# Thesis 2

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# Wearable Antenna for ISM and UWB Applications

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## ABSTRACT

There is an ongoing high demand for wearable technology for applications like health monitoring, location tracking, biosensors, contact-free card payments, smart devices, etc. In order to achieve these, importance of wireless communication has increased which can be implemented using wearable antennas. Wearable devices are required to be small and comfortable to wear, which can be flexible and lightweight, such as textiles. For this reason, textile-based wearable antenna designs are proposed which can be incorporated in a garment to be worn as it provides the ease of movement and flexibility. There are four different antennas, two of them can perform at the ISM (Industrial, Scientific and Medical) band, the other two antennas are ultrawide band antennas designed to fulfil the requirement for various real time applications in which the communication link must be strong and reliable in any environment . It also has the potential to accrue signals from one area and is crucial as it can help give accurate results to the respective user. Efficiency, bandwidth, and other performance related properties depend upon the substrate of antenna and its dielectric constant; thus, a textile material is selected to be the substrate. Polyester and Jeans have been chosen out of the numerous fabrics worn on a day to day basis for their versatile properties. Polyester fabric is non-porous which means it repels the water absorption level to a greater extent, making it breathable and robust. The stretchable factor makes it adaptable to coarse conditions making it a possible addition to every wearable textile irrespective of the place the person is in. Jeans is a fabric that is readily available everywhere and is commonly worn by people in all industries. Another notable factor about both these materials is that, they have a low dielectric constant in comparison to a lot of wearable fabrics in the market. This helps in the prevention of any form of losses when the transmission of the frequency is being emitted. The software used to simulate and obtain results is High Frequency Structure Simulator (HFSS) which a product of ANSYS. The performance of the designed antennas is observed by parameters like return loss, VSWR, gain and the radiation pattern efficiency.

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## STATEMENT OF ORIGINALITY

I, Umm Kulsoom Emad, declare that this thesis, submitted as part of the requirements for the award of Bachelor of Electrical Engineering, in the Faculty of Engineering and Information Sciences, University of Wollongong in Dubai, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications or assessment at any other academic institution.

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## ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ISM | Industrial, Scientific and Medical |
| $\varepsilon_r$ | Relative Permittivity |
| GHz | Gigahertz |
| Mm | millimetre, mm |
| dB | Decibels |
| VSWR | Voltage Standing Wave Ratio |
| HFSS | High Frequency Structure Software |
| ANSYS | Name of the company |
| SAR | Specific Absorption Rate |
| $\Omega$ | Ohms |
| CPW | Coplanar Waveguide |
| WBAN | Wireless Body Area Network |
| GPS | Global Positioning System |
| UWB | Ultrawide Band |

**LIST OF CHANGES**

| Section | Statement of Changes | Page Number |
|---|---|---|
| | Ultrawide band Antennas are added in thesis | |
| 2 | Papers 5, 16, 17, 20, 21 and 23 are replaced with new researched papers | |
| 3.1 | Jeans as a substrate is added | 15 |
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# Chapter 1. **INTRODUCTION**

## 1.1 Background

Wireless communication technology has developed greatly in past few years. Modern smart devices like smart phones, smart assistants, smart homes, smart gadgets and wearable electronics are becoming important parts of everyone's daily life. These automated devices need to connect and communicate with each other during their active mode [4]. As the usage of these devices is increasing in home, industrial, scientific and medical areas, they are expected to become smaller and compact in size [6]. Thus, the demand in reducing the size of antennas which have the same level of performance with high efficiency is becoming more [10]. An antenna is one of the major components for creating wireless communication as it contributes to both transmitting and receiving information [2]. The data needs to be communicated without disruption, under any conditions with high transfer rate, for real time applications like rescuing, locating, hiding intelligence personnel, hearing aid, monitoring heartrate, fitness watches, etc [1][15].

In recent years, wearable technology has become popular and so did the demand of wearable devices for various fields. There are two bands reserved for Industrial, Scientific and Medical (ISM) applications; 2.45GHz and 5.8GHz. [11]. Two textile-based, microstrip patch antenna are proposed for wireless communications which operate at a bandwidth covering the frequency of 2.45GHz and 5.8GHz. This kind of antennas are low-cost and can be used for on-body and off-body applications [9]. Another demand which has increased over the recent years, is for the ultrawide band antennas, which started after the Federal Communication Commission allowed 3.1GHz to 10.6 GHz frequency for commercial use as mentioned in [5], [16-17], [20-21] and [23] . The designing of ultrawide bandwidth is challenging, as it requires the antenna to operate for all these frequencies. These antennas are used for applications like industrial purposes to track the location of the workers, electromagnetic imaging [17] for scientific purposes in applications of space, satellites and missile [8]. Also, in medical purposes for monitoring and aiding the health of a patient, etc.

## 1.2 Scope and Constraints

Wearable microstrip patch antennas are flexible as they are made up of textile, making it different from regular antennas, and can be easily integrated into clothes. They are low-profile and comfortable to wear, allowing ease of mobility. These microstrip patch can be of different shapes like circular, triangular, rectangular, or hexagonal [10]. On the other hand, wearing an antenna causes reduced efficiency due to radiation absorbed in tissues and distorted radiation pattern [18], which is minimized to a great extent by adding a conductive ground plane that eliminates most of the absorption [9]. The figure below shows how the golden-yellow patch is separated from the skin by a purple coloured ground plane.

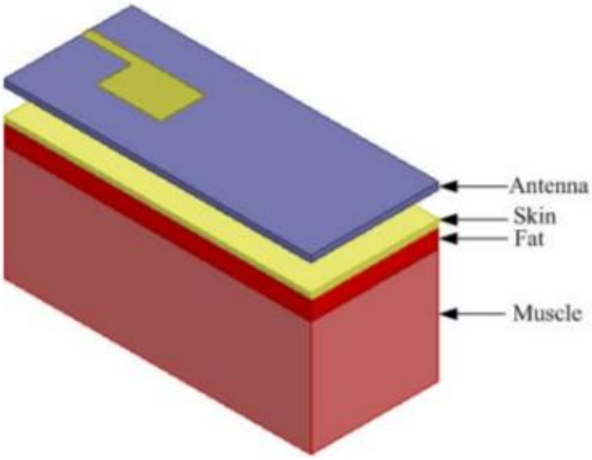



Figure 1.1: Placement of Wearable Antenna on a human body [7]

## 1.3 Problem Statement

The abstract idea of microstrip patch antenna was first introduced in 1950s [28] and then it became popular in 1970s after being developed by Bob Munson in 1972 [6]. After so many years, the concept is still new to many. The basis of conducting this research is to create a design, using the previous investigations, which is simple and adaptable for companies to integrate into their clothing easily. Thus, taking advantage of this concept to the fullest and making it universal.

## 1.4 Objective

The objective of this thesis is to design a simulation of two categories of wearable textile antenna; first category which has a bandwidth covering ISM frequencies and the second which has an ultra-wide bandwidth. This should be achieved using feasible design. The challenge in designing a textile antenna is to achieve the functionality and performance is similar to the rigid antennas, its low-cost, low-profile, efficiency, comfort of wearing and reproducibility.

# Chapter 2. LITERATURE REVIEW

**Paper [1]**

The paper proposes a wearable antenna design for wireless communications like Bluetooth/Wi-Fi. There are two antenna designs proposed in this paper. The first design is to use a textile as a substrate and copper sheet being attached as the electrical conductor. This design is said to be uncomfortable to wear because of being stiff and would have an additional weight. The second design is to have a conductive textile integrated in the clothing so that its flexible, lightweight and comfortable to wear. The substrate of the second design is chosen to be jeans whose thickness is 1.5mm and the conductive garment is 0.08mm thick. These antennas are designed to work at a centre frequency of 2.45GHz for a hearing aid device. The comparisons for the return loss and radiation pattern, were made using the ANSYS HFSS software. The implemented structures were compared using Network Analyser. With the results of the simulations, it can be observed that both designs show low radiation losses and can be used for diverse wearable applications. [1]

**Paper [2]**

The paper presents the designing for patch antenna which could be used for GSM application. The important parameters to consider for analysing the performance are return loss, VSWR and radiation pattern. The radiation pattern shows the relative field strength of antennas at different angles and is shown in different symmetries and lobes. The preference to choose a substrate is to be thick and have a low dielectric constant. The antenna has a ground plane, substrate and patch fed by a feedline. Increasing the width of the patch causes increase in bandwidth and gain but it decreases the resonant frequency. The substrate chosen is FR-4 (Flame Retardant). The HFSS software is used for designing and simulating the antenna. The antenna operates at the resonant frequency of 1.8GHz for GSM application with a VSWR of 1.0717. [2]

**Paper [3]**

The paper proposes the preliminary design for a microstrip patch antenna to operate at 2.40 GHz for WBAN applications like medical, military, navigation, entertainment, and sport. Substrates with low dielectric constants or permittivity reduce the surface losses. This will provide improved and wider impedance bandwidth to have a greater tolerance for resonant frequency which shifts due to change in shape and environment. An ordinary microstrip patch antenna has the disadvantage of high electromagnetic radiation, thus high SAR on human body and it is difficult to keep it hidden. The proposed design has a ground metallic plate under the microstrip patch antenna thus minimizing the SAR to a huge extend and having a textile-based antenna is easily integrated into the clothing. The equations for calculating dimensions of the patch antenna are also mentioned. The antenna has jeans as a substrate and shield it as a conductive textile due to its low resistivity, less corrosion and hydrophobic properties. The edge feeding technique is used. The radiation pattern is chosen to be omnidirectional as its most compatible to human body. The design is simulated using Keysight's Advanced Design Software. Measurements like return loss, impedance matching, radiation pattern and gain are done using the Agilent's Vector Network Analyzer. The antenna has the gain of 2.689 dB, directivity of 8.174 dB, and radiated power of 7.068×10-4 watt at $F_c$ = 2.40 GHz, respectively. [3]

**Paper [4]**

The paper presents a design for multi-band antenna operating at 2.4GHz, 4.735GHz and 5.8GHz, which covers the frequencies for the ISM bands. A U-slot patch antenna is chosen which is said to be appropriate for designing dual-band, multi-band or wide-band applications. The antenna's conductive material for the ground plane and the patch is made of silver sheet as its comfortable to wear, lightweight and flexible. The substrate used is Microwave C-foam having a relative permittivity of 1.06, as it is water repellent. The simulation is done using CST Microwave Studio. The return loss is observed much lesser than -10dB and gain above 3dB at the required frequencies thus achieving the functionality. [4]

**Paper [5]**

In this paper, the antenna design which is proposed works well for various bands within its ultra-wide band range of 3.1GHz to 10.6GHz. The bands include Wimax, C-band and X band. Different slots are used to notch the resonant frequencies of the bands mentioned. The slots shape have C shape and L shape. The patch is suggested to be circular and the patch also includes a circular slot in the middle. These slots make the antenna multiband. A wider bandwidth was made by using a partial truncated ground. The substrate used is FR-4 having the relative permittivity of 4.4. The design was tested using HFSS and the results were observed with return loss under -10dB, VSWR <2, smith chart analysis, radiation pattern, and radiation efficiency was found to be almost 80%. The results showed a promising design for the UWB applications.

**Paper [6]**

There are several factors which have an impact on the performance of wearable textile antennas. The focus of this paper is to analyse the different types of feeding techniques. The advantages and disadvantages are discussed of techniques like Microstrip Line Feed, Coaxial Feed, Aperture Coupled Feed, Proximity Coupled Feed and Inset Feed. The other parameters explained, which determine the performance of an antenna are VSWR, return loss, radiation pattern and gain. [6]

**Paper [7]**

The paper mentions the increasing interest about the antennas made of clothes. The authors propose a wearable dual-band textile antenna for ISM applications. The design consists of denim fabric being used as a substrate in combination with two copper sheets. A side structure on the substrate is selected to remove the stray capacitance and a monopole with a micro strip feedline are used to increase the bandwidth further. Also, different dimensions are suggested for designing the wearable antenna. Due to the chemicals present in the human body, analysis was done in both cases; on-body and off-body. The working frequencies of both cases are measured using the Vector Network Analyser, which range from 1.5GHz to 6.5GHz, covering the requirement of the ISM bands. The resonant frequency, impedance bandwidth and radiation pattern, were found to be slightly different in each case. The simulations and measurements were done using the CST Microsoft Studio Software. The radiation patterns were observed in E-plane being monopole, as well as, in the H-plane being omnidirectional. The antenna had 10dB return loss, satisfying the ISM band’s frequencies of 2.4GHz and 5.8GHz. [7]

**Paper [8]**

The WI-Max is a technology which has the ability to eradicate the problem of telecommunication not being available in rural areas by having antennas with suitable bandwidth. The paper presents the design of an antenna in which it has a dielectric substrate, feed line, ground plane and rectangular patch, in which the ground plane and patch are made of copper and are connected to each other by a thin metal wire. The substrate material is chosen to be air having the dielectric constant to be 1.0. If the height of the substrate is increased too much then surface waves start flowing and they scatter at the bends of the radiating patch, thus decreasing the performance of the antenna. The ground plane should always be greater than the patch in size. A feed line of 50ohms is used. The return loss of the antenna can be minimized by adjusting the height of the substrate. This antenna can be used for various Wi-Max applications like satellite, missile, and spacecraft. [8]

**Paper [9]**

The paper presented a microstrip patch antenna for Wireless applications WiMAX to be operated at a centre frequency of 5.3GHz. The substrate chosen in this design is Rogers R04232 which has less moisture absorption and has a high reliability and flexibility. The antenna has the ground plane, substrate and patch. The design has four slots of the same dimensions. The simulation of different parameters is done using HFSS. A gain of 5.858 dB has been achieved with the simulation of the antenna designs. Observing the results, it can be said that the operating frequency is dependent upon the substrate, dimension of the patch and the feeding technique used for the antenna. [9]

**Paper [10]**

The paper presents a microstrip patch antenna with a ground plane and substrate, to be operated at 2.4GHz for wireless communications. The performance of a textile antenna depends upon the dimension of antenna, substrate material and the feeding technique. A thick substrate with a low dielectric constant provides better radiation, efficiency and larger bandwidth. The proposed substrate is Rogers RT Duroid. The three parameters for designing a microstrip patch antenna are frequency of operation, dielectric constant of substrate and height of the substrate. The simulation is done using HFSS, and the return loss was found to be 12.2dB at 2.4Ghz and -18.75dB at 2.24GHz. [10]

**Paper [11]**

The paper presents a wearable antenna to be operated at a 2.45GHz frequency from the ISM band for WBAN applications. The dielectric constant of the substrate material affects the efficiency and bandwidth of the antenna. Wearable antennas are advancing to be low profile and to improve wireless communications. The substrate chosen is Rogers Duroid RO3003 which is capable of producing omnidirectional, having the relative permittivity of 3 and loss tangent of 0.0010. These properties influence the bandwidth, size, gain and efficiency of an antenna. The analysis is also done in bending conditions by simulating in CST Microsoft Studio over a vacuum cylinder. Referring to the simulation results, the return loss is -17dB at 2.45GHz which is acceptable. The implemented antenna is tested using the Vector Network Analyser. This paper also talks about SAR and its effects on the human body. [11]

**Paper [12]**

The paper compares different substrates for a wearable textile antenna. The parameters of an antenna like bandwidth and efficiency, depend upon type of substrate material used. The dielectric constant of the substrate is the factor which affects the above-mentioned parameters. The suggested way for choosing the dielectric constant is by using the resonant frequency of patch antenna. The following table is the list of the textile substrates calculated and their electrical parameters.

Table 2.1: Comparison of different substrates [12]

| Fabric material | $\varepsilon_r$ | L*W | Loss Tan δ | Feed Point (mm) | $S_{11}$ | Gain (dBi) | BW (Return loss) | Directivity (dBi) | Efficiency (η) | VSWR | 3dB beam width | Impedance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cotton | 1.60 | 46*53 | 0.0400 | 13.5 | -32 | 3.8 | 0.097 | 8.44 | 35% | 2.4680 | 73°, 78° | 48-j0.789 |
| Polyester | 1.90 | 43*50 | 0.0045 | 8.0 | -35 | 6.8 | 0.040 | 7.90 | 76% | 1.0879 | 75°, 87° | 48-j1.849 |
| Cordura | 1.90 | 43*50 | 0.0098 | 9.5 | -29 | 5.9 | 0.050 | 7.93 | 64% | 1.0944 | 75°, 87° | 50-j2.450 |
| Lycra | 1.50 | 48*54 | 0.0093 | 9.0 | -31 | 6.8 | 0.048 | 8.59 | 67% | 1.0917 | 73°, 75° | 47-j0.740 |

It was concluded that low value of dielectric constants minimizes the return loss and thus improving the efficiency. [12]

**Paper [13]**

The paper talks about the challenge of designing wearable antennas is that they should have efficient performance in maintaining the radio frequency and reliable communication while being be flexible, robust low-cost and light weight. The study also compares the thin film also known as non-fabric antenna and fabric-based antenna technologies. In thin-film antenna, the fabrication is achieved by depositing metal on thin substrates like paper, Kapton, polyethylene terephthalate (PET), etc. Different fabrication methods include screen-printing, inkjet printing and photolithography. In fabric-based antennas, flexible conductive materials are deposited on textile substrates having low dielectric constant like cotton, polyester, cordura, felt, etc. Different fabrication methods for this technology include copper tape, embroidery using conductive e-thread, and electro-textile-based antennas using pure copper taffeta fabric. These techniques were discussed in detail with their advantages and disadvantages. [13]

**Paper [14]**

The paper presents comparison between two different substrates; polyester and jeans, comparison between two different conductive textiles; like pure copper taffeta and zelt, to design dual-band antenna for 2.45GHz and 5.8GHz bands. The design of this antenna is to have a substrate and a conductive patch on top of it. A coplanar waveguide (CPW) feedline provides the input impedance of 50 ohms. The simulation of different combination of substrate and conductive textile is done using CST Microwave Studio and the result is shown below.

Table 2.2: Comparison of different combinations using Jeans and Copper [14]

| Substrate | Realized gain (dB) | | Directivity (dBi) | |
|---|---|---|---|---|
| | 2.45 GHz | 5.8 GHz | 2.45 GHz | 5.8 GHz |
| *Polyester- Pure Copper* | 0.591 | 2.36 | 2.51 | 3.22 |
| *Jeans cotton- Zelt* | 0.622 | 2.61 | 2.41 | 3.68 |
| *Jeans cotton- Pure Copper* | 0.644 | 2.39 | 2.67 | 3.68 |

The return loss is of jeans substrate is lesser compared to polyester. Therefore, jeans is chosen to be the substrate in combination with Zelt, as it has a better conductivity and low resistivity when compared to copper. The different application for this antenna is WiMax and WLAN. This design can be improved by adding a ground plate to reduce radiation when it is close to human body. [14]

**Paper [15]**

The paper presents an antenna to operate at a frequency of 2.4GHz frequency of the ISM band. The design of the antenna is L shaped with two layers; the top layer is the conductive textile and the layer under it, is the denim fabric as a substrate, and uses a coplanar waveguide (CPW) as a feeding technique. The design is for wider bandwidth and robustness. Denim is chosen because of being an ordinary and everyday clothing and is easier to integrate. The HFSS software is used for simulation and tuning the properties of the antenna. In addition, return loss of this antenna is observed to be below 10dB in both; on-body and off-body experiments. It can be said that the antenna parameters like radiation pattern and return loss have negligible discrepancies. [15]

**Paper [16]**

The antenna proposed presented in this paper using a jeans substrate with a thickness of 1mm dielectric constant of 1.7 and loss tangent of 0.025. the simulated and measured results show a bandwidth of 13GHz which is observed with software like CST and FEKO. The communication aspects of a wearable antenna were discussed in this paper like navigation, tracking and energy harvesting, etc and how the substrate should be flexible, thus the use of textile. The antenna has a circular patch with diamond shaped slot in the middle and half circle slot at the corner with a partial ground. The difference of radiation patterns at different frequencies helps in selecting for which purpose it should be used. For example, omnidirectional antenna is good for a device in medical field but not for monitoring applications in the same field. Moreover, the radiated power, return loss, VSWR and fabrication methods were also discussed. [16]

**Paper [17]**

This paper discusses the need for UWB as the allow higher data rates for communication in comparison to the third generation and various design techniques and requirements in order to achieve better performance. The UWB is recommended to have a wider bandwidth, radiation efficiency which is high, matching circuits and the use of various shapes and sizes of slots for notching of frequency. it also discusses how low dielectric constant is good for omnidirectional radiation bandwidth. In addition, parameters like the shapes of patch e.g. circular, elliptical, rectangular, hexagonal were analysed along with different kinds of geometries. The effect of substrate's thickness was also discussed as it provides better frequency which can be achieved by stacking. A variation of the geometry of the ground was suggested to be observed for making the bandwidth larger. [17]

**Paper [18]**

The paper proposes the idea of a dipole wearable antenna system for wireless tracking and safety applications. The simulation for this antenna system is done using CST Microwave Studio and makes use of Finite Integration Technique (FIT). The antenna in this system operates at 2.45GHz and coaxial feeding technique is used, with laminate as a substrate. The analysis is done using the model of a human body. The position for operating this antenna system is chosen to be on the shoe. Two antennas are used, one on the back side of the shoe and one on the front side of the shoe showing better performance results in comparison to any other position. [18]

**Paper [19]**

The paper discusses the importance of designing an antenna that could retain its original shape after applying pressure or any other sort of bending. This has to be achieved using a low-cost, efficient and lightweight textile substrate. The substrate proposed is denim fabric. The design is a semi-triangle shaped dual band monopole antenna which supports WLAN and WBAN. Coaxial cable for 50 Ohm is used to feed the antenna and copper tape as the conductor. When simulated using HFSS, the are only minor difference values for return loss and gain. The antenna on foam cylinders of different radii are used for testing the performance under bent conditions and the testing for SAR is done as well. VSWR of the antenna remained less than the acceptable value of 2, regardless of the pressure applied. [19]

**Paper [20]**

This paper proposes an antenna to overcome the issue with Ultrawide band antenna as some wireless frequencies intervene in the wideband. It also mentions how trying to notch the frequencies has been done in earlier work but has a negative impact on the performance of the antenna. Furthermore, some designs are too complex to be implemented and maintain the low cost, low profile and robust criteria of designing a textile-based antenna. The proposed antenna has FR-4 as a substrate with a thickness of 1.6mm, a partial boat like ground, a S shaped slot in the patch and U-shaped slot in the microstrip feedline. The parameters like return loss, VSWR, directivity and gain of the antenna were observed in simulation performed in CST microwave studio. [20]

**Paper [21]**

Denim textile has advantages over other textiles due to it being easily available, comfortable to wear and inelastic physical properties, and at the same time being low cost and having a dielectric constant preferred for designing antennas. Thus, it is used as a substrate for this design. This paper also mentions about previous researches of using stubs, different patch shapes and partial grounds for widening the bandwidth. The design proposed has a eclipse shaped patch with coplanar wave feedline of length 3.5mm. It has a partial ground, truncated at the feedline position. The conductive material is copper tape. The software used for simulating is the CST microwave studio. The results of this antenna layout show an ultrawide bandwidth; for simulation it is from 2.4GHz to 12.8GHz and for the physical antenna it is 2.52 GHz to 13.35GHz. [21]

**Paper [22]**

The paper analyses the different shapes of antenna to be operated at 2.4GHz. The design has a feedline, substrate and a microstrip patch. The three shapes of patch analysed are rectangular, circular and corner truncated. The substrate which has low dielectric constant would produce better radiation. The substrate chosen is FR-4, which is thick, therefore contributes in larger bandwidth and greater efficiency. Feedline’s resonant input impedance is almost zero at the centre of the patch. As the height of the substrate increases, the efficiency decreases, and the surface waves increase. The simulation and design are done using HFSS. The following table is the summary of the results of different shapes.

Table 2.3: Comparison of different shapes of patch [22]

| | Freq (GHz) | Return loss(dB) | Directivity (dB) | BW (MHz) |
|---|---|---|---|---|
| Rectangular Patch | 2.41 | -18.03 | 3.39 | 75.0 |
| Circular Patch | 2.41 | -12.63 | 3.76 | 80.0 |
| Corner Truncated Patch | 2.41 | -15.59 | 3.51 | 90.0 |

It can be observed that corner truncated patch balanced return loss and balanced gain in comparison with rectangular patch and circular patch, therefore optimal results are obtained from truncated patch. [22]

**Paper [23]**

The paper proposes a design for covering the bandwidth which is allowed by FCC; 3.1GHz to 10.6GHz with dual notches. The layout of the patch is octagonal with two slots; both of them are T shaped. It has a microstrip feedline technique. The feedline length is almost the same as the length of the patch; length of the patch is 16.5mm and length of the feedline is 16mm. It has a partial ground, and the substrate height is 1mm with relative permittivity of 4.4. The effect of inserting one T shaped slot, two T shaped slots, and their different dimensions are also presented in this research. The results of different parameters like VSWR and radiation pattern validated that the antenna could be used for UWB applications without obstructing the WLAN and WiMAX applications.

# Chapter 3. METHODOLOGY AND DESIGN

This chapter includes the preliminary design of the wearable antennas for wideband range. The challenge in creating an antenna is not only to design a microstrip patch antenna which fulfils its functionality and works at its required frequency but to also have larger bandwidth, and it being hidden, lightweight, low-cost and flexible so that it is wearable.

The simple and basic form of a wearable antenna is to be three layered with a feedline. The bottom layer is a ground plate, the middle layer is the substrate and the top layer is a patch. The ground plate, the patch and the feedline are supposed to be of the same conductive material, whereas the substrate of a wearable antenna should be a textile material. The most suitable materials for these layers, are to be chosen considering different factors. The figure below shows the layout of an ordinary wearable microstrip patch antenna.

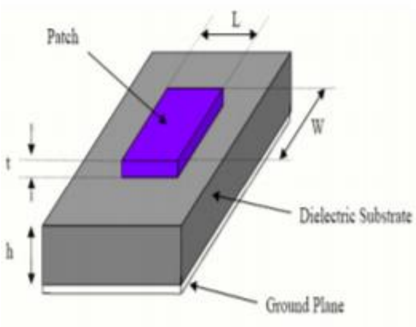



Figure 3.1: Layout of a patch antenna [2]

There are four different designs of antennas proposed in this paper, two of which cover the ISM bandwidth and the other two antennas cover the ultra-wide bandwidth of 3.24GHz to 10.69GHz. One antenna from each category is made from jeans and the other antenna is made from polyester.

### 3.1 Choosing the substrate material

The substrate material affects the bandwidth, gain and efficiency of the antenna [11]. It is vital to opt for non-fragile substrate. For selection of substrate, its vital to opt for non-fragile substrate and consider properties like its height, its dielectric constant and loss tangent are considered, and their effects are analysed [14]. Thick substrate and small value of $\varepsilon_r$ (dielectric constant), decreases the surface losses and produces better radiation [12], greater efficiency and larger bandwidth [2][10]. The recommended range of dielectric constant is between 2.2 to 12 [6][22]. After researching in previous works, about the performance of different substrates and their properties, the substrates were chosen. Jeans whose dielectric constant is 1.7 and polyester whose dielectric constant is 3.2, are chosen as they both are in the recommended range.

### 3.2 Choosing the conductive material

The material used for the ground plate and the patch is normally a conductive material like copper, gold, silver or shield it. The patch affects the radiation of the antenna and the ground plate is used to minimize the SAR exposed to the body. It is required to have high conductivity and low resistivity. [1]

The chosen conductive material is pure copper due to its low surface resistivity and high conductivity when compared to shield-it in [3], silver in [4] and zelt in [14].

### 3.3 Choosing input impedance

Input impedance relates the current and the voltage at the input side of the antenna. The radiated or absorbed power is represented by the real part of impedance whereas, non-radiated power which is near the antenna field is the imaginary part of the impedance [25].

A lumped port having the input impedance of 50Ω is chosen for the feed as it is the impedance value for the majority of radio frequency devices or systems. Therefore, the impedance for the input of microstrip lines [29].

### 3.4 Choosing the feeding technique

Feeding technique is an important design consideration as it has an impact on the antenna’s return loss and VSWR. It also contributes in the efficiency of power transfer, radiation and the input impedance. There are different feeding techniques available like the edge feeding, coaxial feeding, inset feeding, coplanar waveguide feeding, etc.

The chosen feeding technique microstrip line feed. It provides planar structure and for patch with stairs (will be explained in next section), it contributes to making  current is maximum at the centre of the patch, and the impedance becomes almost zero and VSWR is the lowest [22] thus, input impedance is achieved easily. It is feasible to implement structure without any error, thus minimizing the risk of not achieving required functionality [6].

### 3.5 Designing the antenna's shape

After selecting the substrate, conductive material, fabrication method, and feeding technique, the next element is to compute the size of the patch, the feedline and the ground plane.

In the proposed design, the approach of the geometry for all the four antennas is analysed step by step in the same manner, the difference is in the substrate and the dimensions. The selection of substrate is done in section 3.1 and the geometry and its dimensions are obtained by carrying out simulations on simple rectangular patch and analysing its results. Then making the necessary changes in geometry according to the recommendations in research papers, investigating the effects of different dimensions and then again obtaining the results to achieve promising results.

The approach for designing antenna has the following steps:

**<u>Step 1:</u>** Calculate the Width and Length of a regular patch antenna using an operating frequency and dielectric constant of the substrate

The formula following formulas were used

1. For calculating width of the patch [2]

$$W = \frac{c}{2f_r\left(\sqrt{\frac{\varepsilon_r + 1}{2}}\right)}$$

- (Equation 1)

2. For calculating the effective dielectric constant [2]

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

- (Equation 2)

3. For calculating the length of the patch [8]

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

- (Equation 3)

   a. Effective length due to fringing

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}}$$

- (Equation 4)

   b. Increased dimension due to fringing

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

- (Equation 5)

**Step 2:** A microstrip feedline is attached in the middle of the patch which has the same length as the length of the patch or slightly less, as similar design dimensions were observed in [index the papers] to make the bandwidth wider.

**Step 3:** The length of the ground, 'Lg' is varied as partial grounds provide wider bandwidth and the effect on the return loss is observed. The width of the ground is kept constant as the and the same as the width of the substrate.

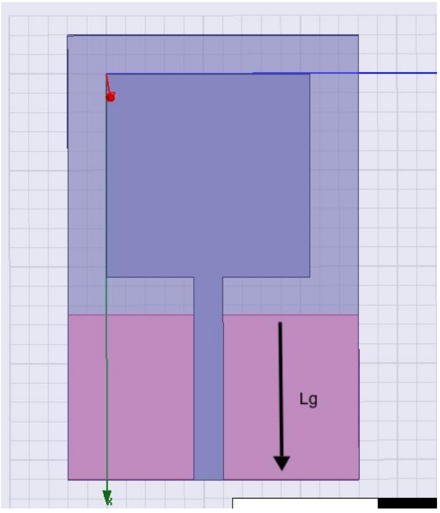



Figure 3.2: Layout 1

**Step 4:** Two slots are created at the bottom corners; one slot is at the left side on the left extreme and one slot is at the right side on the right extreme, shown in the figure below.

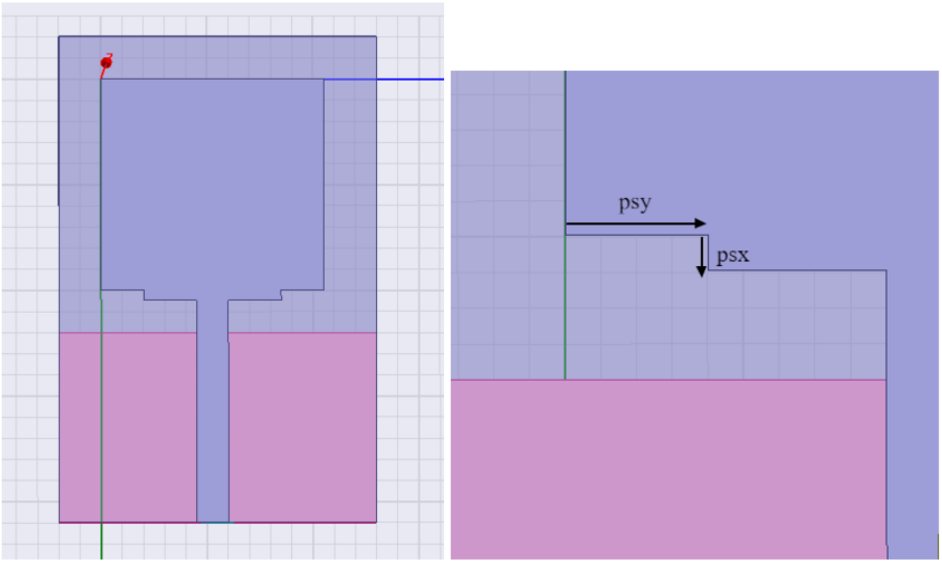



Figure 3.3: Layout 2 (zoomed out on left and zoomed in on right)

The length of the patch slots, ‘psx’ is kept constant, but the width of the patch slots, ‘psy’ is varied and the effect on the return loss is observed.

**Step 5:** Two slots are created at approximately middle of the feedline in the; one slot is at the left side and one slot is at the right side, as shown in the figure below. They are added to widen the bandwidth and enhance the performance.

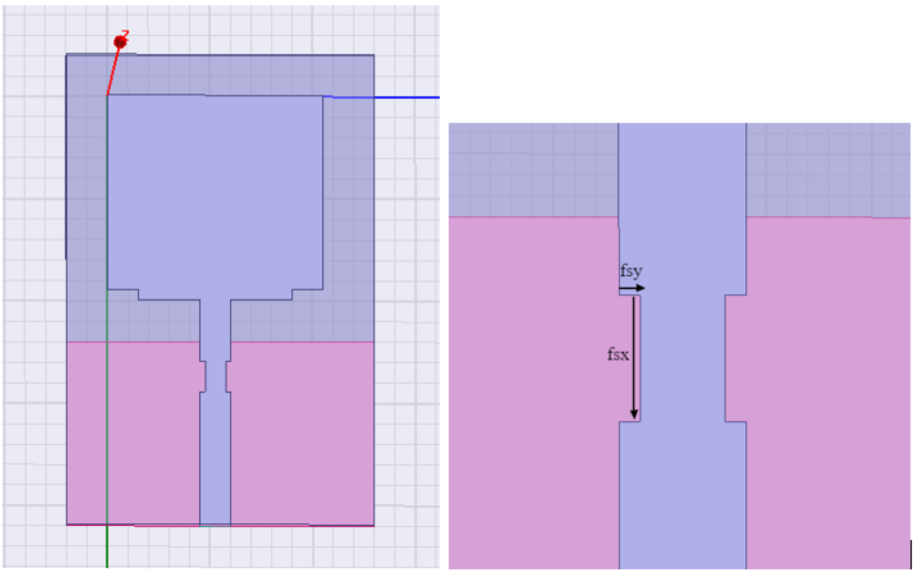



Figure 3.4: Layout 3 (zoomed out on left and zoomed in on right)

The width of the feedline slots, ‘fsx’ is kept constant, but the width of the feedline slots, ‘fsy’ is varied and the effect on the return loss is observed.

Note:

- → In all cases, the values on the left side are equal with the values on the right side, that is why one variable is used to represent the values on both sides.
- → The return loss is observed in a way to choose the value of dimension which has a value less than -10dB and widens the bandwidth.

## 3.6 Choosing the simulation software

When creating any new structure, prototype or system, simulating the design is very important in order to check its correctness, performance and results. For designing an antenna, the most used software’s are ANSYS HFSS and CST Microsoft Studio. The chosen software for simulating the antenna and observing its results is ANSYS HFSS.

**HFSS**

HFSS- High Frequency Structure Simulator is a software by ANSYS. It is used for simulating, solving and designing products which have high frequency electromagnetic full-wave structures. It is powerful, fast and accurate. Moreover, easy to learn for a beginner.

## 3.7 Determining antenna dimensions using Simulation

The steps mentioned above were carried out to design two antennas covering the ISM bandwidth and two antennas covering the ultrawide bandwidth. In both cases, one antenna is designed using jeans substrate and one is designed using polyester.

### 3.7.1 Antenna with ISM Bandwidth

**Using Jeans**

It has a thickness of 1mm with a dielectric constant of 1.7. Using the resonant frequency to be 5.8GHz, the length was found 20mm and width to be 21mm.

Firstly, the different lengths of ground were simulated, the partial ground helps in increasing the bandwidth [20] [21], and return loss was observed for the length of ground, lg=46mm which is a full ground and lg=18, 19, 19.5 and 21 mm.

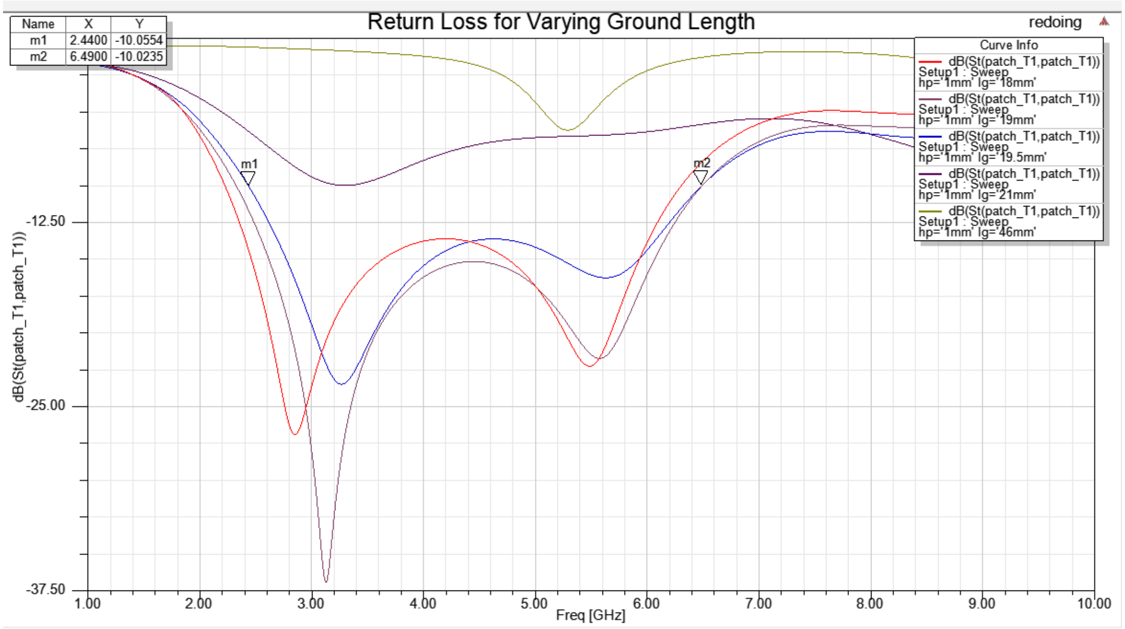



Figure 3.5: S11 Graph for ground length

By analysing the graph, it is interpreted that the layout 1 has a bandwidth of 2.44 to 6.49GHz.

Then the slots were added at the both left and right end corners of the patch to widen the bandwidth. The length of both the patch slots was kept constant at 1mm and their width was varied with 3, 5, and 7mm each.

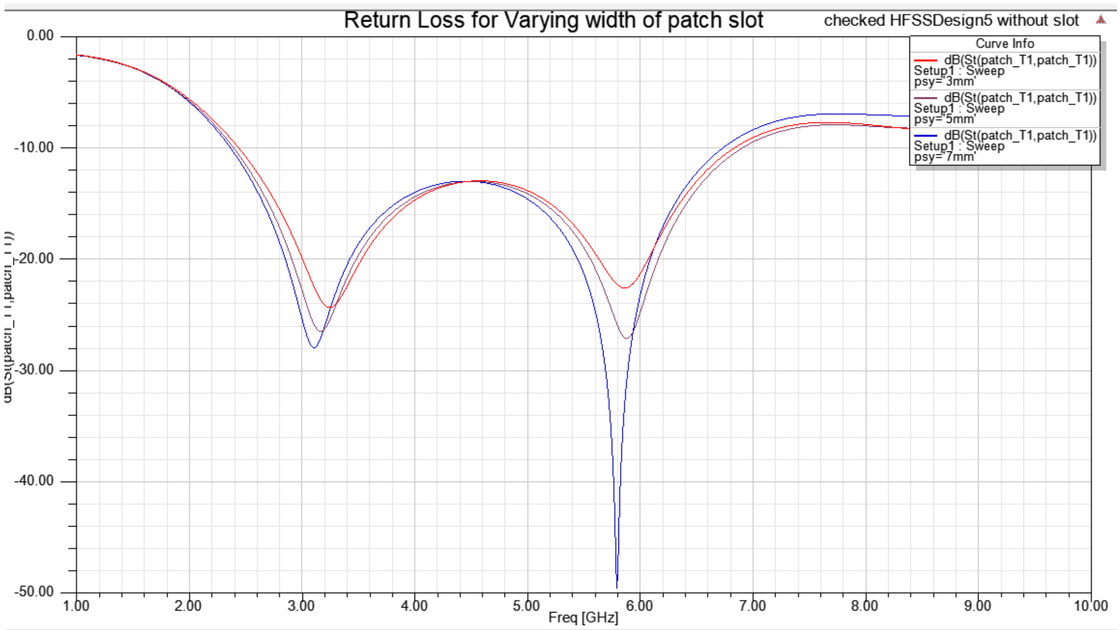



Figure 3.6: S11 Graph for width of patch slots

From the result, it is observed that the suitable width of slot is found to be 5mm, and the bandwidth has widened a little bit with 2.40 to 6.88GHz.

Lastly, slots are added to both sides of the feedline to expand the bandwidth and have better antenna performance. The slots were roughly added in the middle of the feedline, and their feed slot width was kept constant as 0.5mm but their lengths, fsx values were varied as 6, 4, 3 and 0.5mms each.

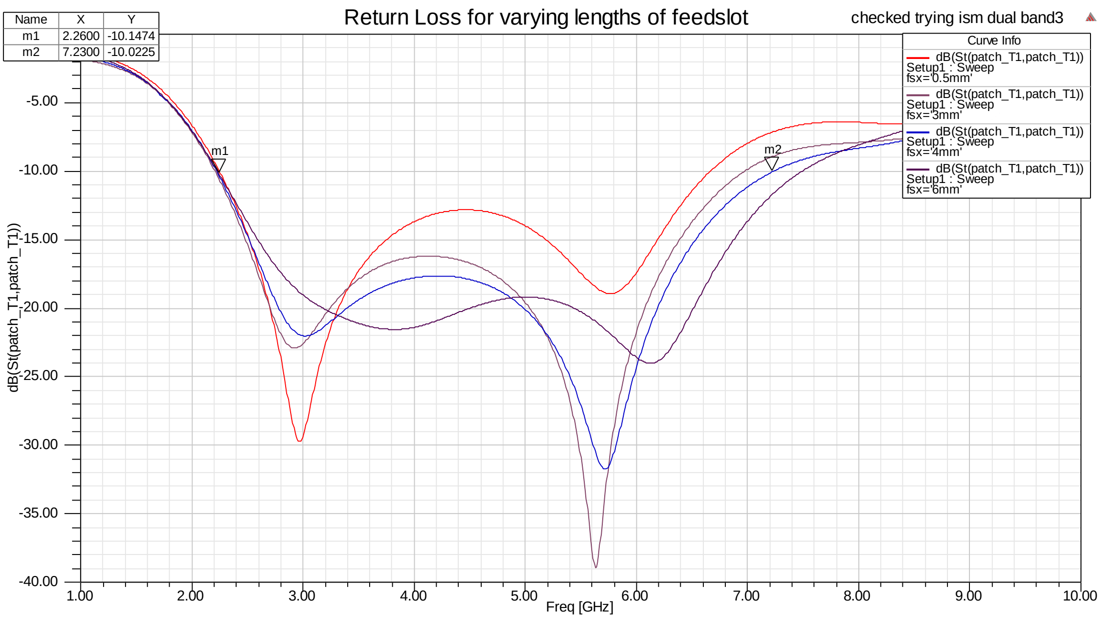



Figure 3.7: S11 Graph for length of feed slots

Observing the results, the starting frequency for all values is the same but ending frequency and the return loss depth are different. The feed slot length is chosen to be 4mm as it stretches bandwidth of 2.26 to 7.23GHz.

**Using Polyester**

The antenna patch's length, width and feedline dimensions were the same as the dimensions for jeans. Before carrying out layout 1, the substrate thickness to be 0.7 and result is observed, and then double and triple the thickness 1.4mm and 2.1mm is used to see the effect of stacking the substrate.

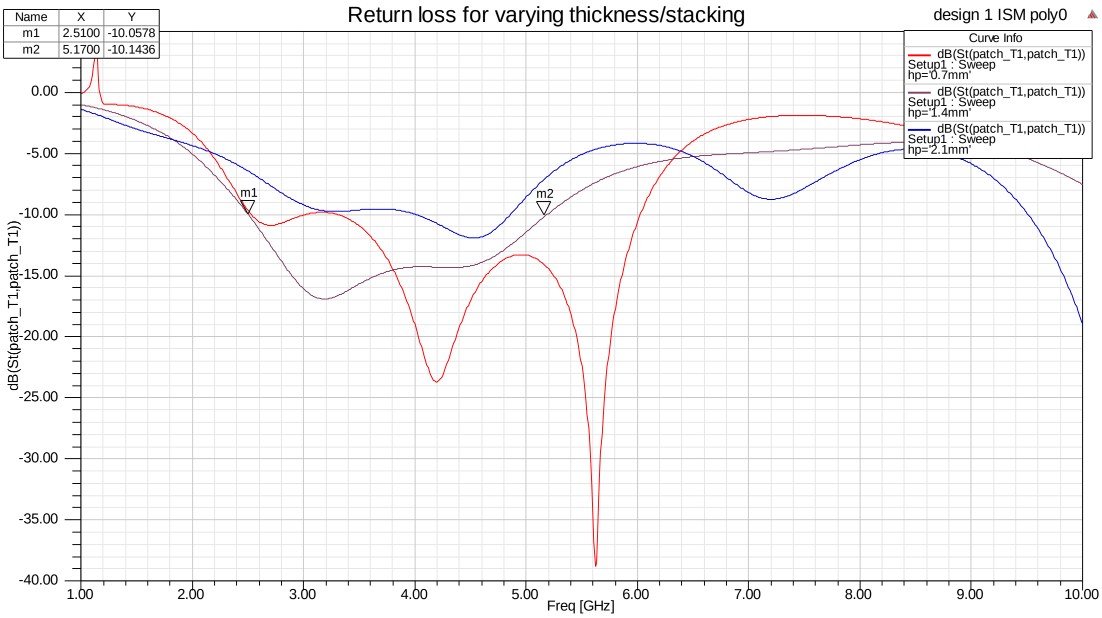


Figure 3.8: S11 for stacking purpose

Observing the graph, it is interpreted to use double the thickness for polyester, stacking method, giving 1.4mm as the substrate height, with the bandwidth of 2.51 to 5.17GHz

For layout 2, from the Jeans antenna, it is derived not to use full ground length, thus the values for ground to be analysed are 17, 18, 19.5 (same as jeans) and 21mm.

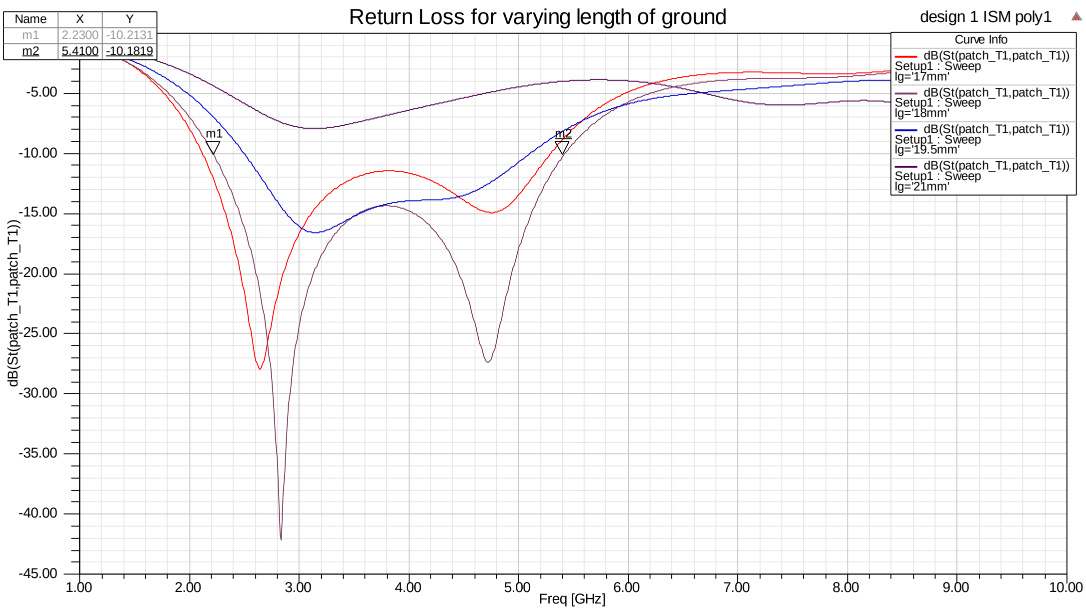


Figure 3.9: S11 for Ground Length

Analysing the graph, the Lg value is chosen to be 18mm expanding the bandwidth to 2.23 to 5.41GHz.

For, the corner patch slots' length is kept constant at 1mm, and different width values are simulated like 3, 4, 5 and 6mm each.

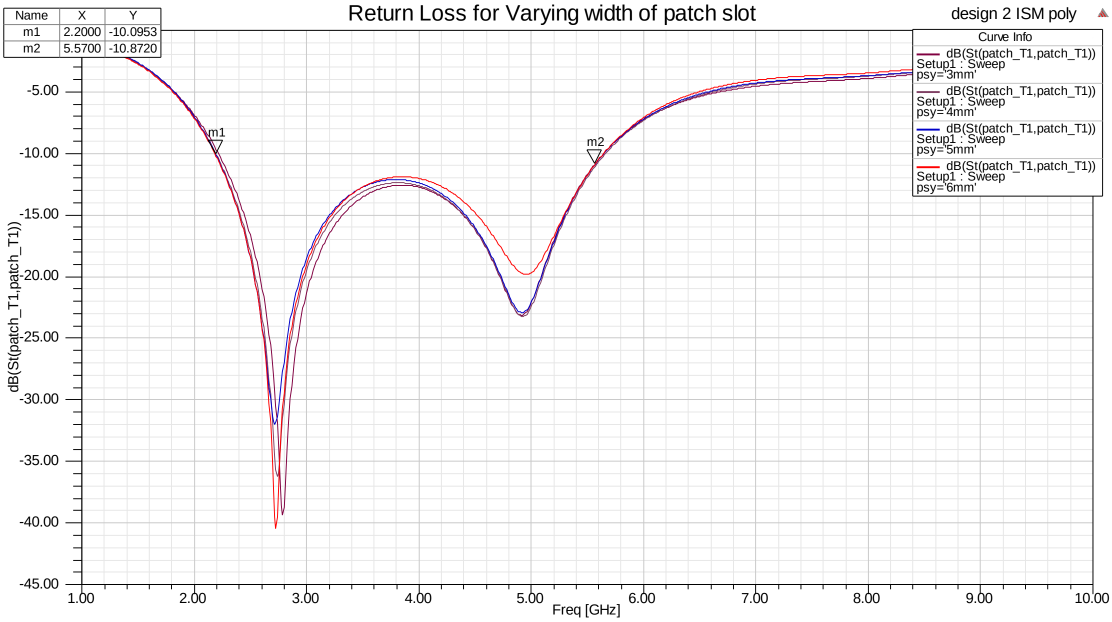



Figure 3.10: S11 Graph for patch slot

Looking at the graph, the patch sloth width's, psy all values give similar expansion to the bandwidth which is 2.22 to 5.57GHz but depending on the notch's sharpness, 3mm is chosen because at around 2.8 GHz it doesn't have as sharp notches as others and also at around 5GHz it doesn't have small notch like the 6mm graph.

For Layout 3, the feedline slots' width is kept constant to be 0.5mm, but the effect of width length, fsx is observed for values 0.5, 1, 3, 5 and 6mms each.

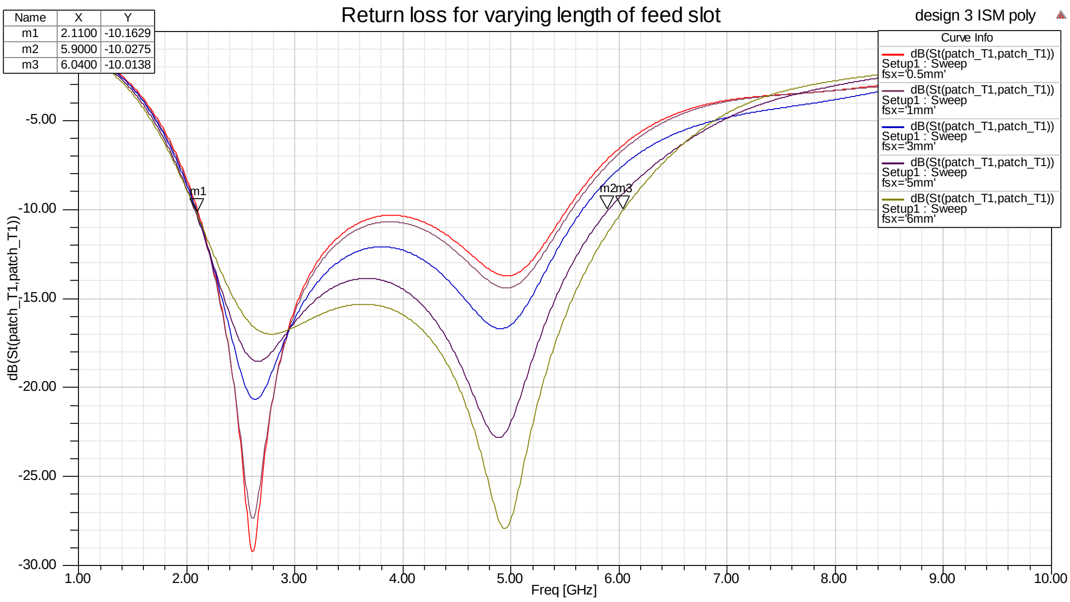



Figure 3.11: S11 Graph for Feed slot

Analysing the graph, a lot of variation is shown due to different values of the feed slots' length. Its value is chosen to be 5mm expanding the bandwidth to 2.11 to 5.90GHz with almost two notches on respective frequencies.

### 3.7.2 Antenna with Ultrawide Bandwidth

**Using Jeans**

Using the resonant frequency to be 5.8GHz, the length was found 14mm and width to be 15mm. Same steps will be followed as section 3.7.1. The effect of stacking is simulated by making the thickness of jeans doubled, from 1mm to 2mm.

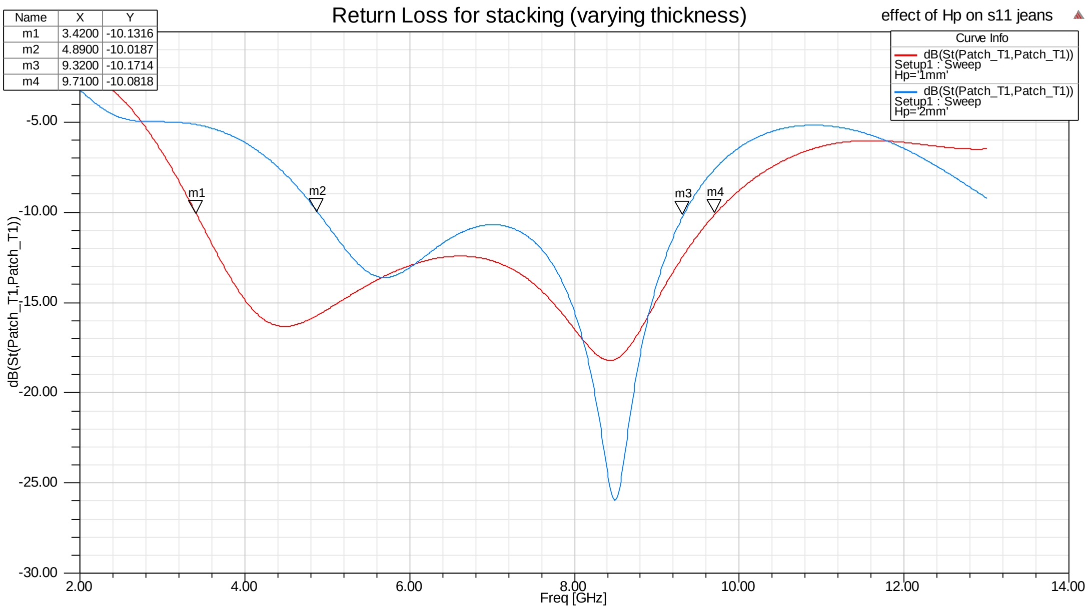



Figure 3.12: Graph for stacking

From the graph, it can be observed that the jeans substrate shows a wider bandwidth without being stacked.

For Layout 1, the effect of varying lengths of grounds was simulated, started with full ground to be 35mm, then partial ground values to be 11, 12, 13, 14 and 15mm

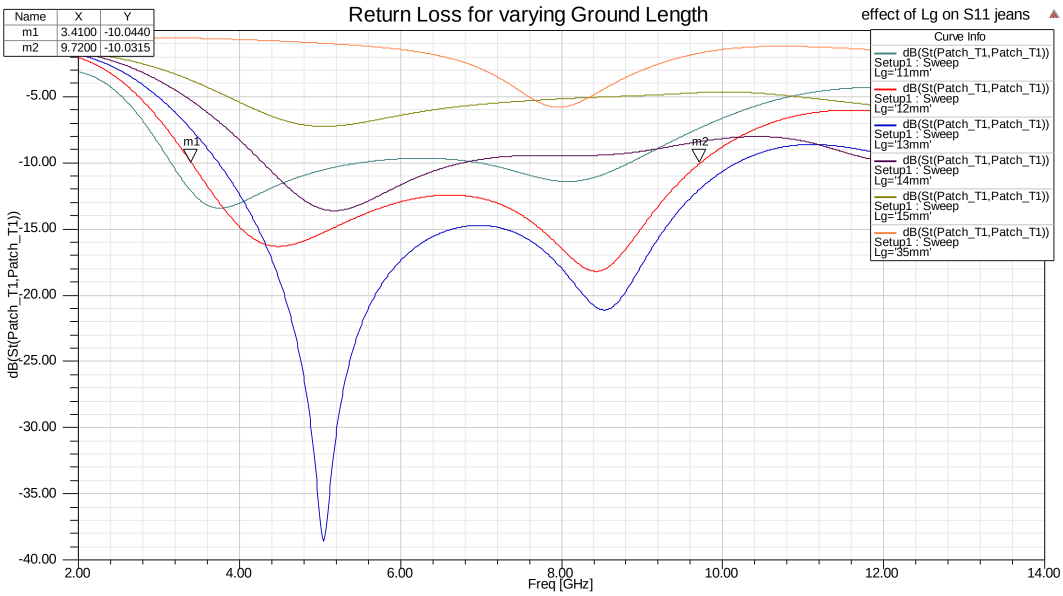



Figure 3.13: S11 Graph for ground lengths

Investigating the graph, it is shown that the most appropriate length of ground, lg is found to be 12mm with bandwidth from 3.41to 9.72GHz.

For Layout 2, the effect of slots on each bottom corner was observed by keeping the length of the slots constant at 1mm, and varying the width of the slots, psy for the values 1, 2, 3, 4, an 5mm on each side. (in the legend of the graph psy is denoted by ups).

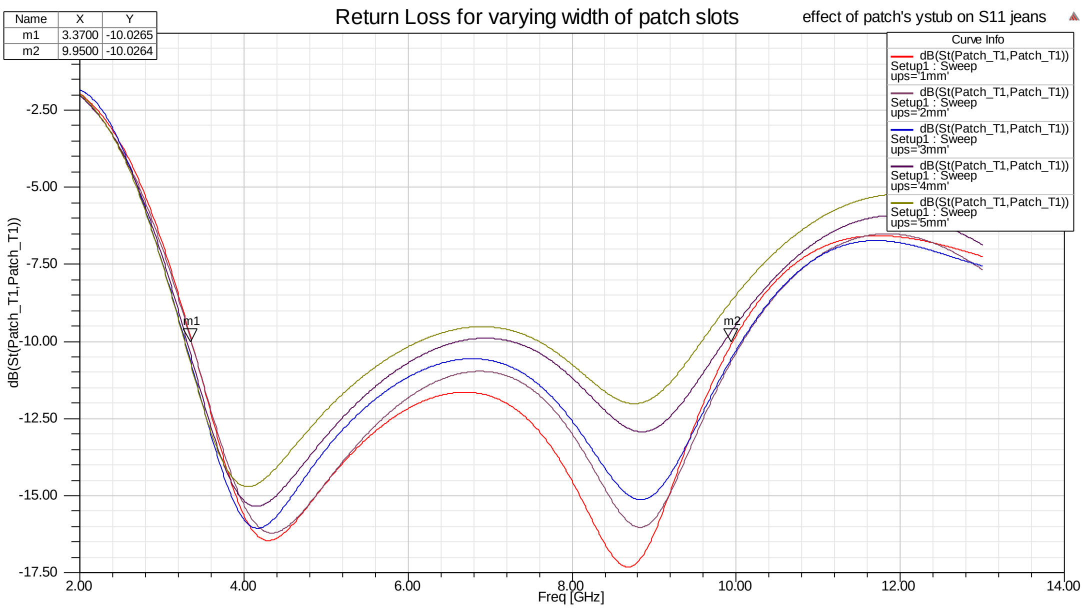



Figure 3.14: S11 Graph for Patch slots

From the graph, the width of the patch slots, psy of 1mm gives the least return loss value and bandwidth is widening from bandwidth of 3.37 to 9.95GHz

For Layout 3, The width of the feed slots, fsy is kept constant at 0.5mm, and the length, fsx was varied with values 0.5, 1, 2, 2.5 and 3mm on each side.

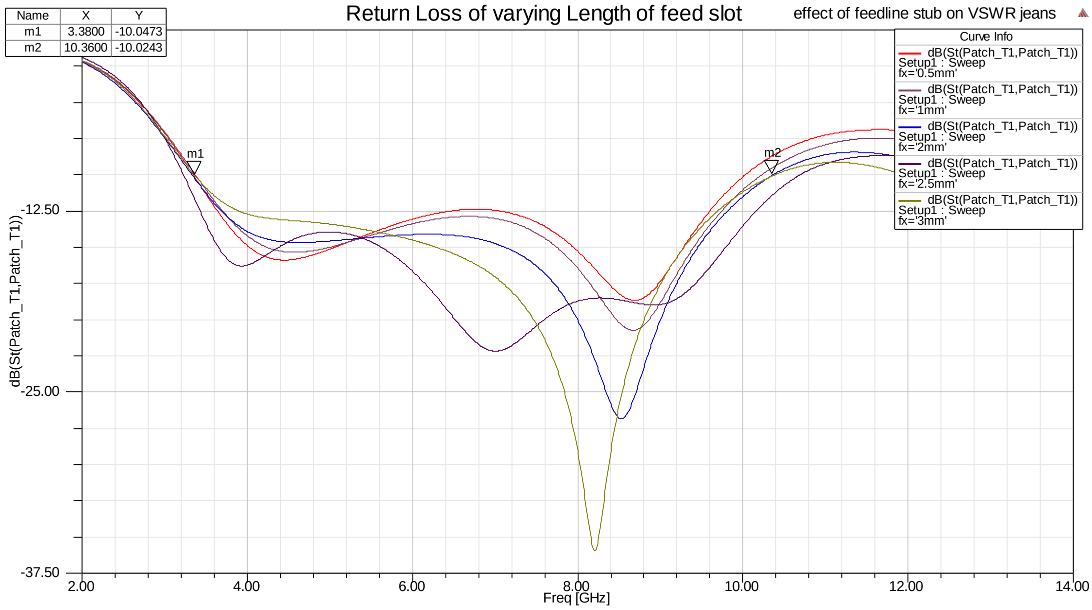


Figure 3.15: S11 Graph for feed slot

Analysing the graph, it is observed that feed slots' lengths give bandwidths which are very close to each other but then the sharpness of notches are different. For example, when fsx (labelled as fx in graph's legend) value is 2.5mm, it has three soft notches on different frequencies. When fsx is 3mm, it only has one sharp and steep notch at around 8.2GHz. The rest of the values have one sharper notch around 8GHz and one small around 4GHz. Thus, it can be said that depending upon which specific resonant frequency is required, the length of the feed slots can be altered. For this design, 2.5mm is chosen.

**Using Polyester**

As previously done in section 3.7.1, the thickness of polyester was doubled by considering stacking method, the values simulated were 0.7mm and 1.4mm.

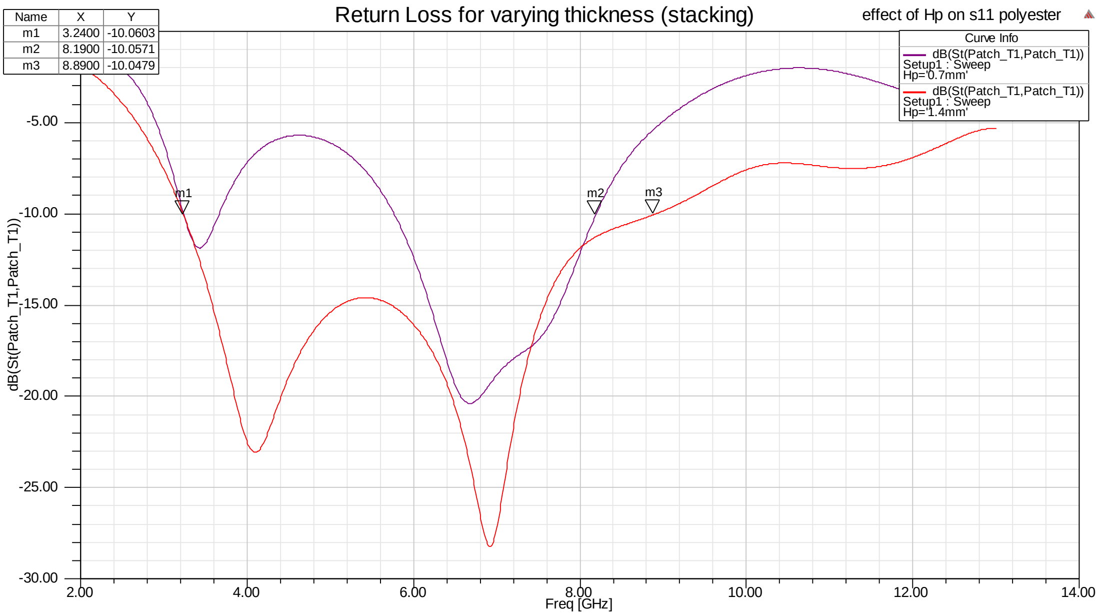



Figure 3.16: S11 Graph for stacking

From the graph, it is clear that double the thickness is good for better results.

For Layout 1, different lengths of ground were simulated having the values of 35mm for full ground and 11, 12 and 13mm for partial ground.

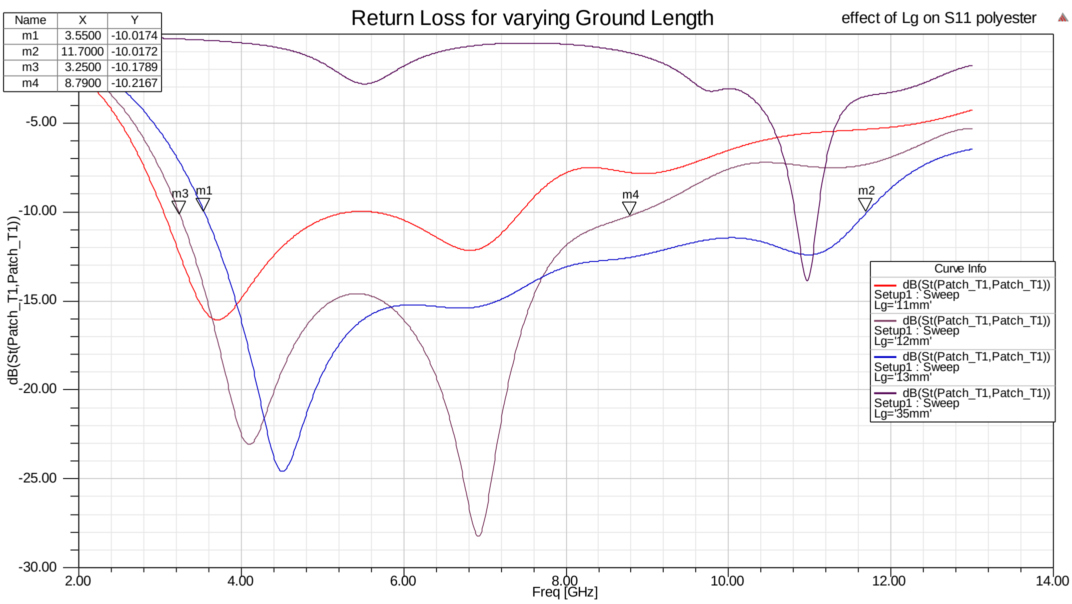



Figure 3.17: S11 Graph for Ground Lengths

It can be interpreted that the appropriate length of the ground is 12mm covering the bandwidth from 3.25 to 8.79GHz

For Layout 2, the length of the patch's slot is kept constant at 1mm and the width, psy is varied with values 1, 2, 3 and 4mms each.

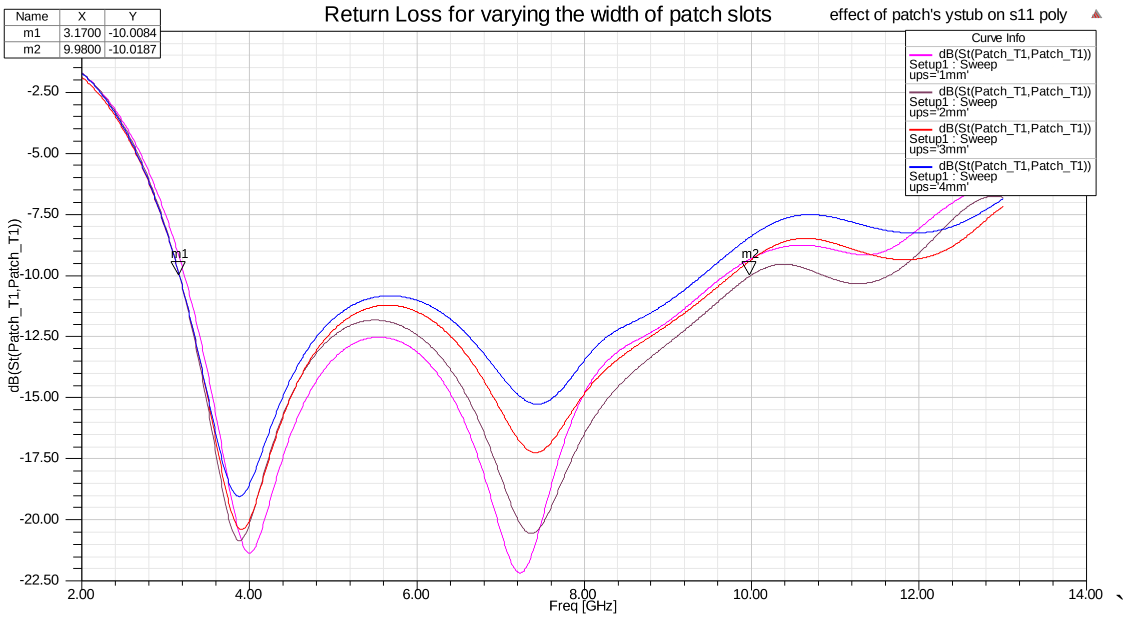



Figure 3.18: S11 Graph for feed slot

Observing the graph, the suitable width of patch slot, psy (in graph legend represented by ups) could be 1mm or 2mm) as 1mm gives lower notches but a slightly smaller bandwidth. In comparison, for 2mm the notches are a bit higher, but it expands the bandwidth from 3.17 to 9.98GHz, thus 1mm is chosen.

For Layout 3, the width of the feed slots, fsy is kept constant at 0.5mm and its length, fsx is varied at the values 1, 2, 2.5 and 3mm each.

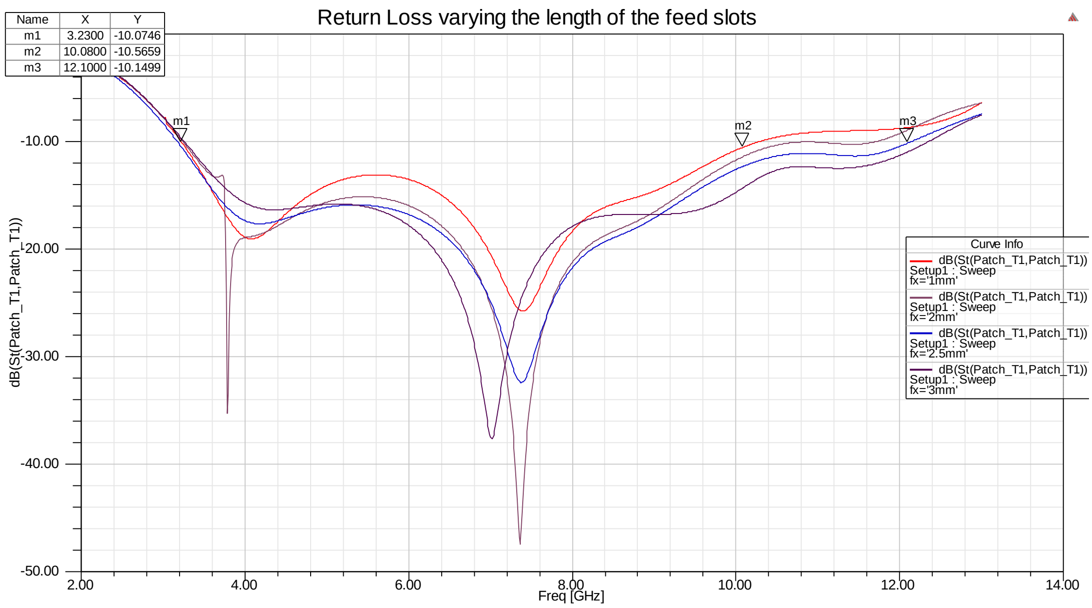



Figure 3.19: S11 Graph for feed slot

From analysing the graph, it is observed that 1mm gives the smallest bandwidth. For this design of antenna, 2.5mm is chosen to achieve an ultra-wide bandwidth of 3.23 to 12.1GHz.

## 3.8 Summary of All Antenna Design Dimensions

This section includes the summary of all antenna dimensions and their view. The substrate has a transparency that is why the front view(patch) and the back view (ground) can be seen from the front view.

### 3.8.1 Antennas for ISM Bandwidth

Table 3.1: Dimensions for Jeans and Polyester (ISM Bandwidth)

| | Jeans | Polyester |
|---|---|---|
| Section of the Antenna | Value (mm) | Value (mm) |
| Length of Patch | 20 | 20 |
| Width of Patch | 21 | 21 |
| Thickness of Substrate | 1 | 1.4 |
| Length of Feedline | 22 | 22 |
| Width of Feedline | 3 | 3 |
| Length of Ground, lg | 19.5 | 18 |
| Length of Patch Slot, psx | 1 | 1 |
| Width of Patch Slots, psy | 5 | 3 |
| Length of Feed Slots, fsx | 4 | 5 or 4 |
| Width of Feed Slots, fsy | 0.5 | 0.5 |

### 3.8.2 Antennas for Ultrawide Bandwidth

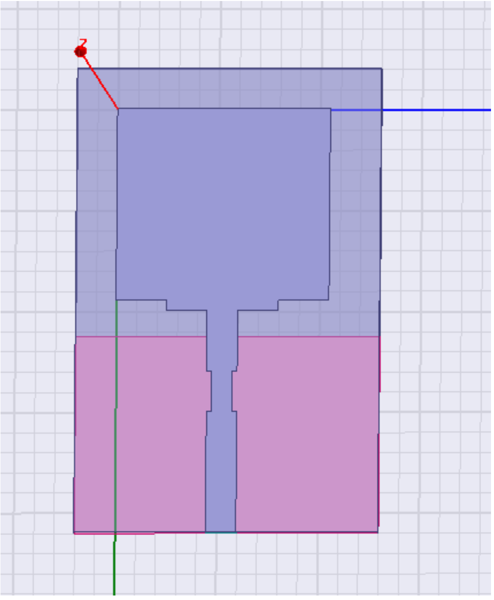
Table 3.2: Dimensions for Jeans and Polyester (Ultrawide Bandwidth)

| | Jeans | Polyester |
|---|---|---|
| Section of the Antenna | Value (mm) | Value (mm) |
| Length of Patch | 14 | 14 |
| Width of Patch | 15 | 15 |
| Thickness of Substrate | 1 | 1.4 |
| Length of Feedline | 14 | 14 |

| | | |
|---|---|---|
| Width of Feedline | 3 | 3 |
| Length of Ground, lg | 12 | 12 |
| Length of Patch Slot, psx | 1 | 1 |
| Width of Patch Slots, psy | 1 | 2 |
| Length of Feed Slots, fsx | 0.5 | 0.5 |
| Width of Feed Slots, fsy | 2.5 | 2.5 |

### 3.9 Final Layout of all Antennas

3.9.1 ISM Antennas



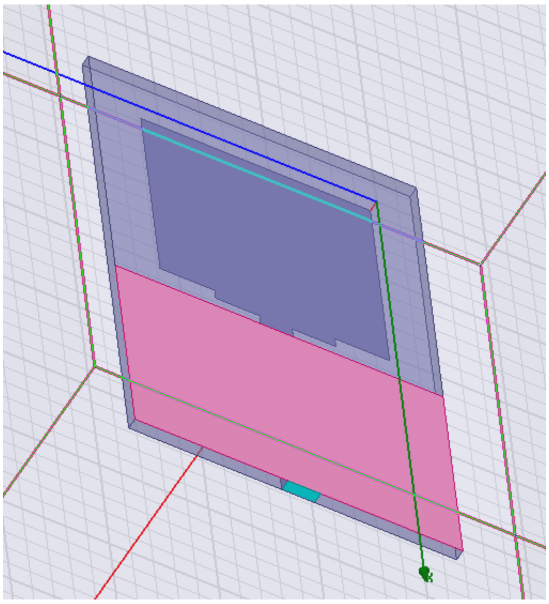
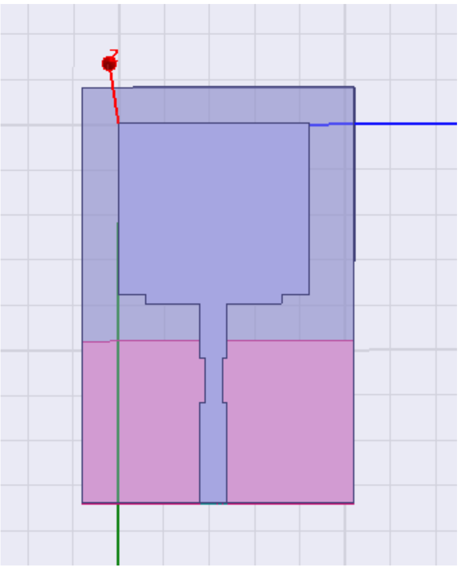


Figure 3.20: (Left) Front View of ISM Jeans Antenna
Figure 3.21: (Right) Back and Side View of ISM Jeans Antenna



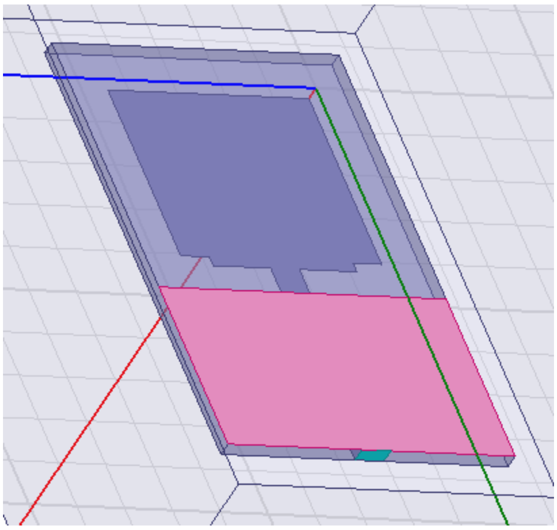
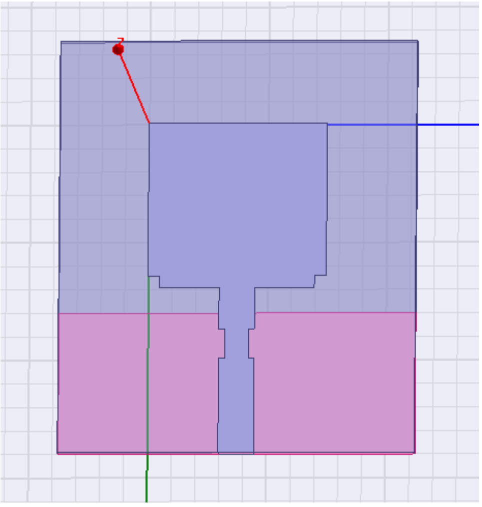


Figure 3.22: (Left) Front View of ISM Polyester Antenna
Figure 3.23: (Right) Back and Side View of ISM Polyester Antenna

### 3.9.2 UWB Antennas



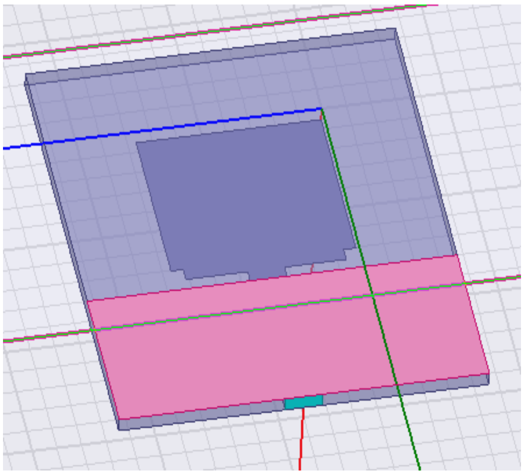
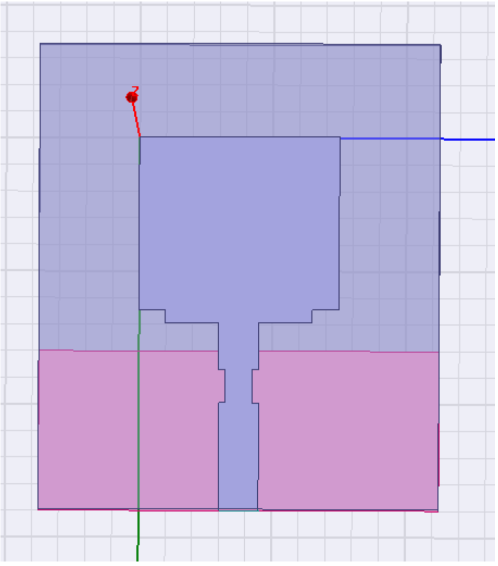


Figure 3.24: (Left) Front View of UWB Jeans Antenna
Figure 3.25: (Right) Back and Side View of UWB Jeans Antenna



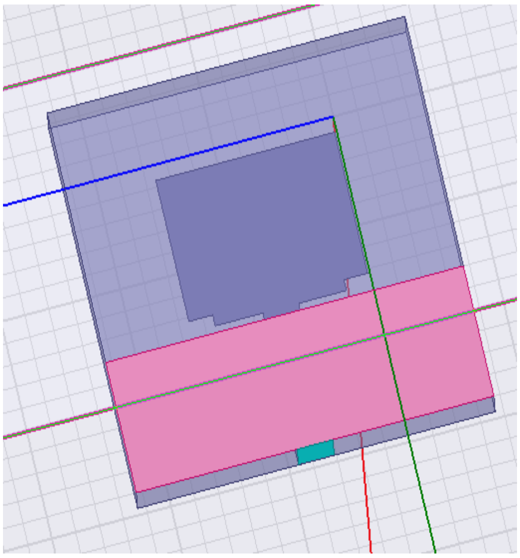


Figure 3.26: (Left) Front View of UWB Polyester Antenna
Figure 3.27: (Right) Back and Side View of UWB Polyester Antenna

# Chapter 4. **RESULTS AND DISCUSSION**

This chapter includes the final results for all four antennas designed in chapter 3. Each testing parameter of an antenna is defined first, then graph/result of that parameter, is shown for all four antennas.

*Note: The figures are high in definition and quality; this document can be zoomed in for clarity.*

## 4.1 Return Loss

Return loss, S11 is an important antenna parameter to be observed for antenna's performance. It shows the power loss in the signal which is reflected by a transmission line. For ensuring a good performance the return loss should be below -10dB [3] [6].

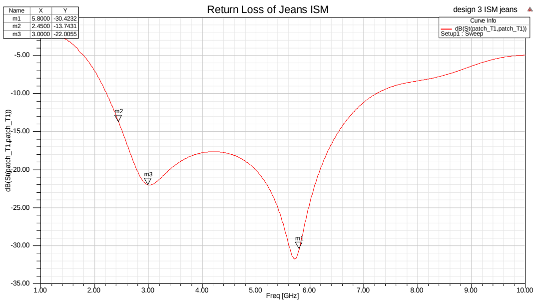



Figure 4.1: Return Loss for Jeans (ISM)

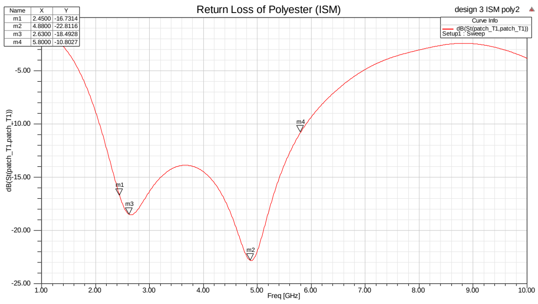



Figure 4.2: Return Loss for Polyester (ISM)

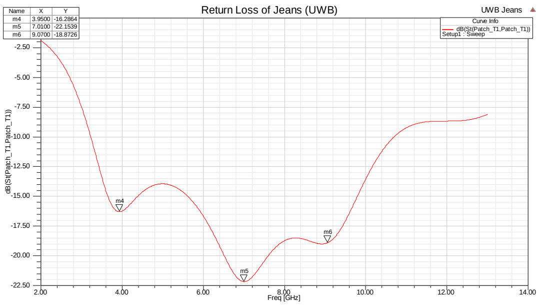



Figure 4.3: Return Loss for Jeans (UWB)

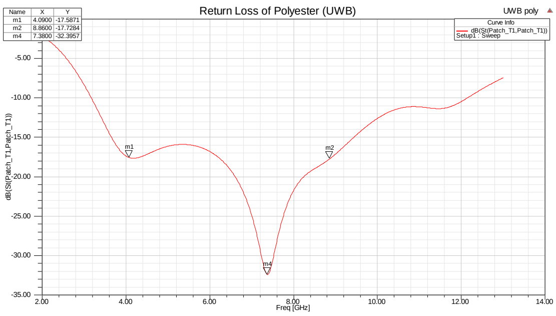



Figure 4.4: Return Loss for Polyester (UWB)

In the case of ISM bandwidth, it was necessary to have return loss value less than -10dB for ISM frequencies of 2.45GHz and 5.8GHz, which was obtained.

- For the Jeans (ISM) antenna, there were two sharp notches observed, at 3GHz and 5.73GHz with a return loss (S11) value of -22dB and -31.68dB. The frequency 2.45GHz has -13.74dB and 5.8GHz has -30.42dB of return loss.

- For the Polyester (ISM) antenna, there were two sharp notches observed, at 2.63GHz and 4.88GHz with a return loss (S11) value of -18.49dB and -22.81dB. The frequency 2.45GHz has -16.73dB and 5.8GHz has -10.8dB of return loss.
    - If 2.45GHz is supposed to be used, then polyester antenna is supposed to be used as it has a lower return loss in comparison to jeans.
    - If 5.8GHz is supposed to be used, then jeans antenna is supposed to be used as it has a lower return loss in comparison to polyester.

In the case of UWB bandwidth, it was necessary to cover have wide range of frequencies having return loss value less than -10dB which was obtained.

- For the Jeans (UWB) antenna, there were three notches observed, at 3.95GHz, 7.01GHz and 9.07GHz with a return loss (S11) value of -16.28dB, -22.15dB and -18.87dB.
- For the Polyester (UWB) antenna, there is sharp notch at 7.38GHz with a return loss (S11) of -32.4dB and a soft notch at 4.09GHz at -17.72dB.
    - Depending upon the application and its frequency, either jeans or polyester antenna can be chosen.

## 4.2 Bandwidth

The bandwidth of an antenna is the range of frequency at which the antenna can operate. If the range is small, then its known as narrow bandwidth and if the range is large then its known as wide bandwidth [24].

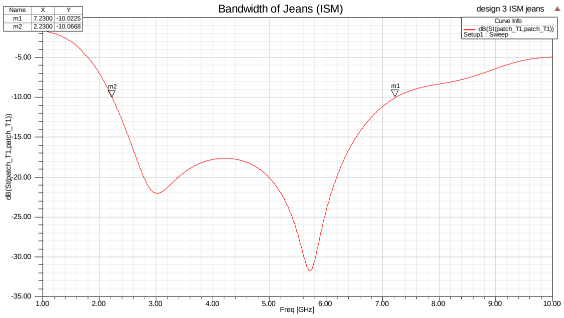



Figure 4.5: Bandwidth for Jeans (ISM)

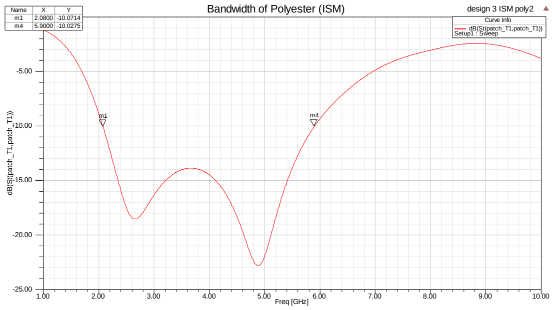
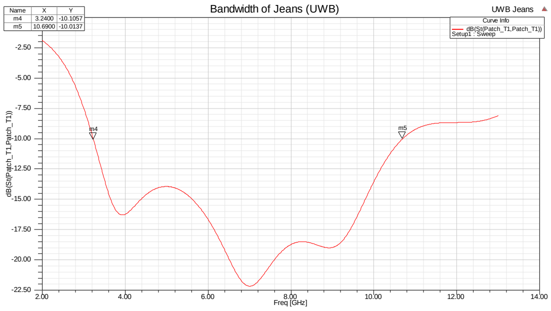



Figure 4.6: Bandwidth for Polyester (ISM)



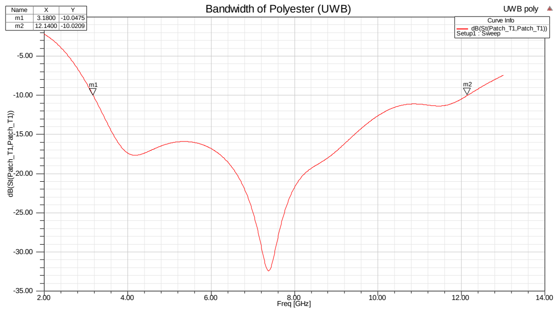
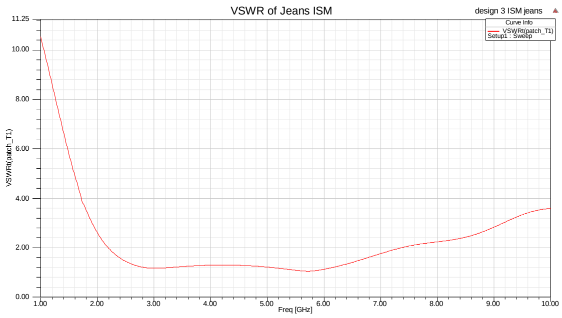




Figure 4.7: Bandwidth for Jeans (UWB)     Figure 4.8: Bandwidth for Polyester (UWB)

- The bandwidth of Jeans ISM antenna ranges from 2.23 to 7.23GHz. It has a bandwidth of 5GHz.
- The bandwidth of Polyester ISM antenna ranges from 2.08 to 5.9GHz. It has a bandwidth of 3.82GHz.
- The bandwidth of Jeans UWB antenna ranges from 3.24 to 10.69GHz. It has a bandwidth of 7.45GHz.
- The bandwidth of Polyester UWB antenna ranges from 3.18 to 12.14GHz. It has a bandwidth of 8.96GHz.

### 4.3 VSWR

Voltage Standing Wave Ratio is a parameter which defines the reflected power of the antenna and determines the impedance mismatch at the feedline and patch intervals. The VSWR value is always positive [6]. The value should be in the range 1 to 2 [19]. The ideal value is 1, which means no power is reflected [6].



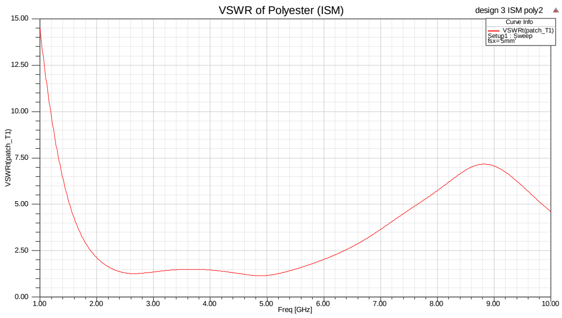




Figure 4.9: VSWR for Jeans (ISM)     Figure 4.10: VSWR for Polyester (ISM)


Figure 4.11: VSWR for Jeans (UWB)

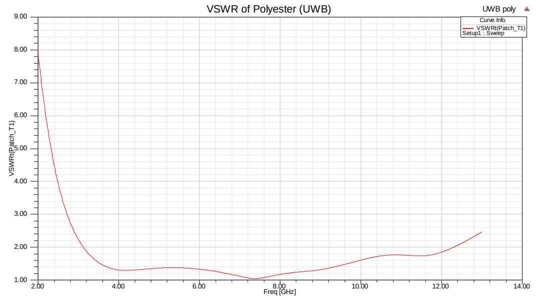
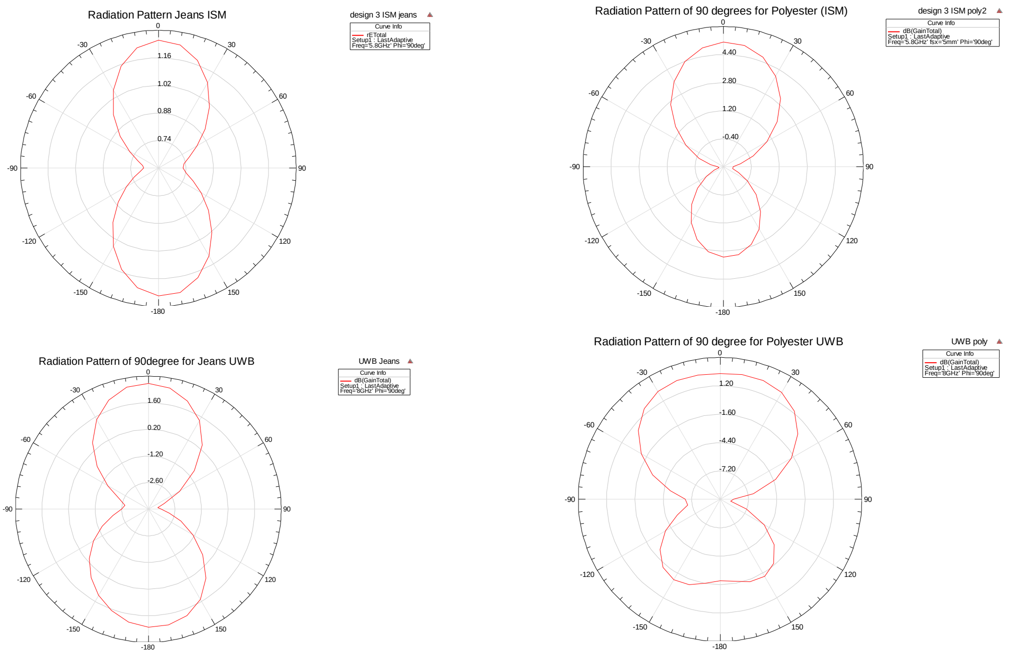



Figure 4.12: VSWR for Polyester (UWB)

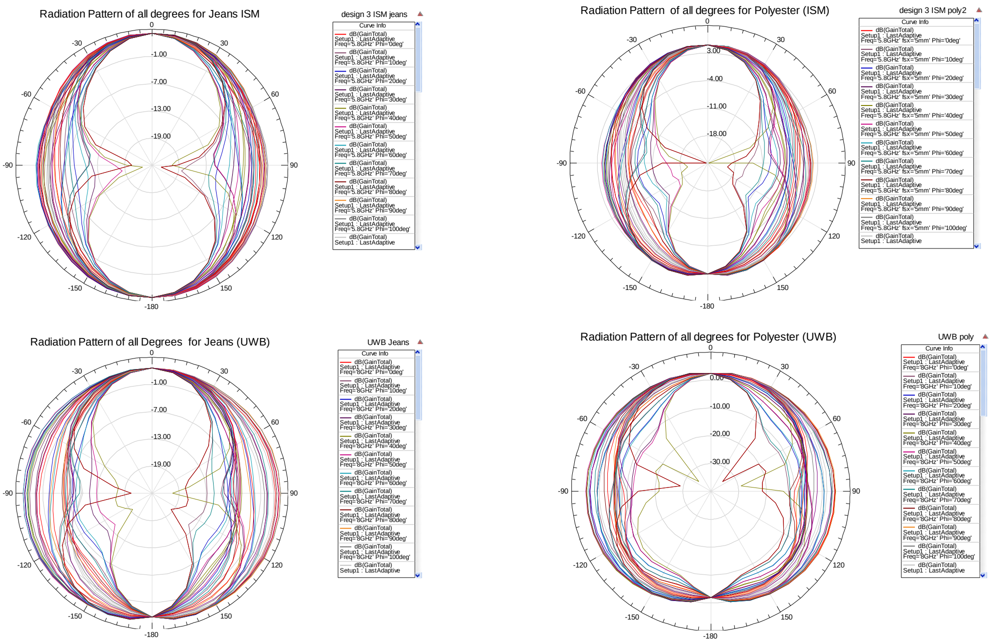
The VSWR graphs of all four antennas show that the VSWR is between 1 to 2, for their entire bandwidth, which is in the optimum range.

## 4.4 Radiation pattern

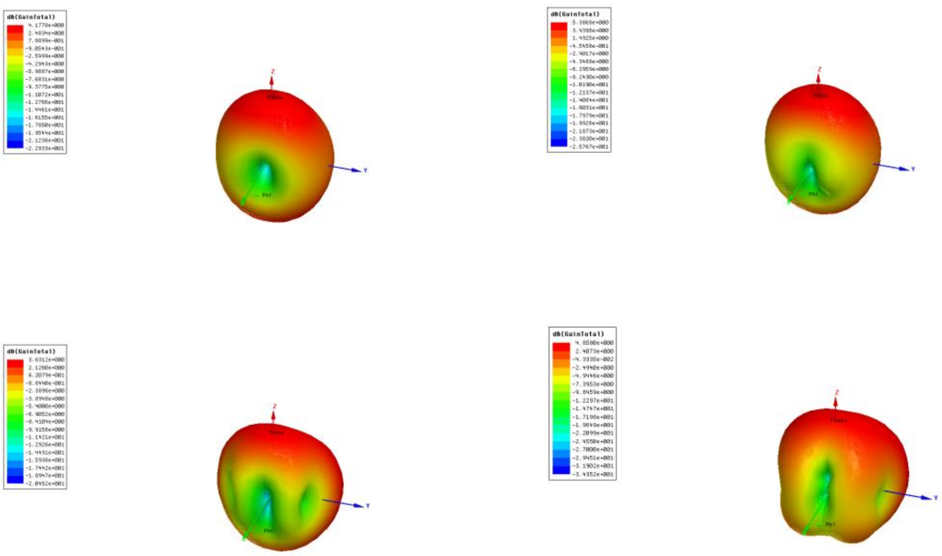
It is the graphical representation describing the radiation power of the antenna in the far field area [2] [9]. The following are the radiation pattern 2D graph for 90degrees angle and all angles, and 3D polar plot.




Figures 4.13 to 4.16: Radiation pattern at 90 degrees for all antennas (graphs are labelled)




Figures 4.17 to 4.20: Radiation pattern at all degrees for all antennas (graphs are labelled)



Figures 4.21 to 4.24: 3D plots for all antennas

(Left Top) Jeans ISM

(Right Top) Polyester ISM

(Left Bottom) Jeans UWB

(Right Bottom) Polyester UWB

### 4.5 Computed Antenna Parameters

There are several antenna parameters, like its gain, directivity and efficiency. The table in the figure below is computed by the HFSS software. It presents the parameters of the operating antenna.

<u>For ISM Antennas</u>

Antenna Parameters:

| Quantity | Freq | Value |
|---|---|---|
| Max U | 5.8GHz | 0.0020806 W/sr |
| Peak Directivity | | 2.7995 |
| Peak Gain | | 2.6169 |
| Peak Realized... | | 2.6146 |
| Radiated Power | | 0.0093393 W |
| Accepted Power | | 0.0099912 W |
| Incident Power | | 0.01 W |
| Radiation Effici... | | 0.93475 |
| Front to Back R... | | 1.0221 |
| Decay Factor | | 0 |

Figure 4.25: Parameters for Jeans (ISM)

Antenna Parameters:

| Quantity | Freq | Value |
|---|---|---|
| Max U | 5.8GHz | 0.0024009 W/sr |
| Peak Directivity | | 3.2697 |
| Peak Gain | | 3.2902 |
| Peak Realized... | | 3.0171 |
| Radiated Power | | 0.0092275 W |
| Accepted Power | | 0.0091699 W |
| Incident Power | | 0.01 W |
| Radiation Effici... | | 1.0063 |
| Front to Back R... | | 2.0495 |
| Decay Factor | | 0 |

Figure 4.26: Parameters for Polyester (ISM)

Antenna Parameters:

| Quantity | Freq | Value |
|---|---|---|
| Max U | 8GHz | 0.0018118 W/sr |
| Peak Directivity | | 2.4426 |
| Peak Gain | | 2.3074 |
| Peak Realized... | | 2.2769 |
| Radiated Power | | 0.0093213 W |
| Accepted Power | | 0.0098678 W |
| Incident Power | | 0.01 W |
| Radiation Effici... | | 0.94462 |
| Front to Back R... | | 5.0406 |
| Decay Factor | | 0 |

Figure 4.27: Parameters for Jeans (UWB)

Antenna Parameters:

| Quantity | Freq | Value |
|---|---|---|
| Max U | 8GHz | 0.0024191 W/sr |
| Peak Directivity | | 3.0174 |
| Peak Gain | | 3.0605 |
| Peak Realized... | | 3.04 |
| Radiated Power | | 0.010075 W |
| Accepted Power | | 0.009933 W |
| Incident Power | | 0.01 W |
| Radiation Effici... | | 1.0143 |
| Front to Back R... | | 10.043 |
| Decay Factor | | 0 |

Figure 4.28: Parameters for Polyester (UWB)

# Chapter 5. **CONCLUSION**

There were four wearable textile antennas designs proposed, all of which have the same geometrical design but different dimensions. These four antennas were divided into two categories; ISM antennas which have a bandwidth covering both; 2.45GHz and 5.8GHz of frequencies, and UWB antennas which have bandwidth greater than 7GHz. For each category, there were two antennas, one with jeans as a substrate the other with polyester as a substrate. These textile materials, used as substrates, can commonly be worn by people of all ages and in almost all locations. The frequencies at which these antennas operate are supported by numerous applications, devices and systems. Thus, this antenna can be used in fields of medical, science and entertainment, for different purposes like location tracking, health monitoring, smart watches, satellites, radar, safety, electromagnetic imaging, and many other systems which require wireless communication. The designing of all the antennas is done on HFSS and is evaluated by the return loss which is lower than -10dB and VSWR being less than 2, for the frequencies included in the bandwidth, thus validating the criteria of an effective antenna. The gain, directivity, radiation pattern and radiation efficiency were also presented. All the performance parameters are acceptable, therefore, ensuring the good performance. The textile antenna is wearable for long duration with great comfort as it is flexible and lightweight and is hidden due to its small size.

The future work of this include the implementation of the antenna, using copper taffeta as the conductive material and the substrate, polyester or jeans. The copper taffeta is a textile which has properties of copper. These could be attached to each other using conductive glue or sewing (the fabrication methods are discussed in [13]). The SMA connector would be used to test the antenna with the Vector Network Analyser.

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# APPENDIX A: PROJECT PROPOSAL

| 1. Candidate Details | |
|---|---|
| **Name:** Umm Kulsoom Emad | **Student No:** 5529657 |
| **Supervisor:** Dr. Mohd Fareq Abd Malek | |
| **Title of Project:**<br><br>Wearable Antenna for Triple Band | |

1. **Brief Overview:**

There is an ongoing high demand for wearable technology for applications like health monitoring, location tracking, smart watches, biosensors, contactless card payments, smart soldiers, etc. In order to achieve these, importance of wireless communication has increased which can be implemented using wearable antennas. Wearable devices are required to be small and comfortable to wear such as textiles, which can be flexible and lightweight [1].

The proposed wearable antenna will operate at triple bands to achieve novelty for various applications.

**2. Project Description:**

With the advancements of technology, communications are becoming wireless and are required in various Industrial, Scientific and Medical applications. A wearable antenna is proposed to operate at triple bands efficiently for aiding the wireless communications.

A textile based wearable antenna can be incorporated in a garment to be worn as it provides the ease of movement and flexibility. A suitable substrate is to be chosen after considering its dielectric constant. This antenna would be able to transmit data at required frequency, designed to fulfil the requirement for various real time applications in which the communication link has to be strong and reliable in any environment. [3]

**3. Project Plan**

Extensive research would be done, by referring to different studies discussed in journals, research papers, conferences and reliable primary/secondary sources, to attain the functionality. Furthermore, different designs are simulated in ANSYS HFSS to check the operation parameters, then the design would be implemented using materials, followed by testing the antenna's performance.

*Table 1: Project Plan for Thesis 2 (ECTE458)*

| Weeks | Description |
|---|---|
| 1-2 | Researching about the possible changes and improvements |
| 3-4 | Working on new designs and resubmission of proposal |
| 5-6 | Continue working on new designs and altering the software design |
| 6-8 | Implementing the hardware and testing it |
| 8-11 | Working on the thesis report by rewriting the chapters |
| 12-13 | Drafting and submitting the final thesis report |

**4. Resources Required:**

The software ANSYS HFSS is used to design and test the antenna functionality.
Hardware like denim fabric textile, copper taffeta, conductive glue is used to make the antenna.
Vector Network Analyzer and SMA connector is used for testing the implemented antenna and evaluating its performance.

**5. Literature Planner:**

Attach as an appendix

**6. Mind Map:** (single A4 page)

Attach as an appendix

**Student Signature**
***Declaration by the student: I have understood the feedback provided to me by the supervisor.***

| | Signature | Date |
|---|---|---|
| **Student Name:**<br><br>Umm Kulsoom Emad | Kulsoom | **18/02/20** |

**Section 5: Literature Planner**

Reference Number: 1
**Authors:** Pavel Schilingovski, Vladimir Vulfin, Shai Sayfan-Altman and Reuven Shavit
**Title of Article:** Wearable Antennas Design for Wireless Communication
**Type:** Conference Publication: IEEE
**Year Published:**
**What themes were discussed in the Literature Review?**
Wearable Antenna, Bluetooth/Wifi, Antenna on jeans, Human-body, ANSYS HFSS
**What was the research question?**
Designing textile antenna for enhancing the communication range
**Design:**
Microstrip patch antenna on jeans substrate, F shaped, for hearing aid
**What was the finding?**
Two types of antennas:

1. Copper with radiation losses of 0.6dB
2. Conductive Garment with radiation losses of 0.9dB

For increasing the bandwidth, use a thicker substrate
**What were the gaps?**
Copper adds weight, it is stiff and visible

Reference Number: 2
**Authors**: George Hardesty
**Title of Article:** ISM Band of Frequencies and Allocation
**Type:** Website
**Link:** https://www.data-alliance.net/blog/ism-band-of-frequencies-and-allocation/
**Year Published:** 2019
**What themes were discussed in the Literature Review?**
ISM bands, equipments, consumer devices, radio frequencies
**What was the research question?**
Difference between 2.4GHz and 5GHz of ISM bands
**Design:**
None
**What was the finding?**
There is no need of licensing required to use the 2.4GHz band.
Using a designated frequency contributes to almost zero or no interference.
**What were the gaps?**
Consumers are supposed to abide by the rules and regulations set by the authorities to ensure safety and avoid interference.

Reference Number: 3
**Authors:** Et al. M. Ali, G. Biffi Gentili, C. Salvador , A. Toccafondi, F. Zani
**Title of Article:** Design and Analysis of a Wearable Antenna System for Wireless Safety Applications
**Type:** Conference
**Publication:** 2015 9th European Conference on Antennas and Propagation (EuCAP)
**Year Published:** 2015
**What themes were discussed in the Literature Review?**
Wearable antennas, dipole antenna, safety systems, human body model, simulations, CST studio software
**What was the research question?**
Analysing small antenna for applications in wireless safety location and tracking of human worker via electromagnetic simulations
**Design:**
Dipole antenna positioned in shoe at a frequency of 2.45GHz

**What was the finding?**
The antenna gives better result when positioned at front-back arrangement when compared to left-side arrangement
**What were the gaps?**
There is a monotonic decreasing in the power received

Reference Number: *not mentioned in this paper*
**Authors:** Albert Sabban
**Title of Article:** Small New Wearable Antennas for IOT, Medical and Sport Application
**Type:** Conference
**Publication** 2019 13th European Conference on Antennas and Propagation (EuCAP)
**Year Published:** 2019
**What themes were discussed in the Literature Review?**
Printed antennas, Body Area Network, metamaterial, Split Ring Resonator
**What was the research question?**
Passive and active wearable antennas for IOT, medical and sport applications
**Design:**
Fractal metamaterial antenna of 3.7GHz with SRR which is printed on a substrate of 2.2 dielectric constant. Dual band antenna of 5GHz with SRR which is printed on the above-mentioned substrate. Ultra-wide banded fractal antenna which is T shaped.
**What was the finding?**
The active antenna gain is 12±2dB for frequencies between 1GHz to 2.5GHz.
**What were the gaps?**
The size of the slot antenna may be reduced to adjust the centre antenna frequencies

Reference Number: *not mentioned in this paper*
**Authors:** Albert Sabban
**Title of Article:** Small Wearable Antennas for Wireless Communication and Medical Systems
**Type:** Conference
**Publication:** 2018 IEEE Radio and Wireless Symposium (RWS)
**Year Published:** 2018
**What themes were discussed in the Literature Review?**
Fractal antenna, metamaterial, split ring resonators, ADS Software
**What was the research question?**
New technologies for designing antennas like meta material and fractal printed antennas
**Design:**
Fractal antenna was printed on a substrate of 2.2 dielectric constant. A patch radiator is printed on a substrate of 4.5 dielectric constant. The distance between the two layers can be adjusted to get wider bandwidth. T shaped antenna was also suggested.
**What was the finding?**
The gain and directivity of the patch antenna with SRR is better than the one without SRR.
The wearable slot antenna bandwidth is 57% for VSWR 2:1 and 90% for VSWR 3:1 and gain is 3dBi.
The fractal antenna gain is around 8dBi with 90% efficiency
**What were the gaps?**
The volume of all the antennas mentioned could be reduced by optimizing the feed network configuration.

**Section 6: Mind Map**

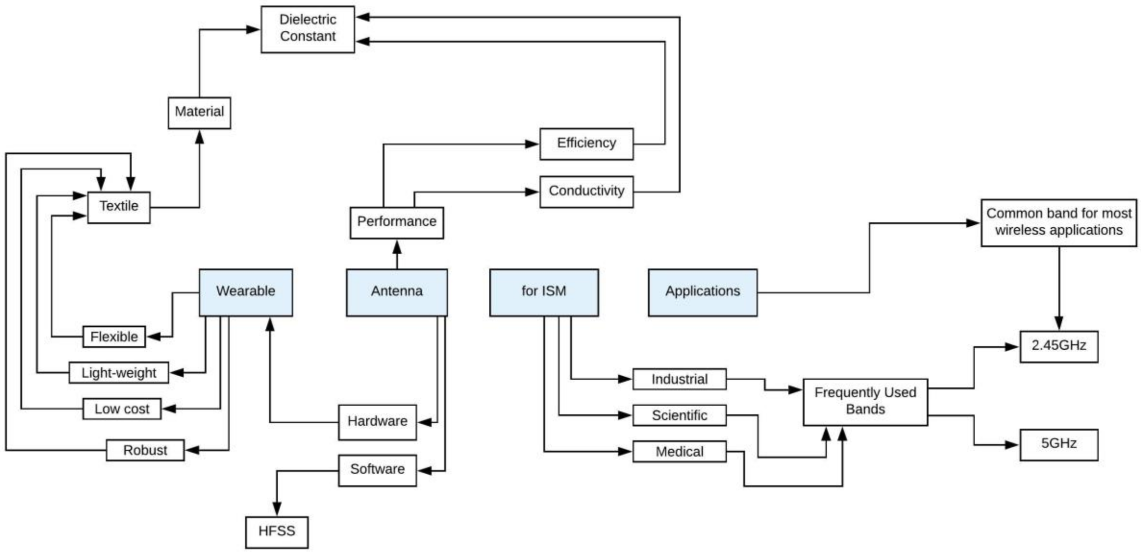


*Figure 1: Mind-map*

## References


[1] P. Schilingovski, V. Vulfin , S. Sayfan-Altman, and R. Shavit, "Wearable antennas design for wireless communication," *2017 IEEE International Conference on Microwaves, Antennas, Communications and Electronic Systems (COMCAS)*, 2018.

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**Only in Literature Planner**

A. Sabban, "Small wearable antennas for wireless communication and medical systems," *2018 IEEE Radio and Wireless Symposium (RWS)*, 2018.

A. Sabban, "Small New Wearable Antennas for IOT, Medical and Sport Applications," *2019 13th European Conference on Antennas and Propagation (EuCAP)*, 2019.

# APPENDIX B: LOGBOOK SUMMARY

A Logbook Summary Signature Sheet

**Faculty of Engineering and Information Sciences**

ECTE458 Thesis: Logbook Summary Sheet

| Week No. | Date | Comments, if applicable | Student’s Signature | Supervisor’s Signatu |
|---|---|---|---|---|
| 1. | - | | | |
| 2. | 4/2/20 | | Kulsoom | Mohd Fareq |
| 3. | 11/2/20 | | Kulsoom | Mohd Fareq |
| 4. | 18/2/20 | | Kulsoom | Mohd Fareq |
| 5. | 25/2/20 | | Kulsoom | Mohd Fareq |
| 6. | 3/3/20 | | Kulsoom | Mohd Fareq |
| 7. | 24/3/20 | | Kulsoom | Mohd Fareq |
| 8. | 31/2/20 | | Kulsoom | Mohd Fareq |
| 9. | 7/4/20 | | Kulsoom | Mohd Fareq |
| 10. | 14/4/20 | | Kulsoom | Mohd Fareq |
| 11. | 21/4/20 | | Kulsoom | Mohd Fareq |
| 12. | 28/4/20 | | Kulsoom | Mohd Fareq |
| 13. | 4/5/20 | | Kulsoom | Mohd Fareq |

## APPENDIX C: SUBMISSION CHECKLIST

## D Submission Checklist

**ECTE458 Report - Submission Checklist**

Please ensure that all boxes are ticked before you submit your report. **Students who have not completed this checklist will not be allowed to submit their Thesis report**. Note that *partial* submission of *some* of the components below is **NOT allowed**.

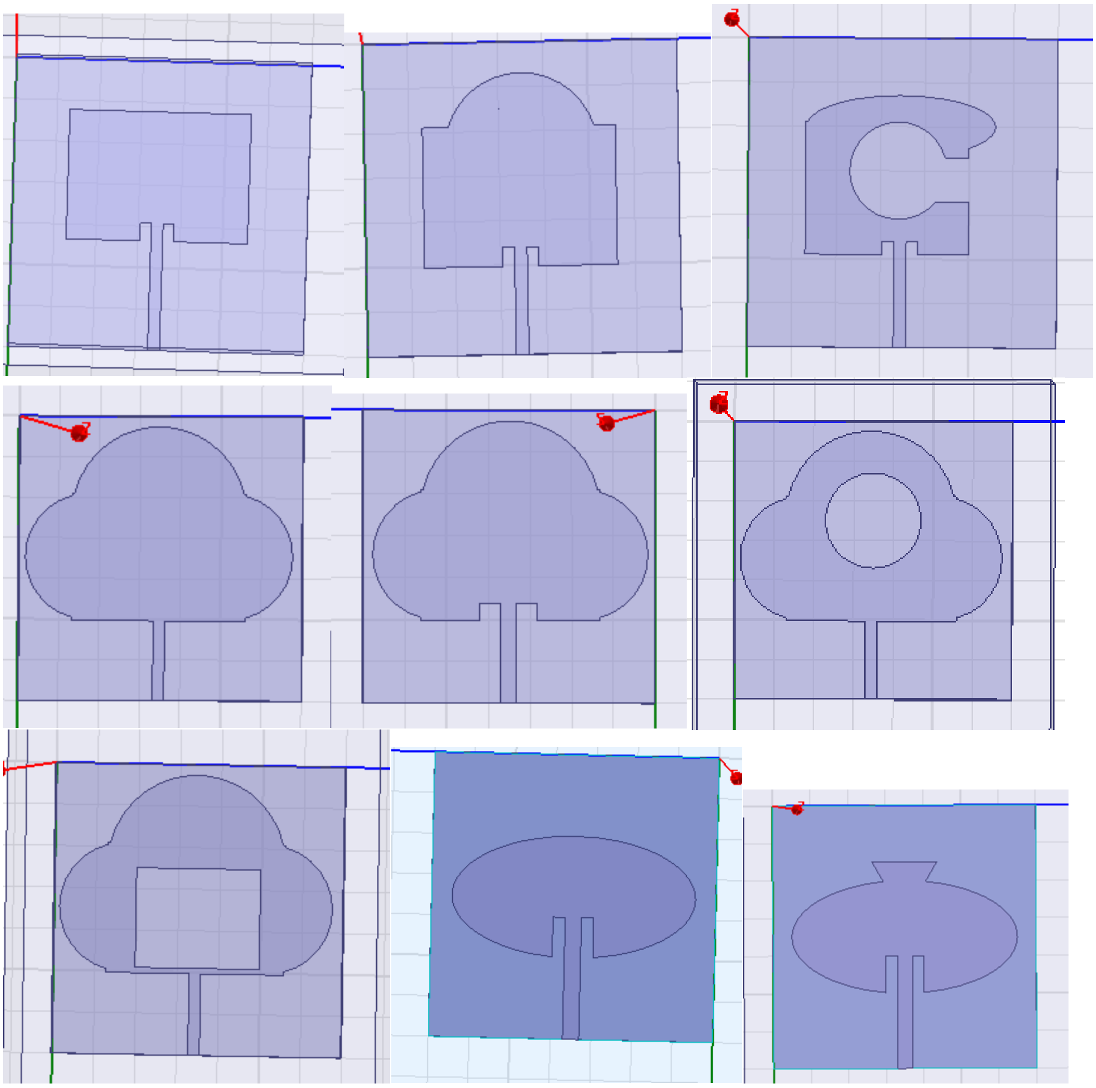
| | |
|---|---|
| Laboratory Logbook is being submitted. | ☑ |
| Inclusion of the FIRST page from the **Turnitin similarity** report for your thesis report. | ☑ |
| Completed assignment cover sheet. | ☑ |
| Statement of originality is included. | ☑ |
| I understand that I may be asked to orally defend the work included in this thesis report. | ☑ |
| A total of **two hard copies (bound)** being submitted. | ☑ |
| Front and rear covers have been included (stapled, with cloth tape). | ☑ |
| One soft copy of the thesis report, with supplemental material compressed as a single ZIP file, submitted to the Moodle drop-box. | ☑ |
| The main body of the report does not exceed **50** pages. | ☑ |
| The appendix of the report does not exceed **10** pages. | ☑ |
| The original project specification is included as Appendix A. | ☑ |
| The revised project specification (if required) is included. | ☑ |
| The report formatting complies with the rules in the thesis information booklet. | ☑ |
| The Innovation Fair Talent Release Form is signed and submitted. | ☑ |
| This checklist is submitted along with all of the above. | ☑ |

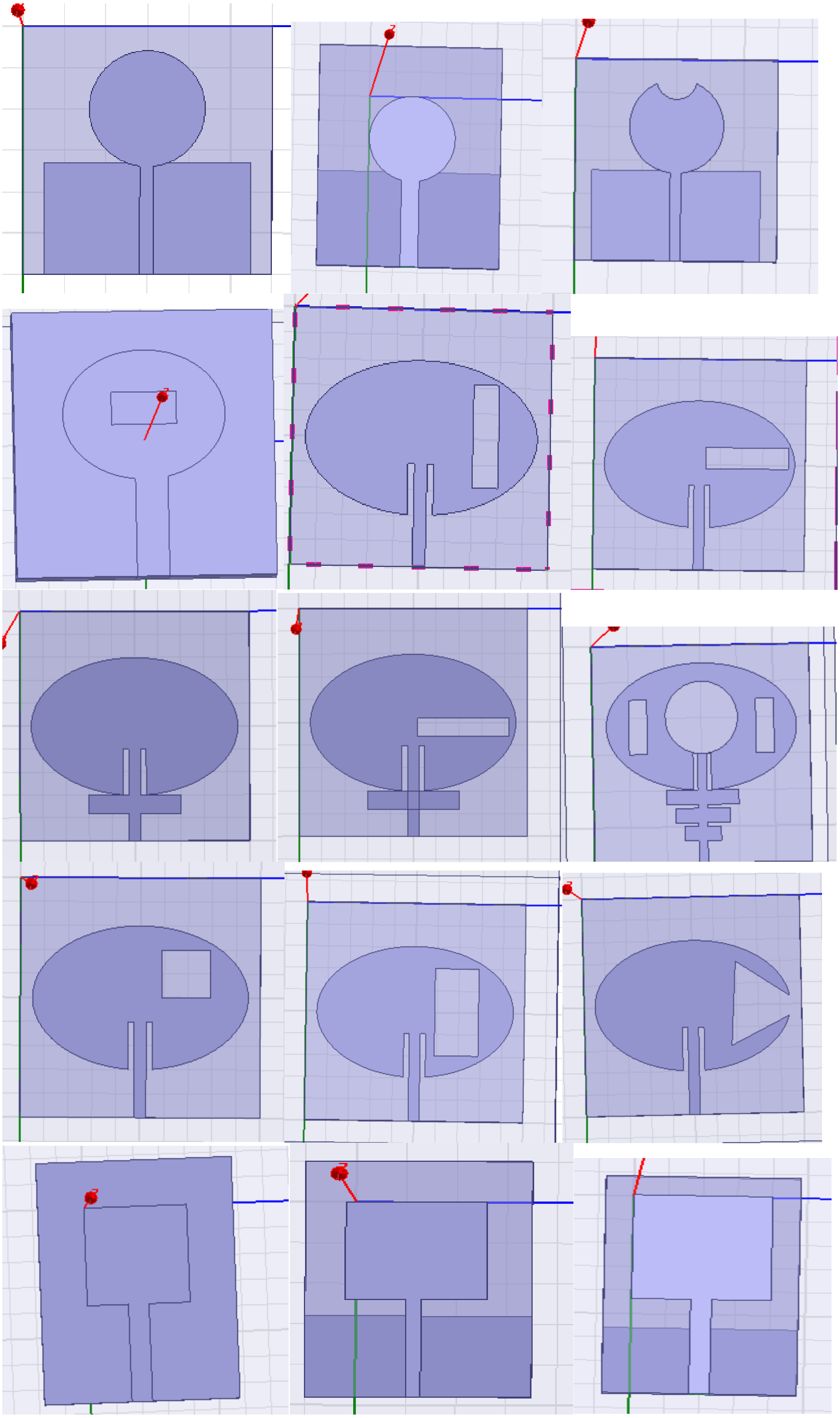
Name: Umm Kulsoom Emad Student Number: 5529657

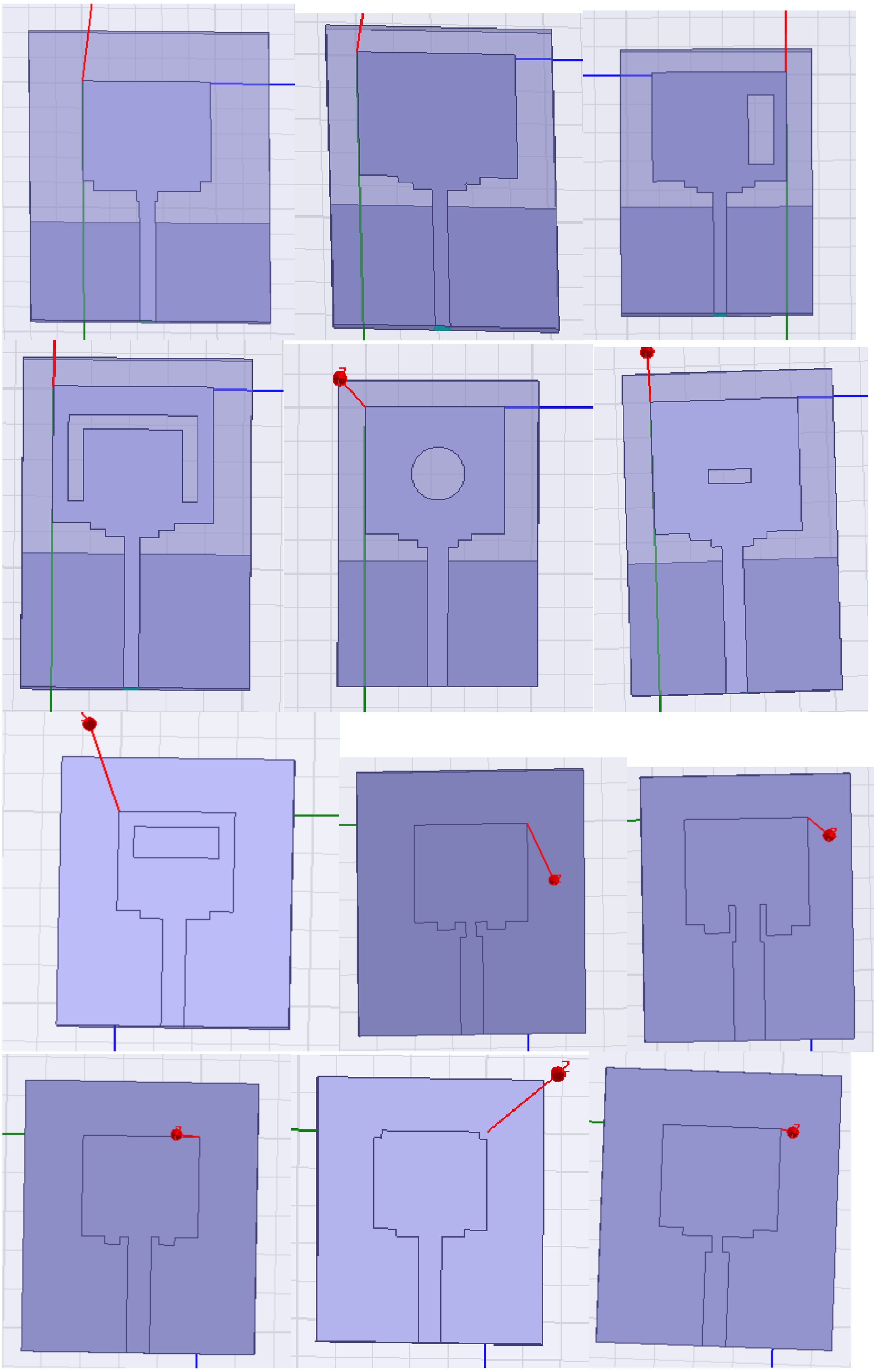
Signature: Kulsoom Date: 5/5/20

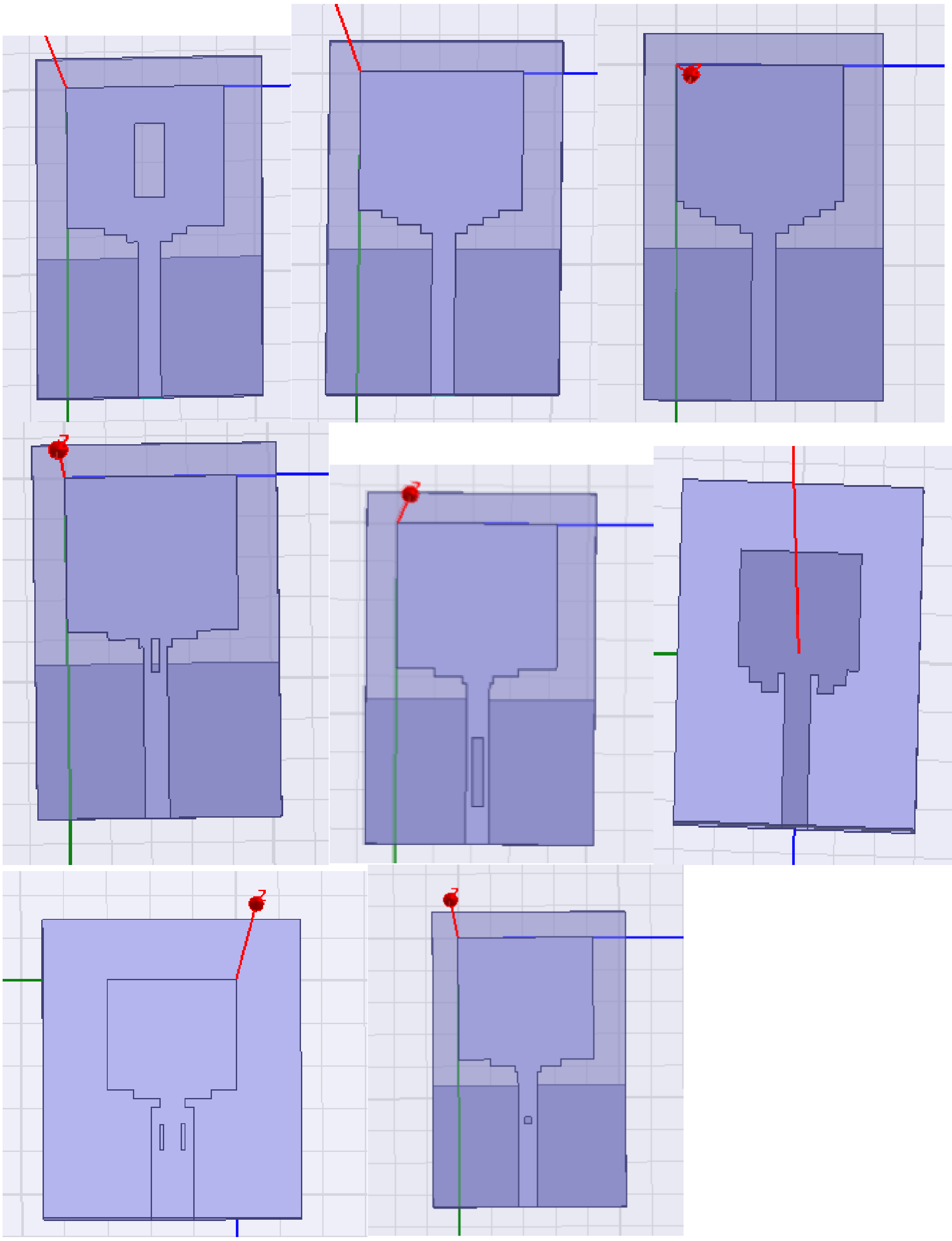
# APPENDIX D: PREVIOUSLY SIMULATED DESIGNS

This section of appendix shows only some of the simulated designs that were attempted. Not only these designs were tried but also different variations of these designs were tried which includes different lengths and widths of each patch, stub, feedline, ground length, and different positions. Also, different thickness and material for the substrate. Some changes did not have any effect on the results, some had only minor and some had major effects. Over the course of designing, better understanding and usage of the HFSS software was achieved because of which use of variables and sketching output of different dimensions was used in the main body of the thesis. Please note the presentation of the figures below does not show the order in which they were attempted.









Constraints while Implementing the Project

In ECTE451, it was expected to have a hardware (physical design) of the antenna and its results using Vector Network Analyser with SMA connector, for ECTE458. Unfortunately, due to the pandemic situation, the delivery of copper taffeta from another country became impossible and even the usage of VNA as many students had to use it for their projects and the country (entire world) was on a lockdown.