# DUAL MICROSTRIP PATCH ANTENNA DESIGN AT 2.45 GHZ USING DENIM SUBSTRATE FOR MEDICAL APPLICATION

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## DECLARATION

"I hereby declare that the work in this report is my own except for quotation and summaries in which have been duly acknowledge"

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# ABSTRACT

A wearable antenna can be defined as an antenna which is designed and meant for part of clothing. The antenna requirements are given by the particular specification, but common to all applications are light weight, conformal forming, simply to manufacturing, low cost, no maintenance, no set-up requirements, no damage from obstacles. Microstrip antenna reception apparatus is a perfect decision for this remote correspondence. Flexible and textile antennas have becoming ever more attractive due to the medical application in wearable systems. In this thesis, two different configuration of microstrip patch antenna, rectangular patch antenna and circular patch antenna using denim textile as substrate are analysed. The design of antenna has been discussed .The manual calculation for the design of antenna and the output results of the textile antenna which is used for the 50 ohm system (as GPS or WLAN ) at 2.45 GHz The main challenge is using denim textile as the substrate for Industrial, Scientific and Medical (ISM) band application at 2.45GHz and 5.8GHz. The design performance of antennas is in terms of return loss, radiation pattern and gain of the antenna are extensively investigated and carried out simulated by Computer Simulation Technology (CST). The first design antenna that from rectangular patch is 9.18 dB gain with return loss -15.17 and its operating frequency ranges from 2 to 3 GHz while the second design of circular patch suffers frequency range 2 to3 GHz and 7.81 dB gain with return loss -20.06 dB respectively.

***Key words:*** *Patch antenna, Computer Simulations Technology (CST), Rectangular Patch, Circular Patch.*

# ABSTRAK

Antena kebolehpakaian ditakrifkan sebagai antena yang direka bagi bertujuan untuk menjadi sebahagian daripada pakaian. Keperluan antena diberikan oleh spesifikasi tertentu, tetapi kebiasaannya semua aplikasi adalah yang ringan, pembuatan berbentuk konformal yang kecil, kos yang rendah, tiada penyelenggaraan, tidak perlu disusun atur dan tiada kerosakan yang besar. Penerimaan isyarat mikrostrip antena radas adalah yang terbaik bagi jaringan penghantaran isyarat frekuensi antenna ini. Kebolehlenturan dan tekstil antena yang menarik dapat diaplikasikan dalam sistem boleh pakai khususnye dalam bidang perubatan. Dalam tesis ini, dua konfigurasi antenna mikrostrip yang berbeza antena mikrostrip iaitu berbentuk segi empat tepat dan bulat dengan menggunakan tekstil denim sebagai substrat untuk dianalisis. Reka bentuk segi empat tepat dan bulat antena mikrostrip telah dibincangkan. Pengiraan manual untuk mereka bentuk antena dan keputusan keluaran antena tekstil yang digunakan untuk sistem ialah 50 ohm (GPS atau WLAN) pada 2.45 GHz. Cabaran utama adalah menggunakan denim tekstil sebagai substrat untuk bidang perubatan (ISM) Industrial, Saintifik dan Medical pada 2.45GHz dan 5.8GHz. Prestasi reka bentuk antena adalah dari segi kehilangan pulangan, corak radiasi dan keuntungan atau kekuatan kenaikan antena secara meluas disiasat dan dijalankan menggunakan Computer Simulation Technology (CST). Reka bentuk antenna yang pertama iaitu segi empat tepat adalah 9.18 dB kekuatan kenaikan antenna dengan kehilangan pulangan -15.17 serta julat frekuensi operasi 2 hingga 3GHz manakala reka bentuk kedua iaitu bulat mengalami julat frekuensi 2 hingga 3 GHz dan 7.81 dB kekuatan kenaikan antena dengan kehilangan pulangan 20.06 dB mengikut reka bentuk kedua-dua antenna .

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| | |
|---|---|
| € | Euro |
| Ω | Ohm |
| % | Percent |
| Γ | Gamma |
| © | Copyright |
| Δ | Delta |
| Er | Dielectric Constant |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| CST | Computer Simulation Technology |
| EM | Electromagnetic |
| ISM | Industrial, Scientific, and Medical |
| RF | Radio-frequency |
| SMA | SubMiniature Version A |
| UWB | Ultra-Wideband |
| WBAN | Wireless Body Area Network |
| WLAN | Wireless Local Area Network |
| HF | High Frequency |
| BW | Bandwidth |
| MPA | Microstrip Patch Antenna |

# CHAPTER 1

# INTRODUCTION

## 1.1 OVERVIEW

In recent years, a lot of research work has been done on implantation of biomedical devices inside and on the human body. These days we are using different electronic gadgets like mobiles, radio, WiFi, etc. which include antenna for reception and transmission of signals. Basically, antennas are a very important component of communication systems. By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space.

With the exponential development of these wireless communication technologies, researchers are now focusing on the study of Wireless Body Area Network (WBAN), which allow the communication between wearable devices (on-body communications), between body-worn devices and surrounding devices (off body communications), and finally between implanted devices and devices mounted on human body surface (in-body communications). The WBAN's domain comprises a wide range of applications including military, rescue, healthcare, sports, and entertainment, which are summarized in Table 1 [1].

**Table 1.1**: Wearable applications based on [1].

| *Application* | *Description* |
|---|---|
| Healthcare/Medical | Smart diagnosis, treatment and drug delivery system, patient monitoring, aging care, sleep control. |
| Business | Wireless transactions, identification of individual peripheral devices. |
| Entertainment | Wireless Digital Video Disc, wearable computing. |
| Military/Space/Rescue | Smart suits, battlefield personnel care and intelligence, astronaut monitoring, fire detection. |
| Other | Tourism, security, intelligent transportation systems, real-time streaming, aiding professional and amateur sport training. |

In order to reach all of these application fields, several frequency bands have been assigned for WBAN, such as Medical Implant Communication Service (MICS) 400 MHz band, the 2.45 GHz and 5.8 GHz Industrial, Scientific, and Medical (ISM) bands.

Microstrip antenna have several advantages over conventional microwave antenna therefore are widely used in many practical application. The patch antenna and planar inverted F antenna gives a strong radiation away from the surface, suitable for the free-space links. So, a micro strip patch antenna is used in this research. This is because it's lighter in weight, low volume, low cost, low profile, smaller dimension and ease of fabrication and conformity. There is a need for more compact antennas due to speedy decrease in size of personal communication devices.

As communication devices grow to be smaller due to larger integration of electronics, the antenna becomes a drastically large section of the overall package deal volume. This results in a demand for similar mark downs in antenna size and low profile antenna designs. The microstrip antennas used in an extensive vary of purposes from communication device systems to satellite and biomedical applications [2].

For medical use, 2.45 GHz resonating frequency is proposed for microstrip antenna. When the antenna designed on the body surface is placed inside of the body, its resonating at 0.8GHz. This decrease is due to the high permittivity of the muscle tissues and conductivity of tissues. Antenna must be fabricated by biocompatible materials that will not elicit and adverse biological response.

### 1.1.1 ANTENNA IN MEDICAL APPLICATION

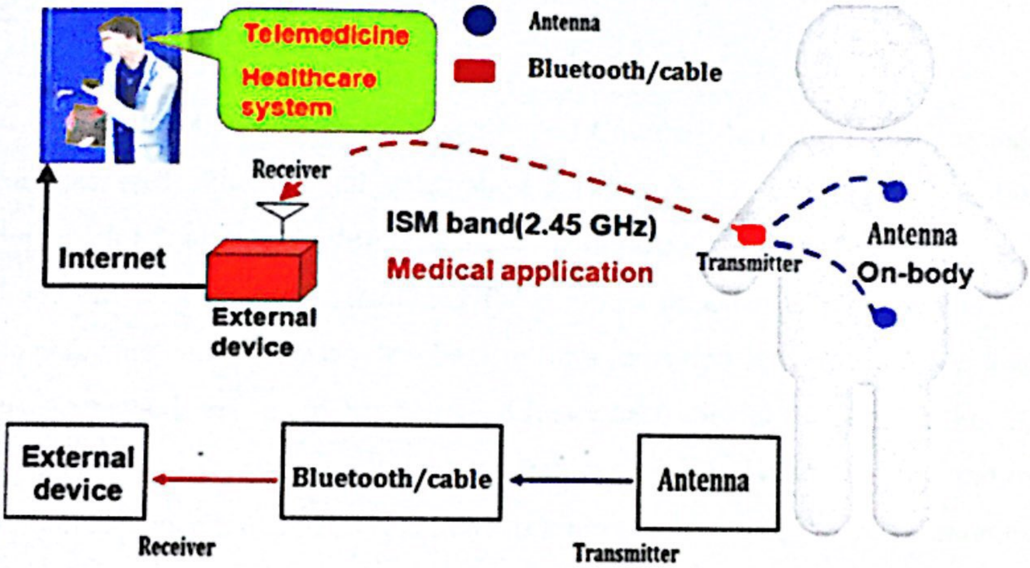



**Figure 1.1:** This research is focus on the area of designed the on-body.

There are some applications at present, where the antennas are used to continuously monitor the biometric data of human body. In order to do this, they need to be so close to the human body all the time so that they can continuously monitor the biometric data and send the information to the outside world. If the antenna is hard it is not suitable to always keep them attached with the human body as they can make some harm due to their physical structure. If the antenna is made of textile material they will not make any harm to human body and will be totally wearable. This is the main motivation to do the thesis.

In this project, the general design procedure of wearable microstrip antennas for medical applications is presented. The process starts with the selection and dielectric characterization (electric conductivity, loss tangent, relative permittivity), textile materials denim substrates, because it can be easily integrated into clothes. . By merging the microstrip technology with textile technology, the person easily to move around while doing their job. The next step consists on defining the antenna geometry including the ground plane, radiating element, and the feeding structure. The thesis work here presents the design, calculated and optimized output results of the textile antenna which is used for the 50 ohm system (as GPS or WLAN ) at 2.45 GHz and also antenna for complex impedance IC at the frequency 2.45 GHz for medical application.

The design of both Rectangular and Circular Microstrip Patch antenna has been discussed .The manual calculation for the design of antenna and the simulation result has also been presented. Also the impedance matching technique for 50 ohm and complex conjugate matching for complex impedance has been shown. There are many methods of feeding mechanism for microstrip patch antenna. The four most popular methods are microstrip line feed (inset-fed), coaxial feeding (Pin Feed), aperture coupling and proximity coupling. As the inset-fed is easy to fabricate and to obtain input impedance match, this research work has opted to design a patch antenna with inset-fed.

The antenna is usually connected to the transmitter or receiver through foil microstrip transmission lines. The radio frequency current is applied (or in receiving antennas the received signal is produced) between the antenna and ground plane. Microstrip antennas have become very popular in recent decades due to their thin planar profile which can be incorporated into the surfaces of consumer products, aircraft and missiles. Then, designs and numerical simulations are performed using The Computer Simulations Technology (CST) software. Finally, the critical parameters (return loss, radiation pattern, efficiency) of the antenna are applied [1].

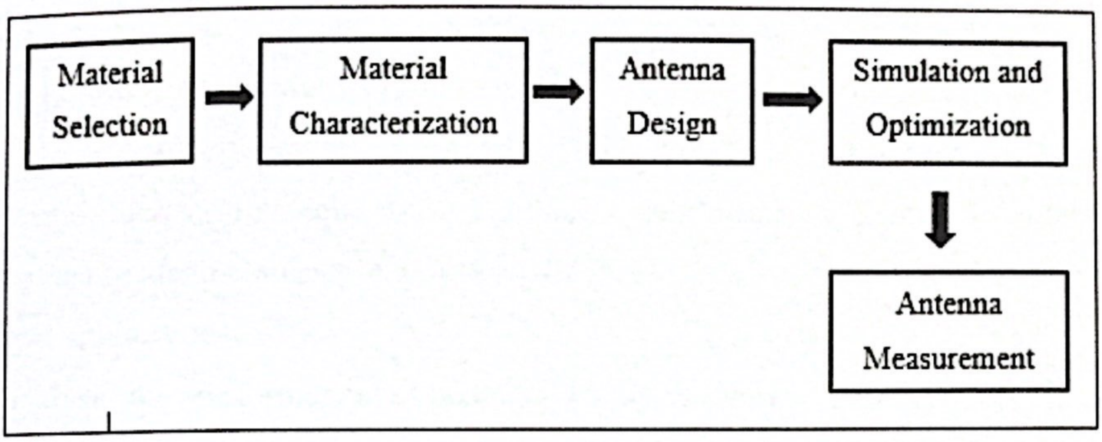



**Figure 1.2**: General design procedure of a wearable antenna.

## 1.2 PROBLEM STATEMENT

In recent years, wired technology electronic applications have arising in the commercial market. The used of this antenna technology is no longer suitable because it difficult to move around while doing job and most conventional antennas have a rigid structure, a big size and expensive material. It also cannot be attached to the garment.

To solve this problem, wearable microstrip is designed by using fabric (denim) as the substrate, the person can wear the wearable device into their cloth (denim). For the advised patient can monitoring includes home and hospitalization monitoring wireless system will increase the coverage, reliability and quality of monitoring system [3].

By using fabric as the substrate, every person who is using wired technology device easily to move around while doing their job. The person can wear the wearable device into their cloth. So, the problems of limited movements are considered solved.

## 1.3 OBJECTIVE

The detail objective of this study as follow:

- To design microstrip antenna using 2 different shapes (Rectangular and Circular Patch) using denim substrate operating at 2.45 GHz; specific frequency for medical applications.
- To analyse the performance of antenna by its parameter (gain, return loss, operating frequency band and radiation patterns) simulated in Computer Simulations Technology (CST) software.
- To compare simulated results between 2 configurations for similar substrate.

Generally, this project aims at analyzing the behavior of this antenna in several scenarios, comparing the simulated and compared results.

## 1.4 SCOPE OF PROJECT

The scope of this project is to simulate wearable antenna by operating 2.45 GHz. Design rectangular and circular microstrip wearable antenna with using textile materials denim substrate. The characterization of denim fabric properties including permittivity and loss tangent has been determined using inset-fed technique following the previous research. The proximity of on human body, bending effect and wetness effect not to be tackled in designing textile antenna.

The project analysis of the simulated result is using The Computer Simulation Technology (CST) in terms of antenna properties such as return loss in microstrip frequency range, radiation pattern, and gain. Generally, the performance of the antenna analysis comparison between both design antenna patch.

## 1.5 SIGNIFICANT

This study is to simulate and design two types of wearable antenna such as rectangular and circular shape micros wearable antenna by operating 2.45 GHz frequency range. This antenna can be lightweight, compact and almost free maintenance device is the most required criteria in any communication and medical design. By using denim fabric as substrates, the user can wear the wearable device into their cloth.

Denim fabric as substrate is easy to obtain and can attached to user's cloth which easily to move around while doing their job.

The discuses about the various feeding techniques that can be applied towards the design that can be used for biomedical application.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Antennas are a very important component of communication systems. By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of the radio system to which it is connected, otherwise the reception and the transmission will be impaired. When a signal is fed into an antenna, the antenna will emit radiation distributed in space in a certain way. A graphical representation of the relative distribution of the radiated power in space is called a radiation pattern.

This chapter concerned about literature review on the associated work. Nowadays, growths in wearable electric devices have already shown the growing trend towards modest wearable electronics. They are seen as the next step in the adaptation of electronic devices into daily surroundings. Five literature reviews will be explained in the next paragraph. Those selected references are very useful for this project. Next, the theoretical and advantages of wearable antenna designs are explained in this chapter.

## 2.2 BASIC DEFINITIONS

### 2.2.1 RETURN LOSS

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following:

$$\text{Return Loss (in dB)} = 20\log_{10}\frac{SWR}{SWR-1}$$

Or,

$$RL = -10\, log_{10}\, [S_{(11)}]^2 = -10\, log_{10}[r]^2$$

### 2.2.2 RADIATION INTENSITY

Radiation intensity of an antenna in a given direction is defined as the power radiated from an antenna per unit solid angle. Radiation intensity at a given point is obtained by the product of radiation density and the square of distance from the radiating element is given by:

$$U = r^2 * Wrad$$

where, U is radiation intensity (W/ unit solid angle), r is distance (m) and Wrad is radiation density ($W/m^2$) [4].

### 2.2.3 RADIATION EFFICIENCY

Antenna is a radiating element. It receives a finite amount of power at its input, a portion of it is lost in it and remaining power is transmitted. If most of the power input to the antenna is radiated, then the antenna is said to have high radiation efficiency. If most of the input power to the antenna is absorbed as losses in the antenna and only few of it is transmitted then it is said to have low radiation efficiency. Antenna radiates low power because either the power is reflected back resulting in poor impedance matching or the power is lost as ohmic loss because of high resistivity of radiating element and also the power is lost due to dielectric loss. Mathematically the radiation efficiency is expressed as,

***Radiation Efficiency = Power radiated by antenna /Power input to antenna.***

Figure 2.1 illustrates the equivalent circuit of a transmitting antenna. The resistive part of the antenna impedance is categorized into two parts, which are radiation resistance Rr and loss resistance RL. The power dissipated in the radiation resistance is the power radiated by the antenna. On the other hand, loss resistance is the power lost within the antenna itself, which is caused by the losses in the conducting or dielectric parts of the antenna.

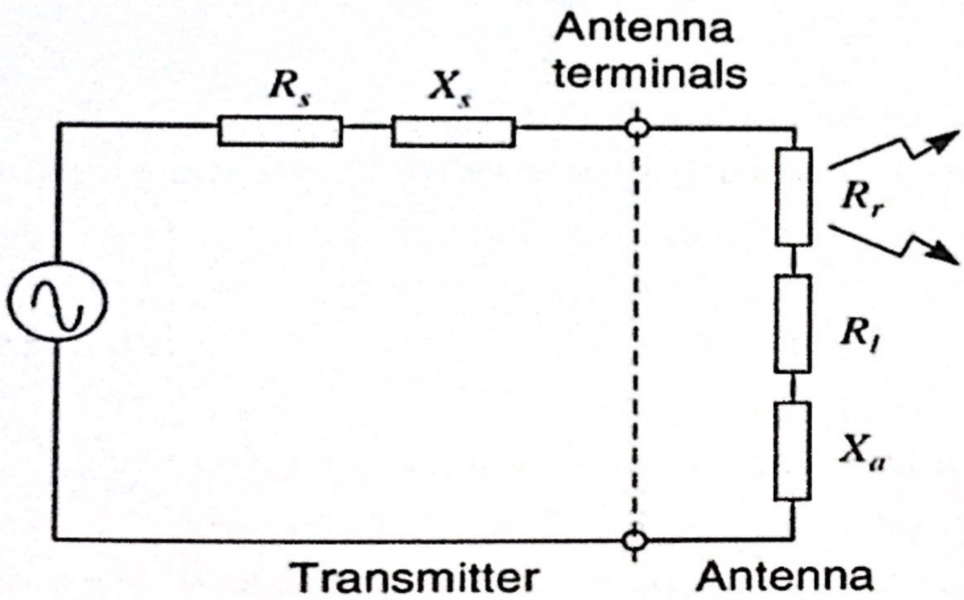



**Figure 2.1**: Equivalent Circuit of Transmitting Antenna.

The radiation efficiency e of the antenna as:

$$e = \frac{Power\ radiated}{Power\ accepted\ by\ antenna}$$

Improving the impedance mismatch and using materials with low resistivity increases the radiation efficiency. Also choosing appropriate height for substrate can give best radiation efficiency.

### 2.2.4 DIRECTIVITY

Directivity is defined as the ratio of radiation intensity by an antenna in the given direction to the radiation intensity in overall direction. In other words, the radiation efficiency is defined as the ratio of radiation intensity by a non-isotropic antenna to that of isotropic antenna. The average radiation intensity or the radiation intensity of isotropic source is given by the ratio of the power radiated by the antenna, divided by $4\pi$.

Directivity is given by,

$$\mathbf{D = U/U_0 = 4\pi U/P}$$

Where, D is directivity, U is radiation in given direction, $U_0$ is radiation intensity of isotropic source, P is power radiated and is constant and is equal to 3.14.

### 2.2.5 GAIN

Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy. The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 3 dB compared to an isotropic antenna would be written as 3 dBi. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies.

The method of measuring gain by comparing the antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a gain transfer technique. Another method for measuring gain is the 3 antennas method, where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

An isotropic antenna radiates equally in all direction. A directional antenna radiates in a fixed direction. Gain of an antenna is the relative measure of power transmitted in the desired direction by the antenna, when compared with an isotropic antenna. Antenna gain is similar to directivity but also takes into consideration the antenna radiation efficiency. Absolute gain is defined as the ratio of radiation intensity in given direction to the radiation intensity by isotropic radiator when the power input is totally radiated without taking losses due to impedance mismatch and polarization mismatch into consideration [2].

The gain of an antenna is related to radiation efficiency as,

**Gain = Radiation efficiency* Directivity**

### 2.2.6 RADIATION PATTERN

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format. The following figure shows a rectangular plot presentation of a typical 10 element Yagi. The detail is good but it is difficult to visualize the antenna behaviour at different directions.

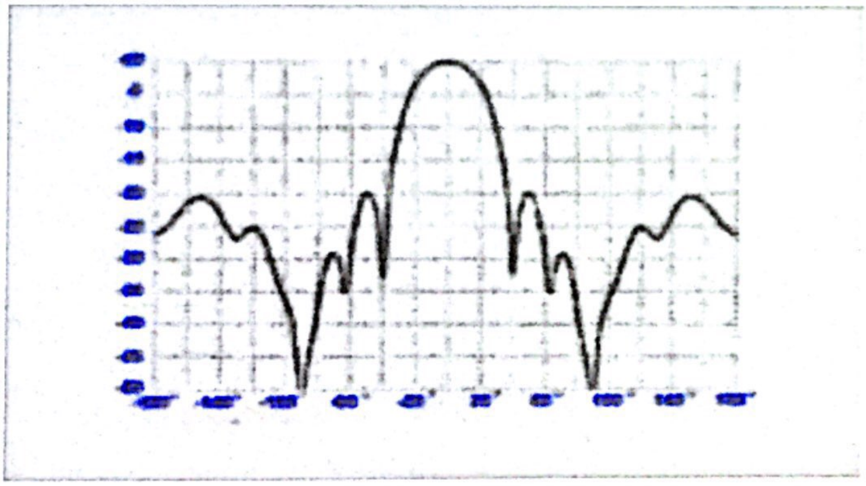


**Figure 2.2**: The radiation pattern graph.

Polar coordinate systems are used almost universally. In the polar coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles. Following is a polar plot.

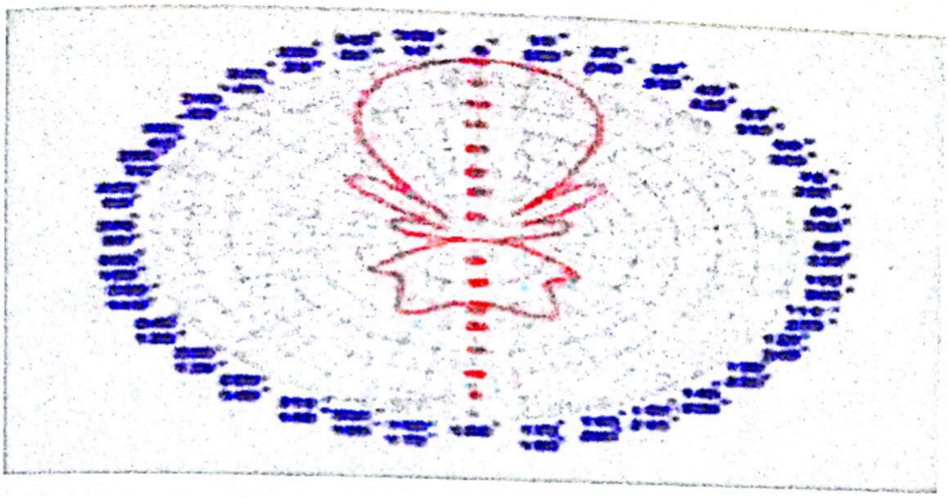


**Figure 2.3**: The radiation pattern polar.

Polar coordinate systems may be divided generally in two classes: linear and logarithmic. In the linear coordinate system, the concentric circles are equally spaced, and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal. For ease of comparison, the equally spaced concentric circles may be replaced with appropriately placed circles representing the decibel response, referenced to 0 dB at the outer edge of the plot. In this kind of plot the minor lobes are suppressed. Lobes with peaks more than 15 dB or so below the main lobe disappear because of their small size. This grid enhances plots in which the antenna has a high directivity and small minor lobes. The voltage of the signal, rather than the power, can also be plotted on a linear coordinate system. In this case, too, the directivity is enhanced and the minor lobes suppressed, but not in the same degree as in the linear power grid.

In the logarithmic polar coordinate system the concentric grid lines are spaced periodically according to the logarithm of the voltage in the signal. Different values may be used for the logarithmic constant of periodicity, and this choice will have an effect on the appearance of the plotted patterns. Generally the 0 dB reference for the outer edge of the chart is used. With this type of grid, lobes that are 30 or 40 dB below the main lobe are still distinguishable. The spacing between points at 0 dB and at -3 dB is greater than the spacing between -20 dB and -23 dB, which is greater than the spacing between -50 dB and -53 dB. The spacing thus correspond to the relative significance of such changes in antenna performance.

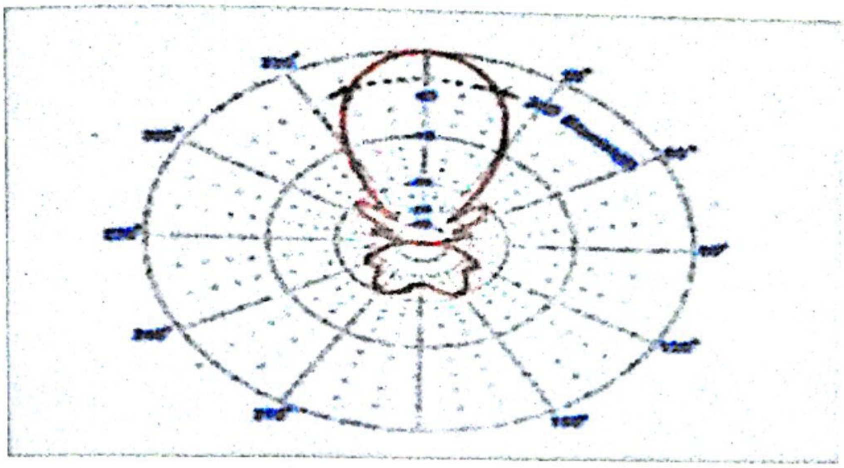


**Figure 2.4**: The logarithmic polar coordinate.

A modified logarithmic scale emphasizes the shape of the major beam while compressing very low-level (>30 dB) side lobes towards the centre of the pattern [6].

There are two kinds of radiation pattern: absolute and relative. Absolute radiation patterns are presented in absolute units of field strength or power. Relative radiation patterns are referenced in relative units of field strength or power. Most radiation pattern measurements are relative to the isotropic antenna, and then the gain transfer method is then used to establish the absolute gain of the antenna.

The radiation pattern in the region close to the antenna is not the same as the pattern at large distances. The term near-field refers to the field pattern that exists close to the antenna, while the term far-field refers to the field pattern at large distances. The far-field is also called the radiation field, and is what is most commonly of interest. Ordinarily, it is the radiated power that is of interest, and so antenna patterns are usually measured in the far-field region.

For pattern measurement it is important to choose a distance sufficiently large to be in the far-field, well out of the near-field. The minimum permissible distance depends on the dimensions of the antenna in relation to the wavelength. The accepted formula for this distance is:

$$r_{min} = \frac{2d^2}{\lambda}$$

where r min is the minimum distance from the antenna, d is the largest dimension of the antenna, and λ is the wavelength.

When an antenna radiates, the field strength of the antenna decrease as the distance increase .The measure of field strength of the radiated signal at a given distance is called the radiation pattern. The radiation pattern determines the direction and strength of electromagnetic radiation for an antenna. The pictorial view of radiation pattern can be obtained as a 2D or 3D image. Radiation pattern can be plotted in either rectangular or polar plot. There are two types of radiation pattern which is commonly used namely absolute radiation pattern and relative radiation pattern.

When the radiation pattern is measured in the absolute unit of field power or strength, it is called absolute radiation pattern and when radiation pattern is measured in relative to another field power or strength, it is called relative field pattern. Generally most radiation pattern is relative which is measured in reference to isotropic antenna. The radiation pattern very close to antenna gives the near field radiation pattern and the radiation pattern at a distance greater than $2*D^2/\lambda$ gives the far field radiation pattern, where D is the antenna length and λ is the wavelength [3].

### 2.2.7 POLARIZATION

An electromagnetic wave consists of E field and H field. When the antenna radiated, the orientation of E-field and H-field may be in different direction with respect to the earth surface. This orientation of E-field with respect to earth surface gives the polarization of an antenna. Polarization does not depend upon the antenna directional properties but on the physical alignment of an antenna. Thus an antenna when mounted vertically will have one polarization and when the same antenna is mounted horizontally, it will exhibit the different polarization. When a signal with a certain polarization is reflected, the polarization may not be the same again. Thus polarization is affected by reflection. Generally two types of polarization are used when designing an antenna namely linear polarization and circular polarization. In linear polarization, the electric field of radiated electromagnetic wave by an antenna is forced to orient in the desired direction with respect to earth surface. If an antenna at the transmitter is linearly polarized and have the vertical orientation, the receiver antenna should have the same polarization and same orientation to receive maximum power. In circular polarization the electric field of electromagnetic wave is not fixed but varies in all possible direction with respect to earth surface.

A linearly polarized antenna can be used to radiate circular polarized wave by feeding at two points in the antenna with the same magnitude and 90 degree phase shift between the two feed. To be able to receive the maximum power transmitted from transmitter antenna, both the antenna should have same spatial orientation and same axial ratio. When the miss alignment of antenna occurs, the power received is greatly reduced. For linearly polarized antenna, loss of power due to polarization mismatch is given as,

$$\textbf{Loss (dB)} = \mathbf{20 \log (\cos\theta)}$$

Where $\theta$ is the misalignment angle difference between transmit and receive antenna.

### 2.2.8 QUALITY FACTOR

The quality factor of an antenna is defined as the ratio of total energy stored in the reactive field to the energy radiated. The quality factor is given by:

$$Q = \frac{2\omega_{max}(W_M W_E)}{P}$$

Where, M W is stored magnetic energy E W is stored energy and P is radiated power [4].

### 2.2.9 BANDWIDTH

Bandwidth is inversely proportional to quality factor. If the total quality factor increase, the fractional bandwidth decrease. If the conductor surface wave losses and dielectric losses are ignored, the bandwidth is directly proportional to the height of the conductor. Thus on decreasing the height of substrate, the quality factor increases and the radiation efficiency decreases. Bandwidth is also affected by surface permittivity and if the substrate permittivity decrease, the bandwidth increase. However this will increase the dimension of antenna. Thus an optimum value of surface permittivity and substrate height is required .The fractional bandwidth is given by:

$$\frac{\Delta f}{f_o} = \frac{VSWR - 1}{Q_t \sqrt{VSWR}}$$

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1. The bandwidth can also be described in terms of percentage of the centre frequency of the band.

$$BW = 100 \times \frac{F_H - F_L}{F_C}$$

Where FH is the highest frequency in the band, FL is the lowest frequency in the band, and FC is the centre frequency in the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the centre frequency. Different types of antennas have different bandwidth limitations.

### 2.2.10 INPUT IMPEDANCE

The input impedance of an antenna can be described in several ways. First, the input impedance of an antenna may be described as impedance presented by an antenna at its terminal. It is also the ratio of voltage to current at the pair of terminal. Another way of described input impedance is the ratio of the appropriate components of electric field, Eto magnetic field, H at a point. Hence the input impedance is given as:

$$Zin = Rin + jXin$$

Where Zin is the antenna impedance at the terminals, Rin is the antenna resistance at the terminals and Xin is the antenna reactance at the terminals.

The part of the antenna that is resistant which includes the radiation resistance Rr and loss resistance RL. The imaginary part, Xin models the energy stored in the antenna near-field. It indicates the amount of power that is reflected, or amount of the voltage and current that is out of phase. It is particularly difficult to achieve impedance matching in antennas, for the impedance has to remain constant throughout the frequency spectrum. Therefor it is common to design antennas to a standard input impedance of 50 Ohm.

## 2.3 SUBSTRATE MATERIAL

The relative permittivity, εr of dielectric substrate is in range 1 to 10. Each material has its own value of dielectric permittivity. There are some important parameters of dielectric substrate in order to design the microstrip transmission line, which are:

- Dielectric constant
- Dielectric loss tangent

In this project, denim fabric is used as a substrate. The advantages of denim are long wearing, easy-care clothing, and cheap. It was made from a 100 percent of cotton. However, there are denim textiles that are composed of cotton blends. The base cotton fibres are woven with spandex, silk, and metallic threads.

Denim clothing never goes out of style. It is perfect for most casual occasions. Denim most common as the fabric in jeans, but is also used for shirts, jackets, skirts, dresses, handbags and more. There are many types of denim fabric, such as cotton serge, raw denim, selvage denim, stretch denim, poly-denim and ramie denim. Each denim fabric has own criteria. As examples, cotton serge denim is 100 percent cotton serge while stretch denim usually includes 2 or 3 percent spandex material. However, cotton denim fabric is chosen become the substrate [9].

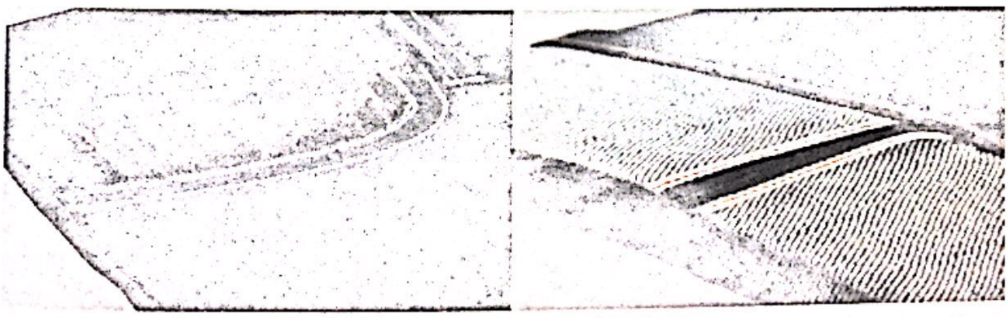


**Figure 2.5**: Denim fabric.

## 2.4 ANTENNA

Antenna is basic component of any electronic system which depends on free space as a propagation medium. An antenna is a device used for radiating or receiving radio waves. It is a transducer between a guided electromagnetic wave and electromagnetic wave propagating in free space. The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiver. This antenna can be mounted on the surface of high performance aircraft, spacecraft, and satellites [5].

The antenna can be in a form of Microstrip. Microstrip is a type of electrical transmission line which can be fabricated using printed circuit board (PCB) technology, and is used to convey microwave frequency signals. It consists of a conducting strip separated from a ground plane by a dielectric layer known as the substrate. Microwave components such as antennas, couplers, filters, power dividers etc. can be formed from microstrip, the entire device existing as the pattern of metallization on the substrate. Microstrip is much less expensive than traditional waveguide technology, as well as being far lighter and more compact.

Microstrip antennas became very popular primarily for space borne applications. Today they are used for government and commercial applications. These antennas comprise a plurality of generally planar layers including a radiating element, an intermediate dielectric layer, and a ground plane layer. The radiating element is an electrically conductive material imbedded or photo etched on the intermediate layer and is generally exposed to free space. Depending on the characteristics of the transmitted electromagnetic energy desired, the radiating element may be square, rectangular, triangular, or circular and is separated from the ground plane layer. The metallic patch can take many different configurations, the rectangular and circular patches are the most popular because of ease of analysis and fabrication, as well as their attractive radiation characteristics, especially low cross-polarization radiation [6].

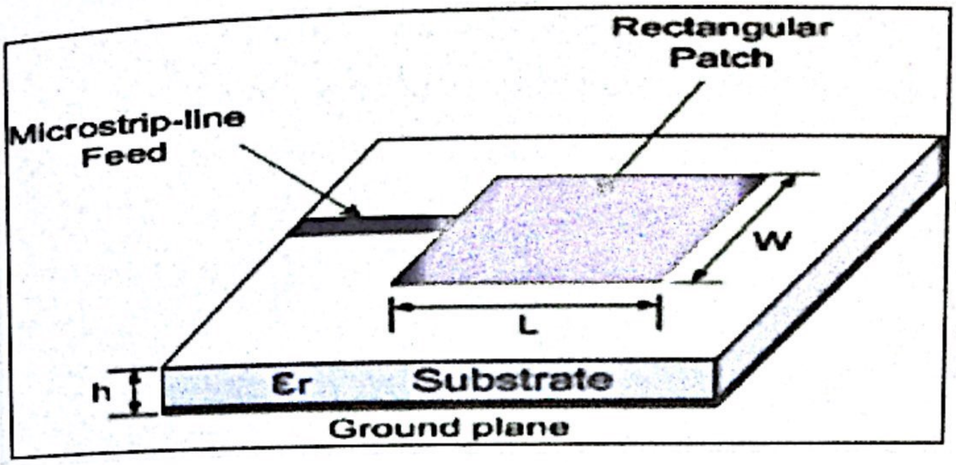



**Figure 2.6**: Microstrip patch antenna.

## 2.5 MICROSTRIP PATCH ANTENNA

Microstrip patch antenna is formed by overlaying a conducting plane over the ground plane and a dielectric material sandwiched between them. Microstrip antenna is used where size, cost, weight, ease of installation is of prime concern. These antennas are low profile antenna which can be built in any shape and are also very simple to manufacture and at the same time are cheaper in cost.

Microstrip antenna gives a very stable output and they are mechanically robust when manufactured in a printed circuit board. It is very easy to form a large array of antenna and is light weight. These antennas are very flexible in terms of resonant frequency, pattern, impedance and polarization and if a load is added between the ground plane and the patch, a radiating element with variable resonance frequency, pattern, impedance and polarization can be designed.

Microstrip antenna is generally designed to have a broadside radiation pattern, having maximum radiation along the direction normal to the patch. For a microstrip patch to resonate at a certain resonance frequency, the length of the patch L where ʎo is the wavelength. Various dielectric substrates can be used when designing a microstrip patch having the dielectric constant where Єr is the dielectric constant [7]. There are also some limitations of patch antenna as these antennas have low efficiency, low power handling and lower bandwidth. However there are methods to improve the efficiency and bandwidth such as increasing the height of dielectric substrate but this result in increase in surface waves which is generally undesirable because they degrade the antenna polarization property and pattern. Microstrip patch antenna can be designed in various shape as shown below.

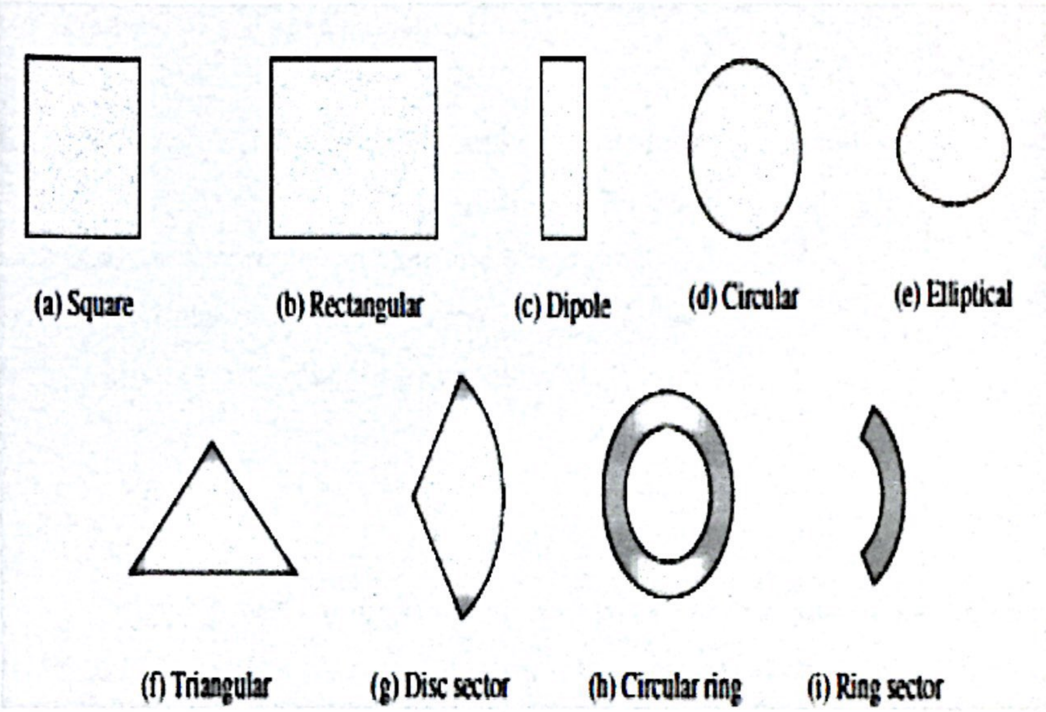



**Figure 2.7:** Different structure of microstrip patch antenna.

### 2.5.1 MICROSTRIP ANTENNA ADVANTAGE AND LIMITATION

Microstrip patch antennas have numerous advantages compared to conventional microwave antennas, and for that many applications cover the broad frequency range from 100 MHz to 100 GHz. Some of principle advantage of microstrip antenna is presented [5].

i. Light weight, low volume, and thin profile configurations, which can be conform.
ii. Low fabrication cost, eagerly amenable to mass production.
iii. Linear and circular polarizations are possible with simple feed.
iv. Dual frequency and dual polarization antennas can be easily made.
v. Can be easily integrated with microwave integrated circuit.

vi. Feed lines and matching networks can be fabricated concurrently with the antenna structure.

And the limitation of microstrip antenna compared with conventional microwave antennas.

i. Narrow Bandwidth (BW) and associated tolerance problems.
ii. Complex feed structure required for high performance arrays.
iii. Unrelated radiation from feeds and junction.
iv. Excitation of surface waves.
v. Lower power handling capability (100 Watt).

### 2.5.2 FEEDING MECHANISMS

Power can be coupled in or out of an antenna by a diversity of methods that can be classified to contacting and non-contacting. Contacting feeds mean direct connection of a transmission lines, can be coax or microstrip lines to the patch antenna. The input impedance depends on the location of the connection within the patch boundaries. For non-contacting feeds, electromagnetic field coupling is used to transfer the power between feed lines and the radiating patch. This type is hard to design but provide more degree of freedom than contacting feed. Most popular techniques are microstrip lines, coaxial probe, aperture coupling and proximity coupling.

An antenna feed refers to the components of an antenna which feed the radio waves to the rest of the antenna structure, or in receiving antennas collect the incoming radio waves, convert them to electric currents and transmit them to the receiver. Antennas typically consist of a feed and additional reflecting or directive structures (such as a parabolic dish or parasitic elements) whose function is to form the radio waves from the feed into a beam or other desired radiation pattern.

In simple antennas the feed usually consists of the feed antenna (driven element), the part of the antenna which actually converts the radio frequency currents to radio waves or vice versa, and the feed line (transmission line), which connects the feed antenna with the receiver or transmitter. For example, in a rooftop Yagi television antenna, the feed consists of a dipole driven element, which converts the radio waves to an electric current, and a coaxial cable or twin lead transmission line which conducts the received signal from the driven element into the house to the television receiver. The rest of the antenna consists of rods called parasitic elements, which strengthen reception from a given direction.

In more complex antenna systems the feed can be more complicated. The antenna feed is usually considered to be all the components between the beam-shaping part of the antenna and the receiver's first amplifier (called the RF front end, the LNB or LNA). For a transmitting antenna, the feed consists of everything after the last power amplifier, and might include an antenna tuner unit and impedance matching sections at the antenna. In a radar or satellite communications antenna the feed might consist of a feed horn, orthomode transducer, polarizer, frequency diplexer, waveguide, waveguide switches, rotary joint, etc [4].

Particularly with a transmitting antenna, the antenna feed is a critical component that must be adjusted to work correctly with the antenna and transmitter. Each type of transmission line has a specific characteristic impedance. This must be matched to the impedance of the antenna and the transmitter, to transfer power efficiently to the antenna. If these impedances are not matched it can cause a condition called standing waves on the feed line, in which the RF energy is reflected back toward the transmitter, wasting energy and possibly overheating the transmitter. This adjustment is done with a device called an antenna tuner in the transmitter, and sometimes a matching network at the antenna. The degree of mismatch between the feedline and the antenna is measured by an instrument called an SWR meter (standing wave ratio meter), which measures the standing wave ratio (SWR) on the line.

#### 2.5.2.1 MICROSTRIP LINE FEED

Microstrip line feed is a method of a conducting strip is connected directly to the edge of the microstrip patch as shown in figure 2.8. The conducting strip is smaller in width compared to the patch. This kind of feeding has an advantage that the feed can be etched on the same substrate to provide a planar structure.

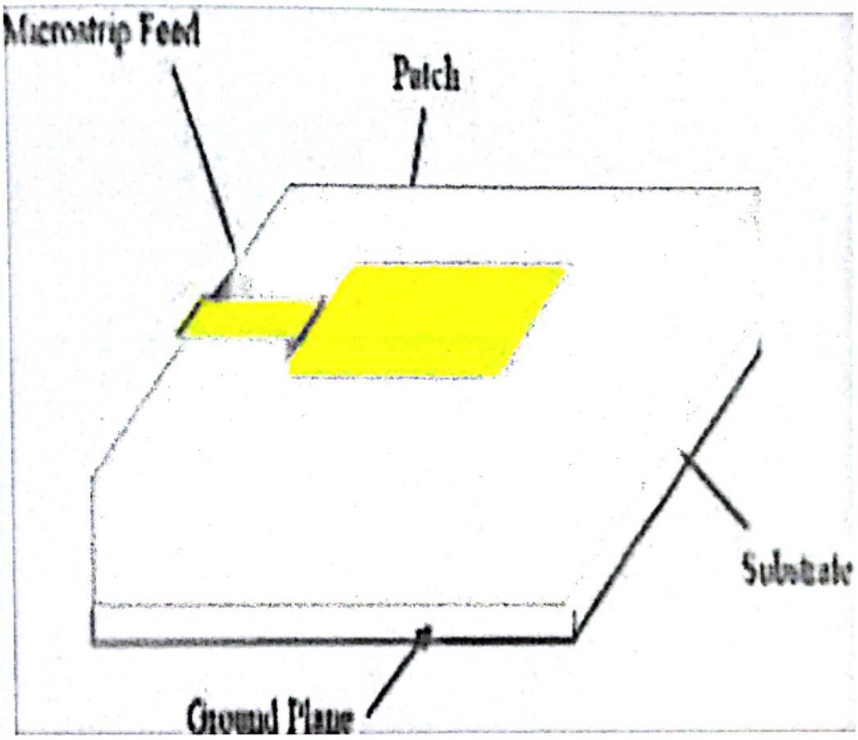



**Figure 2.8**: Microstrip Feed Line [13].

The purpose of inset cut of the patch is to match the impedance between the feed line and the patch. Therefore, it is easy to fabricate and simple to match by controlling the inset position. In this paper, the chosen feed line microstrip line with circular microstrip patch.

#### 2.5.2.2 MICROSTRIP INSET-FED

Since microstrip antennas are often integrated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design.

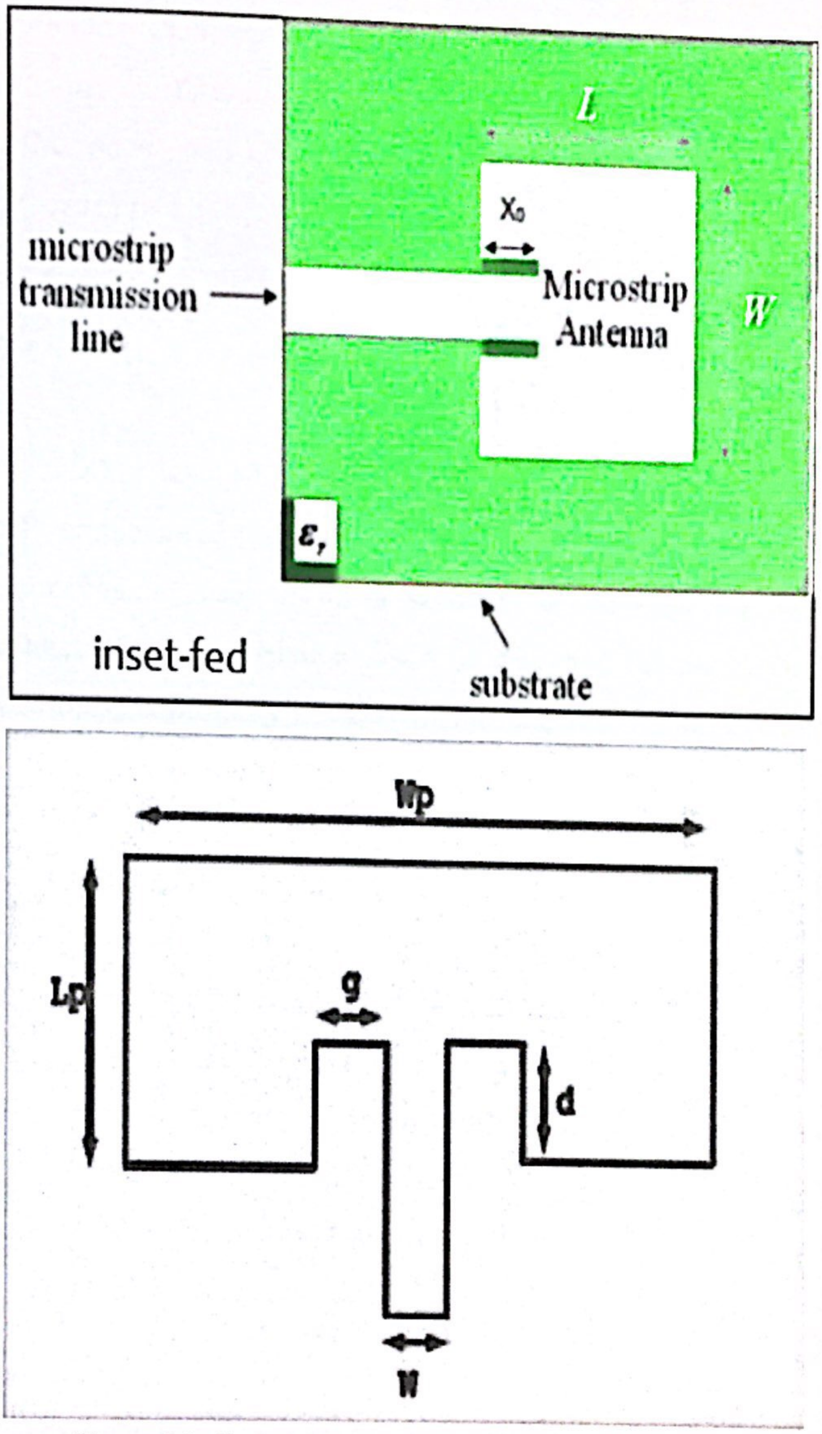



**Figure 2.9**: Geometry of inset-fed microstrip patch antenna.

Often microstrip antennas are referred to as patch antennas. The radiating elements and the feed lines are habitually photo etched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip, circular, elliptical, triangular or constituting any other configuration. Square, rectangular, thin strip and circular microstrip patch configurations are the most common because of their ease of analysis, fabrication, and their attractive radiation characteristics, especially the low cross-polarization radiation. There are many configurations that can be used to feed microstrip antennas. In this paper, the chosen inset feed microstrip line with rectangular microstrip patch [5].

### 2.5.3 SMA CABLE

SMA (SubMiniature version A) connectors are semi-precision coaxial RF connectors developed in the 1960s as a minimal connector interface for coaxial cable with a screw-type coupling mechanism. The connector has a 50 Ω impedance. SMA is designed for use from DC to 18 GHz, but is most commonly used for hand-held radio and mobile telephone antennas, and more recently with WiFi antenna systems and USB Software Defined Radio dongles.

SMA connectors can be visually confused with the standard household 75-ohm type F coax connector (diameters: Male 7⁄16 inch (11 mm) circular or hex; female 3⁄8 in (9.5 mm) external threads), as there is only about a 2 mm difference overall in the specifications.

The SMA name is also used for a superficially similar optical fiber connector.

**SMA connector**

**Figure 1. Standard male SMA connector: male body (inside threads) with male inner pin.**

| Type | RF coaxial connector |
| --- | --- |
| **General specifications** | |
| Diameter | Male: 0.312 in (7.9 mm) HEX |
| Cable | Coaxial |
| Passband | Typically 0—18 GHz, some up to 26.5 GHz |

**Figure 2.10**: SMA connector cable.

## 2.6 ISM BAND 2.45 GHZ

ISM band is (Industrial, Scientific and Medical band) A part of the radio spectrum that can be used for any purpose without a license in most countries. In the U.S., the 902-928 MHz, 2.4 GHz and 5.7-5.8 GHz bands were initially used for machines that emitted radio frequencies, such as RF welders, industrial heaters and microwave ovens, but not for radio communications.

In 1985, the FCC Rules (Part 15.247) opened up the ISM bands for wireless LANs and mobile communications. In 1997, it added additional bands in the 5 GHz range under Part 15.407, known as the Unlicensed National Information Infrastructure (U-NII). Europe's HIPERLAN wireless LANs use the same 5 GHz bands, which are titled the "Broadband Radio Access Network." [10].

The ISM band is for Industrial, Scientific and Medical band. There are several applications in wireless communication field in the ISM band around the frequency around 2.4 GHz. The miniaturization in such wireless devices, like mobile phones, laptops etc. is due to the smaller size of the antenna in it. As the revolutionary generation goes on, the new technique or the innovation is must to get the better output in a smarter way from the wireless devices especially in medical applications.

**Table 2.11**: Examples of medical application.

| Application | Description |
|---|---|
| Healthcare/Medical | Smart diagnose, treatment and drug delivery system, patient monitoring, aging care, sleep control. |

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

A work flow is made from the beginning to make sure the project is done on time Shows the work flow of this project. The figure summarizes all the work that will be done throughout the process to complete the wearable antenna. First of all, research via internet, books, and IEEE paper are done on properties of antenna. This is to further understanding about fundamental, theory and properties of the antenna. The research on wearable antenna has to be completed to know the overall designing process [5].

Then, designing and simulation is done using The Computer Simulation Technology (CST). In the earlier stage, rectangular and circular wearable antenna is design. The denim substrate is used for this design. The value of permittivity of the substrate is get from the IEEE paper. The process is continued by altering and optimized the shape of the patch. To achieve the best performance of the antenna, analyzing the behavior of this antenna in several scenarios, comparing the results [3].

## 3.2 SIMULATION PROCESS

Using The Computer Simulation Technology (CST) is a specialist tool for the 3D EM simulation of high frequency components. CST MWS unparalleled performance is making it first choice in technology leading R&D departments.

CST enables the fast and accurate analysis of high frequency (HF) devices such as antennas, filters, couplers, planar and multi-layer structures and SI and EMC effects. Exceptionally user friendly, CST MWS an insight into the EM behavior of your high frequency designs [6].

CST promotes Complete Technology for 3D EM. Users of our software are given great flexibility in tackling a wide application range through the variety of available solver technologies. Beside the flagship module, the broadly applicable Time Domain solver and the Frequency Domain solver, CST offers further solver modules for specific applications. Filters for the import of specific CAD files and the extraction of SPICE parameters enhance design possibilities and save time. In addition, CST can be embedded in various industry standard workflows through the CST STUDIO SUITE® user interface.

## 3.3 FLOW CHART

Flow Chart below will show that the whole process to implementing this project and it has been descripted with detail explanation for every step of the process.

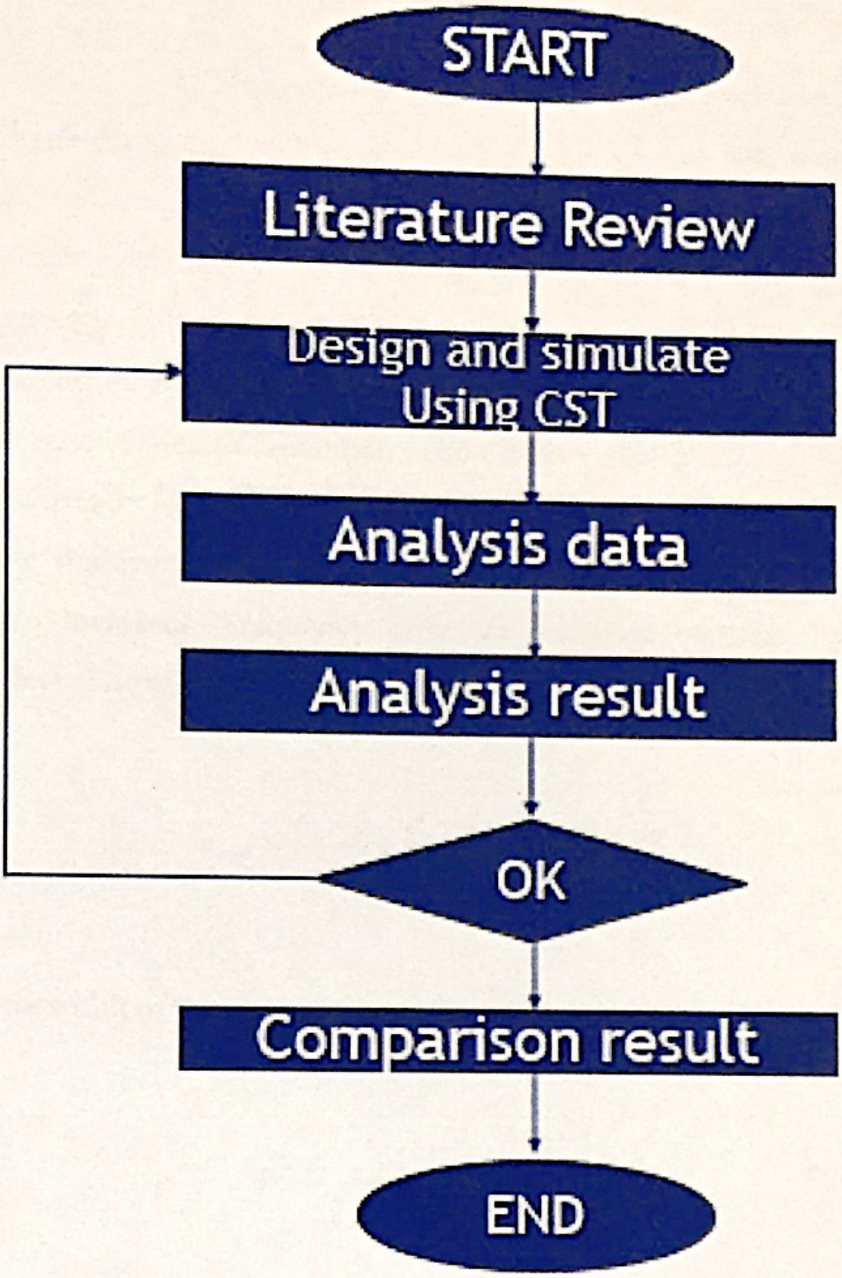



**Figure 3.1**: Flow chart whole project.

## 3.4 WEARABLE ANTENNA DESIGN

### 3.4.1 ANTENNA DESIGN

In this section, structure of patch antennas are discussed, rectangular patch and circular patch configuration are simulated by CST software in order to decrease return loss and increase gain.

### 3.4.1.1 RECTANGULAR PATCH ANTENNA

A microstrip patch antenna consists of a radiating element, a ground and a dielectric substrate sandwiched between them. The radiating patch consists of finite edges and hence fringing occurs. Fringing is mainly dependent on dimension of substrate, height of dielectric substrate and dielectric constant. It can be observed from above figure that for the microstrip line, the electric field lies in both air and dielectric material. This makes the microstrip line looks electrically longer. The effective dielectric constant is almost same for low frequency, but as the frequency increase, the dielectric constant also increases. Frequency effective dielectric constant has a finite effect. The effective dielectric constant is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{-1/2}$$

The width of the microstrip patch is calculated by:

$$W = \frac{1}{2f_r\sqrt{\mu_o \varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Due to fringing, the length of the patch increases electrically. Thus the increase in length is given by:

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

Where, ΔL is the increase in length.

The length is increased on both side of the microstrip patch. Thus the effective length is given as:

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

$$L = \frac{\lambda_{eff}}{2} - 2\Delta L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L$$

Thus the resonance frequency for the microstrip antenna with length L and dielectric constant Єr is given as:

$$f_r = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_o\varepsilon_o}}$$

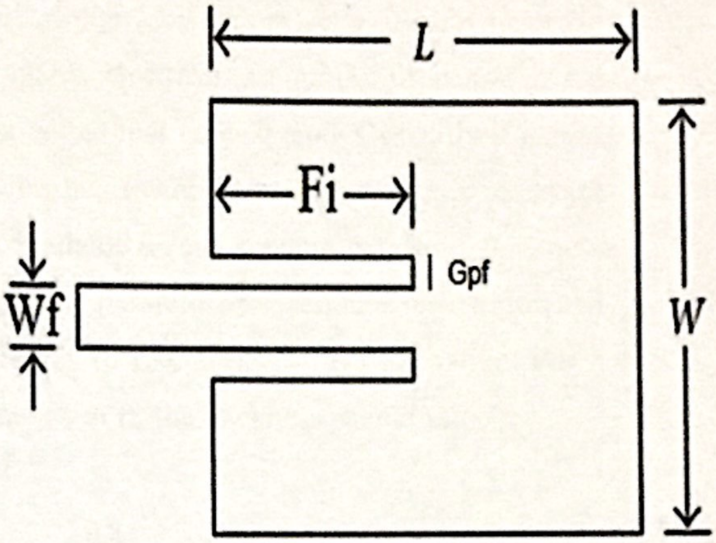
When the fringing has finite impact, the effective length and effective dielectric constant is to be considered. In this case, the resonance frequency can be computed by:

$$f_{rc} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}}$$

Rectangular patch antenna is designed and simulated here. Dimension is given in fig. 1. Dimensions of patch are calculated using and optimized dimensions are L=55.2mm,W= 46mm.Substrate with dielectric constant 1.69 and height 8.85 mm , x=3.137 mm. Patch is designed for operating frequency 2.45 GHz.

**Table 3.2**: Dimension of rectangular patch.

| Parameters | mm |
|---|---|
| W | 46 |
| L | 55 |
| Fi | 8.85 |
| Wf | 3.137 |
| Gpf | 1 |
| Lg | 2*L |
| Wg | 2*L |



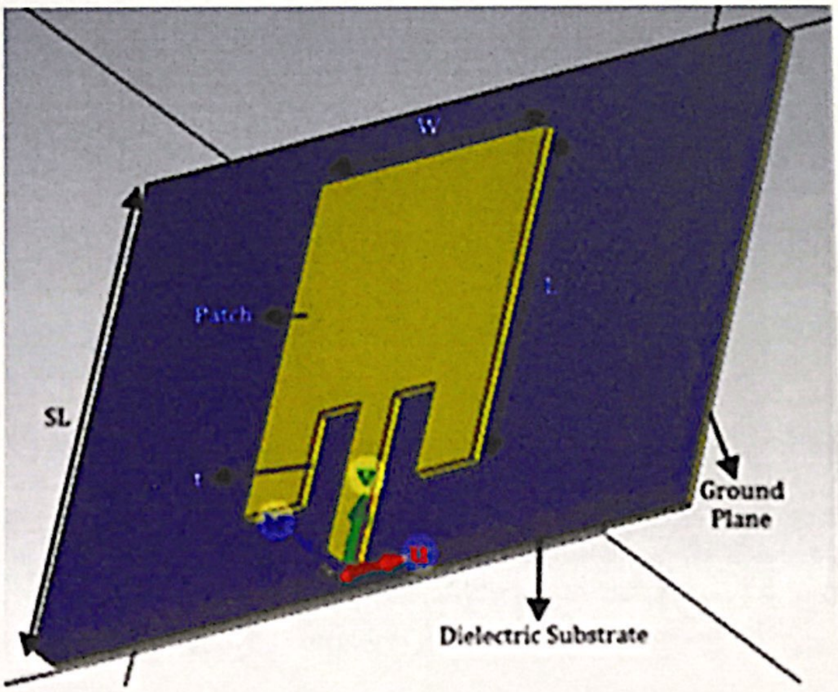




**Figure 3.3**: Top and Side view of rectangular patch antenna.

### 3.4.1.2 CIRCULAR PATCH ANTENNA

Consider a circular patch of radius a over a ground plane with a substrate of thickness h and a relative dielectric constant εr, as shown in Figure 1. The first design step is to select a suitable dielectric substrate material. The major electrical properties to consider are relative dielectric constant εr and loss tangent tanδ. Generally it is best to select a substrate with the lowest possible dielectric constant consistent with the space available for the antenna. Substrate thickness should be chosen as large as possible to maximize bandwidth and efficiency, but not so large as to risk surface-wave excitation. For a maximum operating frequency of fr, the thickness should satisfy;

$$h \leq \frac{0.3c}{2\pi fr\sqrt{\varepsilon_r}}$$

where c is the velocity of electromagnetic waves in free space [7].

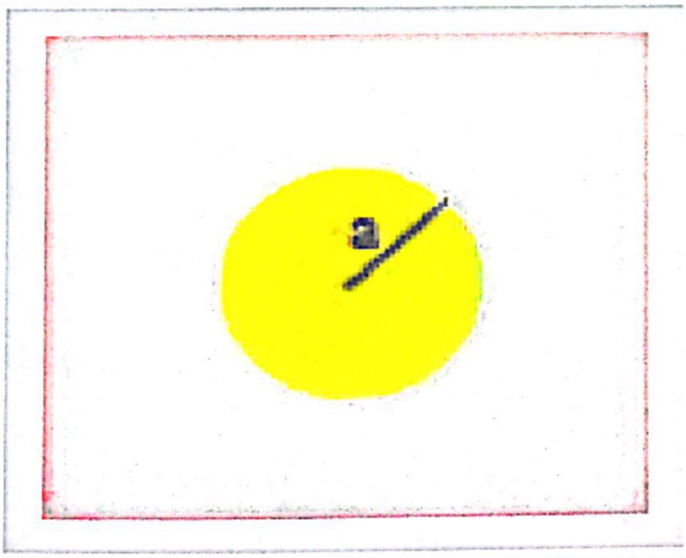


**Figure 3.4**: Geometry of circular microstrip antenna.

Dimension of circular patch is similar with rectangular patch antenna with specific dimension L=55mm, R=25mm and t=1.5mm is given in Table 3.5.

**Table 3.5**: Dimension of circular patch.

| ***Parameter*** | ***Optimized dimension (mm)*** |
|---|---|
| Patch Radius, R | 25 |
| W (width) | 55 |
| L (length) | 63 |
| T (thickness of substrate) | 8 |

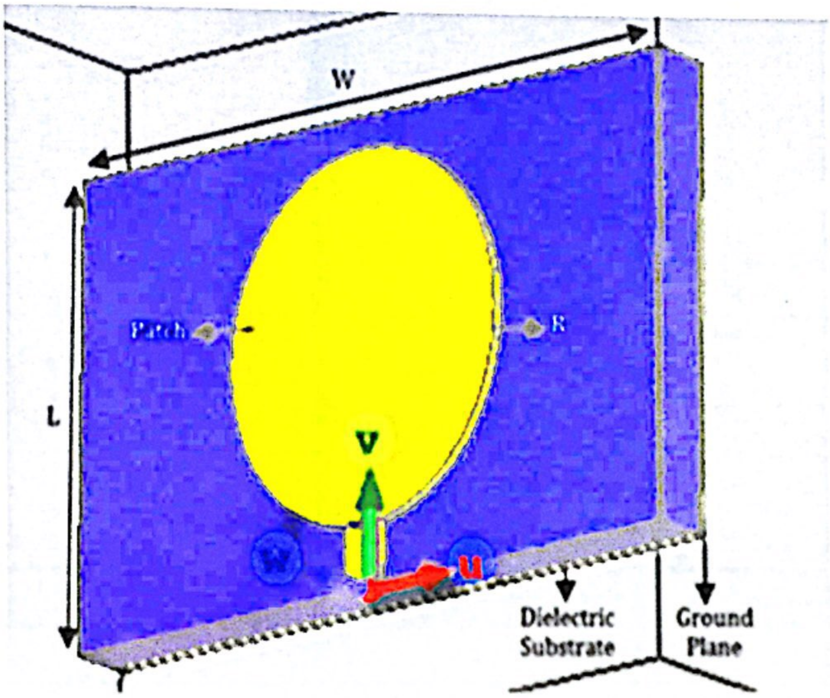



**Figure 3.6**: Top and Side view circular patch antenna.

### 3.4.2 DESIGN SPECIFICATION

The Rectangular and Circular wearable antenna is designed using CST Computer Simulation Technology. The design specifications are shown in table 3.7.

**Table 3.7**: Design Specification

| PARAMETER VALUE | VALUE |
|---|---|
| Operating Frequency Range | 3-5 GHz |
| Return Loss | Less than 10dB |
| Radiation Pattern | Directional |
| Polarization | Linear |
| Gain | Low |
| Transmission Line | Microstrip Line |
| Half Power Beam Width | Wide (>60%) |
| Physical Profile | Small, Compact, Planar |

### 3.4.3 MATERIAL SPECIFICATION

The substrate use in this project is denim jeans textile. The specifications of the substrate are listed in Table 3.8 [10].

**Table 3.8**: Electrical Properties of Denim Textile.

| MATERIAL | VALUES |
|---|---|
| Thickness,h(mm) | 1 |
| Dielectric Constant, $\varepsilon r$ | 1.69 |
| Loss Tangent | 0.025 |

# CHAPTER 4

## RESULT AND DISCUSSION

### 4.1 INTRODUCTION

The fundamental aim for this project is to develop a wearable antenna which can cover the frequency from 3-5GHz. The antenna designs were obtained previously.

The performances of the antenna were analyzed in two different antenna within rectangular and circular wearable antenna to comparing the simulated and measured results.

The powerful simulation software, CST Microwave studio, is a specialized toll for the fast and accurate simulation of high frequency problems. It can generate result of return loss and also the radiation pattern as well. The 3D polar plot of the antenna also can be observed [11].

## 4.2 RESULT

### 4.2.1 RECTANGULAR PATCH ANTENNA

#### 4.2.1.1 RETURN LOSS

After Simulation return loss is obtained -15.17 dB with gain 9.175. Frequency vs Return Loss plot. Radiation pattern is shown in figure 4.1.

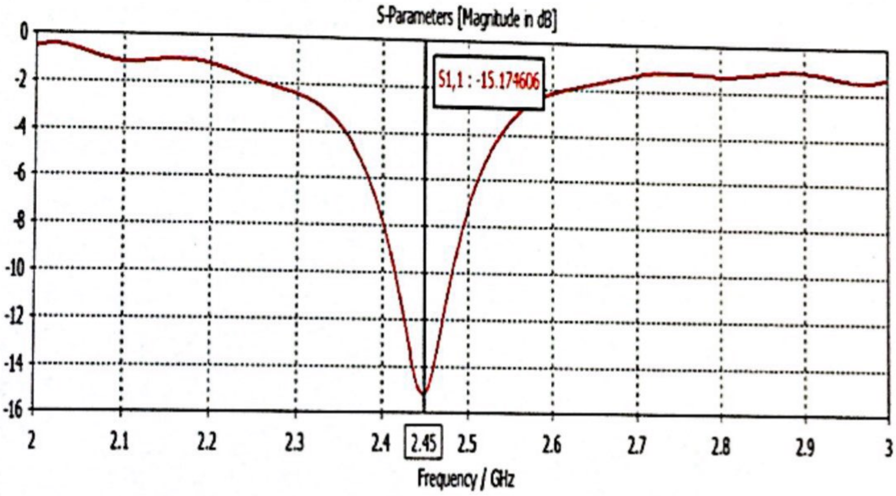



**Figure 4.1**: Frequency vs Return Loss for rectangular patch.

#### 4.2.1.2 RADIATION PATTERN

Figure 4.2 and 4.3 shows the behavior of polar plot and 3D radiation pattern of antenna at 2GHz until 3GHz. As in figure below, at low frequencies, the radiation patterns of the antenna are almost the same. The pattern is directional in the rectangular shape. The pattern is like ring shape.

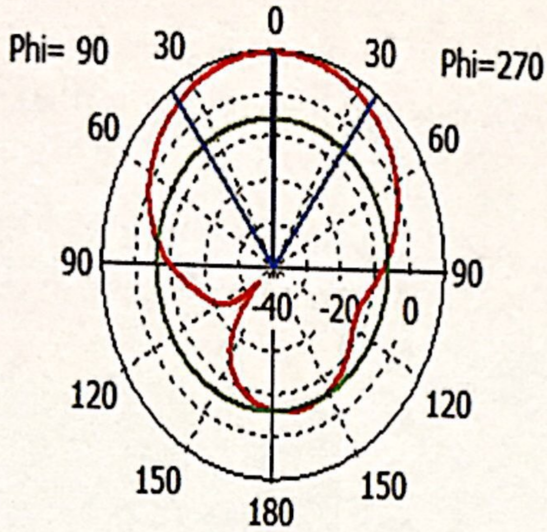



**Figure 4.2**: Polar plot of Radiation Pattern for rectangular patch antenna.

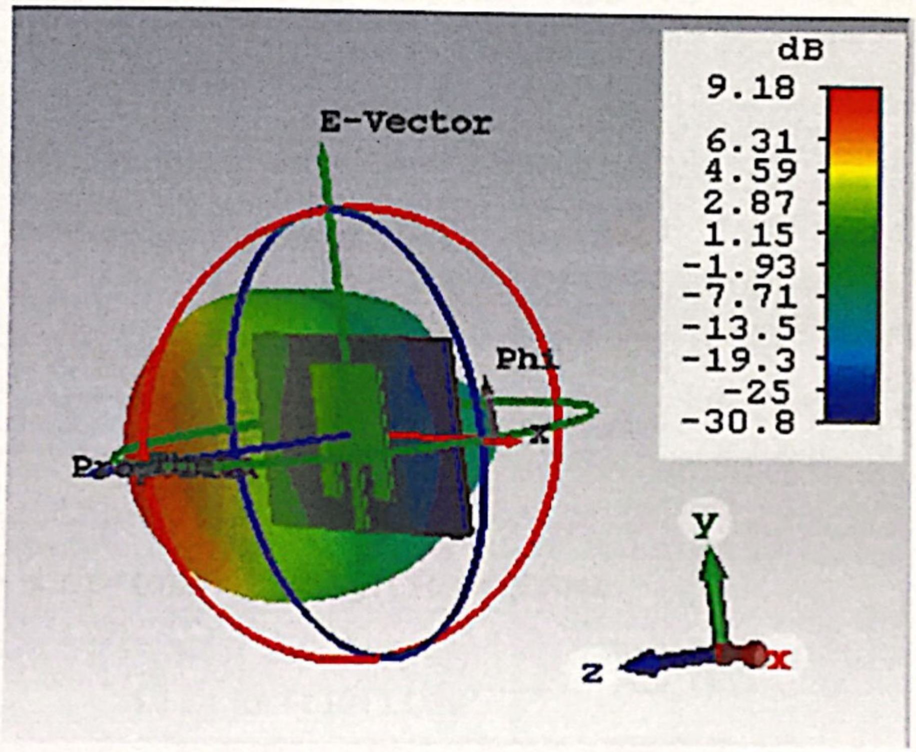



**Figure 4.3**: Far-Field view 3D radiation pattern for rectangular patch antenna.

### 4.2.1.3 GAIN

Figure 4.4 show the gain of rectangular patch. Gain or power gain shows how efficiently the available power at input terminals of antenna is transmitted. The unit of gain is dB. The Gain is 9.175 dB for rectangular patch.

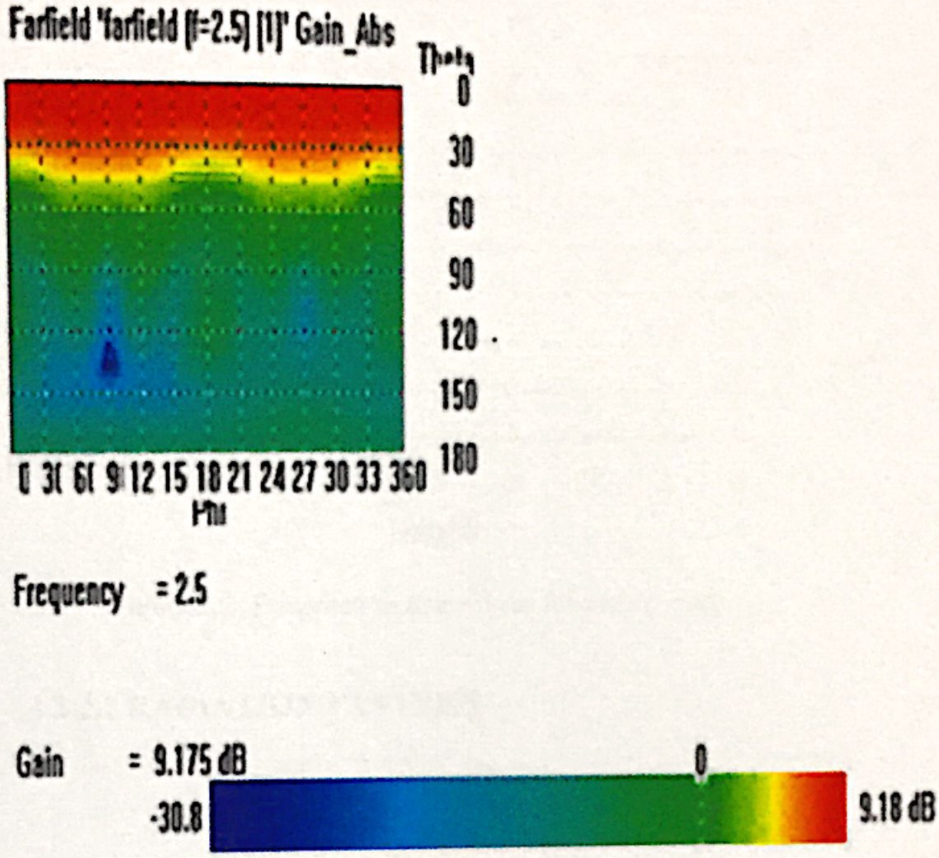



Figure 4.4: Gain of rectangular patch.

### 4.2.2 CIRCULAR PATCH ANTENNA

#### 4.2.2.1 RETURN LOSS

The Return loss characteristics are shown in the Figure 4.5. From Return loss (RL) curves it is observed that the optimized RL at 2.45 GHz is -20.06 dB with gain 7.81 dB. It has been observed that as the feed location is moved away from designed location, the center frequency deviates slightly but return loss changes noticeably the proposed antenna at 2.45 GHz.

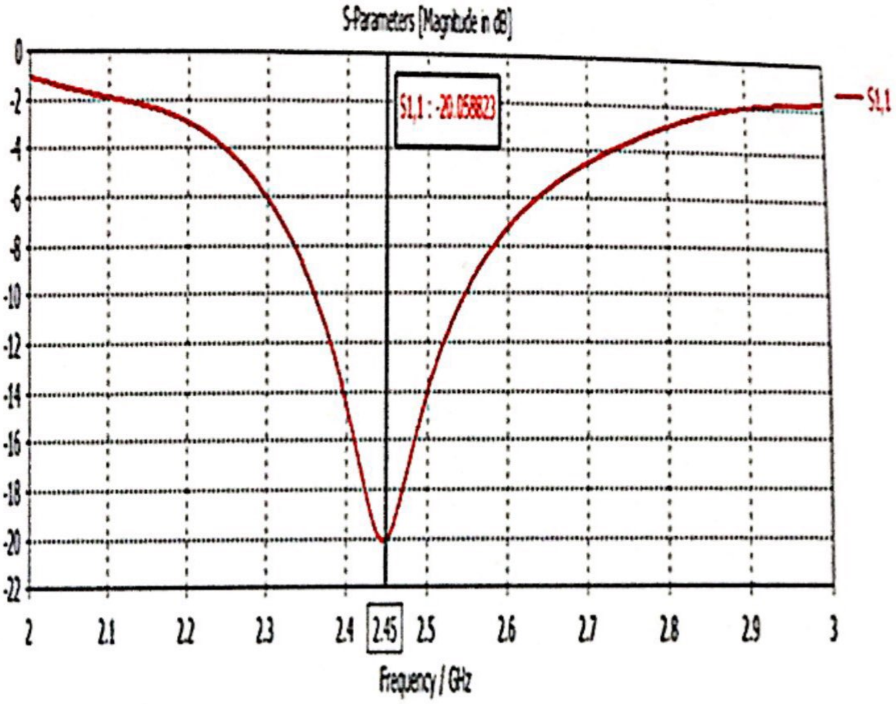



**Figure 4.5**: Frequency vs Return Loss for circular patch

### 4.2.2.2 RADIATION PATTERN

Table 4.6 shows the behavior of 3D radiation pattern and polar plot of antenna at 2GHz until 3GHz. 3D radiation pattern consists of circular pattern an. For the explanations, the frequencies ranges is 3-5GHz.

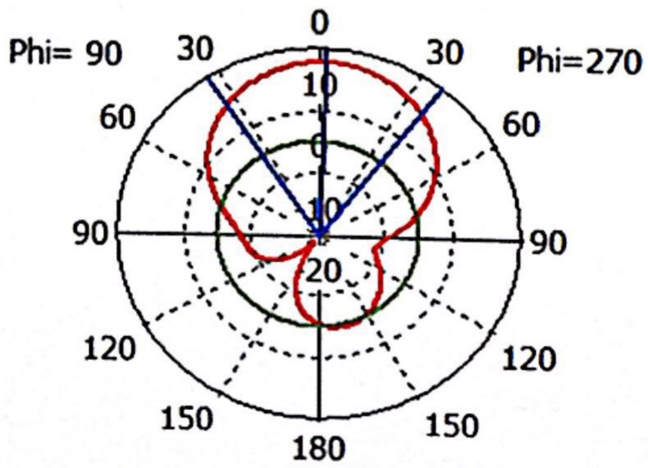



**Figure 4.6:** Polar plot of Radiation Pattern for circular patch antenna.

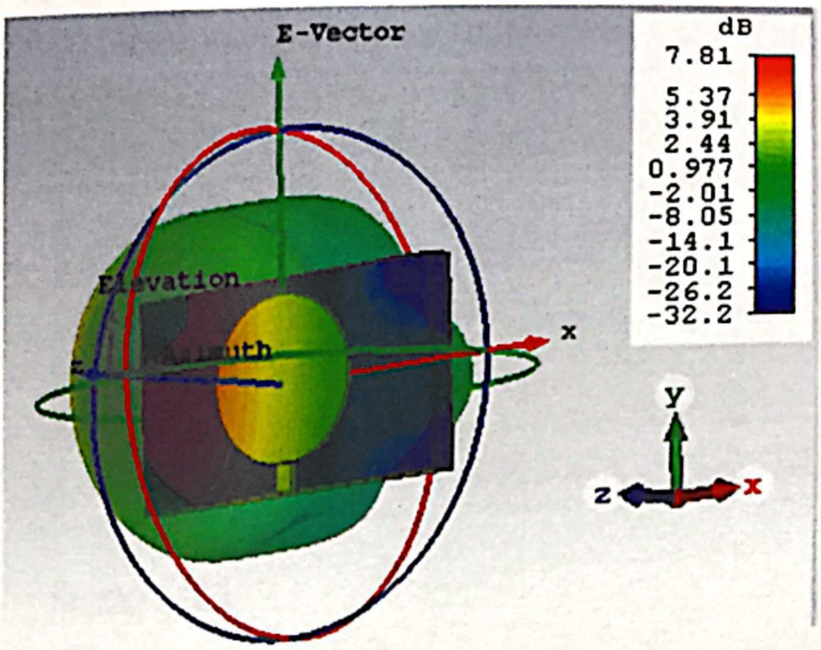



**Figure 4.7**: Far-Field view 3D radiation pattern for circular patch antenna.

#### 4.2.2.3 GAIN

Figure 4.8 show the gain of circular patch. Gain or power gain shows how efficiently the available power at input terminals of antenna is transmitted. The unit of gain is dB. The Gain is 7.81 dB for circular patch.

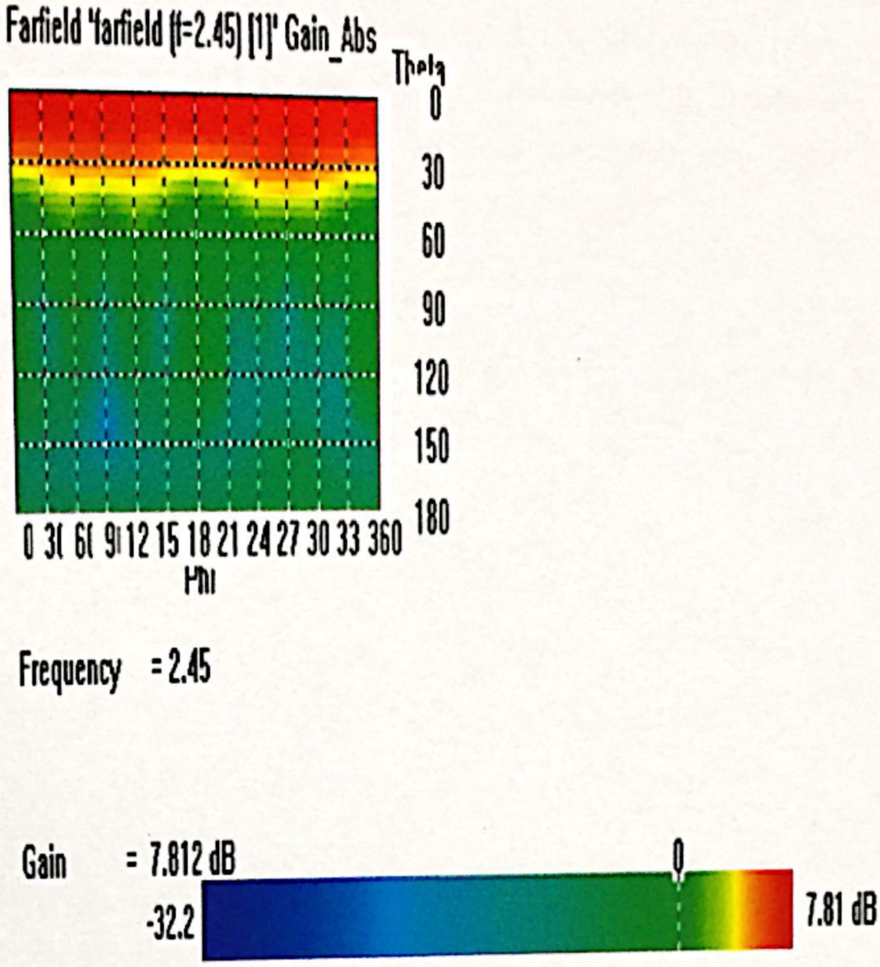



**Figure 4.8**: Gain of circular patch.

## 4.3 COMPARATIVE ANALYSIS

In this section, comparative of two configurations is shown in table form. Return loss, gain and frequency is compared in table 4.9.

**Table 4.9**: Comparative analysis of two configurations of Antenna.

| No | Parameters | Rectangular Patch Antenna | Circular Patch Antenna |
|---|---|---|---|
| 1. | Gain (dB) | 9.18 | 7.81 |
| 2. | Return Loss (dB) | -15.17 | -20.06 |
| 3. | Frequency (GHz) | 2.5 | 2.45 |

After Simulation, it is found that rectangular patch antenna has low return loss with high gain and bandwidth. Simulated return loss is -15.17 with gain 9.18 dB is obtained from rectangular patch antenna.

# CHAPTER 5

## CONCLUSION AND FUTURE WORK

### 5.1 CONCLUSION

The fundamental aim for this project is to develop the wearable textile antenna, which can cover the frequency from 2 to 3GHz. To design microstrip antenna using 2 different shapes (Rectangular and Circular Patch) using denim substrate operating at 2.45 GHz; specific frequency for medical applications. The objective of this project is achieved whereby the antennas were successfully developed by using Computer Simulations Technology (CST) software and fabricated prototypes.

The performance of both antennas were analyzed and investigated by using simulation. All the simulation results are agreed with the results in term of return loss. For both antennas design is found to achieve return loss at frequency ranges from 2-3GHz. So, it can be conclude that all the antennas achieve the specification of UWB antenna.

In term of radiation patterns results, all the antennas are found that have almost similar results. For both the antennas, the radiation pattern at 2-3GHz is directional.

Besides, in terms of gain and efficiency of the antennas, both of the antennas have low power consumption. These are great due to the design specification of wearable antenna design. All the antennas also have high efficiency of data rate. This is good for the wearable antenna.

## 5.2 RECOMMENDATION FOR FUTURE WORK

To have better performance of the antenna, future work is needed. Human errors during the fabrication process are the major cause of the differences between simulated and measured results. Hence, some development have to be done to help the fabrication process is easier to handle and get more accurate design and result

.

All the measurement of the antennas was carried out freely in a room. However, this wearable antenna will be attached onto the human body. These antennas have partial ground plane. Subsequently, our body will suffer the power radiated from the antenna. Thus, the effect of the antenna to the body should be investigated. For the alternative, the antenna design can be matched using coaxial feed line.

Basically, the wearable antenna system is transmitting low power level which limits the area of coverage. In order to improve the quality of service, the directional wearable is needed to be designed. Therefore, the research on directional wearable should be carried out.

In this project, denim fabric is used as a substrate. To have better performance, the other can attempt to research using the other fabric that have higher thickness than the denim fabric like leather textile. However, the dielectric permittivity also should take consideration to design the wearable antenna.

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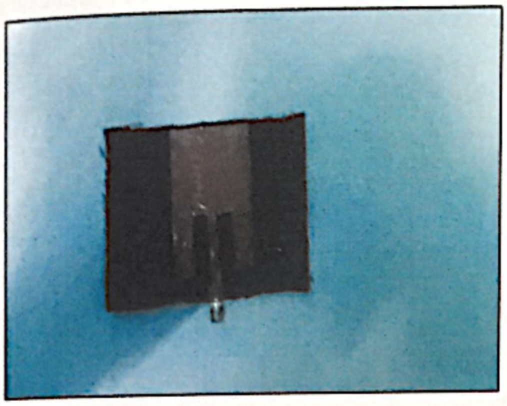
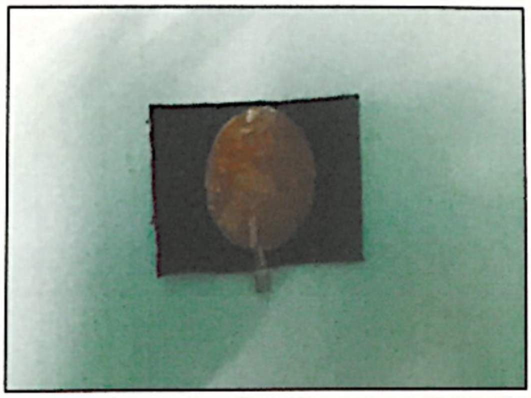
**APPENDIX A**

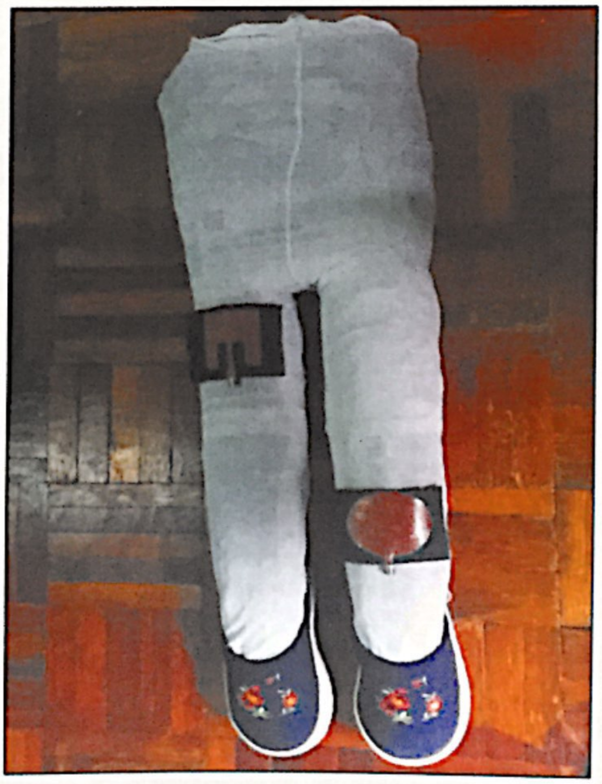
Antenna Fabricated Prototypes



Rectangular Antenna Prototypes



Circular Antenna Prototypes

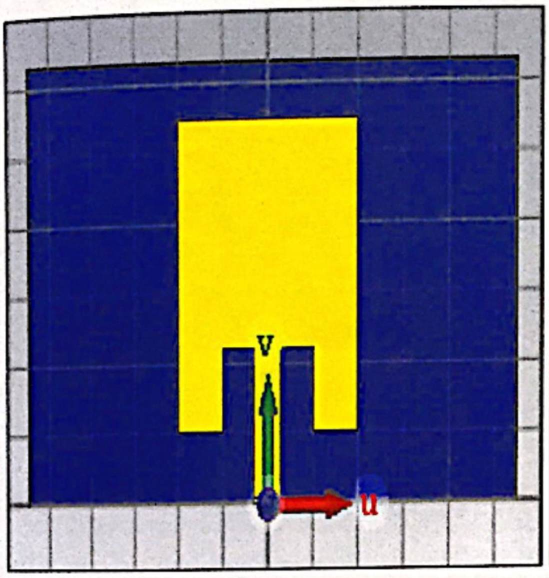


Wearable Antenna attach to denim pants prototypes

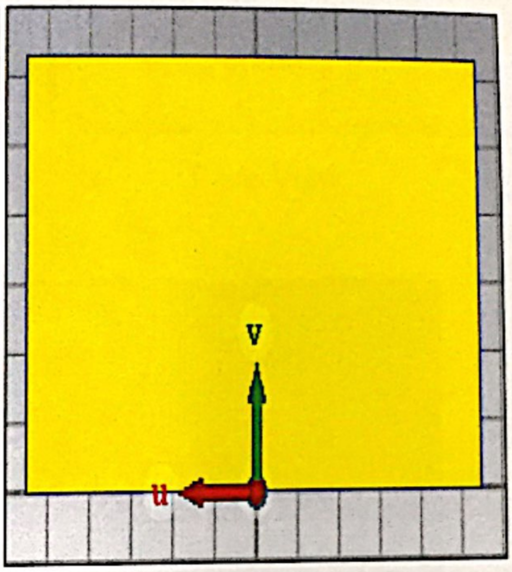
## APPENDIX B

# CST SIMULATION DESIGN

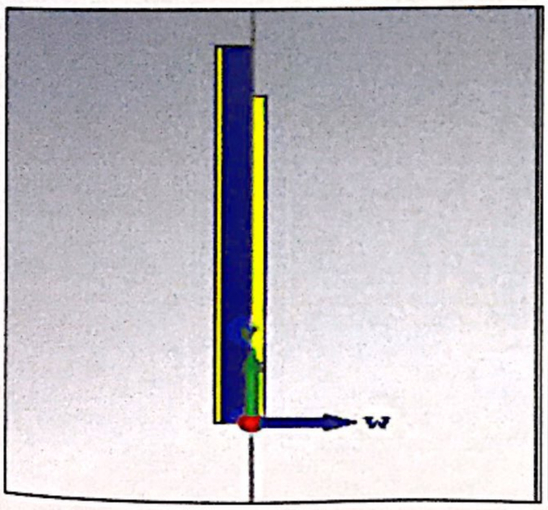
Rectangular Patch Antenna Design



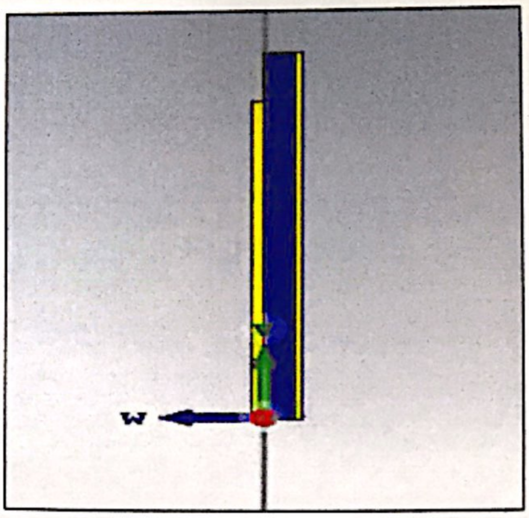

Front View




Back View

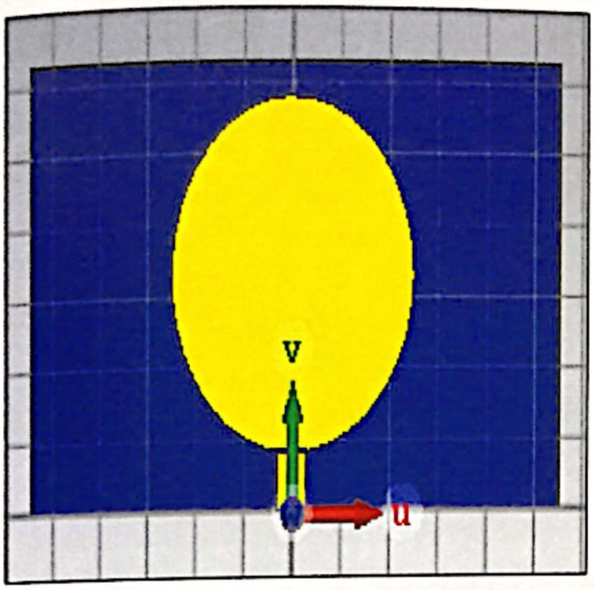



Left View

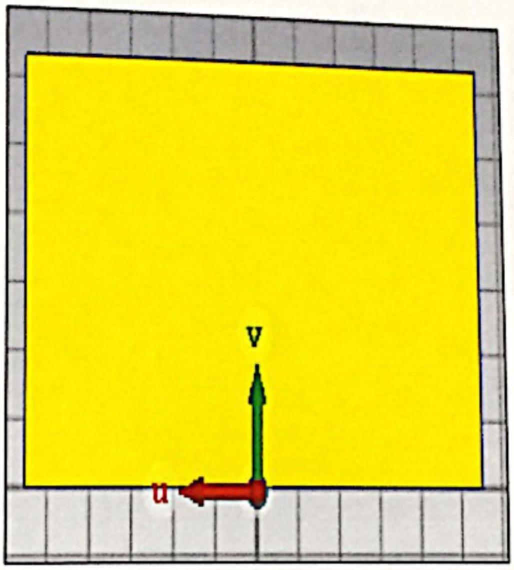



Right View

Circular Patch Antenna Design




Front View

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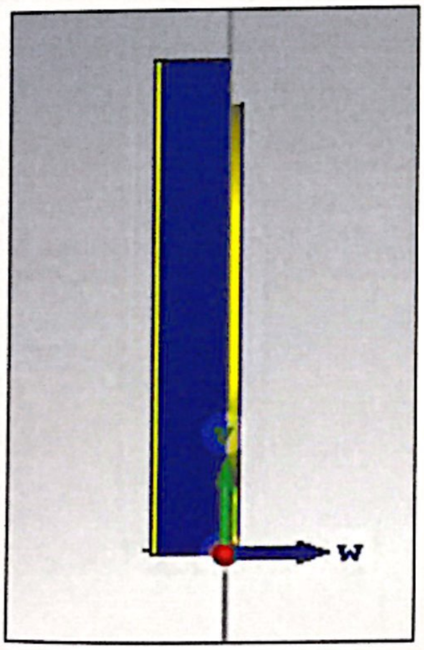
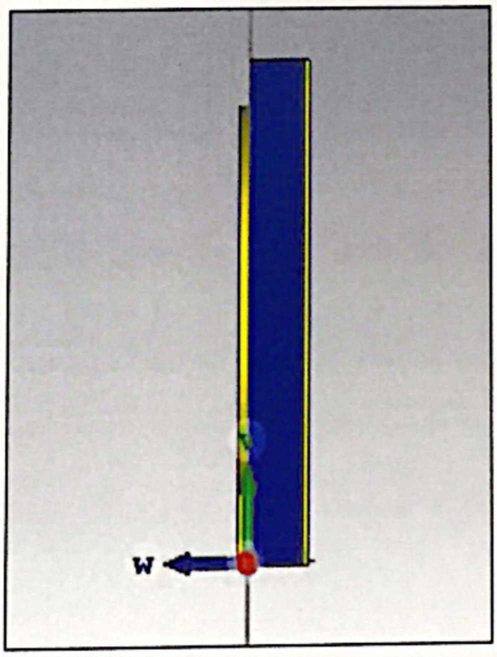



Left View




Right View