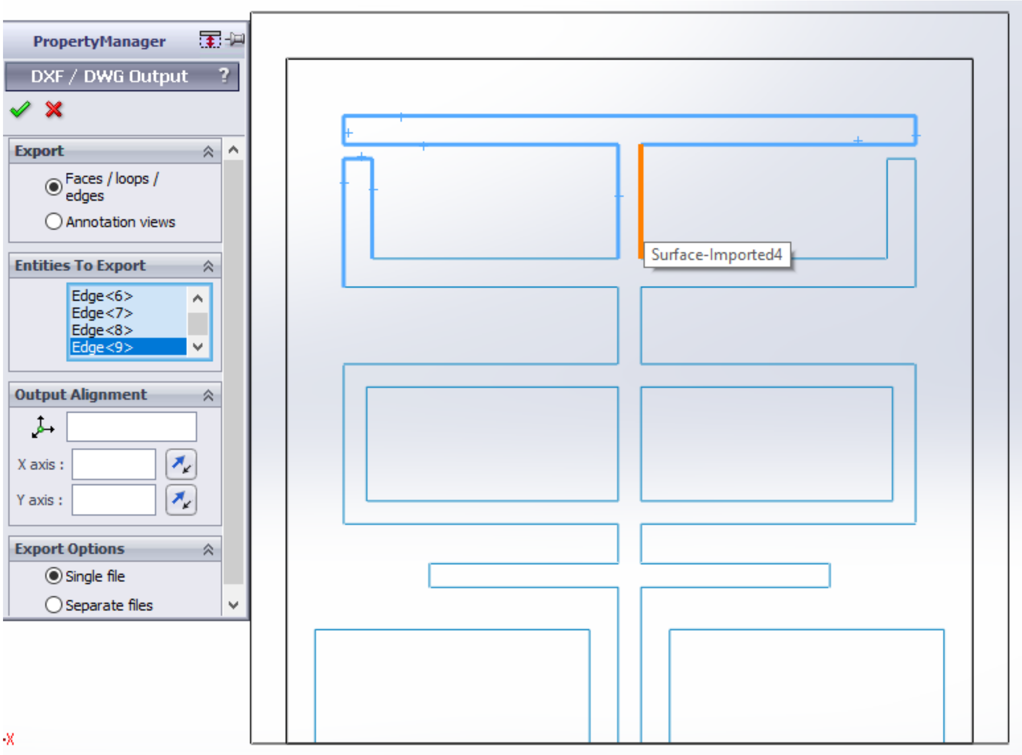

Figure 3.30: Select the edges of designed for DWG outputs

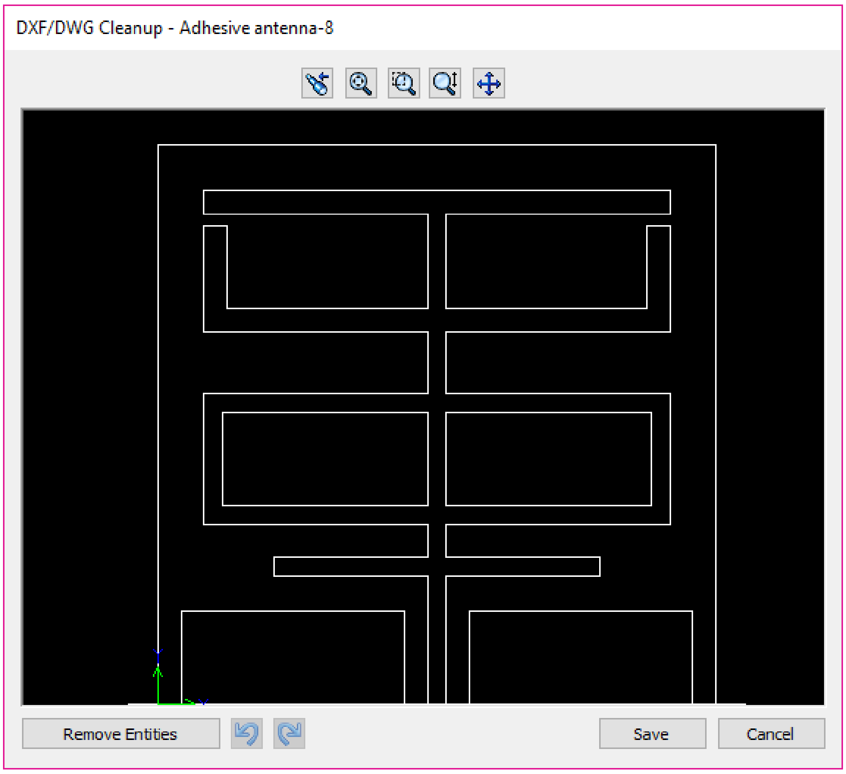

Figure 3.31: Save the selected work to DWG format

3.8.2 Procedures in DraftSight 2018 software

1. Open the DWG file save in SolidWorks software earlier.
2. Select "Hatch/Fill" function to hatch the copper layer of the antenna as Figure 3.32.
3. In "Hatch/Fill" window, change the pattern of ANSI31 into SOLID pattern and clicked "Specific point" at the boundary setting as Figure 3.33.
4. Select the area that the non-copper layer needs to be as Figure 3.34. The white colour is indicated as non-copper layer and black colour is indicated as copper layer.
5. Turn off CCS (X-Y axis) icon to get full size of antenna for fabrication as Figure 3.35.
6. Crop the antenna designed and save the antenna into JPG format as Figure 3.36.

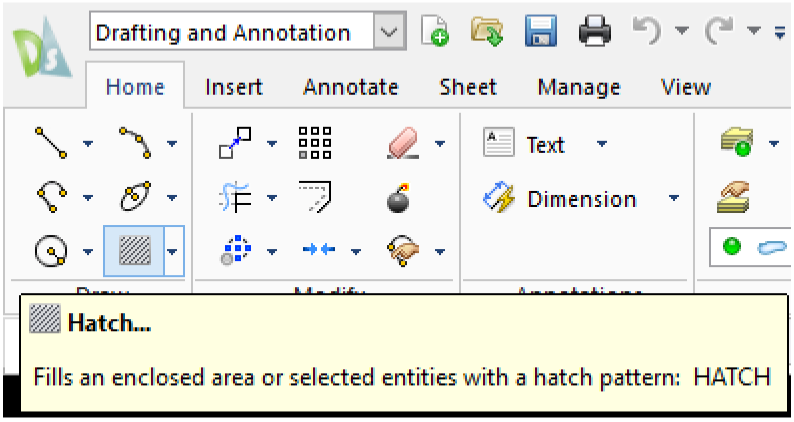

Figure 3.32: Selecting the Hatch file

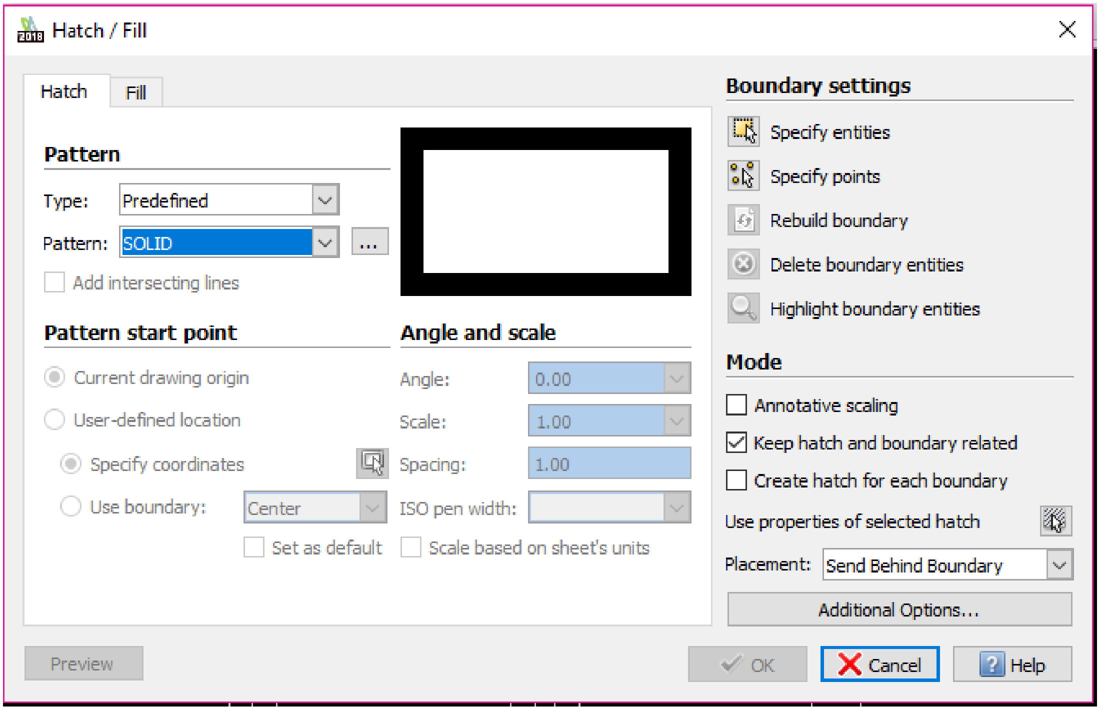

Figure 3.33: Selecting SOLID pattern and specify points

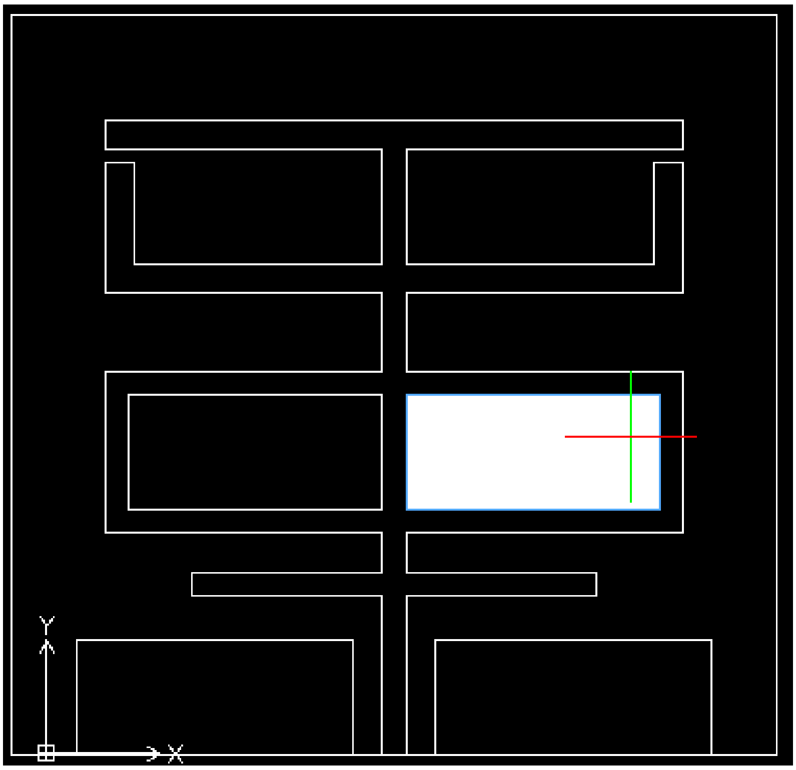

Figure 3.34: Selecting the non-copper layer areas

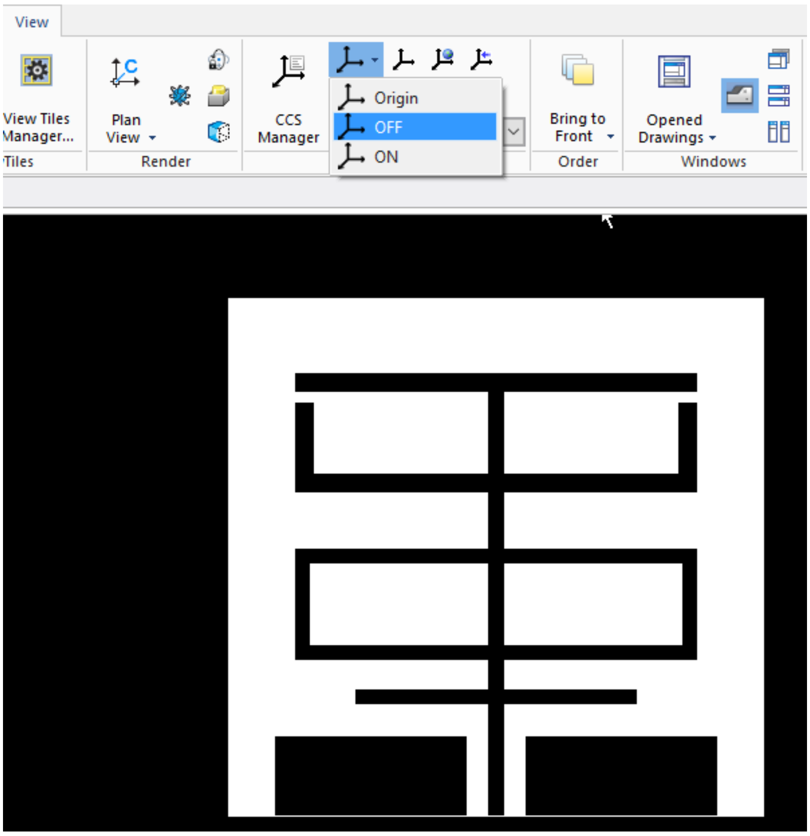

Figure 3.35: Turned off the CCS (X-Y axis)

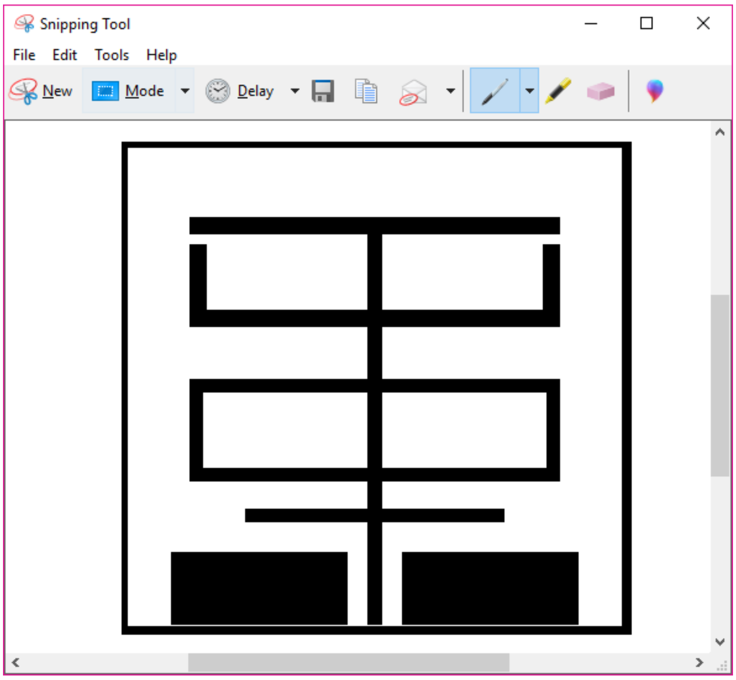

Figure 3.36: Cropped the designed and save into JPG format

3.8.3 Procedures in Microsoft Word

1. Change the size of the layout to A4 at the size setting.
2. Paste the JPG format save earlier into Microsoft word as Figure 3.38.
3. Change the size of the picture from mm to cm according to designed antenna's size.
4. Save the file into PDF format.
5. Print out and measure the size again for the confirmation before fabricating.

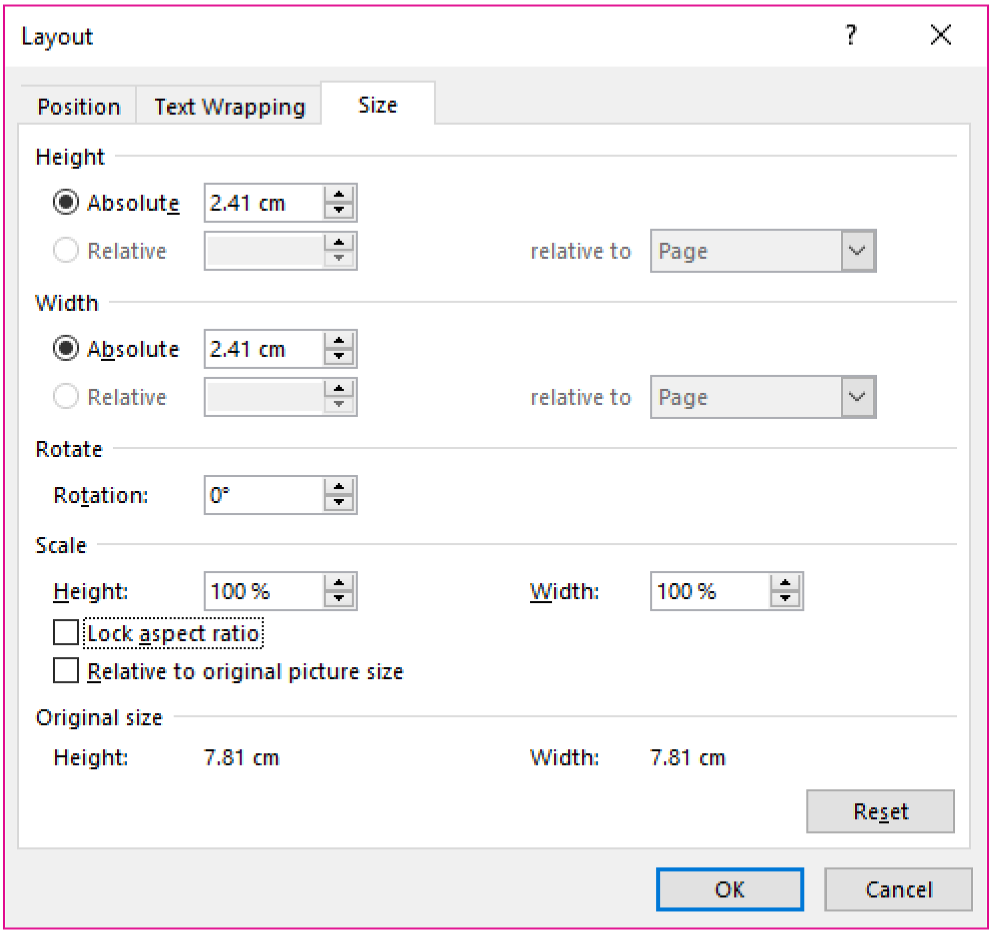

Figure 3.37: Change the absolute height and width based on the size of antenna

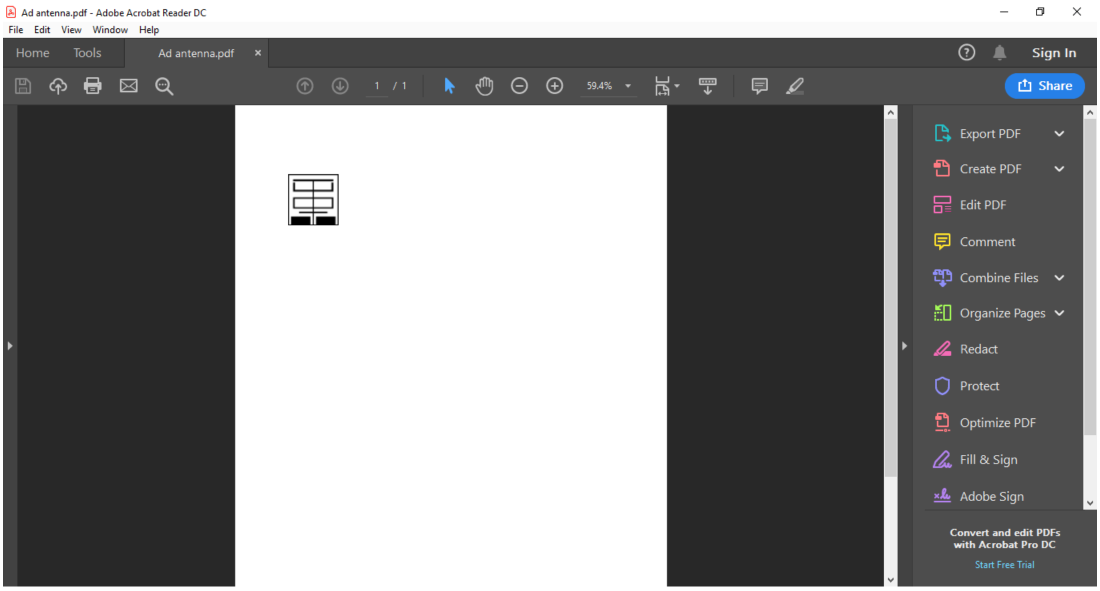

Figure 3.38: Save the antenna into PDF format and ready to be fabricated

3.9 Measuring Adhesive Antenna using Vector Network Analyzer

The adhesive antenna is measured using Vector Network Analyzer (VNA). The reflection coefficients S(11) are obtained from the VNA. In order to ensure the accuracy of the VNA, calibration has to be performed using a calibration kit before the reflection coefficient is measured. Two types of measurements have been taken. In the first type of measurement, the adhesive antenna was applied onto the human skin; In the second type, the antenna was measured when it is suspended in free space. The data were collected and exported in Microsoft Excel format.

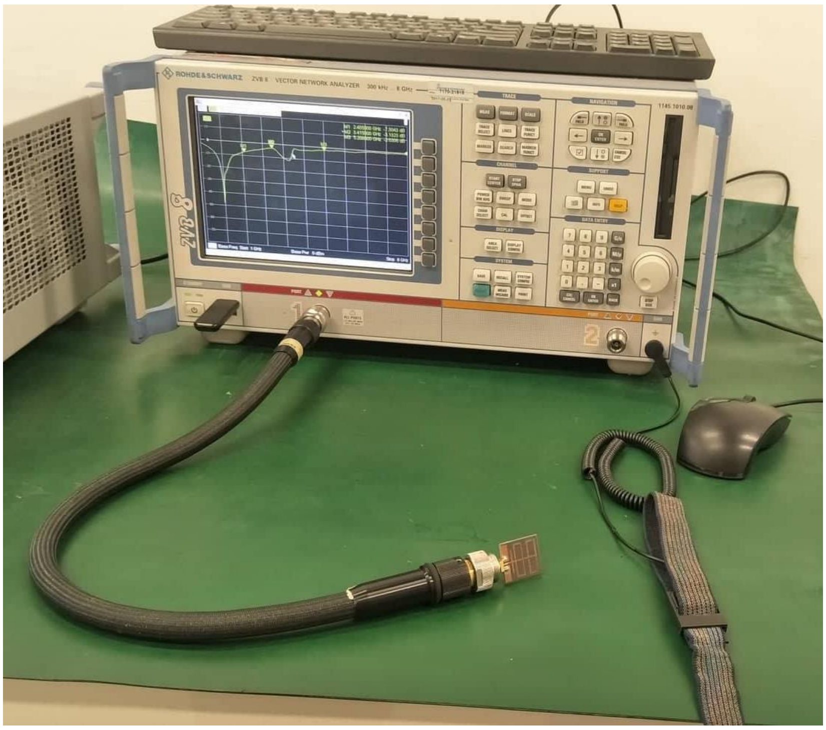

Figure 3.39: Vector Networ Analyzer

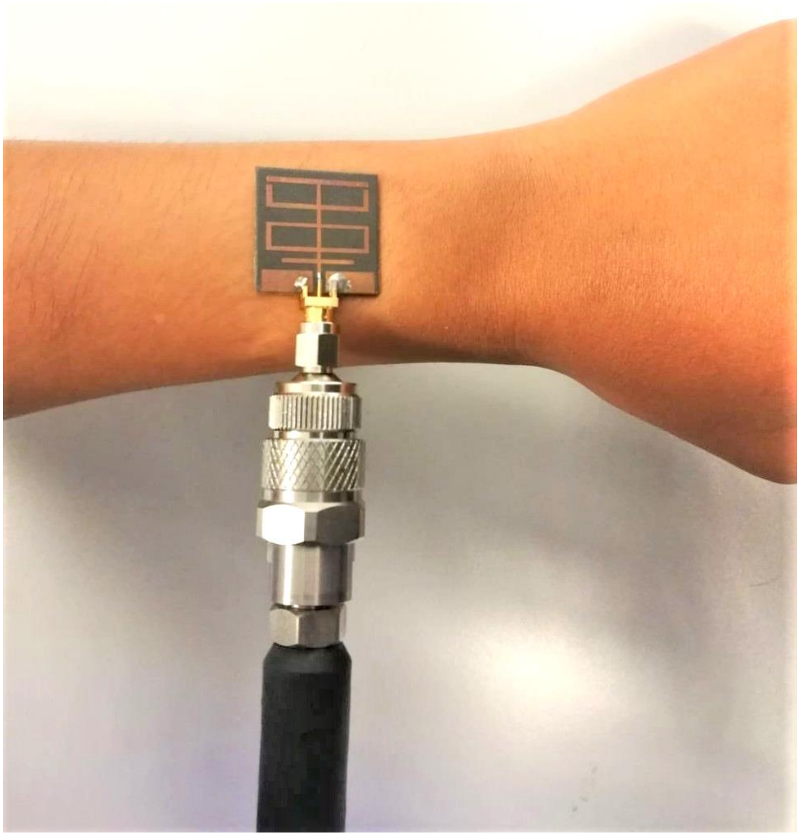

Figure 3.40: Measuring Adhesive Antenna on Skin using Vector Network Analyzer

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this project, a planar monopole adhesive antenna was designed using High Frequency Structure Simulator software (HFSS). This antenna was manufactured on a dielectric substrate called Rogers RT/ duroid 5880 with dielectric constant 2.2 and attached with SubMiniature version A (SMA) connector. Furthermore, the designed planar monopole adhesive antenna can operate at three frequencies bands which are ISM band (2.4 – 2.5GHz), WBAN (3.1-10.6 GHz) and WLAN (5.150 – 5.725 GHz). The detailed dimension and measurements of the designed adhesive antenna are shown in Figure 4.1 and Table 4.1.

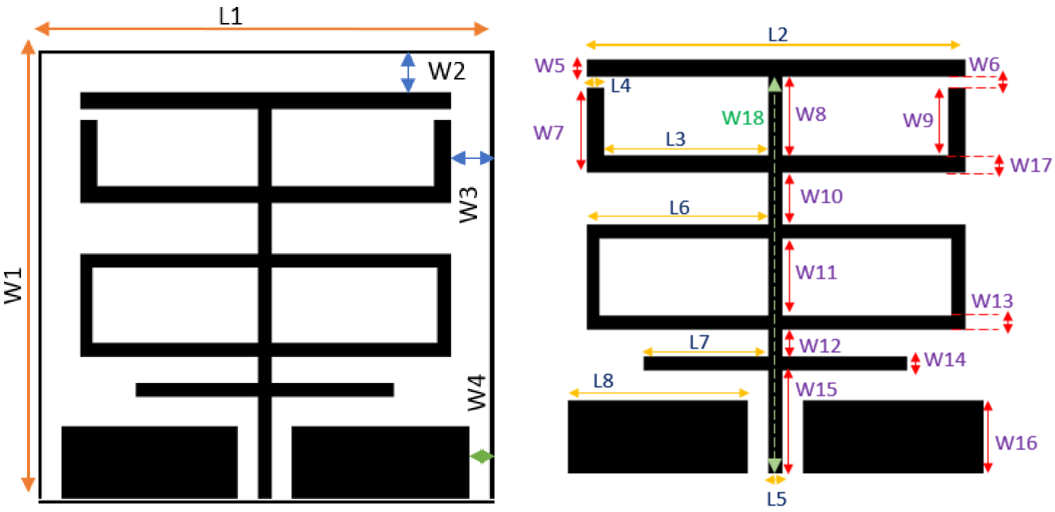

Figure 4.1: The size and dimension of designed adhesive antenna on RT/duroid 5880

Table 4.1 : Measurements of planar monopole adhesive antenna designed

Parameters	Values (mm)
L1	24
L2	20
L3	8.6
L4	1
L5	0.8
L6	9.6
L7	6.6
L8	9.6
W1	24
W2	2
W3	2
W4	1
W5	1
W6	0.5
W7	4.5
W8	4
W9	3.5
W10	2.7
W11	4
W12	1.389
W13	0.8
W14	0.833
W15	5.478
W16	4
W17	1
W18	21

4.2 Fabricated Antenna

The planar monopole adhesive antenna was fabricated on Rogers RT/duroid 5880 with 24mm × 24mm × 1mm size. The size of the antenna is as small as 20cent as shown in Figure 4.3 and was soldered with an SMA connector. The SMA connector is used to connect the coaxial cable connected to the Vector Network Analyzer (VNA).

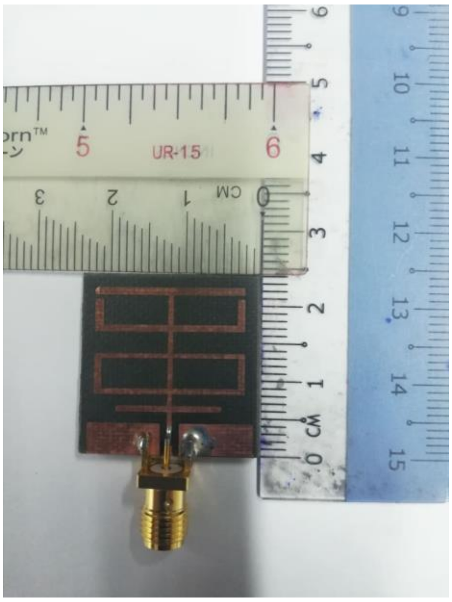

Figure 4.2: Fabricated Adhesive Antenna

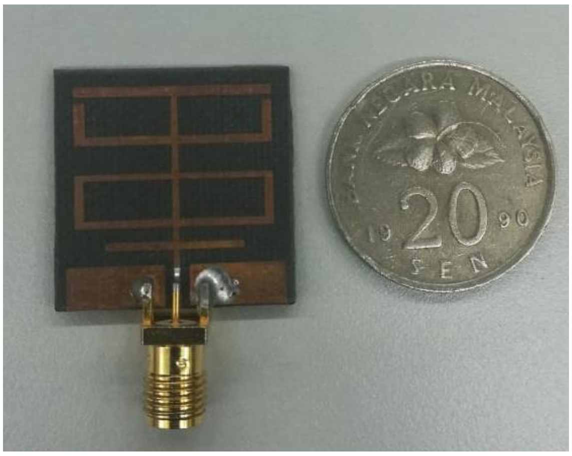

Figure 4.3: Comparison of Size between Fabricated Adhesive Antenna and 20cent

4.3 Reflection Coefficient (S11) Report

The simulation was run in the HFSS software after completed in designing the planar monopole adhesive antenna. From the simulation, a report of reflection coefficient (S11) for the antenna was obtained. Coefficient of reflection, S11 is the amount of power that the antenna reflects. The antenna reflects the power and when the S11 is 0 dB, nothing is radiated. Figure 4.4 shows the reflection coefficient obtained from the simulation result of the designed adhesive antenna.

From the Figure 4.4, it is observed that the first resonant frequency fall at 2.41 GHz with -16.5696 dB reflection coefficient. The reflection coefficient at second resonance frequency 3.27 GHz is -21.6394dB. Whereas the reflection coefficient of the third resonance frequency at 5.06 GHz is -19.4462dB. The antenna has a 10dB impedance bandwidth of 341.3 MHz from (2.2119 to 2.5532 GHz), 92.5 MHz from (3.2240 to 3.3165 GHz) and 492.5 MHz from (4.8464 to 5.3389 GHz). Figure 4.5 shows the comparison of reflection coefficient of the adhesive antenna obtained from both the experimental measurement and simulation result. Both results are reasonably close between each other. Both results show that the antenna resonates at the ISM, WBAN, and WLAN bands. The results convincingly show that the designed antenna is able to act as a gateway. It is able to collect signal radiated at the ISM band and transmit it to the base station via the WBAN or WLAN bands.

Figure 4.6 show the comparison of measured antenna on the hand and the leg. As observed from figure, the result is consistent for the experimental. Figure 4.7 shows the coefficient of reflection result of the antenna tested in the air. It is clear from the figure that the bands are significantly distorted. The result deviated for the three resonant bands designed for the antenna. It is worthwhile noting; the antenna resonates at 2GHz instead. It has 10dB impedance of 400 MHZ (1.8 to 2.2 GHz) while usually find applications in wireless communication such as Bluetooth and WiFi.

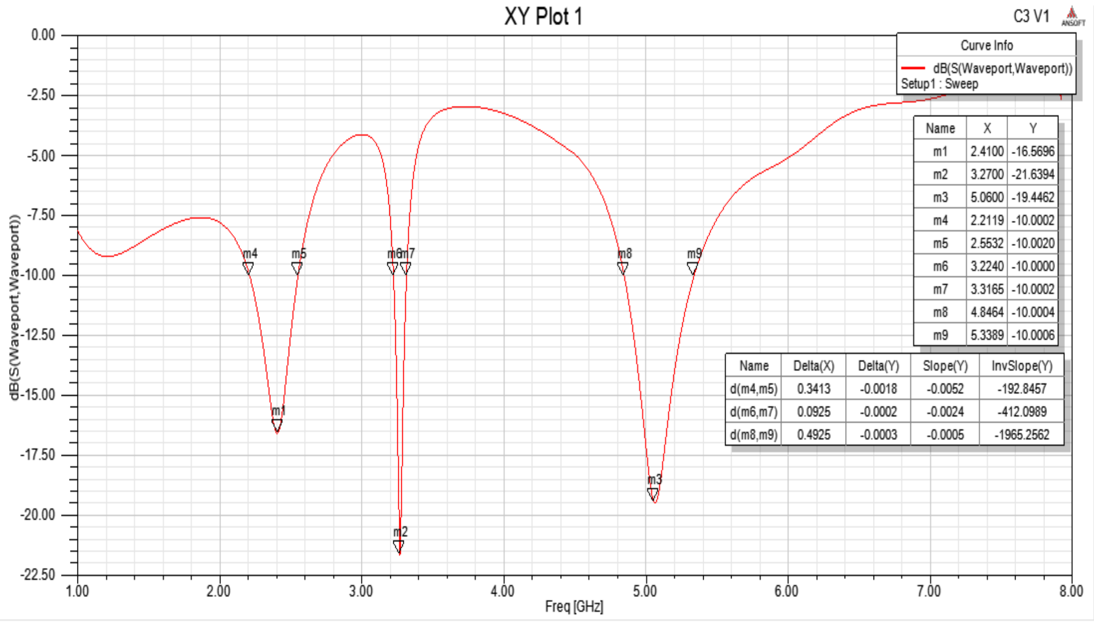

Figure 4.4: Reflection Coefficient of an Adhesive Antenna

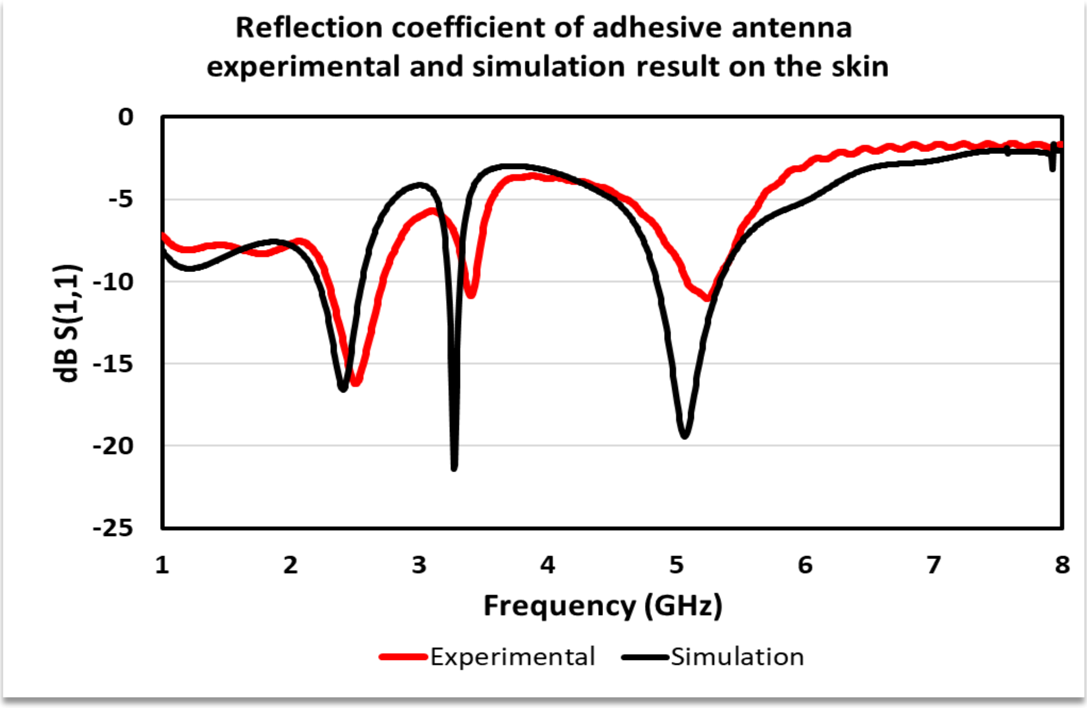

Figure 4.5: Reflection Coefficient of Adhesive Antenna in Experimental and Simulation Result on the Skin.

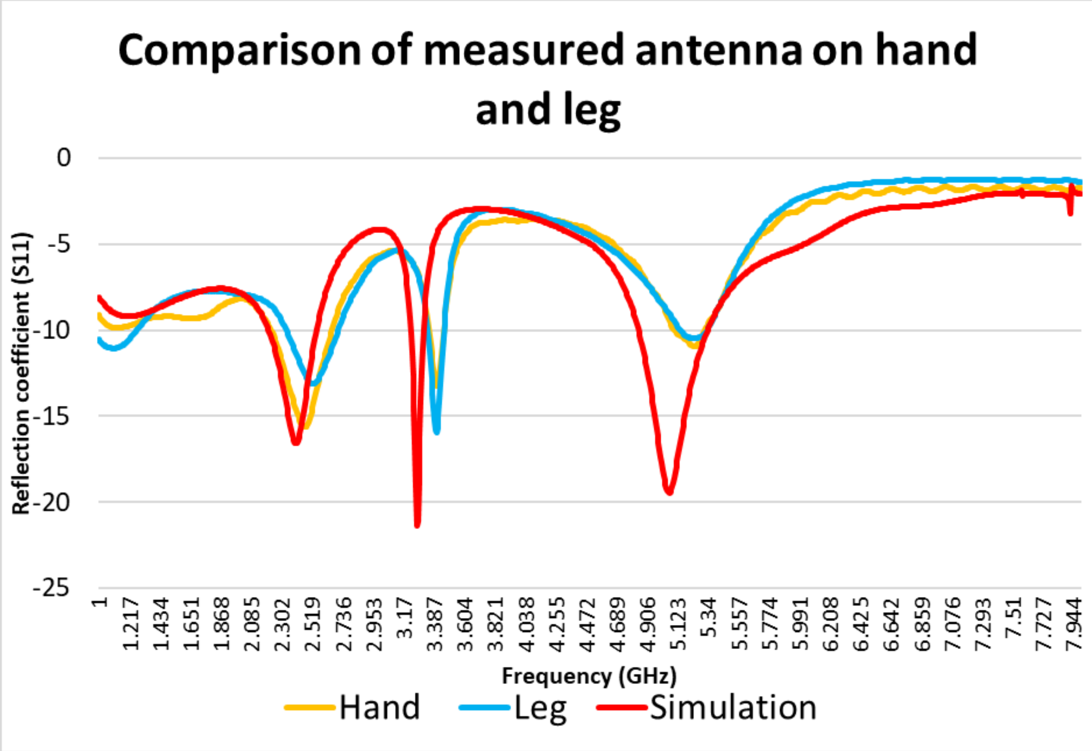

Figure 4.6: Comparison of Measured Antenna on Hand and Leg

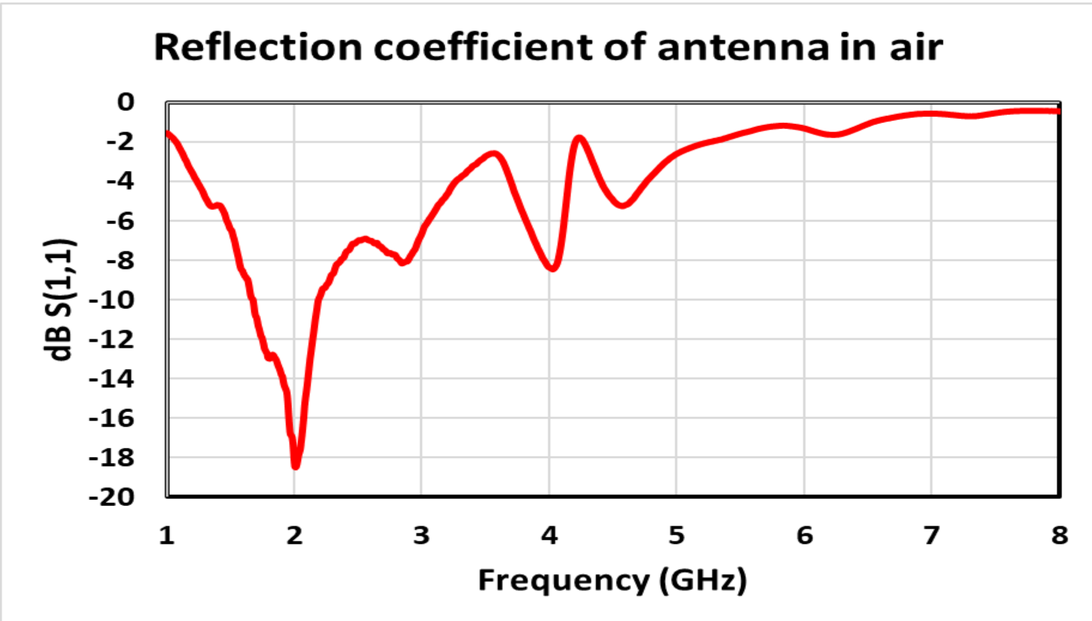

Figure 4.7: Reflection Coefficient of Antenna in Experimental Result in the Air

Table 4.2: Summarize of the Adhesive Antenna Information

Band	Categories	Actual Bandwidth (GHz)	Designed Bandwidth (GHz)	Resonance Frequency (GHz)	Reflection Coefficient (dB)
ISM	Simulation	2.4 - 2.5	2.211 -2.553	2.41	-16.5696
	Experimental		2.295 – 2.701	2.51	-16.1148
WBAN	Simulation	3.1 -10.6	3.224 - 3.316	3.27	-21.6394
	Experimental		3.366 – 3.429	3.40	-10.8387
WLAN	Simulation	5.15- 5.725	4.846 - 5.338	5.06	-19.4462
	Experimental		5.088 – 5.312	5.24	-11.0049

4.4 Radiation Pattern Report

In Figure 4.8 to Figure 4.10 shows the radiation pattern measured for ISM band, WBAN and WLAN in the E and H - plane. The dotted blue line denotes the power at the E – plane (Phi = 0°). Whereas the solid red line denotes that at the H-plane (Phi = 90°). E-plane and H-plane are be 90° apart. It can be seen that the radiation patterns at 2.41 GHz and 3.27 GHz in Figure 4.8 and 4.9 respectively are almost omnidirectional in the E and H – plane and their radiate powers are at least 2dB. The radiation pattern at 5.06 GHz in. Figure 4.10 is omnidirectional in the E – plane with 3dB of radiate power.

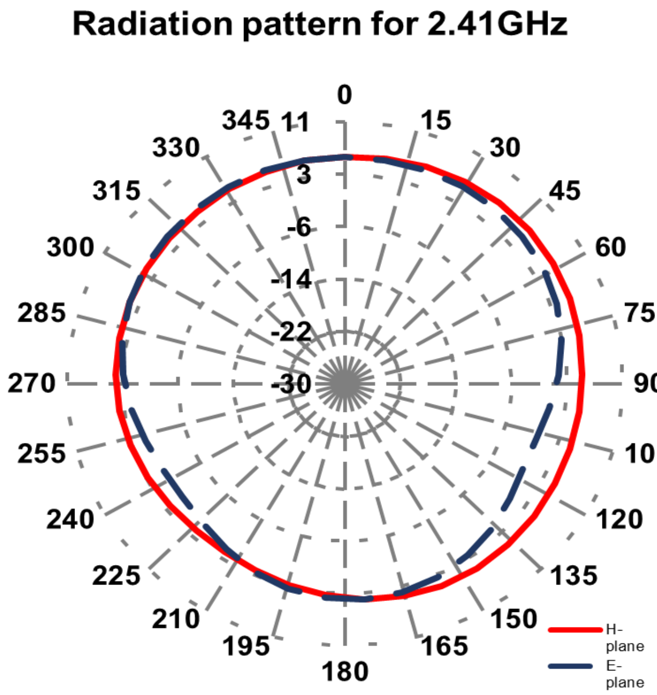

Figure 4.8: Radiation Pattern for 2.41GHz (ISM band)

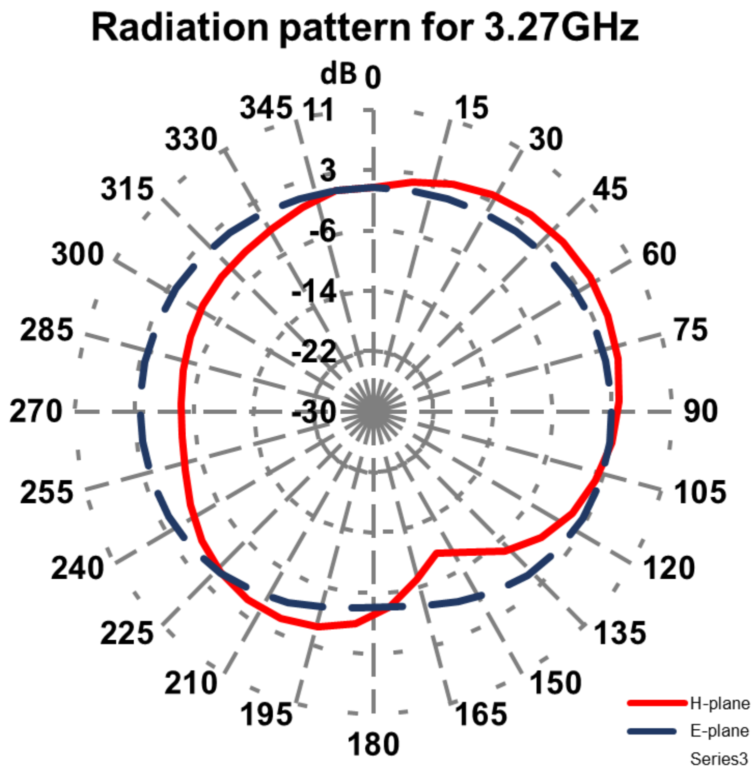

Figure 4.9: Radiation Pattern for 3.27GHz (WBAN)

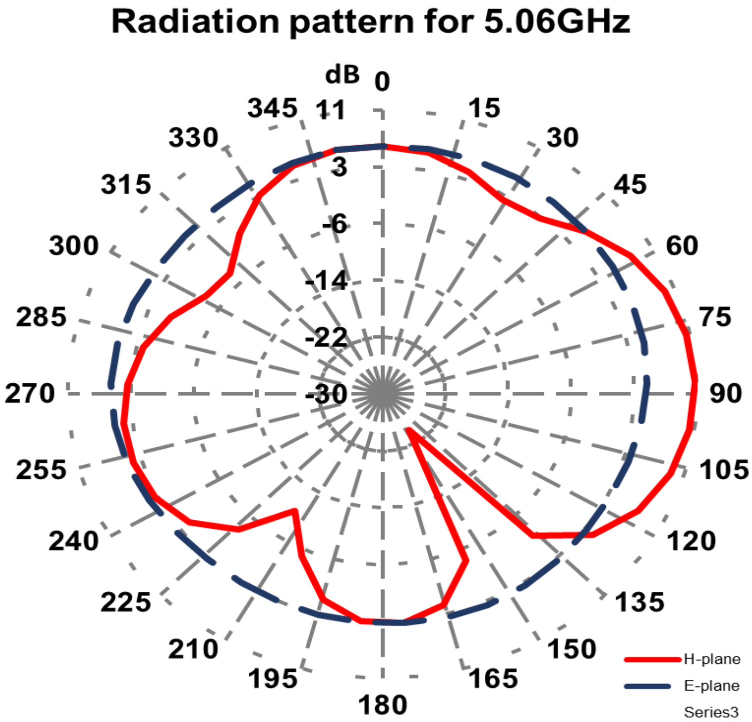

Figure 4.10: Radiation Pattern for 5.06GHz (WLAN)

4.5 Current Distribution

Figure 4.11 to 4.13 show the surface current distribution at resonant frequency 2.41 GHz, 3.27 GHz and 5.06 GHz. It can be seen from the figures that the peak distributions concentrate at different parts of the designed surface for different resonant bands. As can be observed from Figure 4.11, the highest surface current density concentrates at the middle strip of the designed. Next, at 3.27 GHz of the resonant frequency, the highest surface current is more widely distributed at the upper part of the designed. Lastly, Figure 4.13 shows that the highest surface current located at the lower part of the designed. From these three figures, it can be concluded that the three resonant frequencies have the highest surface current density concentrates at different parts of the structures in the designed.

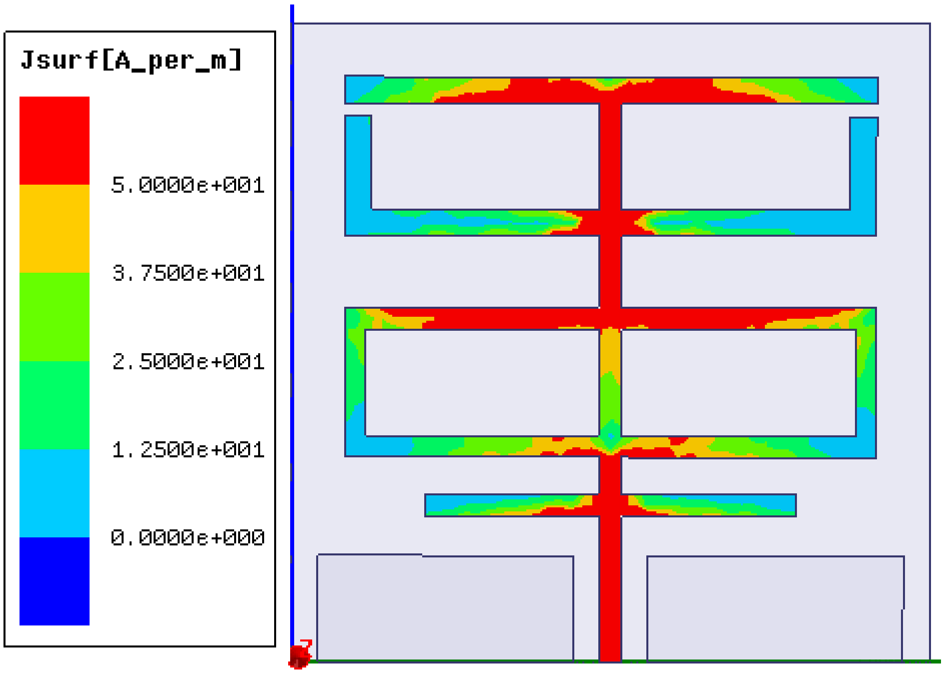

Figure 4.11: Current Distribution of 2.41GHz

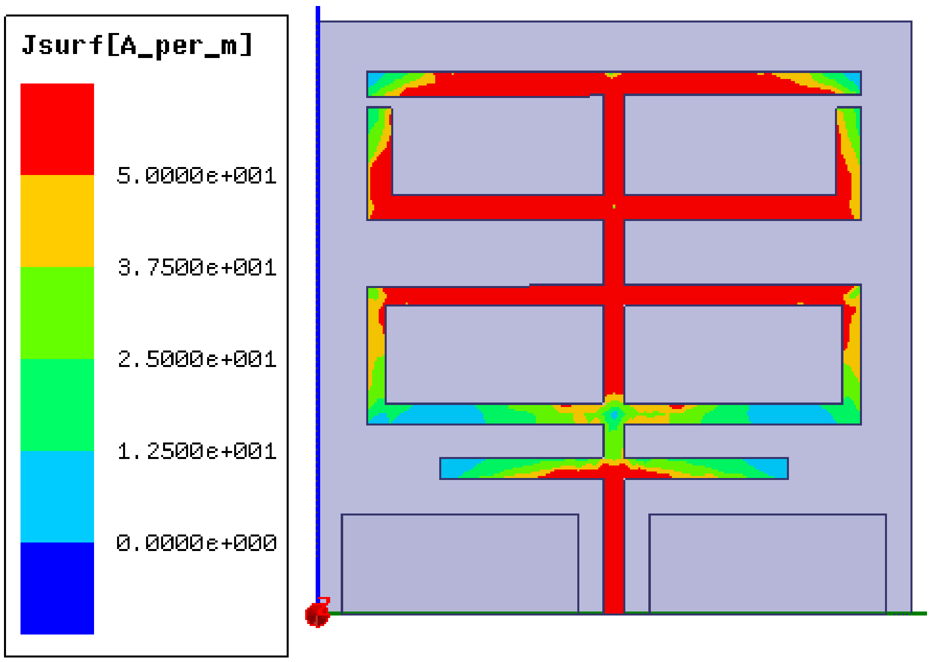

Figure 4.12: Current Distribution of 3.27GHz

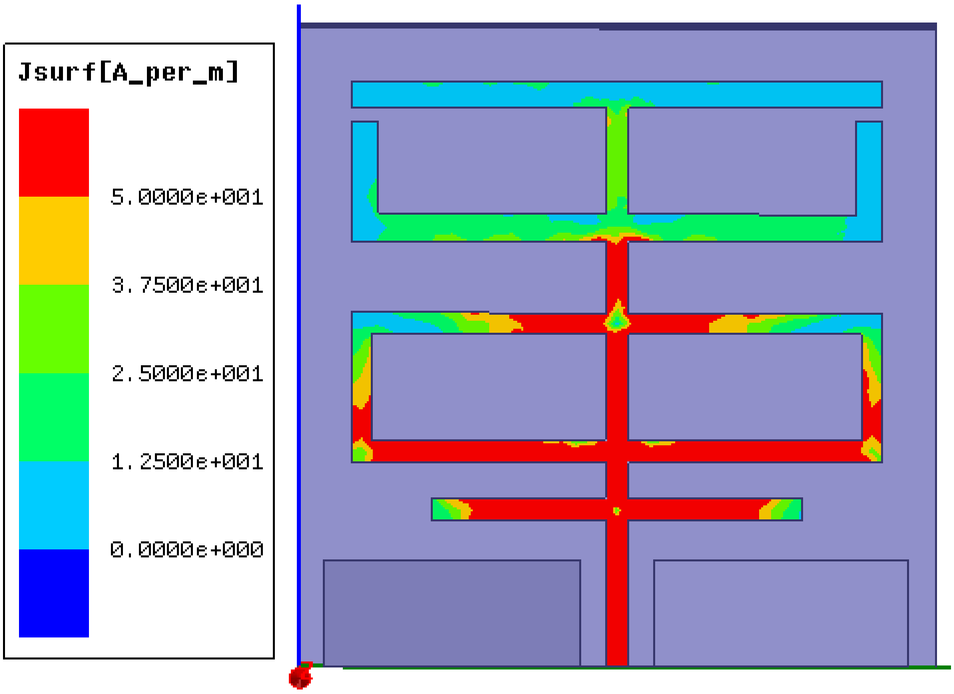

Figure 4.13: Current Distribution of 5.06GHz

4.6 Gain

In Figure 4.14 shows the obtained gains at ISM, WBAN and WLAN bands. As can be observed from the figure, the lowest gains are -12.2197 dBi, -13.5724 dBi and -7.28334 dBi for 2.41 GHz, 3.27 GHz and 5.06 GHz respectively. A realized gain higher than or equal to -20dBi for the ISM band is acceptable as the signal propagating within the skin layers is lossy (Alrawashdeh, 2005).

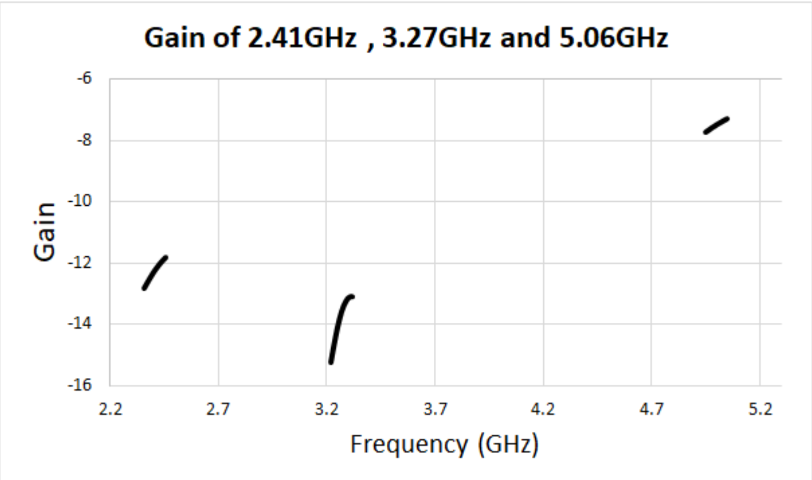

Figure 4.14: Result of Gain for 2.41GHz, 3.27 GHz and 5.06 GHz

4.7 Specific Absorption Rate (SAR)

Figures below show the SAR field for ISM, WBAN and WLAN bands. Based on Figure 4.15, the simulated average SAR based on 1 W input power for 2.41 GHz is below 0.12868 W/kg. Besides, the simulated average SAR for 3.27 GHz and 5.06 GHz are 0.2814 W/kg and 1.1140 W/kg respectively. However, according to the limitation of the regulatory effective radiated power (EPR), the delivered input power should be limited to 25 μW (Chien, Cheng, Yang, Jiang and Luo, 2010). Therefore, the average SARs at 2.41 GHz, 3.27 GHz and 5.06 GHz are below 3.217 μW/kg, 7.035 μW/kg and 27.85 μW/kg when they are normalized to 25 μW. These values strongly suggest that the proposed antenna is suitable for attach within human bodies as it is well below the limits set by the two IEEE standards.

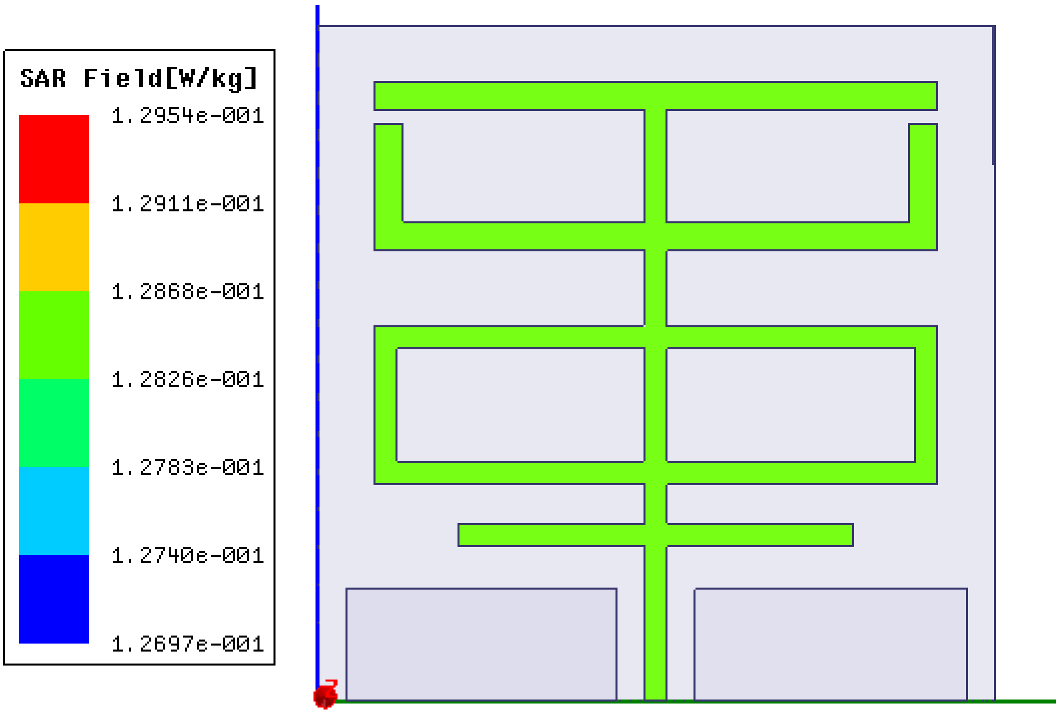

Figure 4.15: Simulated Average SAR for 2.41 GHz Resonant Frequency

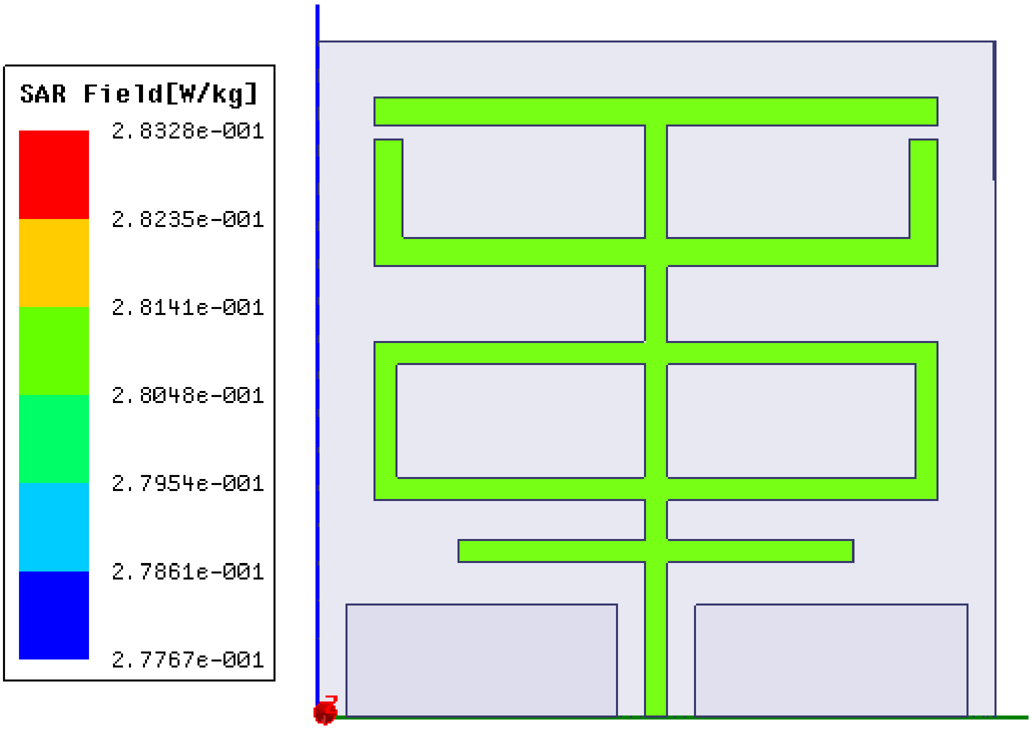

Figure 4.16: Simulated Average SAR for 3.27 GHz Resonant Frequency

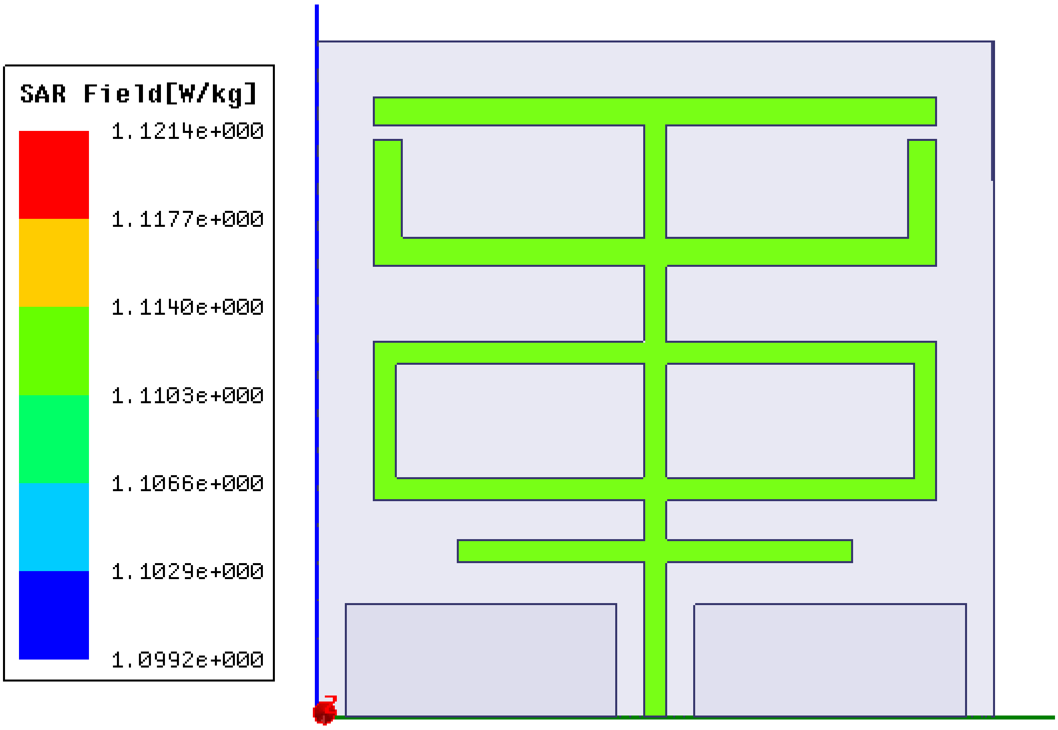

Figure 4.17: Simulated Average SAR for 5.06 GHz Resonant Frequency

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This project presents a novel 24mm × 24mm × 1mm of designed planar monopole adhesive antenna, which is fabricated on a dielectric substrate, Rogers RT/ duroid 5880. In the simulation, the body tissues (skin, fat and muscle) were included into the design as a medium. This is because the fabricated antenna will be attached on the skin surface. Thus, the antenna is affected by both the electrical properties of the air and the body tissues.

5.2 Conclusion

A tri-band planar monopole adhesive antenna was designed. The antenna resonates at the ISM (2.4 - 2.5 GHz), WBAN (3.1 – 10.6GHz) and WLAN (5.150 – 5.725 GHz) bands. The simulation results show that antenna exhibits 10 dB impedance bandwidth of 341.3 MHz from (2.2119 to 2.5532 GHz), 92.5 MHz from (3.2240 to 3.3165 GHz) and 492.5 MHz from (4.8464 to 5.3389 GHz). The measured and the simulated results are in great agreement. Furthermore, the gain of the proposed antenna is acceptable as it was below -20dBi. Lastly, the values of average SAR for the antenna is below than the limitation set by IEEE standards. Thus, the antenna is safe and suitable to use on human body.

5.3 Future Improvement

The current design can be further improved by reducing the size of the adhesive antenna. It would be more convenient to have an antenna with minimal footprint attached to the patient's body since a bigger one will certainly hamper his/her daily living. Next, the Medical Device Radiocommunications Service (402 -405 MHz) frequency band should be incorporated into the antenna. This is because physiological data is mostly transmitted via the MedRadio band. Last but not least, the bands are to exhibit omnidirectional radiations. This is to ensure that, the signal can be radiated equally in all directions.

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