Development of a Wearable Patch Antenna for Patient Monitoring

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ABSTRACT

This research sees to developing a miniature/wearable microstrip patch antenna which will be lightweight and have a reasonable flexibility limit. Within this study thus, microstrip patch antenna (MSA) using CST studio was sized and designed. In this regard, this research sees to developing a miniature/wearable microstrip patch antenna for patient monitoring applications. The features of the antenna are specifically chosen to ensure that it meets up with the requirement of the patch antenna. This is to ensure its compact size, effective length and good transmissions which are all pre-requisite for a patch antenna intended for patient monitoring purpose as it's designed to be worn on the body.

The study comprises of an introductory chapter which gives a general information on the study background, problem statement, justification of study, scope of research, aim and objectives, advantages and disadvantages and the thesis guide. The chapter two encapsulates the review of literature, the third chapter covers the methodology and procedure for the simulation of antenna, the chapter four introduces the results and discussion of the simulation and chapter five concludes the research with recommendations.

Keywords: Telemedicine, Biomedical, Patient Monitoring, Microstrip Patch Antenna, Simulation, CST Studio.

ÖZ

Bu araştırma, hafif olacak ve makul bir esneklik sınırına sahip olacak minyatür / giyilebilir bir mikroşerit yama anteni geliştirmeyi amaçlamaktadır. Bu çalışmada, CST studio kullanılarak mikroşerit yama anteni (MSA) boyutlandırıldı ve tasarlandı. Bu bağlamda, bu araştırma hasta izleme uygulamaları için minyatür / giyilebilir bir mikroşerit yama anteni geliştirmeyi amaçlamaktadır. Antenin özellikleri, yama anteninin gereksinimini karşıladığından emin olmak için özel olarak seçilmiştir. Bu, vücuda giyilmek üzere tasarlandığı için hasta izleme amacına yönelik bir yama anteni için ön koşul olan kompakt boyutunu, etkili uzunluğunu ve iyi iletimlerini sağlamaktır.

Çalışma, çalışmanın geçmişi, sorun açıklaması, çalışmanın gerekçesi, araştırmanın kapsamı, amaç ve hedefleri, avantaj ve dezavantajları ve tez rehberi hakkında genel bilgi veren bir giriş bölümünden oluşmaktadır. İkinci bölüm literatürün gözden geçirilmesini kapsıyor, üçüncü bölüm antenin simülasyonu için metodoloji ve prosedürü kapsıyor, dördüncü bölüm simülasyonun sonuçlarını ve tartışmasını tanıtıyor ve beşinci bölüm araştırmayı önerilerle sonuçlandırıyor.

Anahtar Kelimeler: Teletıp, Biyomedikal, Hasta İzleme, Mikroşerit Yama Anteni Simülayson, CST Stüdyosu.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

η	Antenna Efficiency
ΔL	Extended Patch Length
D	Antenna Directivity
dbi	Decibels relative to isotropic
Ea	Electric Field Intensity
f_o	Operating Frequency
f_c	Center Frequency
f_H	Upper Frequency
f_L	Lower Frequency
G	Antenna Gain
H	Substrate Thickness
L	Patch Length
Lg	Ground Length
W	Patch Antenna Width
W_g	Ground Width
Z_o	Line Characteristic Impedance
Z_L	Load Impedance
π	PI
Ω	Ohm
ADS	Advanced Design System
BW	Bandwidth
CST	Computer Simulation Technology
DGS	Defected Ground Structure

FS	Free Space
HFSS	High Frequency Structural Simulator
IE3D	Integral Equation Three-Dimensional
ISM	Industrial, Scientific & Medical
PDMS	Polydimethylsiloxane
PEC	Perfect Electric Conductor
RMPA	Rectangular Microstrip Patch Antenna
SAR	Specific Absorption Rate
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Network

Chapter 1

INTRODUCTION

1.1 Background of the Study

The incessant and avoidable mortality of people, especially in rural communities, could be attributed to the inability to afford nor access quality healthcare services. A way of alleviating some of these problems could be by developing not just innovative, but also low-cost technological solutions that would make health care services more cost-effective and efficient to such individuals, and then in extension to others.

The right to a healthy life is seen as an inalienable human right, and access to it has become a crucial component of our daily lives, costing us money. Due to the necessity of running hospitals, which affects time, traffic, finances, and employment, it is also having an impact on many different public services. In most cases, it impacts older people in addition to the public sector. Health monitoring system is a practical and affordable technical solution to such issues [1]. Instead of spending money on a pricey nursing home, this technology enables the patient to receive the required medical assistance where it is most convenient for him. [1]. Therefore, health monitoring systems are viewed in this context as being crucial to providing pleasant, high-quality treatment at a reasonable cost. The fundamental component of a health monitoring system is wireless technology [2], [3], [4], [5], [6]. Numerous methods that identify various health metrics and extract data in an effort to improve habitat behavior are available at the current state of the art. In [4], a system that detects changes in indoor environments is described. It consists of a RADAR and a wirelessly connected base station for data processing. Recently, research on wireless body area networks (WBANs) has been established for both medical and non-medical field applications. Since it serves as the focal point for wireless sensors, wearable antenna has attracted interest.

One of the things that makes a device work better is the material utilized to make it. Because of its dielectric qualities and flexibility, polymer nanocomposites are widely used nowadays. Depending on the type and quantity of nanofillers added to the polymer, the electrical, mechanical, and chemical properties of the polymer nanocomposite have altered [9]. Nanofillers are added to polymers to improve their surface area and conductivity, however doing so reduces the material's flexibility. One of the key elements affecting how well a microstrip patch antenna performs is the substrate's permittivity value. Low permittivity substrates perform better in terms of return loss and directivity, and high permittivity substrates lead to the downsizing of antennas [10], [11], [12]. By adjusting the concentration of added nanofiller, polymer nanocomposite permittivity value can be changed. Doping with a little amount of nanofiller increases the surface area while maintaining the process ability and flexibility. Researchers are currently focusing on stretchy and lightweight antennas because they offer excellent efficiency at an affordable price. Dielectric nanocomposite preparation via nanoparticle introduction into the polymer matrix is a difficult endeavor since it offers strong dielectric strength in terms of electrical properties.

Modern electronics are exhibiting a trend of circuit shrinking. The polymer's nanometer-scale nanofiller produces a thin dielectric coating with a large surface area, which leads to the downsizing of circuits [13], [14]. The size of wearable electronic devices should be minimal since they are either sewn into clothing or are linked directly to the human body to monitor activities in real time [15]. A dielectric substrate is put between a radiating patch and a conductive ground plane in a typical microstrip patch antenna. Reduced antenna size and improved return loss and bandwidth are produced by cutting a U-shaped slit from the patch [16]. The U-shaped slot microstrip patch antenna creates higher order modes that gradually expand the overall bandwidth of the antenna [17] and are employed for wireless biomedical applications [18], [19]. These modes overlap the original bandwidth of the antenna. Because it is worn on the foot, wrist, and even close to the heart, antenna in biomedical devices need to be durable and flexible [20], [21], [22]. Due to its chemical and thermal stability, non-toxicity, and flexibility, Polydimethylsiloxane (PDMS) is an elastomer dielectric material used in biomedical devices. Multi-walled carbon nanotubes (MWCNTs), for example, function as semiconductors when doped in polymer matrixes, exhibiting unusual electrical, mechanical, and dielectric properties that can be applied to a variety of applications [23], [24].

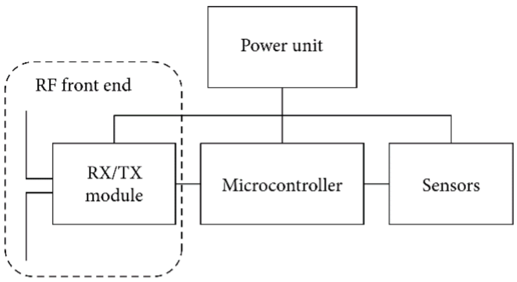


Figure 1.1: Diagram of wireless monitoring

Figure 1.1 depicts a wireless health care monitoring system's overall architecture. There are four main blocks that can be seen:

⇒ The radio frequency (RF) front end, which includes an antenna and RX/TX module for receiving and transferring data from and to the data monitoring unit,

⇒ A microcontroller for processing the sensor data and sending it to the block

⇒ The sensor, and

⇒ The power supply required to run all the preceding blocks.

All four of these electronic building elements need to be integrated into clothing or worn accessories for wearable wireless systems to function effectively consequently, it is necessary to use unconventional fabrication methods and materials together with unique design methodologies.

1.1.1 Advantages of microstrip antennas

a) They function at microwave frequencies, where standard antennas are impractical to construct.

b) Because the microstrip patterns are visible and accessible from the top, the microstrip based antennas are simply etched on any PCB and will also allow easy access for diagnostics during design and development.

c) They are simple to make and comfy to wear on curved areas of the device.

d) The patch antennas are fed along the centerline to symmetry, which reduces the excitation of other undesirable modes and so improves the radiation efficiency in some way.

e) Microstrip patches of various shapes, such as rectangular, square, triangular, and so on, may be etched quickly.

f) They have a reduced cost of fabrication and so may be mass produced.

g) They can support numerous frequency bands (dual, triple).

h) They accommodate both linear and circular polarization types.

i) When installed on the gadgets' hard surfaces, they are both light in mass and robust in strength.

1.1.2 Disadvantages of microstrip patch antennas

a) These antennas may have low efficiency due to dielectric and conductor losses, lower gain, intrinsically smaller impedance bandwidth, and, as a result, lower power handling capabilities for high-power applications.

b) In the field structure of arrays, they are prone to large ohmic loss.

c) They generally have lower efficiency and narrow bandwidth.

d) Innately known to have surface wave excitation and low gain.

e) Because feeds and other junction points have possibilities of also radiating, the microstrip antenna configuration has a higher level of cross polarization radiation.

The microstrip patch antennas (MPAs) as seen in figure 1.1 are generally a sort of planar antenna and are not just very popular among antenna designers but have also found immense employment in a variety of wireless communication applications, more especially in critical military infrastructure as well as telemedicine.

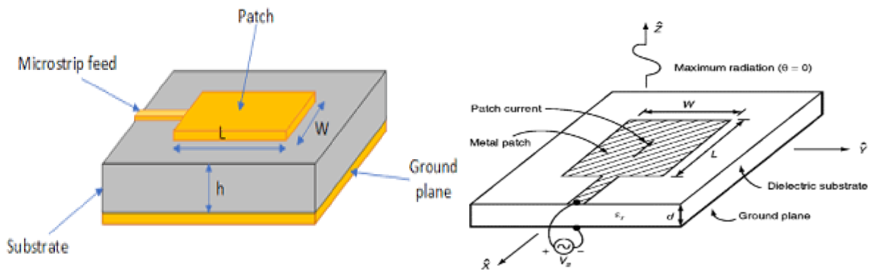


Figure 1.2: Schematics of a microstrip patch antenna
(Source: Chowdhury, Hossain, Hossain & Cheung, 2019)

Microstrip patch antennas are also becoming more popular as they can be printed right onto a circuit board; they are also inexpensive, have a low profile, and are quite simple to manufacture. A microstrip transmission line is used to feed this antenna, as shown in Figure 1.2. A high conductivity metal is also used for the patch antenna microstrip transmission line and ground plane (generally copper). From figure 1.2 also, the patch length is L, width is W, and generally sits on a substrate (any dielectric circuit board) with permittivity or dielectric constant and thickness "h".

1.2 Statements of research problem

Research on antennas and propagation has gained exceptional momentum as it attempts to solve problems with wireless biosensor networks. The test subject to be measured is typically positioned on or very close to these biological sensors. A typical design trend for antennas is to make them physically smaller and more compact, which makes them more user-friendly and less intrusive. For clinical medical applications, size is not the only consideration that needs to be made carefully. This study explores the properties of wearable antennas in the 2.42–2.47 GHz and 5.55-5.57 GHz ISM frequency range and considers whether they are appropriate for wireless monitors in the medical field. The features of the antenna are specifically chosen to ensure that it meets up with the requirement of the patch antenna. The total size of the antenna is 35x40mm^2 while the substrate that is used is made from fabric material having the permittivity of 1.54. While defected ground is used. A square cut of 2.5x7mm^2 is introduced on the ground. The antenna possesses dual band characteristic having a high gain of 5.73dBi and 2.19dBi gain at 2.4GHz.

1.3 Aims and objectives

The aim of this research is to design and simulate a miniature/wearable microstrip patch antenna for patient monitoring application. The specific objectives are thus:

a) To design the Simulation of a patch Antenna using fabric, with an operating frequency of 2.4 and 5.6GHz GHz.

b) To achieve maximum gain of more than 2 dbi. And efficiency above 90%.

c) To simulate the patch antenna using CST, studio for performance evaluation.

d) To analyze and validate the performance of the antenna VSWR near 2.5 of the designed antenna.

e) To recommend for patient monitoring application.

1.4 Research justification

Considering that this antenna would be developed, and performance evaluation carried out through a dedicated software tool as CST Studio, it would enable uncountable variation of the design parameters till the exact of optimized design requirement has been met, almost at no extra cost. This type of antenna is also chosen specifically for this study because of all the numerous advantages mentioned in the section above.

Amidst several social advantages that this research would offer, it would foster remote health care services to the less-financially stable people in rural communities that would not be able to afford specialized medical assessments from professionals far away advanced countries; hence they could be treated remotely through special intervention of government arrangement with the use of the developed wearable telecommunication antenna.

1.5 Research methodology

In the design of this microstrip antenna, numerous important parameters such as the voltage standing wave ratio (VSWR), the bandwidth, return loss, surface current, radiation efficiency, directivity and gain are investigated and studied. All the parameters are computed using mathematical equation for the development of the microstrip patch antenna. The optimization of the antenna dimensions is achieved using CST optimizer.

1.6 Research scope

This study is centered on the design of a flexible and wearable microstrip patch antenna using CST studio as the simulation software. The antenna is developed using a single band and multi band applications on fabric substrate that function in wireless body area network (WBAN) application. The result of the experiment validates the outcome of the simulation as well as the performance analysis achieved as the return loss of around 20dB, VSWR estimated to 2.5 for the designed antenna. It is important to state that this research does not take into cognizance the body phantom with effect on the body environment.

1.7 Research guide

The first is the introductory section of the thesis, it provides a study background, followed by a problem statement, and an aim and objective section, which thus lead to the research justification, research methodology and scope. Chapter two is basically the review of literature which includes previously published work on flexible antenna, mathematical equations and other related aspects of the study. Chapter three encompasses the methodology of the study which involves the design and simulation of the antenna. The fourth chapter discusses and analyses the results from the simulation such as the VSWR, radiation patterns, efficiency, directivity, surface current and the antenna gain. The concluding chapter is the chapter five which rounds up the research it contains conclusion and recommendation of the practical application of the study and other area where improvement is possible for future research.

Chapter 2

LITERATURE REVIEW

2.1 Overview of antenna

Antennas are important in today's world of wireless communication because they efficiently convert electronic signals to electromagnetic waves. Antennas are critical elements of every electrical circuit because they connect the transmitters to free space or the receiver to free space. Summarily, an antenna gets electrical signals from a transmission line and converts them to radio waves in a transmitting antenna: however, in a receiving antenna, the reverse is the case since it gathers radio signals from space, converts them to electrical signals, and sends them to a transmission line. Different various types of antennas are discussed herein.

2.1.1 Rectangular microstrip

Low profile antennas classified as rectangular microstrip antennas or patch antennas are often recommended for spacecraft or aircraft applications based on characteristics like as size, cost weight, ease of installation, performance, amongst several others. The feed line, which is generally located behind the ground plane, is all that is required for these antennas, as shown in figure 2.1.

The main drawback of employing these antennas in such applications is their ineffective and very small bandwidth, which is usually a fraction of a percent or a few percent at most. However, it has found immense application in miniature/wearable antenna designs.

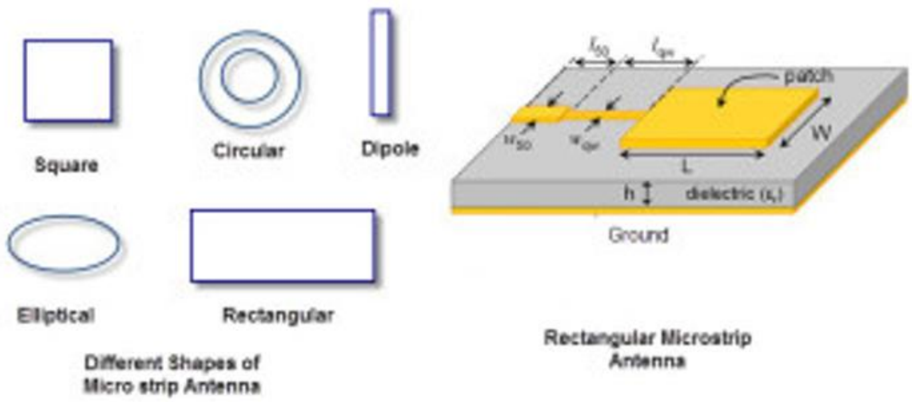


Figure 2.1: Different shapes of microstrip antennas

2.2 Antenna theories

Antennas are related with a few basic parameters in various applications. These are sometimes referred to as antenna characteristics or qualities. The following are some of the properties of an antenna.

- Radiation Pattern of Antenna
- Intensity of Radiation
- Polarization of Antenna
- Effective Aperture
- Bandwidth
- Gain & Directivity
- Power Gain & Radiation Efficiency
- Effective Length
- Polar diagram
- Input Impedance

Some essential antenna parameters, such as the return losses (S-parameters), radiation pattern, Specific Absorption Rate (SAR), and radiation efficiency are discussed herein, with a focus on wearable antenna designs.

2.2.1 Return losses of (S_{11} parameter)

In radio frequency (RF) engineering, scattering parameters, also known as S-parameters, describes the reflection and transmission interactions between incident waves and transmitted or reflected waves from a network, and are thus referred to as the return losses or reflection coefficient. A portion of an RF signal incoming onto one port of a multi-port system, for example, is reflected from that port, while the rest is transmitted to, or scatters to, some or all of the other ports. S-parameters are used to quantify or even qualify this transmitting process. Normally, S-parameters are evaluated throughout a range of frequency. As a result, a two-port network model is typically employed for antenna evaluations. As observed in equation 2.1, Port 1 in the system represents the feed port of the antenna under test (Antenna Under Test), and S11 indicates the ratio of the voltage reflected at just that port,

$$S_{11} = \frac{V_{refected\ at\ port\ 1}}{V_{towards\ port\ 1}} = \frac{Z_{input} - Z_0}{Z_{input} + Z_0} \tag{2.1}$$

Where:

V is voltage

Z is impedance

Z_0 is the characteristics impedance.

As a result, the parameter S11 is utilized to evaluate the impedance matching between both the antenna and its feed network in general. In practice, the ratio of the voltage reflected from the antenna feed to the incident voltage is indeed a major concern because it represents power that is reflected and thus lost in the system; higher reflected power leads to lower power efficiency, that can create problems in the feed circuit. The S11 parameter is frequently expressed in decibels (dB) and can be calculated using the equation below.

$$S_{11}(dB) = 10\,log\,{S_{11}}^2 = 20\,log\,S_{11} \qquad (2.2)$$

The frequency range with S11 less than 10 dB (showing power loss due to reflection with less than 10%) is generally regarded the effective bandwidth for a conventional antenna. This bandwidth is also known as the impedance bandwidth since it assesses the antenna's and feed network's impedance match. Figure 2.2 shows an example of simulated return loss for a typical microstrip patch antenna (S11 in dB) simulated return loss for a typical microstrip patch antenna (S11 in dB).

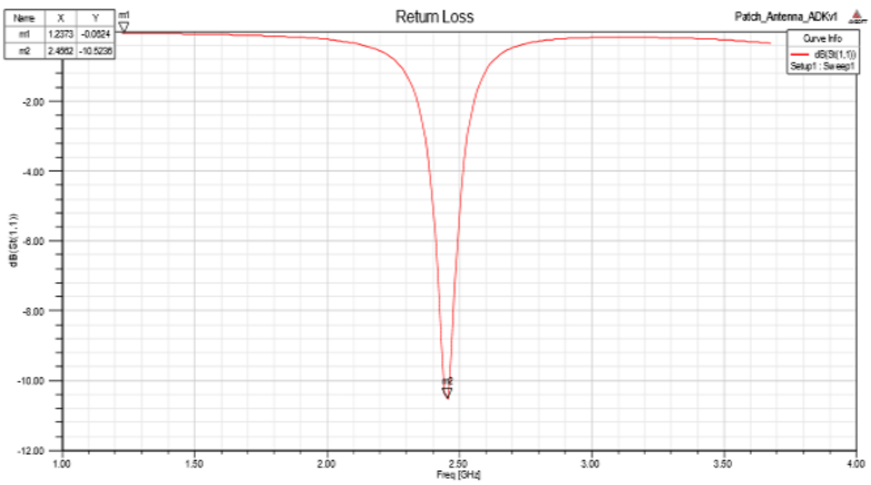


Figure 2.2: Simulated results for S_{11} Parameter
(Source: Hussain, et al., 2019)

When an antenna is put in close proximity to the human body, the return losses parameter for a stand-alone device then changes significantly or is perceived differently during analysis. Typically, In the frequency range of 10 Hz to 10 GHz, human body tissues are usually extremely lossy, therefore a significant amount of power radiated near to the human body is absorbed by the body tissues around it. As a result, the dielectric characteristics of biological tissue have a big impact on antenna performance; it is then vital to note that these properties are usually also frequency dependent. Table 2.1, for example, displays the relevant properties of muscle and blood over a frequency range of 2 GHz to 10 GHz, indicating that the relative permittivity of the two tissue types ranges between 40 and 60.

Table 2.1: Dielectric properties for body tissues at one given frequency

Frequency (GHz)	Relative Permittivity		Loss tangent	
Tissue Type	Blood	Muscle	Blood	Muscle
2	59.022	53.290	0.33290	0.24520
4	55.677	50.821	0.33364	0.26665
6	52.184	48.217	0.39010	0.32321
8	48.610	45.497	0.45628	0.38511
10	45.109	42.764	0.52326	0.44666

A shift in frequency to an antenna in close proximity could be caused by this comparatively strong permittivity. It can also be shown that dielectric loss increases with frequency as relative permittivity decreases with RF frequencies. When compared to other materials specialized to circuits and RF applications (e.g., FR4 with a loss tangent of 0.017 to 0.025, which is already considered lossy for several RF applications), bodily tissues are generally quite lossy to the antenna. As a result, when an antenna is evaluated in conjunction with the human body (whether utilizing a voxel human model in simulation software or testing with a physical humans), there is a significant drop in S11; this drop would be even greater if the antenna were implanted further into the body instead of worn close to or pinned on the body surface. The reduction in S11 might cover a greater frequency range, resulting in a larger impedance bandwidth. So generally, antennas in close proximity will experience severe frequency shifts and efficiency degradation as a result of body tissues. Because a larger impedance bandwidth often does not imply a larger usable bandwidth, other characteristics such as antenna gain, and radiation efficiency become more essential when evaluating the antenna's performance.

2.2.2 Gain

Antenna gain simply refers to how well an antenna transmits (or receives) electromagnetic radiation in a specific direction. The antenna gain is commonly expressed in dBi, which refers to the ratio of the antenna's power to the power which would be radiated by an ideal isotropic antenna. An isotropic antenna however is a hypothetical antenna which radiates the same amount of energy throughout all directions. A gain-comparison method, which involves the usage of a standard gain antenna as a reference, could be employed to obtain antenna gain measurements. The half-wavelength dipole and the pyramidal horn are the two most common types of the reference antennas. The equation (as in 2.3) is then used to guide the calculation procedure.

$$G_{AUT} = G_{ref} + 10\, log_{10} \frac{P_1}{P_2} \tag{2.3}$$

Where:

G_{AUT} is the gain of the antenna under test

G_{ref} is the gain of the reference antenna

P_1 is the received power from the first measurement

P_1 is the received power from the second measurement.

Aside from the gains mentioned herein, the term realized gain is also commonly used. This term specifically refers to the gain value when all losses (i.e., mismatch loss, conduction and dielectric loss) have been considered.

2.2.3 Antenna efficiency

In general, antenna efficiency is just the ratio of radiated power from the antenna to the power delivered to the antenna by the source. The efficiency of an antenna can be divided into two categories: radiation efficiency and overall efficiency. The ratio of the power radiated/emitted to the power received just at antenna input terminal is known as radiation efficiency. Conduction and dielectric losses are included in this efficiency. The ratio of radiated/emitted power to power from the feed source is then called total efficiency. For this total efficiency to be evaluated thus, other potential losses like that due to mismatch loss caused by reflection between the antenna port and the feed network are considered. Thus, antenna efficiency generally then refers to the radiation efficiency of a well-matched antenna design. However, the antenna's total efficiency is to be taken into account in this study because the human body contact to the antenna will be taken into account throughout the design and simulation of the antenna.

2.2.4 Specific absorption rate

An antenna's Specific Absorption Rate (or SAR) is essentially a measurement of how much RF energy is received/absorbed by the human tissues surrounding the antenna. The electrical conductivity (measured in Siemens/meter), the induced E-field from the radiant energy (measured in Volts/meter), and the tissue mass density (measured in kg/cubic-meter) are all factors that influence SAR. As shown in the equation below, the SAR is derived by aggregating (or integrating) over a particular volume (usually a 1 gram or 10-gram area).

$$SAR = \int_{sample} \frac{\sigma(r)|E(r)|^2}{\rho(r)} \quad (2.4)$$

SAR is measured in W/kg or mW/g, depending on the context/environment. The SAR limit for mobile phones in the United States for example is around 1.6 W/kg, averaging over 1 gram of tissue, whereas the SAR limit in Europe is 2.0 W/kg, averaging over 10-grams of tissue. These are generally suggested so that the radiation from these antennas does not cause harm to the surrounding tissues.

2.3 Wearable antennas

With the introduction of devices such as smartwatches, fitness bands, and virtual reality glasses, the wearables consumer electronic marketplace has exploded in recent years. Many of these wearable gadget’s function in a wireless manner to improve the customer experience; these have necessitated more deployment of wearable antennas. Wearable antenna designs have gotten a lot of interest from the scientific community in recent years because of this reason. Generally, wearable antennas are designed to work in close proximity to the human body and for extended periods of time. As a result, depending on the device's individual work atmosphere, special antenna design requirements apply. Conventional antennas on Circuit boards, tiny dielectric resonator antennas, or antennas upon metal frames are commonly employed for these applications (Su, et al., 2015). Conventional antennas on Circuit boards, tiny dielectric resonator antennas, or antennas upon metal frames are commonly employed for these applications (Su & Hsieh, 2015). Transparent conductive materials have recently been used to construct transparent antennas on glass for some cutting-edge system designs. Antennas implanted in specialist clothing, such as life jackets and protective garments, have then found extensive use for the health and rescue fields. These designs are often flat and low-profile, then are designed for to allow for distortion and stretching during use. Some wearable antenna designs have also employed components that allow them to be merged with common items; thereby allowing them to achieve greater antenna efficiency through their distinct natural materials properties and design dimensions. Button, shoelaces, watch straps, belt, and even zipper antennas are examples of this.

Applications that necessitate an antenna to be inserted or administered into the human body typically presents a unique set of challenges. A wireless capsule endoscope is indeed a typical epitome of this, as it employs an antenna to transmit real visuals from within human body to a receiver from the outside. An omnidirectional radiating pattern is typically required for this type of application. The most important aspect of the design is determining the features of the tissues and substances surrounding the antenna and then assessing the radiation efficiency. Conformal loops or meander lines are commonly used in this type of application. (Wang, et al., 2018).

According to research, wearable antenna designs can be split into two categories: soft-substrate centered antennas and accessory-like antennas. Soft-substrate antennas include planar antennas having malleable substrates as well as conductive layers, whereas Accessory-like antennas have been modelled after typical wearable items in terms of shape and size. Both types of antennas are discussed in this section.

2.3.1 Soft-substrate antennas

Soft-substrate antennas are typically designed to be sewn into a garment or pieces of apparel. The difficulties in developing such antennas are mostly divided into two categories: material selection and fabrication procedures. Here, a few of the material selection requirements, as well as fabrication procedures have been addressed.

2.3.2 Conductive material selection

The formation of a planar and layered antenna design, which is commonly observed in wearable antennas, necessitates the use of conductive as well as dielectric materials.

The two most crucial factors in providing stable, high-efficiency antenna performance for the conductive materials are strong conductivity and stabilized performance during deformation (be it stretching, bending, crumpling, etc.): In most cases, electro-textiles give a single solution that meets the conductivity criteria. Previously, conductive fabrics had low conductivity and large losses, which resulted in lower antenna performance and gain (Paracha, *et al.*, 2019). Recent advancements in the production of conductive fabrics, on the other hand, have increased the efficiency of embroidered antennas and circuitry. Metal-plated threading is extensively used to make electro-textiles; for example, the silver-plated thread is commonly used given its high conductivity, and nickel is occasionally incorporated to improve the thread's corrosion resistance. Silver-plated threads have indeed been combined with numerous substrates to create planar antennas; one example is illustrated in Figure 2.6, which is a planar spiral antenna embroidered with these threads. Improved embroidery processes are already permitting conductive fibers manufactured with silver-plated threads to also be utilized in fabricating antennas and circuitry that match the high-efficiency and low-loss standards, according to recent novel studies.

Figure 2.3: Planar antenna Fabricated with conductive threads
(Source: Zhong, et al., 2017)

This is being used in a typical RF energy harvesting system, with conductive fiber antennas achieving a radiation efficiency of around 77.3 per cent at 2.45 GHz and also on some rectifying circuits: achieving an efficiency beyond 70% in just the same operating band.

The conductance of a single thread may not truly project the loss of conductive textile material in the RF band due to the intricacy of thread makeup and orientations. As a result, hypothetically quantifying the loss is ever challenging. The loss of the conductive fiber can thus be assessed by manufacturing a transmission line that uses the standard thread and fabrication procedure, and then determining the transmission coefficient of that transmission line. As illustrated in Figure 2.4, (Vital, et al., 2018) constructed and tested three transmission lines. The substrate material for all three transmission lines was Polydimethylsiloxane (PDMS). The conductive substance was the major distinction between them.

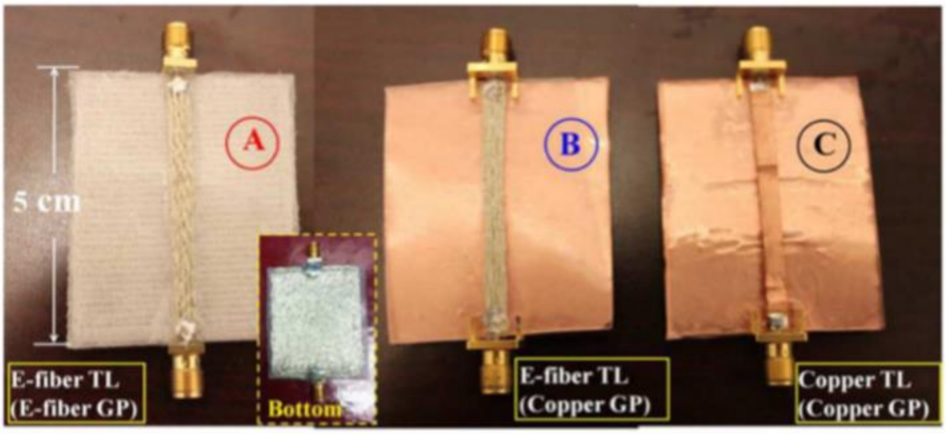


Figure 2.4: Three transmission line (TL) samples.
(Source: Vital, et al., 2018)

Sample A in Figure 2.4 employs conductive E-fiber both for the transmission line top layer and the ground plane; Sample B utilizes conductive E-fiber for the top layer and copper for the ground plane: Copper is used both for top layer and the ground plane in Sample C, which is a typical comparison. The study examined the transmission loss per unit length (cm) in dB for the three transmission lines: 0.21 dB/cm, 0.17 dB/cm, and 0.14 dB/cm for cases A, B, and C, respectively were obtained.

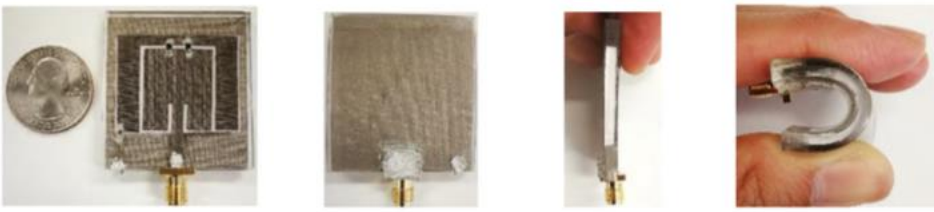
Electro-textiles with varied sheet resistances include nickel-plated (corrosion resistant), Electron (copper-coated nylon fabric), silver-plated (strong and flexible), and Nora conductive fabrics. In comparison to woven/embroidered textile antennas, the performance of antennas composed of conductive polymers deteriorates very little when stretched. Carbon nanotubes, silver nanoparticles, and graphene nanofibers are progressively being employed to give existing polymer-based substrates like Polydimethylsiloxane (PDMS) more tensile strength and flexibility. It is worthy of being noted here that stretching is a common problem with textile and flexible antennas. Stretchy conductive materials have attracted a lot of attention as a result of the often-deformable circumstances in these wearable antennas;

nonetheless, the fundamental disadvantage of elastic wearable antennas remains their reduced radiation efficiency when strained (Vital, et al., 2018). Various stretchable materials then apply diverse conductive doping elements to alleviate this deficiency.

Additional conductive materials, such as graphene and conductive ink, have also been used in antenna designs in complement to the conductive fibers. These materials are also capable of achieving the desired conductivity. For example, graphene on a paper substrate was used to make a low-cost dipole antenna with a radiation efficiency of around 32% (Leng, et al., 2016). A smooth, stable, and homogenous substrate is normally required for the introduction of graphene or conductive ink. For wearable technologies thus, such substrate requirements could be an issue.

2.3.1.2 Substrate material choice

The dielectric substrate substance is vital in determining an antenna's performance; the dielectric constant and the loss tangent of the substrate are still the two most critical properties impacting antenna performance. A high dielectric constant means a smaller antenna, which is advantageous for wearable applications and yet also means a reduced operational bandwidth, which may be inconvenient for some applications. The substrate's dielectric loss would also have a direct impact on the antenna's efficiency; hence it is avoided as much as possible during design. As a result, the design parameters would call for a soft substrate with an adjustable dielectric constant and a low loss tangent, hence enabling for a compromise among bandwidth and size while maintaining good radiation efficiency. Textiles are indeed a popular choice for wearable substrate because they allow antennas to be manufactured directly into clothes. Felt, fleece, Cordura, as well as spacer fabric are among the most commonly used materials. Normal textiles have a relative permittivity of 1.3 to 1.95 as well as a loss tangent between 0.0004 to 0.0400. Given that the dielectric properties of textiles are highly dependent on their thickness, weave, any dye added, and the inherent properties of the thread, evaluations of textile material parameters should always be undertaken before the simulation and manufacture of the antennas are done. Polymer-based substrates have recently received interest based on their flexibility and stretch-ability, as previously mentioned. One potential poly-based substrate material is polydimethylsiloxane (PDMS). Figure 2.5 depicts a conductive fabric antenna imbedded in PDMS and demonstrates its flexibility.



(a) (b) (c) (d)

Figure 2.5: An example of a fabricated PDMS-Embedded conductive fabric antenna showing (a) the top view, (b) the bottom view, (c) the side view and (d) the bent view

Doping several powders into a PDMS substrate could modify its dielectric characteristics; thereby making the material adaptable to varied uses. Stretchable wearable antennas thus can be made from PDMS layered around conductive rubber. The relative permittivity of PDMS substrates utilized for wearable applications ranges from 2.8 to 6. This value is much higher than standard fabrics, which range from 1.3 to 1.95. As a result, the average antenna size possible with PDMS substrate is likely to be smaller than with alternative textile fabric substrates.

2.3.1.3 Fabrication technique for soft substrate antennas

The manufacturing technologies used to produce soft-substrate wearable antennas often seem to be those conventional techniques already widely associated with the type of substrate material chosen. Screen printing, inkjet printing, and embroidery are examples of these processes. Embroidery is a typical method for making antennas that uses conductive thread and textile as the substrate. Figure 2.6 depicts a common procedure for making an embroidered antenna. Fabrication characteristics such as the number of conductive threads per centimeter, thread alignment, and embroidery tension will all affect the antenna's performance (Vital, et al., 2018). With an automated embroidery machine, however, these parameters can be optimized.

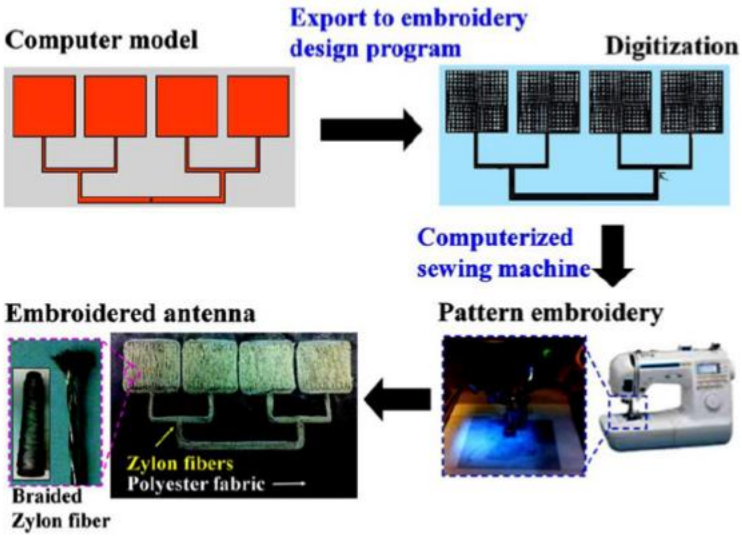


Figure 2.6: Embroidery process of the E-fibres to create RF designs on polyester fabrics (Source: Wang, et al., 2012)

Figure 2.7 then shows a different arrangement, in which conductive fibers are coupled to a PDMS substrate. The antenna design could be constructed to have a tweakable substrate dielectric constant as well as a high conductivity at the designers' discretion using this production method.

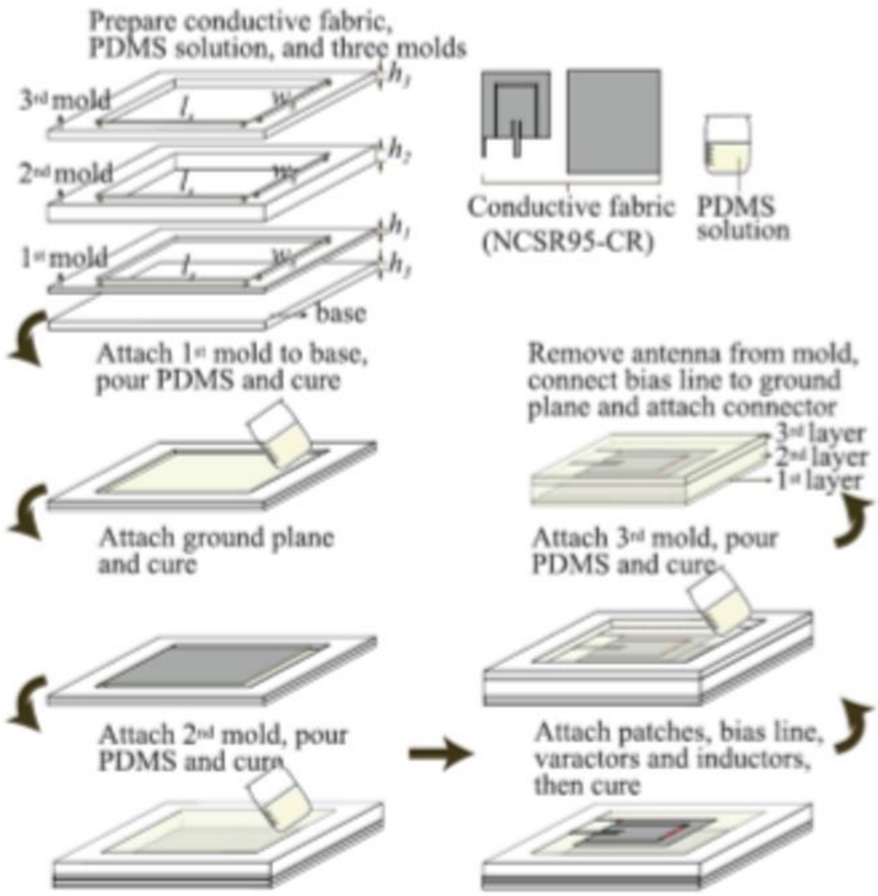


Figure 2.7: Manufacturing process flow for polymer-embeded conductive fabric antennas (Source: Wang, et al., 2012)

The screen-printing technology has also been proven to be a viable method for fabricating wearable antennas. The screen for this technology is often formed of a mesh of textile thread, with the non-image portion covered by something like a stencil and the image (antenna pattern) section left exposed. The printing is done by passing a conductive ink (usually silver-based based) through the screens onto the substrate. (Roshni, et al., 2017), showed the successful construction of an E-shape patch antenna using a multi-layered polyester fabric as shown in Figure 2.8 The polyester fabric does have a water-resistant property and thus can withstand extreme bending. Screen printing has been used on a variety of materials, including graphene and PDMS.

Figure 2.8: Screen printed antenna on polyester fabric
(Source: Roshni, et al., 2017)

Ink-jet printing thereby spreads conductive ink particles over the surface of substrates using a specialized printer. Paper has also been employed as a substrate, similar to traditional printing, and significant efficiency has been achieved in the 1.8 GHz, 2.4 GHz, and 3.5 GHz bands. This approach is now being used to create wearable wideband antennas on leather.

2.4 Conformal wearable antenna

Conformal antennas are a type of antenna that can conform or adopt the shape of structure or shape. They are designed to be mounted on curved or irregular surfaces, such as aircraft, smart watches, vehicles and human phantoms of hand and breast. Conformal antennas are used in a variety of applications like in defense, biomedical and telemetry applications.

The advantages of conformal antennas are their ability to provide better coverage and performance than traditional antennas. By conforming to the shape of the surface, the antenna can be designed to provide a more precise and directional signal. This can be particularly useful in RADAR and Biomedical applications where precise and accurate signals are critical.

Conformal antennas come in various shapes and sizes, depending on the applications and the surface on which they are mounted. Some common shapes are spherical, cylindrical and planar. The design of conformal can be challenging, as it requires careful consideration of the curvature of the surface. The frequency range and the desired applications.

In short, the conformal antennas used in wide range of applications than the traditional antennas because it can be used in wide range of applications including reduced drag, better coverage and performance and seamless integration into the structure of the system.

2.5 Review of past related work

Hussain, Hafeez, Memon, & Pirzada, (2019) developed a wireless body area network patch antenna. This low-profile wearable microstrip patch antenna was built and suggested for constant monitoring of human vital indicators such as blood pressure, body temperature and pulse rate. The antenna's operational frequency was chosen to be 2.45 GHz, which is within the industrial, scientific, and medical (ISM) frequency range. For the substrate, a polyester textile fabric having a relative permittivity of 1.44 was utilized. The inset fed approach was chosen because it offered a planar structure which could be effectively fed by a 50-ohm impedance. The antenna's overall dimensions were 90 x 90 x 2.85 mm3. In comparison to other current wearable antennas, the proposed antenna was developed to achieve improved return loss, VSWR, gain, and a low amount of specific absorption rate (SAR). The antenna is stimulated at a 2.45 GHz, the antenna return loss was about -10.52 dB, with a gain of 7.81 dB. At 2.45 GHz, the VSWR was 1.84, which was acceptable in terms of impedance matching. Other antenna field characteristics such as 2D and 3D gain, as well as the radiation pattern, were also determined. At 2.45 GHz also, the SAR value measured on the 3-layer human phantom model was 0.0640 W/Kg averaged across 1 gram of tissue.

Ullah, Islam, Alam, & Ashra (2018) developed a paper-based flexible antenna towards wearable telemedicine-based applications in the 2.4 GHz ISM band. This study also established the possible antenna's efficiency in the ISM (industrial, scientific, and medical) bands. Using 0.03 mm copper strips a radiating element, the antenna was made from 0.54 mm thick flexible photo paper.

CST (Computer Simulation Technology) Studio suit is a popular 3D electromagnetic (EM) simulation program which is also used for Multiphysics and particle applications. The ability to examine complex systems with many components is flexible. Leading engineering and technology firms from around the world use it. Engineers, designers, and researchers in top organizations and sectors, including aerospace, electronics, automotive, health care, and telecommunications, use it as a licensed tool. Prior to fabricating the antenna, it was designed and tested using Computer Simulation Technology (CST) Microwave Studio software, with the antenna's performance measured in terms of the reflection coefficient in both normal and bending situations. The projected antenna's overall dimensions are 40 by 35 by 0.6 mm3. The antenna was designed to function at 2.33–2.53 GHz in normal conditions, with a fractional bandwidth of greater than 8% represented by the antenna. The antenna was placed onto a homogeneous phantom muscle and a 4 human tissue phantom for the simulation. After simulation, the fractional bandwidth deviation was estimated to be 5.04 percent for the minimum and 24.97 percent for the highest. In addition, the antenna was able to attain up to 70% radiation efficiency having a 2 dB boost. In conclusion, the antenna design was shown to be dependable for wearable telemedicine-based applications.

Al-Sehemi, Al-Ghamdi, Dishovsky, Atanasov, & Atanasova, (2018) developed a dual-band wearable tiny low-profile antenna for body-centric wireless communications (BCWCs) and tested its performance. To achieve better antenna performance and mechanical qualities, the design was based on a modified planar dipole with parasitic elements, meandering lines, and a rectangle reflector implanted within a hydrophobic rubber-textile multilayer substrate. On a simulated and an experimental homogeneous flat phantom, the antenna's structure was then evaluated and optimized in free space (FS). The antenna's overall dimensions were 50mm by 40mm by 4.6mm, with a preliminary mass of 11 g, making it appropriate for practical use in BCWCs. In the Free Space, the fabricated prototype resonated at 2.47 GHz with return losses of -26.90 dB and 5.42 GHz with return losses of 24.60 dB. At lower and higher bands, the measured bandwidths were 500 MHz (2.2–2.7 GHz) and 1000 MHz (4.65–5.75 GHz). The antenna also had a radiation efficiency of 28.44 percent in Free space and a maximum gain of 1.17 dBi at 2.66 GHz. When the antenna was mounted on the simulated phantom at net input power 0.1 W, the 10g average maximum specific absorption rate was 0.165 W/kg at 2.70 GHz and 0.520 W/kg at 5.24 GHz.

Karthikeyan, Gopa, Giri Narendra Kumar, & Ravi (2019) developed and tested a wearable antenna for use in a wireless body area network application. A rectangular piece of copper was utilized as the radiating patch for this antenna, and the ground was likewise made of copper. This antenna's substrate was bed sheet cotton, which has a relative permittivity of 3.27 and a loss tangent of 0.00786. The antenna was thus 40 by 34 by 1.26 mm3 in size. The gain directivity and VSWR were the main performance properties examined for the developed antenna. The results showed that the antenna gave a greater bandwidth in the frequency ranges of 2.1GHz to 2.7GHz and 3.6GHz to 4.3GHz, as well as a 94 percent efficiency. The proposed antenna's SAR value was determined to be 1.25, which is lower than the SAR limit, implying that the antenna will not create radiation problems when put on a human body.

Ingale, Bhirud, Jadhav, & Salunkhe, (2019) developed a textile antenna targetted at on-body communication. The design, simulation, and construction of a wearable textile antenna for the 2.4GHz frequency with multiple substrate materials were presented in the study. In this study, a new textile antenna was constructed using grounded flannel (100 percent cotton) and denim material as substrates exclusively. The developed textile antenna was then shown to be integral with various head caps or clothing of various materials for possible espionage applications, rendering this antenna very much suitable for wireless communication uses such as military and medical employing various substrate materials. Finally, return loss, total efficiency, radiation efficiency, and VSWR were the most essential aspects in this study's antenna performance analysis. Cotton and denim both performed better at the 2.4GHz resonant frequency after assessing the aforesaid performance criteria for the two dielectric materials. The antenna was previously described as being extremely tiny, simple to construct, and fed by a 50 microstrip line, making it ideal for WLAN applications.

Yadav, et al., (2020) investigated Wireless Body Area Networks by developing and producing a wearable textile Antenna for Telemedicine and Mobile Health Systems. Thus, a compact textile ultra-wideband (UWB) antenna with electrical dimensions of $0.24\lambda 0 \times 0.24\lambda 0 \times 0.009\lambda 0$ and an operating frequency of 2.96 GHz was presented for UWB application in this work. Analytical evaluation using circuit theory ideas as well as an antenna cavity model were also used to validate the antenna design. The antenna as found to have a maximum gain of 5.47 dBi at 7.3 GHz, according to the results of the performance evaluation. For short-range communication, the antenna was also discovered to exhibit Omni and quasi-Omni radiation patterns at different frequencies (i.e., 4 GHz, 7 GHz, and 10 GHz). In both side by side and front to front conditions, a consistent group delay of less than 1 ns was also attained over the whole operational impedance bandwidth (2.96–11.6 GHz) of the textile antenna. The specific absorption rate (SAR) value was also examined and found to be 1.68 W/kg, indicating the safe limit to avoid radiation effects on human body.

Ibanez-Labiano, et al., (2020) developed and constructed a Graphene-based soft wearable antenna. ML graphene sheets were used in this study to build a soft, textile-based communication platform that does not compromise sensory comfort and compliance. As a result, the antenna design described herein was based on a multidisciplinary approach that integrates electromagnetic engineering with material science, as well as the use of graphene as a long-term replacement for metal components. The antenna was developed to cover a wide bandwidth of 3GHz to 9GHz, making it a potential choice for a fast data rate and effective communication link. The impact of bending and closeness to the human body upon the overall performance of the antenna was also discussed. Overall, the findings suggested that graphene-based soft antennas could be a feasible alternative to the present rigid, limiting, and hazardous techniques for a completely integrated textile-based communication interface.

Gupta, Kansal, & Chawla, (2020) developed a wearable MIMO antenna deployed with an inverted U-shaped ground stub for diversity performance enhancement. Thus, a compact multiple input multiple output (MIMO) antenna operating at 2.45GHz industrial scientific and medical band was presented herein for wearable devices. The antenna dimensions were reduced by using open-end slotting. To reduce mutual coupling, an inverted U-shaped ground stub were also included. A 3-layered equivalent tissue phantom model was employed to examine on-body performance virtually. The overall dimension of the proposed MIMO antenna was 28 by 25 by 0.51 mm3. A low SAR value of 0.512W/Kg was achieved from simulation findings, as well as a wide bandwidth of 300MHz and port isolation of 30dB from the observed results. When set at a distance of 4mm from the body, the antenna showed a 40 percent efficiency and a directivity of 4.56dBi. At 2.45 GHz, the ECC value was 0.025, the DG was 9.98dB, and the CCL was 0.12 bits/s/Hz.

Varma, et al., (2021) developed and carried out performance analysis upon a compact wearable textile antenna for IoT and body-centric communication applications. Two tiny textile-based planar dipole and loop antennas for wearable communication applications in the 2.4GHz industrial, scientific, and medical radio (ISM) bands were shown in this work. The radiating structure was created using conductive copper threads and a sewing embroidery technique on a 0.44mm thin camouflaged-military pattern cotton denim material. The antennas' design and performance assessments were conducted through simulations, followed by tests in an echoic chamber and an indoor setting to validate the designs. The experiments were conducted in a free space environment and on various parts of the human body, including the limb joints and torso. The efficiency of the antennas was evaluated using the reflection coefficient in both normal and bent situations, which corresponded to the different radii of the human limb sites. Due to antenna bending and body effects, the antennas performed well in free space and on-body situations in flat and bend settings, with return loss below 10dB in all cases and an appropriate resonance frequency close to 2.4GHz. The radiation pattern measurements for free space and on-body scenarios were also provided in this study. As a result, it was discovered that the presence of a human body had a significant impact on the antenna radiation pattern, increasing the front-to-back ratio and making the antenna more directional.

Chapter 3

MATERIALS AND METHODS

3.1 Description of the antenna

The conductive elements (i.e., the patch, and the ground planes would be made of PEC). The PEC strand should have thickness of 0.035 mm, according to standards. The substrate, which is made of fabric material, should have a dielectric constant of 1.54, and a thickness of 1.54 mm (Hs). The antenna's length and width would be computed using typical rectangular patch formulas. The CST microwave studio model would then be utilized in conjunction with some numerical validations and theories to simulate the antenna to verify the proposed and optimal design performance for this study.

3.2 Design of the antenna

Figure 3.1 shows a microstrip antenna supplied by a microstrip transmission line. Herein, a high conductivity metal is used for the patch antenna, microstrip transmission line, and ground plane (typically PEC). The patch is L in length, W in width, and sits at the top of a substrate (some dielectric circuit board) with permittivity or dielectric constant and thickness h. The ground plane's or microstrip's thickness is generally not really critical to the performance of the antenna. The height h is typically much less than the operating wavelength but is typically not less than 0.025 of a wave-length (1/40th of a wavelength) otherwise the antenna efficiency would decline.

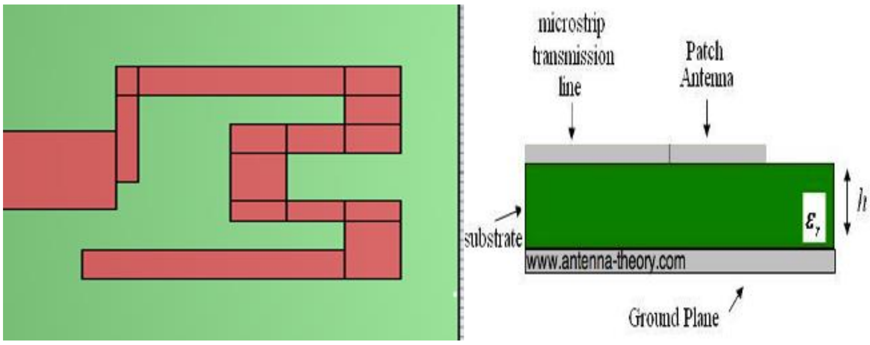


Figure 3.1: Basic dimensional characteristics of a regular microstrip patch antenna

Within the dielectric (substrate) medium, the microstrip antenna must have a minimum length equal to one half of a wavelength, according to the equation above. The input impedance however is controlled by the width W of the microstrip antenna. Wider widths might also boost bandwidth. The input impedance of a square patch antenna fed in this manner will typically be on the order of 300 Ohms. The impedance can then be lowered by increasing the breadth. However, lowering the input impedance to 50 Ohms frequently necessitates the use of a large patch antenna, which takes up a lot of room. In addition to, the width also influences the radiation pattern of the antenna. The parameters to be determined for this microstrip patch antenna will be done by taking into account the resonant frequency and the dielectric medium wherein the antenna will be developed.

3.2.1 Width of the antenna

The width of the patch is calculated using the following equation

$$W = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{3.2}$$

Where:

W is the width of the patch

c_0 is the speed of light

ε_r is the is the value of dielectric substrate

$$W = \frac{3 \times 10^8}{2 \times 2.45 \times 10^9} \sqrt{\frac{2}{4.4 + 1}} = 37.2\ mm$$

3.2.2 Effective refractive index

In the development of a microstrip patch antenna, the effective refractive index value for the patch is an essential property. Some of the radiations that move from the patch to the ground flow through the air, while others penetrate through the substrate (called fringing). Because the dielectric constants of air and substrates differ, we must calculate the effective dielectric constant to compensate for this. The following equation is used to compute the effective dielectric constant.

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-\frac{1}{2}}; \text{for } W/_h > 1 \quad (3.3)$$

Where:

$\varepsilon_{r,eff}$ is effective dielectric constant

h is the thickness of the substrate

$$\varepsilon_{r,eff} = \frac{1.54 + 1}{2} + \frac{1.54 - 1}{2}\left(1 + 12\frac{1.54}{44.34}\right)^{-\frac{1}{2}} = 1.54$$

3.2.3 Length of the antenna

The antenna's electrical dimension is enlarged by an amount of (ΔL) due to the effect of fringing. As a result, the exact increase in patch length (L) must be considered in determining the length of the antenna by employing the following equations below

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{r,eff} + 0.3)\left(W/_h + 0.264\right)}{(\varepsilon_{r,eff} - 0.258)\left(W/_h + 0.8\right)} \quad (3.4)$$

$$L = \frac{c_0}{2f_r\sqrt{\varepsilon_{r,eff}}} - 2\Delta \quad (3.5)$$

$$L = \frac{3 \times 10^8}{2 \times 2.45 \times 10^9\sqrt{1.54}} - 2(\Delta L) = 39.03mm$$

3.2.4 Length and width of ground plane

Once the patch's dimensions have then been obtained, it is then conventional for the substrate's length and width to be the same as that of the ground plane. The following equations thus are used to calculate the estimate the minimum length (Lg) as well as the width of a ground plane (Wg).

$$L_{g,min} = 6h + L \tag{3.6}$$

$$W_{g,min} = 6h + W \tag{3.7}$$

Then

$$L_{g,min} = 6(1.54) + 39.03 = 48.27mm$$

$$W_{g,min} = 6(1.54) + 44.34 = 53.58mm$$

However, considering that they might not be sufficient, the wavelength of the patch antenna is also used to evaluate the maximum length of the microstrip patch; and thus, a compromise is made within both limits for obtaining the length and width of the ground as well as substrate.

$$L_{g,max} = W_{g,max} = L + \frac{\lambda_{eff}}{2} \tag{3.8}$$

$$\lambda_{eff} = \frac{c_0}{f_r}\sqrt{\varepsilon_r} \tag{3.9}$$

Then

$$\lambda_{eff} = \frac{3 \times 10^8}{2.45 \times 10^9}\sqrt{1.54} = 463\ mm$$

$$L_{g,max} = W_{g,max} = 28.5 + \frac{463}{2} = 260\ mm$$

Hence the following conclusive statements could then be made

$$48.27mm \leq L_g \leq 260mm$$

$$53.58mm \leq W_g \leq 260mm$$

Thus, based on frequency tuning within the CST software, dimension of 40 mm x 35 mm was adopted for the antenna's ground length and width accordingly, this deviation is due to optimization.

Table 3.1 shows the optimized dimensions of the antenna in (mm) using fabric material substrate of dielectric constant of 1.54 and thickness of 1.54 mm at center frequency of 2.45GHz and 5.6GHz.

Table 3.1: Dimensions of the Antenna

Design Parameter	Notation	Value (mm)
Patch Length	L_p	27
Quarter Wavelength	L_{f1}	17
Feed Line Length	L_{f2}	16.7
Patch Width	W_p	37.2
Quarter Wave Width	W_{f1}	0.84
Feed Line Width	W_{f2}	4.7
Ground Plane Length	L_s	62.2
Ground Plane Width	W_s	52.2
Substrate Thickness	h	1.5

3.3 Modelling and simulation procedure for the microstrip patch antenna

The antenna was designed within CST studio environment, employing the dimensions as obtained from the calculations before now. The figure 3.2 below shows the schematic model of the microstrip patch antenna.

3.3.1 The design simulation is highlighted thus

a) The substrate, ground plane, patch and microstrip transmission line are modelled accordingly as specified in table 3.1.

b) "Perfect E" conducting boundary condition was then assigned to the patch, transmission line as well as the ground considering that they are made of conducting copper material.

c) Lumped port Excitation energy was then assigned to the port at 50Ω resistance. The port is also seen in figure 3.2 below.

d) From the Analysis setup, a solution step involving sweep modelling of frequency was set. Hence the setup simulation was made to simulate within the range of 1-8 GHz so the resonating frequency of the antenna could be evaluated if it is resonating about the desired 2.4GHz and 5.6GHz as designed for.

e) Validation checks were made, and the solver was initiated to generate solutions for the radiating antenna.

Hence, post processing was then carried out to measure the Return losses (S_{11} parameter), Gain, VSWR and the Radiation pattern.

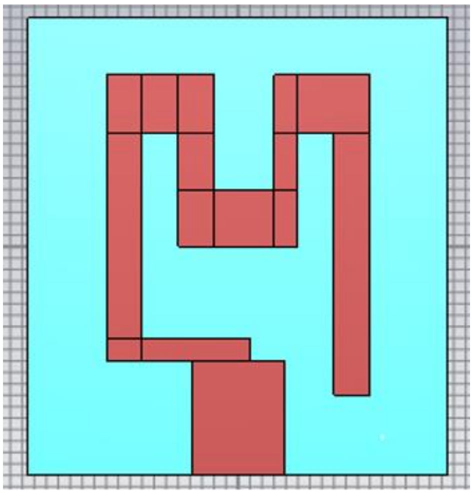


Figure 3.2: Model of the microstrip patch antenna

3.3.2 Methods of making an antenna conformal

There are several ways to make an antenna conformal. Here are some common methods:

a) **Curved substrate:** One way to make an antenna conformal is to use a curved substrate that matches the shape of surface it will be mounted on. This allows the antenna to follow the contours of the surface, creating a conformal shape.

b) **Flexible PCB:** Another way to make an antenna conformal is to use a flexible printed circuit board (PCB) as the substrate. This allows the antenna to bend and conform to the surface it is mounted on.

c) **Conductive fabric:** Conductive fabric can be used to form a conformal antenna. The fabric can be cut and seen into a shape that conforms to the surface it will be mounted on. The conductive fabric can be then connected to the antenna feed point.

d) **Additive manufacturing:** Additive manufacturing, such as 3D painting can be used to create conformal antenna. The antenna can be designed to match the surface it will mount on, and then printed directly into the surface using conductive materials.

e) **Inkjet printing:** In this method, conductive ink can be printed onto the flexible substrate, such as polymer film to form the conformal antenna. Then, the antenna can be cut into the desire shape and mounted onto the surface.

These are some of the methods used to make antenna conformal. Each method depends upon the specific application and materials available. It is essential to consider the antenna's performance and characteristics, such as gain and bandwidth while designing conformal antenna.

3.4 Conformal antenna for patient monitoring purpose

These are the antennas that are designed to conform the shape of an object of surface rather than being a conventional self-standing structure. They can be used in different applications including patient health monitoring.

In the patient health monitoring, it can be used to transmit and receive data wirelessly through a senor or device that are placed on the patient's body. This enables continuous monitoring of clear signs, movement and other health conditions without using wires and cables.

There are several advantages to use conformal antenna in this context. Firstly, they can be designed in such a way that makes it comfortable for patient to wear. As they suit the patient's body, they can provide more uniform and reliable data as compared to the antennas that are place far away.

There are also some challenges while using conformal antennas for patient health monitoring. One of the main challenges is to ensure that the antenna does not interfere in the functionality of other medical devices or implants that the patient may have.

Another challenge is ensuring that the antenna Is capable of transmitting and receiving data precisely even in a lot of interrupted and noisy environments.

Hence, conformal antennas are useful for patient health monitoring if they are designed and implemented carefully to make it risk-free, effective and reliable.

3.5 Wearable conformal patch antenna for blood pressure monitoring applications

Wearable Patch Antennas are type of antenna that is designed to be implanted on the body and can be used for a various medical applications including monitoring blood pressure. In this article, it will be discussed that how wearable patch antenna can be used for blood pressure applications.

Blood Pressure is important physiological parameter that can provide information about a person's overall health. It is typically measured using a sphygmomanometer, which involves wrapping a cuff around the upper arm and inflating it to temporarily stop the blood flow. However, this method is not practical for continuous monitoring, and it can be irritating for a patient as well. This is where wearable patch antennas are used.

A wearable patch antenna consists of small, flat and flexible circuit board that can be attached and adhering. Antenna is typically made up of conductors such as copper or silver. It is designed to transmit and receive electromagnetic waves. By placing antenna on the body, it is possible to measure changes in the electromagnetic field caused by fluctuation in blood pressure.

3.5.1 Methods of blood pressure measurement

There are several methods to measure the pressure of blood flow. Some of them are following:

a) **The impedance method:** The impedance method is one of the methods that is used to measure the blood pressure by using wearable patch antenna. This involves measuring the changes in the impedance of the antenna as the blood pressure fluctuates. The impedance of the antenna is affected by the dielectric properties of the tissue between the antenna and the underlying blood vessels. The change in blood pressure causes the change in the dielectric properties of the tissue that brings change in the impedance of the antenna. By monitoring these variations, it is possible to determine the blood pressure of the patient.

b) The doppler method: The Doppler method is another way to measure blood pressure while using a wearable patch antenna. It measures the changes in the frequency of the electromagnetic waves reflected by the blood vessels as the blood pressure fluctuates. The rise in blood pressure increases the blood flow in the vessels, causing a corresponding increase in the frequency of the reflected waves. By monitoring these changes, it is possible to monitor the blood pressure of the patient.

3.6 The proposed method for blood pressure determination:

Pressure and EM wave propagation do not directly and precisely correlate. We relied on the creation of a conformal, wearable aerial that can track ambient variables like pressure. The formed relationship between the transmitting and receiving antennas, meanwhile, is influenced by variations in the reflected electromagnetic waves from the antennas and is related to variations in radius of the artery and also thickness. Therefore, this implies that any fluctuations in blood pressure levels can be indirectly associated to changes in the characteristics of the heartrate ratio of the artery and can be detected by changes in the shape of electromagnetic waves between the two antennas [32,33]. The new proposed topology is according to two crucial factors of blood pressure detection: i) change in brachial artery, thickness/radius (ii) change in the dielectric constant. This is because the larger the brachial artery radius, the higher the risk of elevating the levels of the blood pressure [34, 35].

Chapter 4

RESULTS AND CONCLUSIONS

4.1 Introduction

This section discusses the performance evaluation results obtained from the simulation carried upon the designed microstrip patch antenna. The major antenna performance indices presented and discussed herein this chapter include the return losses, the radiation pattern, the VSWR (antenna reflection coefficient), impedance and the radiation efficiency of the antenna.

4.2 Parametric studies of wearable patch antenna

During the analysis and designing of the wearable patch antenna it is observed that the antenna is not resonating at 2.4GHz on the parameter calculated from the formulas, so the length and width of the ground at optimized to 35mm and 40mm respectively. Also, several cuts are introduced to get the results at 2.4GHz and 5.6GHz. The parameter height of the substrate is greatly affected as well, as we can see in Figure3.3 the results of the antenna i.e., S11 parameter is mainly related with the thickness of the substrate.

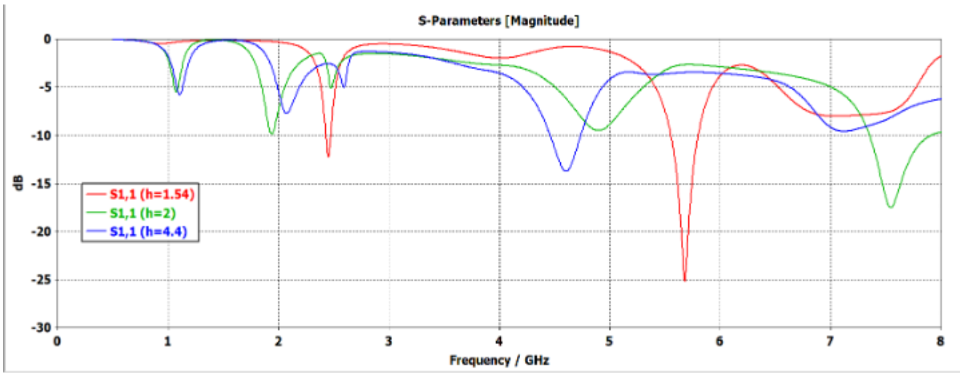


Figure 4.1: S-Parameters at different height of the substrate

Figure 3.3 shows that the most optimized results are obtained at h=1.54mm substrate. Hence, a defected ground is used for the impedance matching purpose. Several techniques were applied to get the most optimum results at 2.4GHz and 5.6GHz. The result without the defected ground is shown below.

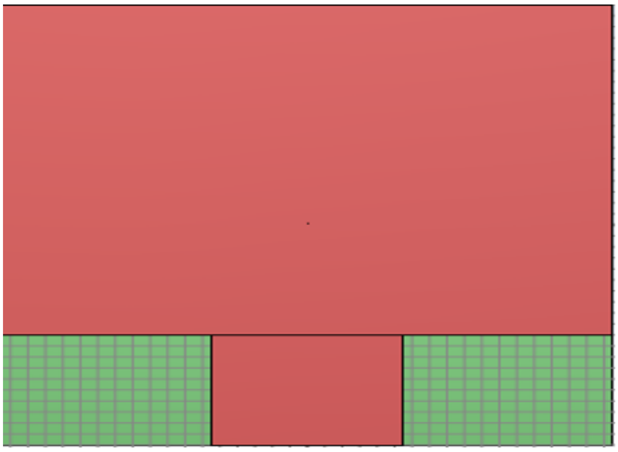


Figure 4.2: The antenna without defected ground

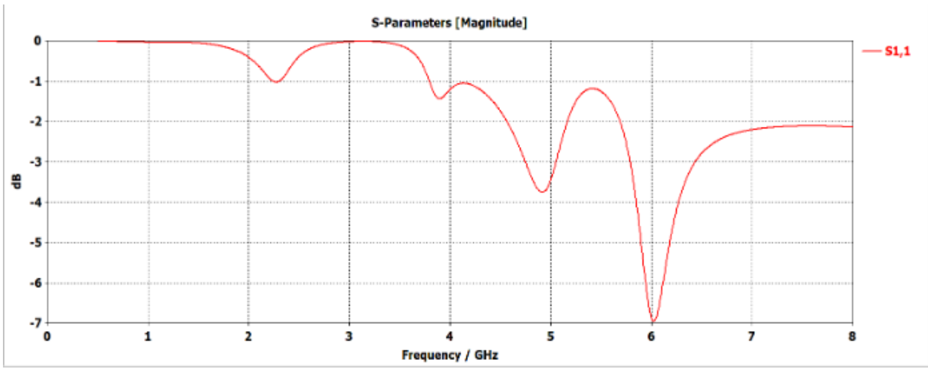


Figure 4.3: S-Parameter results without defected ground

So, from the above results it can be concluded that antenna ground must be defected to get the optimized results.

Also, the antenna patch plays an important role in optimization and getting reasonable gain. Similarly, feed width is also an important factor. Several cuts were introduced to make the antenna resonating at ISM band. Figure 4.4 shows the results of the patch antenna without any slots.

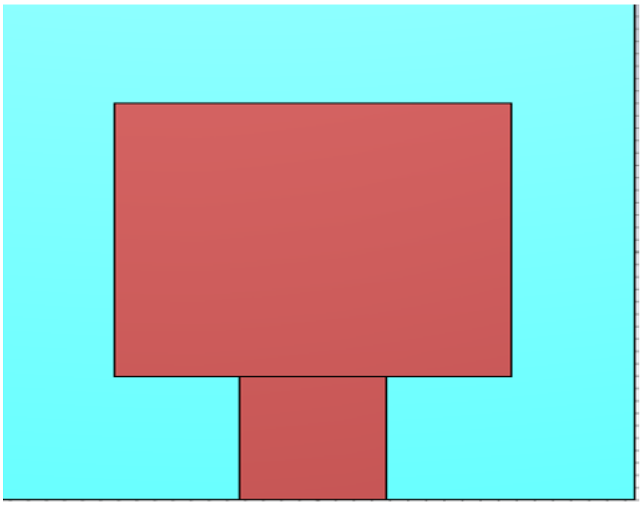


Figure 4.4: The patch antenna without any slots

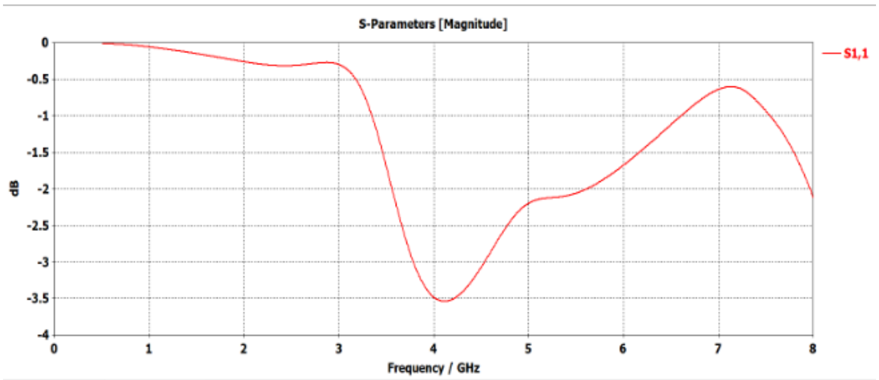


Figure 4.5: Return loss of the antenna

From the above results and parametric studies, it was observed that the defected ground and slotted patch will make the antenna resonating at ISM band.

So based on the study above, it is clear that to achieve the proposed optimized results and making the antenna resonate at 2.4GHz and 5.6GHz the antenna must include précised dimensional slots and defected ground.

The Final outlook and dimension of the proposed antenna is shown in Figure 3.8 below.

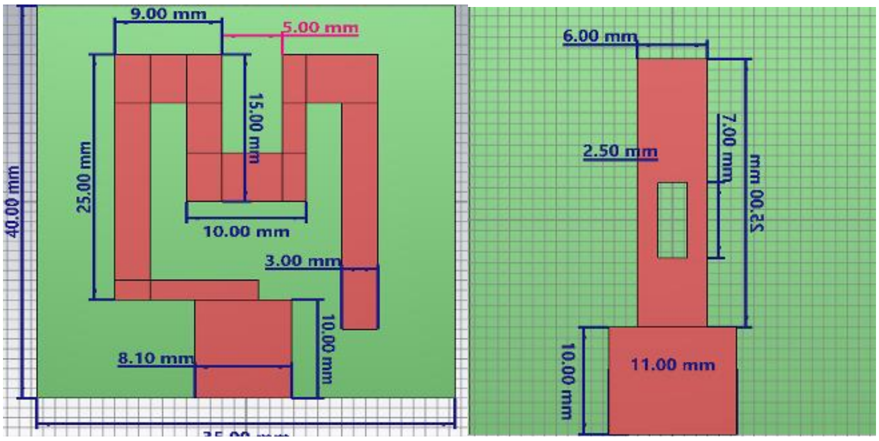


Figure 4.6: Top and bottom of the proposed antenna

4.2.1 Return losses

The S11 parameter is a reliable method used to evaluate an antenna the most frequently. The amount of power being reflected from the current antenna design is shown by the S11 value from this simulation in figure 4.1. For communication systems, a standard value of -10 dB is acceptable as the baseline for good performance. The proposed antenna has a return loss of -15 dB and -23.7 dB at 2.45GHz and 5.6GHz respectively, covering a frequency band of 2.424 GHz – 2.474 GHz and 5.55GHz - 5.79 GHz.

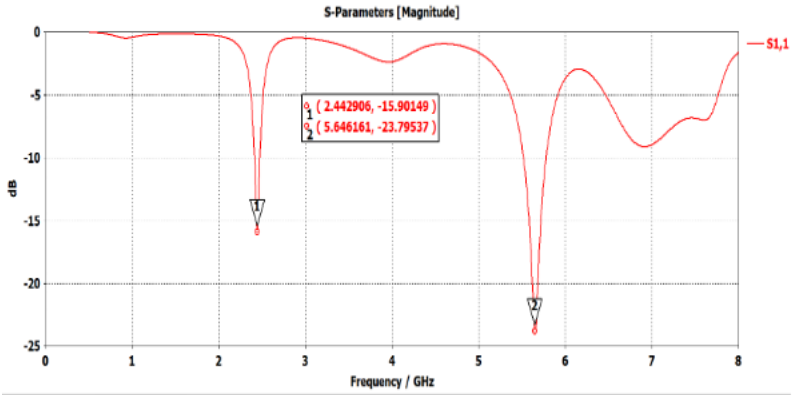


Figure 4.7: Return loss of the antenna

4.2.2 Beamwidth

The Beam width represents the diameter of the main lobe of the antenna. If the antenna has a narrow beam, then the radiation pattern will be directional. If the antenna has the beam width greater than 40 degrees, then the radiation pattern will be Omni directional. Planar antennas are Omni directional. Like in the Figure below represents the Omni directional pattern of the antenna, as it has the beam width of 93.1 degrees.

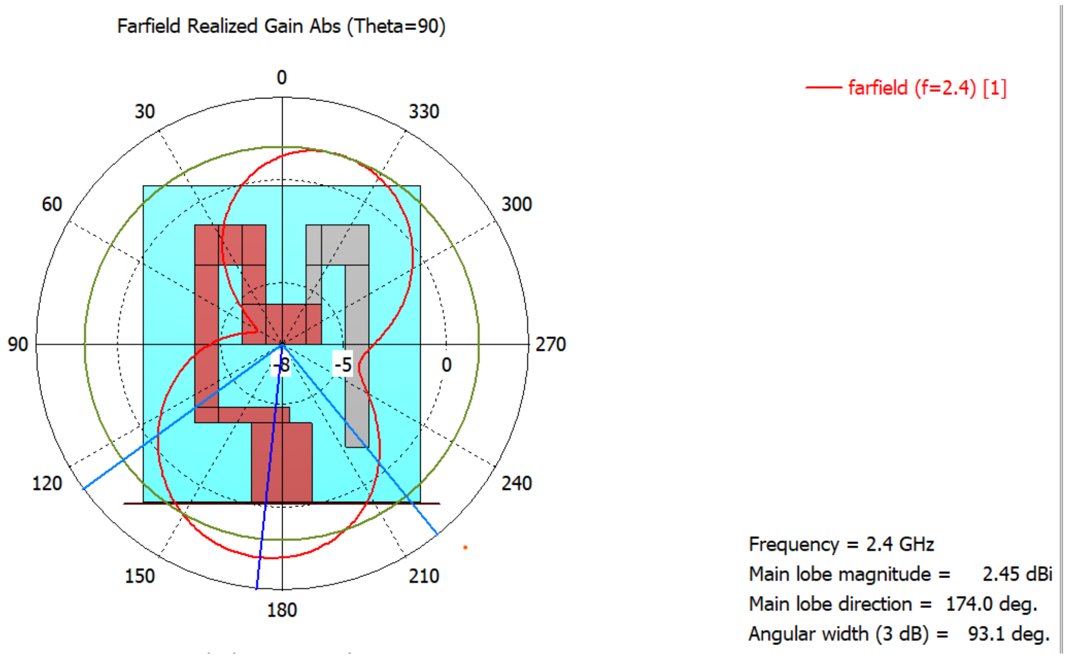


Figure 4.8: Angular width represents the Beam width of the antenna.

4.2.3 Radiation pattern

Figure 4.2 – 4.4 shows the 3D and polar plot radiation pattern at (theta=90, phi=90) respectively of the proposed antenna design. The proposed patch antenna efficiency is intimately connected to the gain performance. The patch antenna design has a gain of 2.67 dBi at 2.45 GHz and 5.73 dBi at 5.6 GHz which is considered acceptable in this scenario of compact antenna design.

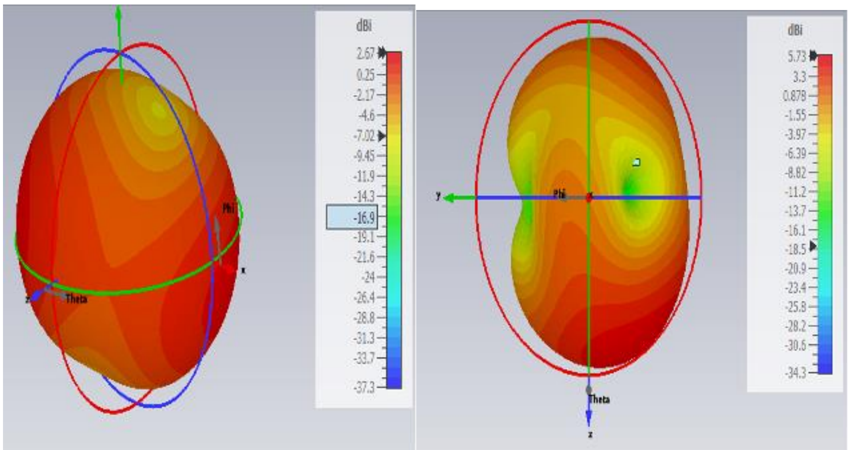


Figure 4.9: 3D radiation pattern at 2.45 GHz and 5.68 GHz

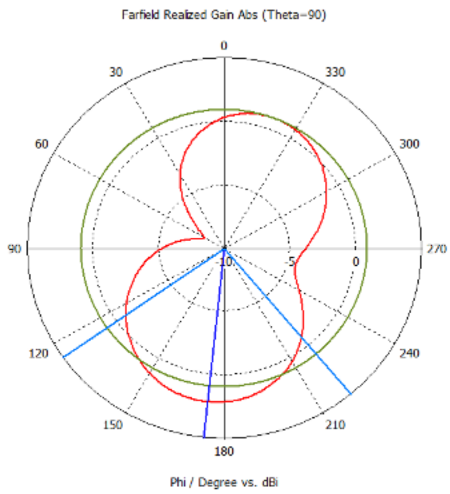


Figure 4.10: H-plane radiation pattern

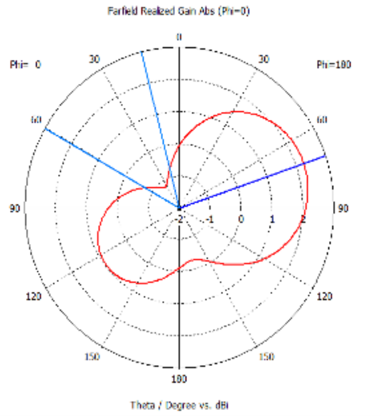


Figure 4.11: E-plane radiation pattern

4.2.3 Voltage standing wave radio (VSWR)

For the antenna to function well, there must be a maximum power transmission between the transmitter and the antenna. Only when the transmitter impedance, Zs, and the receiver impedance, Zin, are matched does this occur. For an antenna to operate well, this specific configuration must be achieved. This reflection of this power then results in standing waves, which are quantified as (VSWR). The voltage standing wave ratio (VSWR), which is the ratio between the maximum voltage and the minimum voltage in the standing wave pattern, is created when power is successfully reflected from a load. For a communication system, the value of VSWR should be small (not more than 2.5 and close to 1.0) in order to ensure proper impedance matching and little amount of reflected power. The antenna design achieved a VSWR of 1.68 at a resonant frequency of 2.45 GHz and 1.12 at 5.6GHz. Moreover, the antenna has VSWR lower than 2 at most of the frequencies excluding some frequency point.

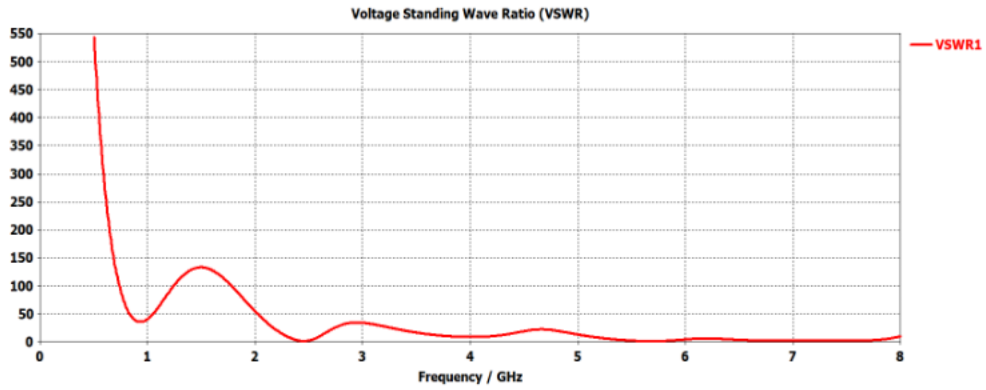


Figure 4.12: VSWR plot against r= radiating frequency for the Microstrip patch antenna

4.2.4 Total efficiency

The antenna performance is greatly related to the antenna total efficiency. Losses degrade the antenna performances. Here is our proposed antenna total efficiency that shows that antenna has the maximum efficiency of 98% at 5.6 GHz, while at 2.42GHz the antenna efficiency is 78%. This shows that the designed antenna is highly efficient.

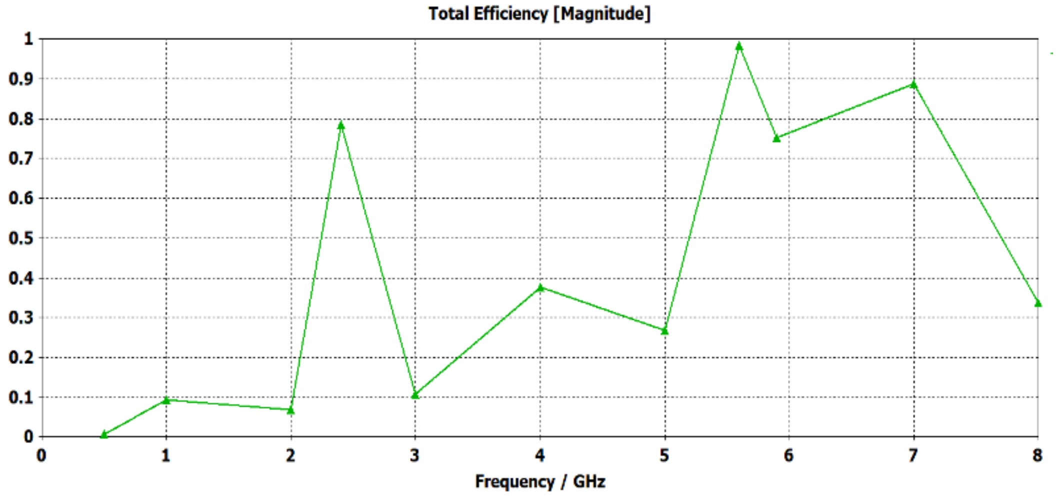


Figure 4.13: Total efficiency of the antenna

4.2.5 Input impedance

The antenna should have 50 ohms input impedance for perfect matching. To remove the mismatches, the antenna should have 50 Ohms at the resonating frequency. If the antenna input impedance is not up to 50 Ohms or 75 Ohms, then most of the power will be reflected. So, antenna input impedance was match at 50 Ohms at most of the frequencies in the range. The antenna is giving good matching at all frequencies except at around 1.3GHz. Other than this the antenna has good matching see Figure 4.5 below.

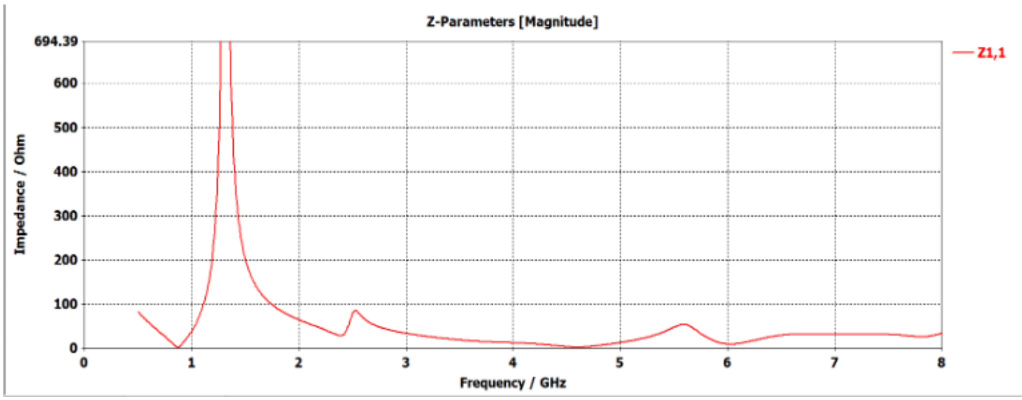


Figure 4.14: Input impedance vs frequency

4.3 How to make the designed antenna conformal

The designed antenna shown in Fig 4.6 is planar structure. But as discussed in the above section the antenna should be conformal on the human hand phantom for this application, therefore the antenna is bent by 15 degrees shown in the figure below.

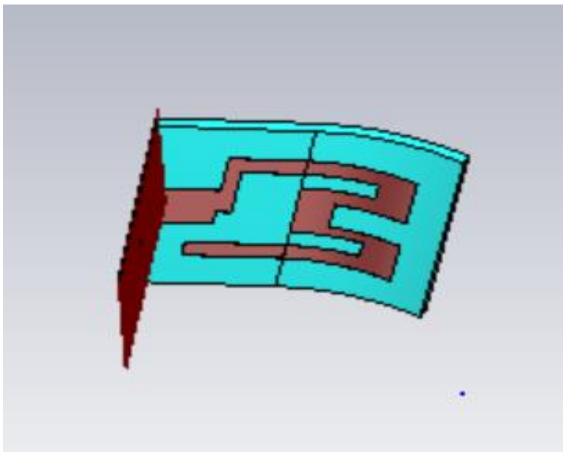


Figure 4.15: Antenna bent by 15 degrees

The antenna bending by 15 degrees, but the antenna cannot be bending beyond some extent for instance if the antenna is bended by 90 degrees the result of the antenna is disturbed very badly. Results of the bent antenna by 15 degrees is shown below.

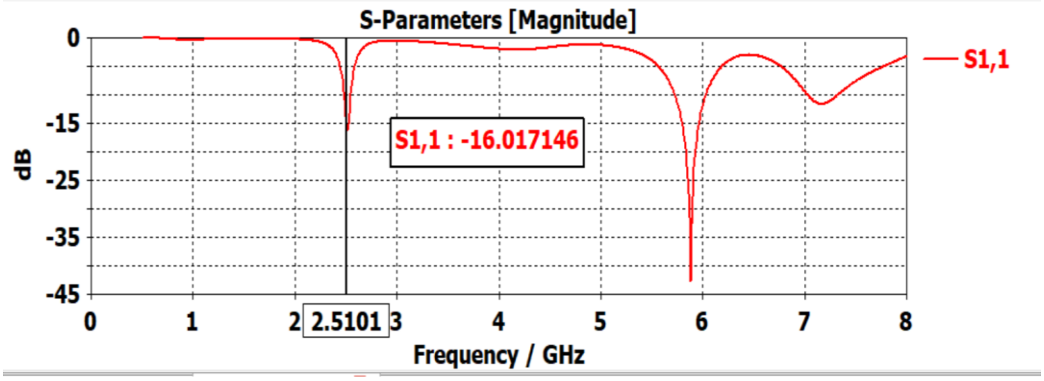


Figure 4.16: S parameters of the antenna at 15 degrees

The return loss of the antenna is shifted to 2.5GHz. this shift is due to the bending of the antenna. But the antenna results are not affected very much. The Gain at 2.45 GHz becomes 2.29dBi. Now to check the results of the antenna at 30 degrees, 15 degrees' bend is added to the previous design.

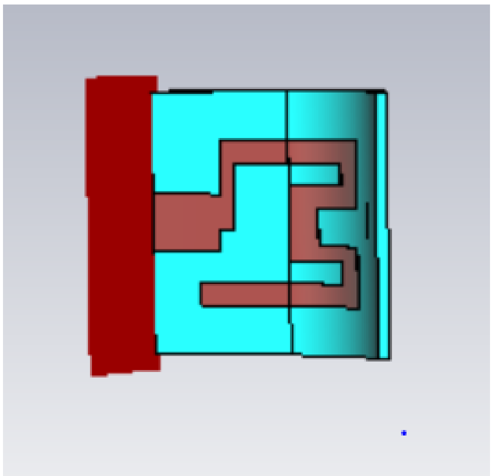


Figure 4.17: Antenna bent by 30 degrees

The antennas are more bended as seen in the above Fig. 4.11 above, the return loss of the antenna at 30 degrees is shown below:

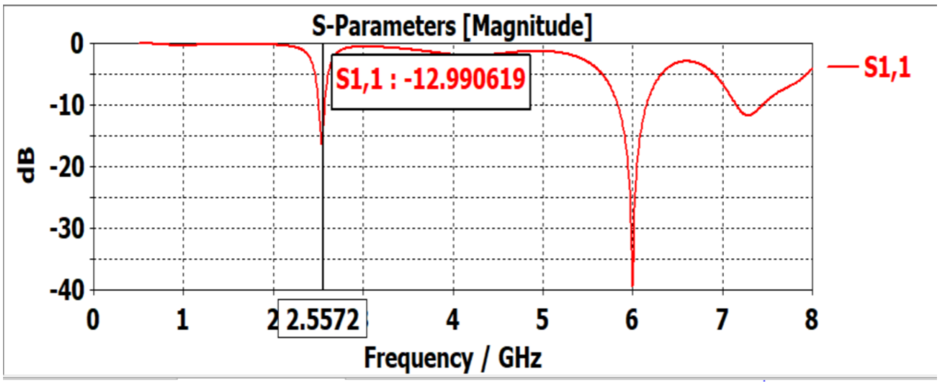


Figure 4.18: S parameter at 30 degrees

The return loss is shifted by 40 MHz again due to the bending. While the gain at 2.45GHz is 1.53 dBi shown below.

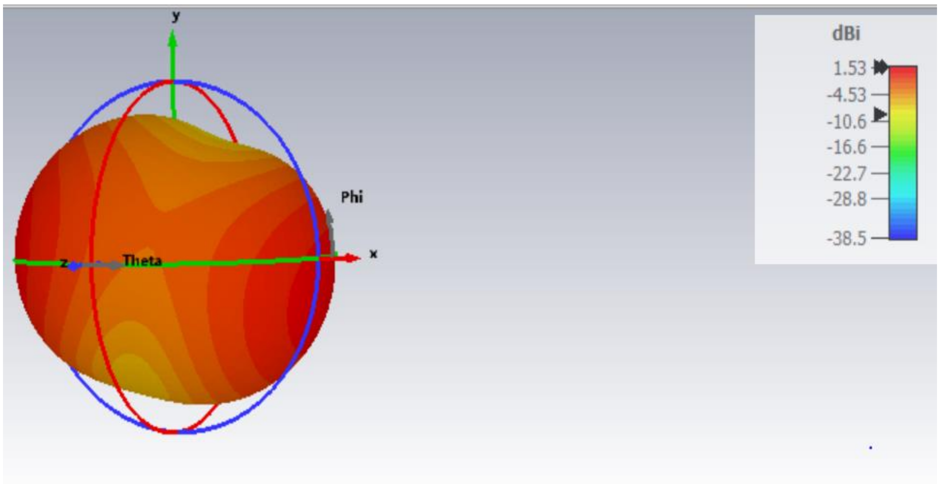


Figure 4.19: Radiation pattern of the antenna at 30 degrees

The gain is reduced due to the disturbance in bending of the antenna. And the main lobe magnitude is disturbed with the increase in SLL. Now the results of the antenna at 45 degrees can be seen below.

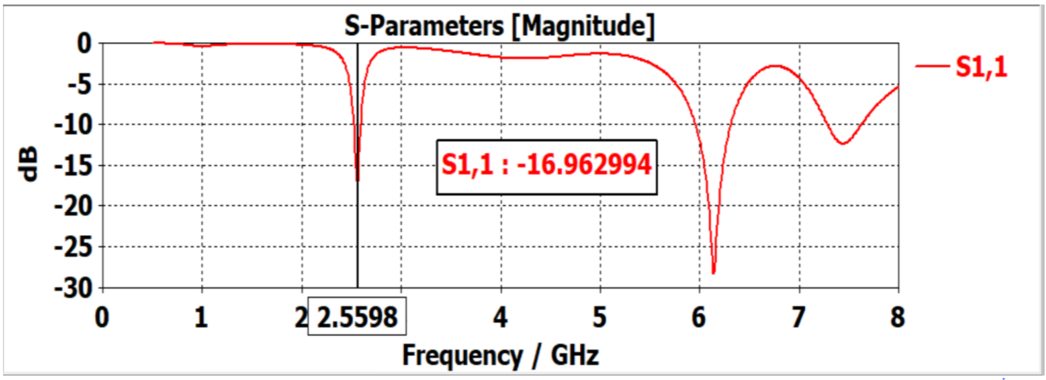


Figure 4.20: S parameters of the antenna at 45 degrees

This result shows that the results are shifted by some MHz this time the gain is 0.9dBi reduced significantly shown below.

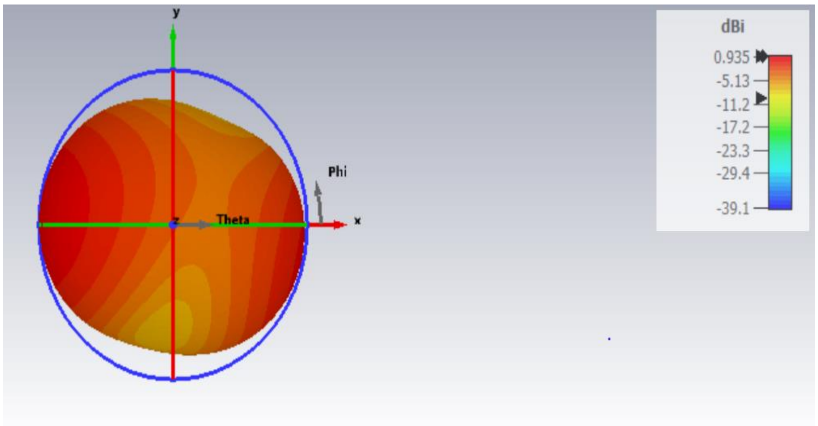


Figure 4.21: Radiation Pattern of the antenna at 45 degrees

Now the comparisons of the return loss among these bending structures show below.

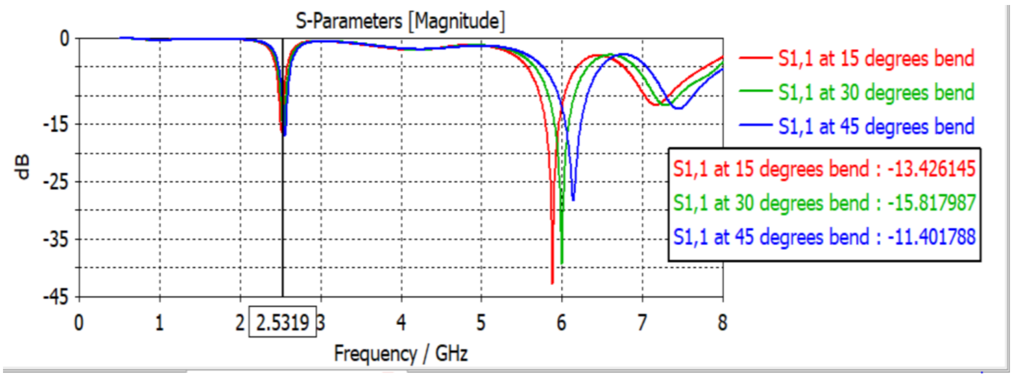


Figure 4.22: Return loss of the antenna at different bending structures

From the above comparisons the results of the antenna are shifted when the antenna is bend is increasing by 15 degrees. The gain is also decreasing when the bend is increasing.

4.3.1 Comparison of return loss of planar and conformal antenna

The return loss of the antenna is greatly related to the radiation pattern of the antenna, as we know that the planar antenna has a good and stable radiation pattern than the conformal one. So, the return loss of the planar antenna will be good than the conformal antenna. The comparison of the return loss can be seen below.

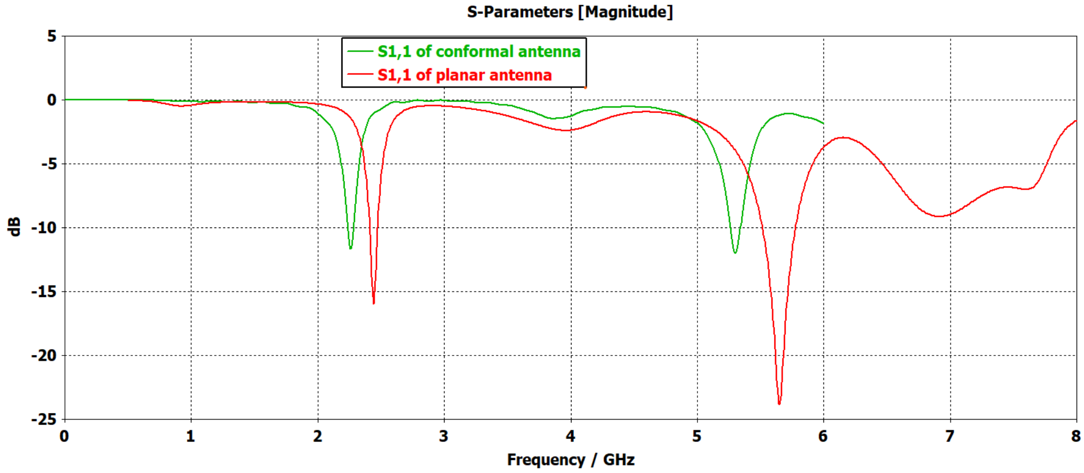


Figure 4.23: Return loss of planar and conformal antenna

Figure 4.18: shows the comparisons of the return loss of the planar and conformal antenna.

From the above figure it can be seen that the return loss of the planar antenna is good and exactly resonate at 2.45 GHz while the conformal antenna resonance frequency is shifted to 2.2 Ghz. This shift occurs due to the bending of the antenna.

4.4 Wearable conformal antenna on human hand phantom

The human hand is composed of bone, muscle, fats and skin. The properties of these compositions are taken from the [28,29]. In this paper the dielectric, dispersion and electrical properties are discussed. The results show that the compositions have a very high dielectric constant. The dielectric constant of these compositions at 2.45GHz are discussed. The dielectric constant of bone is 11.41, muscles has the dielectric constant of 52.79, and fats has 5.28 while the skin has the dielectric constant of 38.06.

In CST human hand is designed in circular cylindrical shape. Like shown below.

Table 4.1: Properties of the tissue

Tissue	εr/2.45 GHz	Conductivity S/m	εr/5.4GHz	Conductivity S/m
Bone	11.41	0.384	9.946	1.010
Muscle	52.79	1.705	49.27	4.266
Fats	5.28	0.102	5.010	0.254
Skin	38.06	1.440	35.61	3.218

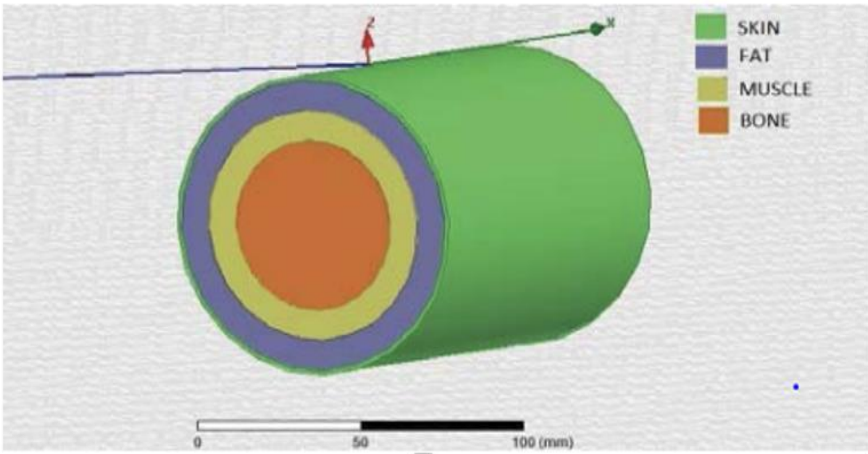


Figure 4.24: Design structure of the human hand phantom

Now the antenna is made conformal on human hand and the antenna was placed 10 mm above the human hand phantom.

4.4.1 The human arm model

Studying each tissue's dielectric characteristics is crucial since the human arm is a diverse medium made up of layers of several tissues with varying permittivity's. integrated into the model. The radius of the computer-generated human arm model was decided to be about 45 mm for an average adult [28]. Figure 4.20 is made to illustrate how the relative permittivity (r) of the blood, bone, skin, and fat in the human arm varies over the frequency range of 2-3 GHz. Reaching the targeted veins and arteries through the skin, muscle, bone, blood, and fat tissue layers is made possible by the changing of dielectric constant with frequency range while keeping adequate sensitivity. This change affects the obtained signal. , it also has an impact on the ratio of vessel radius to sensing wall thickness (h/R).

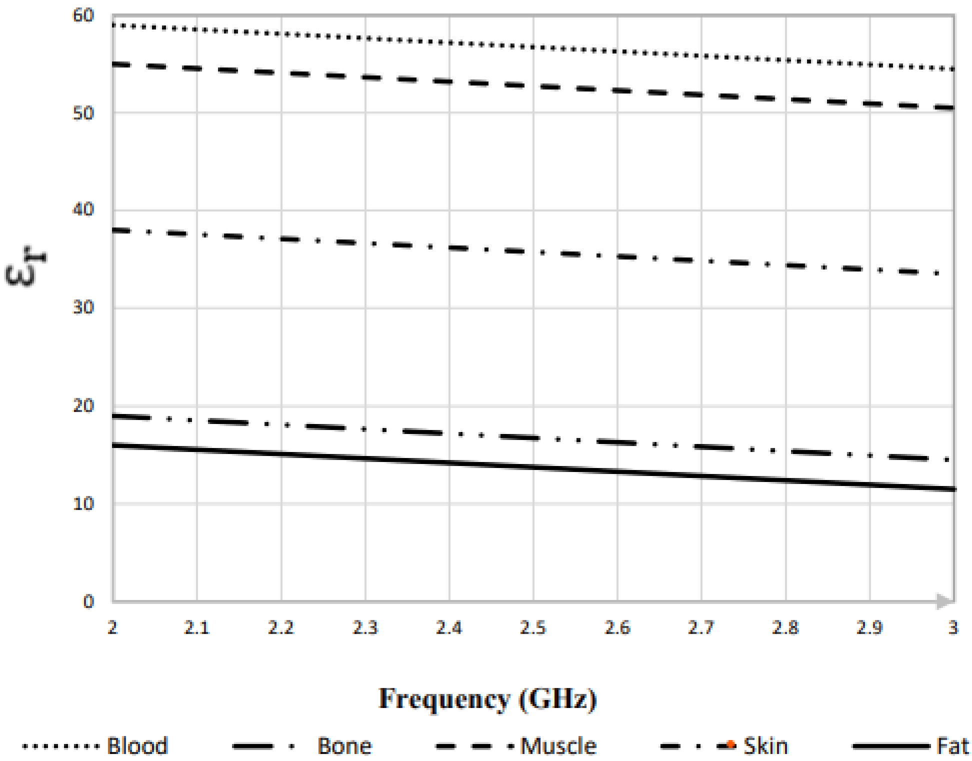


Figure 4.25: Relative permittivity (r) of biological tissues chosen for the diverse simulated sample, frequency ranging from 2–3 GHz

The above figure shows that the blood possesses the highest permittivity, while fat together with bone have similar permittivity. Moreover, it displays various electrical permittivity values and conductivity values. This model is considered reliable since it is comparable to the voxel model, which is capable of collecting anatomical details at a high-resolution level and is cheaper and simpler when performing simulations test for antenna. Also, based on the operating frequency, it describes the various human tissues' dielectric characteristics.

4.4.2 Design of conformal wearable antenna on human hand

For all antennas with curvatures of 15, 30, and 46 degrees, the implementation of a curved antenna resulted in a modest shift in resonating frequency and decreased return loss. There was little difference between the antennas' flat and curved s11 responses as they were configured in various ways across planar or curved surfaces. The many human arms possibilities on which the antennae are mounted for blood pressure measurement are reminiscent of the matching radii. We can infer that the antennas are in good working order and have a respectable operational bandwidth. For bending and planar antennas, d displays a monopole 2D radiation pattern. As predicted, the patterns demonstrate that as the antenna's bending increases, the (3 dB) tends to decrease as well. This makes the antenna ideal for wearable applications.

Due to the body's lossy nature, electrical conductivity, and high dielectric constant the transmission of RF signals from the body into free space suffers significantly. Thus, it is natural for the antenna characterizations to drastically decline because the human body sucks up a considerable amount of the electromagnetic energy.

Therefore, causing the resonating frequency to shift leftwards. The resonance frequency shift to lower bands due to the presence of very heavy lossy materials.

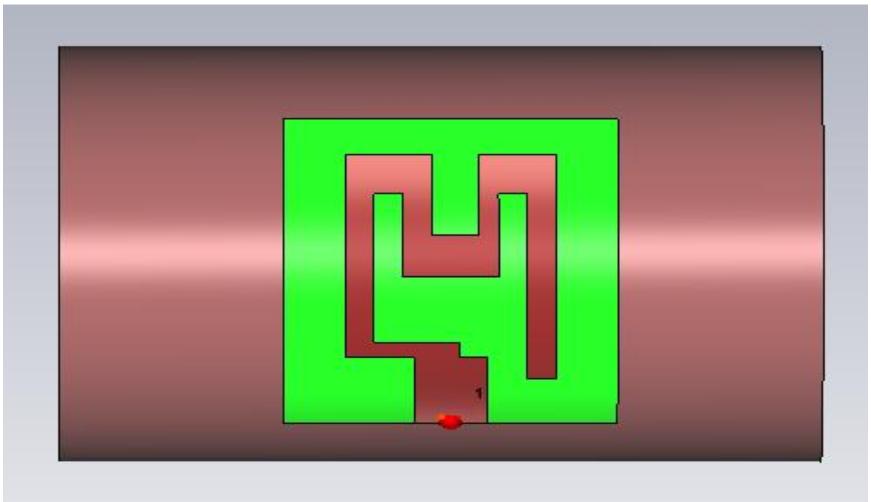


Figure 4.26: This figure shows that the antenna is conformal over the hand phantom created in CST.

The return loss of the antenna over the hand phantom is shown below.

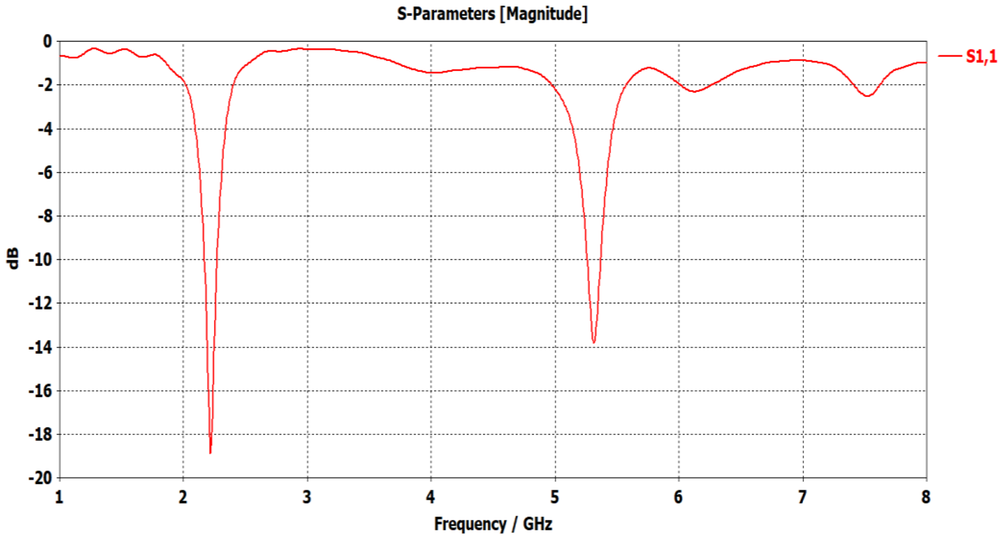


Figure 4.27: Return loss of the antenna over the hand phantom

4.4.3 Voltage standing wave ratio of the conformal antenna on human hand

Voltage standing wave ratio define the ratio of the forward to reverse waves. Ideally it should be one. But practically we consider VSWR should be less than five. Due to the presence of very highly dielectric constant materials the VSWR of the conformal antennas becomes high than the planar antenna. Like from the below comparison it can be seen that the VSWR of the planar antennas is lower than the conformal antenna.

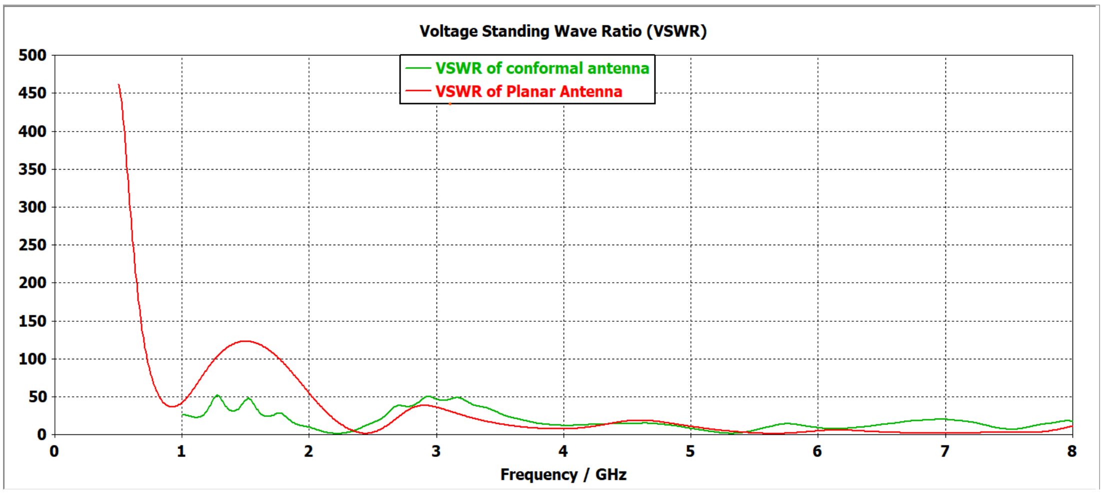


Figure 4.28: VSWR comparison of the planar and conformal antenna

From the above comparison the values of planar antennas VSWR is lower than the conformal antenna.

4.5 Surface absorption ratio (SAR) analysis of the proposed design:

The high permittivity of the human body, which makes it a dispersive material, causes a significant percentage of EM radiation to be absorbed out of wearable antennas. The Specific Absorption Rate (SAR), which is equal to the electrical field squared multiplied by conductivity and divided by mass density, must thus be assessed. It is a gauge for calculating the amount of power absorbed per mass of conductive material, defined as

SAR= $= \frac{\sigma |E|^2}{\rho}$

Where is the material's electrical conductivity, E = RMS strength of the electric field in a certain position and is considered to be the material's mass density [30]. The measuring standards required by the IEEE safety standards, which is 4 Watt per kg averaging over 10 gram of that actual tissue, must be met by specific absorption rate data. If not, a significant quantity of electromagnetic power will be absorbed, which may have negative medical effects [31].

Figure 4.24 demonstrates how CST software is very practical tool for estimating SAR of tissues in this regard. It determined that 3.48 Watt per Kg, which meets with IEEE standards for an average human hand weighing 10 gram, is the pair's safest total transmitted power.

The previously developed simulated human arm model can be a strong contender for SAR evaluation in order to explore the behavior of radio waves in CST, as illustrated in Figure. The simulated source power range for the typical resonant frequency was 1 W to 50 mW. Simulation at 2.4 GHz were conducted at the same time to look at how the SAR values of the arm tissues vary with source power.

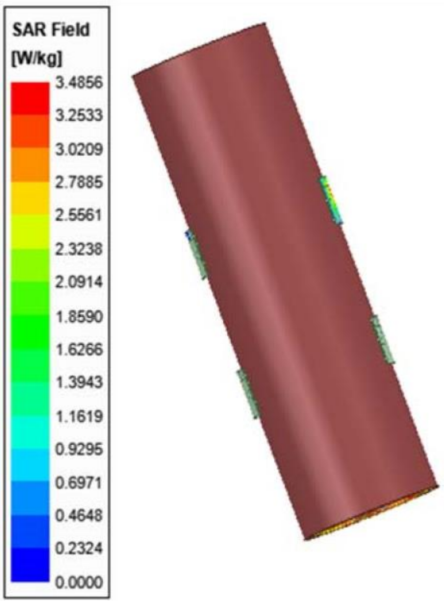


Figure 4.29: SAR of the proposed antenna design

The SAR values for tissues weighing 10 g that were obtained using the CST are shown in Table. The simulations revealed that muscle and blood absorbed the most energy of all the tissues. Bone has the lowest energy absorption of all tissues due to its low density and conductivity. Low SAR levels occur from the reduced input power needed, which is crucial to this.

Table 4.2: SAR at different values of power.

Power in mW	SAR (10 g (W/Kg))
1000	1.4917×10^3
800	1.1933×10^3
600	25.222
400	16.334
200	10.089
100	5.044
50	3.89

4.7 Results discussions

Technically, if S11= 0dB, nothing would be radiated because all power would be reflected from the antenna. Ideally, the majority of the power given to the antenna is intended to be radiated because antennas are often built to be low loss devices. Given that fabric material of permittivity 1.54 was used as the substrate material, the value of -15 and -23.7 reached is a better return loss. This antenna resonates at two desired frequencies of 2.45 GHz and 5.6 GHz.

4.8 Result conclusion

The power radiated from this antenna could be attributed to the thinness as well as the low dielectric constant of the substrate, especially in due to the fact that open ended Microstrip lines ultimately radiate greater power when they are constructed with thick, low dielectric constant substrates. In contrast to the power output that is reflected from an instrument, VSWR measures the amount of power that is sent to the device. As a result, the VSWR also serves as a gauge of how well matched the source and load impedances are. An antenna with ideal stability should have a VSWR of around 2. This antenna as seen in figure 4.3 had approximately 1.6 and 1.2, thereby depicting that the designed antenna is perfectly matched.

4.7.1 Comparison table

Table 4.3: Comparison table between this antenna and previously designed antenna

S/NO	Frequency (GHz)	Gain (dB)	Size (mm^2)	Remarks
[10]	2.45	1.9	30x33	Low gain and Single band
[11]	2.4	2.0	100x100	Low gain and bulk size
This antenna	2.45 & 5.67	2.67 5.71	34x40	Reasonable gain, compact size and dual band

From the above comparison it can be concluded that our antenna is more compact, high gain and most efficient than the state of the art.

4.9 Wearable patch antenna for patient monitoring

In patient monitoring the antenna is implanted on human body. There is a transceiver and microcontroller. From the return loss and radiated power from the antenna implemented on human body will be process in the microcontroller. From the return loss, VSWR and radiated power the microcontroller will process these parameters.

There is a difference in the antenna parameters implanted on human body of normal person and abnormal person. The microcontroller can detect the temperature, heartbeat and other parameters that are processing in the microcontroller unit. Some of the medical applications that this antenna can be used for includes Blood Pressure measurement, Heart rate measurement, Motion detection and even cancer detection.

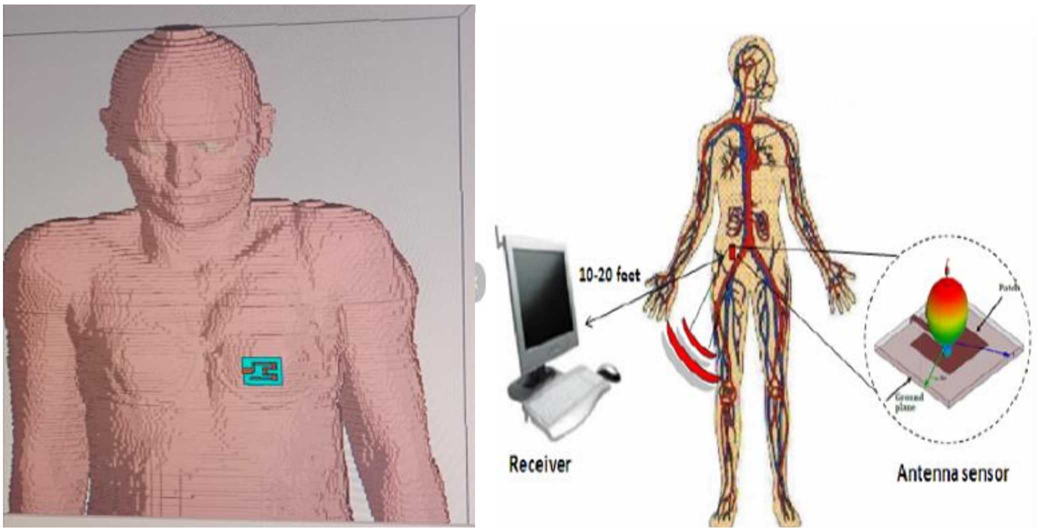


Figure 4.30: Wearable patch antenna for patient monitoring

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, wearable patch antennas have the potential to be used for blood pressure monitoring. They offer a non-invasive, continuous, and cost-effective alternative to traditional blood pressure monitoring methods. While there are still some limitations to overcome. The ongoing research and development in this area may lead to new and improved wearable patch antennas for blood pressure monitoring in the future. In line with the objectives of this research; the following conclusions have been made after the design and simulation modelling of the microstrip patch antenna.

a) The microstrip patch antenna was successfully designed using fabric material of 1.54 mm thickness as the substrate material, and copper for the patch and ground. Line feed was employed within the design for feeding the antenna.
b) Upon simulation of the microstrip patch antenna, return loss of -15 dB and -23 dB was obtained at a maximum resonating frequency of 2.45 GHz and 5.6 GHz.
c) The antenna results are changing by changing the bending of the antenna.
d) The antenna was made conformal then the antenna return loss is reduced to -11.4 at 2.5 GHz and -26 dB respectively.
e) The antenna was made conformal on human hand shows the SAR analysis 25.222W/KG at 600mW].

f) The little power radiated from this antenna could be attributed to the thinness as well as the low dielectric constant of the substrate, especially in due to the fact that open ended Microstrip lines ultimately radiate greater power when they are constructed with thick, low dielectric constant substrates.

g) The VSWR for this antenna was approximately 1.278, thereby depicting that the antenna is perfectly matched.

5.2 Recommendations

Upon completion of the research, a few recommendations to further improve the study and errors encounter have been stated thus:

a) The antenna design parameters could be further optimized to better its performance.

b) Other numerical software such as HFFS could be employed in validating the results obtained.

c) Other feed methods could be implemented on the design, so the optimal design could be adopted.

d) Other substrate materials could be tried upon the design.

e) The antenna could be constructed so experimental and simulated results may be compared.

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