A COMPACT HEXAGONAL SLOT ANTENNA FOR WiFi AND WEARABLE APPLICATIONS

PROJECT REPORT

PHASE-II

Submitted by

LAVANYA V

Register No: 15MCO005

in partial fulfillment for the requirement of award of the degree

of

MASTER OF ENGINEERING

in

COMMUNICATION SYSTEMS

Department of Electronics and Communication Engineering

KUMARAGURU COLLEGE OF TECHNOLOGY

(An autonomous institution affiliated to Anna University, Chennai)

COIMBATORE-641049

ANNA UNIVERSITY: CHENNAI 600 025

APRIL 2017

BONAFIDE CERTIFICATE

Certified that this project report titled **"A COMPACT HEXAGONAL SLOT ANTENNA FOR WiFi AND WEARABLE APPLICATIONS"** is the bonafide work of **LAVANYA.V [Reg.No.15MCO005]** who carried out the research under my supervision. Certified further that, to the best of my knowledge the work reported herein does not form part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

SIGNATURE	**SIGNATURE**
Dr.A.AMSAVENI	**Prof. K.RAMPRAKASH**
PROJECT SUPERVISOR	**HEAD OF PG PROGRAMME**
Department of ECE	Department of ECE
Kumaraguru College of Technology	Kumaraguru College of Technology
Coimbatore - 641049	Coimbatore - 641049

The candidate with University **Register No.15MCO005** was examined by us in the project viva-voice examination held on ....

INTERNAL EXAMINER **EXTERNAL EXAMINER**

ACKNOWLEDGEMENT

First, I would like to express my praise and gratitude to the Lord, who has showered his grace and blessings enabling me to complete this project in an excellent manner.

I express my sincere thanks to the management of Kumaraguru College of Technology and Joint Correspondent **Shri. Shankar Vanavarayar,** for his kind support and for providing necessary facilities to carry out the work.

I would like to express my sincere thanks to our beloved Principal **Dr.R.S.Kumar, Ph.D.,** Kumaraguru College of Technology, who encouraged me with his valuable thoughts.

I would like to thank **Prof. K.Ramprakash, M.E.,** Head of PG Programme, Electronics and Communication Engineering, for her kind support and for providing necessary facilities to carry out the project work.

I wish to thank everlasting gratitude to the project coordinator **Dr.M.Bharathi, Ph.D.,** Associate Professor, Department of Electronics and Communication Engineering, throughout the course of this project work.

I am greatly privileged to express my heartfelt thanks to my project guide **Dr.A.Amsaveni, Ph.D.,** Associate Professor, Department of Electronics and Communication Engineering, for her expert counseling and guidance to make this project to a great deal of success and I wish to convey my deep sense of gratitude to all teaching and non-teaching staffs of ECE Department for their help and cooperation.

Finally, I thank my parents and my family members for giving me the moral support and abundant blessings in all of my activities and my dear friends who helped me to endure my difficult times with their unfailing support and warm wishes.

ABSTRACT

Recent technologies enable wireless communication devices to become physically smaller in size. Antenna size is obviously a major factor that limits miniaturization. In the past few years, new designs of low-profile antennas for handheld wireless devices have been developed. Wearable Antennas are essentially any antenna that is specifically designed to function while being worn. Examples include smart watches glasses, textiles. Utilization of wearable textiles in the antenna segment has been seen on the rise due to the recent miniaturization of wireless devices. A wearable antenna is meant to be a part of the clothing used for communication purposes, which includes tracking and navigation, biomedical applications, mobile computing and public safety.

In this project a compact hexagonal slot antenna is designed and fabricated for WiFi and wearable applications. This slot antenna is designed by using conventional substrates like FR4, RT/Duroid-5880 and textile substrates like Polyester, Jean and Cotton. The dimension of the proposed antenna is 25 × 25 mm^2 and is electromagnetically coupled with hexagonal parasitic patch. Hexagonal slot antenna is powered through micro strip line feed structure. The proposed antenna with conventional and textile substrates structure resonates at 5GHz. Over the resonating frequency the maximum antenna gain is 3dBi. The bandwidth enhancement can be achieved by using parasitic patches and cutting appropriate slots in the main patch and the proposed design can be used in many modern communication devices with size constraints. The proposed work also analyzes the effects of electromagnetic (EM) radiation on human head and hand. The EM radiation is measured based on Specific Absorption Rate (SAR). The specific absorption rate (SAR) is measured at different distances from human head and hand.

The other antenna parameters like radiation efficiency, radiation pattern for resonating frequency, return loss characteristics and directivity have been evaluated in this project. The proposed hexagonal slot antenna is designed and simulated on HFSS (High frequency structural simulator) software, fabricated and tested using network analyser. For SAR calculation the CST (Computer Simulation Technology) is used.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ABBREVATIONS	NOMENCLATURE
GPS	Global Positioning Systems
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network
WiMAX	World Wide Interoperability For Microwave Access
WiFi	Wireless Fidelity
GSM	Global System For Mobile Communication
CDMA	Code Division Multiple Access
RF	Radio Frequency
SAR	Specific Absorption Rate
GPRS	General Packet Radio Service
EDGE	Enhanced Data GSM Environment
UMTS	Universal Mobile Telecommunications System
WAP	Wireless Application Protocol
PCS	Personal Communication System
BAN	Body Area Networks
PDA	Personal Digital Assistant
PIFA	Planar Inverted-F Antenna
CP	Circular Polarization
CPW	Coplanar Waveguide
UWB	Ultra Wideband
PICA	Planar Inverted Cone Antenna
DVD	Digital Video Disc
HIPERLAN	High Performance Radio LAN
FR4	Flame Retardant
HFSS	High Frequency Structural Simulator
CST(MWS)	Computer Simulation Technology(Microwave Studio)
VSWR	Voltage Standing Wave Ratio
CAD	Computer Aided Drafting

EM	Electromagnetic Field
SAM	Specific Anthropomorphic Mannequin
FEM	Finite Element Method
RFID	Radio Frequency Identification
PTFE	Polytetrafluoroethylene
FCC	Federal Communications Commission
ICNIRP	International Commission on Non-Ionizing Radiation Protection
CENELEC	European Committee for Electro technical Standardization

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Wireless is a term used to describe telecommunication in which electromagnetic waves carry the signal over part or the entire communication path. Common examples of wireless equipment in use today include: cell phones, pagers, GPS, cordless computer peripherals such as wireless keyboards, cordless telephone sets, remote garage-door openers, two-way radios, satellite televisions, wireless local area network (WLAN) and wireless personal area network (WPAN). Wireless technology is rapidly evolving, and is playing an increasing role in the lives of people throughout the world. In addition, the larger number of people is relying on wireless technology, either directly or indirectly. More recent examples of wireless communications include the following technologies:

- **Global System for Mobile Communication (GSM):** a digital mobile telephone system used in Europe and other parts of the world;
- **General Packet Radio Service (GPRS):** a packet-based wireless communication service that provides continuous connection to the internet for mobile phone and computer users;
- **Enhanced Data GSM Environment (EDGE)**: a faster version of the Global System for Mobile (GSM) wireless service designed to deliver data at rates up to 384 Kbps and enable the delivery of multimedia and other broadband applications to mobile phone and computer users;
- **Universal Mobile Telecommunications System (UMTS):** a broadband packet based system offering an integrated set of services to mobile computer and phone users no matter where they are located in the world;
- **Wireless Application Protocol (WAP):** a set of communication protocols to standardize the way that wireless devices, such as cellular telephones and radio transceivers, can be used for internet access.

Wireless can be divided into three categories: fixed, mobile, and portable. Fixed wireless refers to the operation of wireless devices or systems in fixed locations such as homes and offices. Mobile wireless applications refer to devices or systems aboard moving vehicles. Examples include the automotive cell phone and onboard GPS system. Portable wireless applies to the operation of autonomous, battery-powered wireless devices or systems outside the office, home, or vehicle; examples include handheld cell phones and personal communication system (PCS) units. Recent technologies enable wireless communication devices to become physically smaller in size. Antenna size is obviously a major factor that limits miniaturization. Antenna physical size is inversely proportional to its operating frequency. However, reducing the antenna physical size also means reducing its electrical size since the operating frequency of these devices does not change. Electrical size is expressed as a fraction of a wavelength, λ. For example, the electrical size, of a half-wave dipole antenna operating at 1800 MHz ($\lambda = c/f = 16.6$ cm) is 8.3 cm long because its electrical size is 0.5 λ. If a wireless device is required to have a physically small antenna, say half the size or 4.15 cm, and still operate at 1800 MHz, then it requires an antenna with a physical size of 4.15 cm, corresponding to an electrical size of 0.25 λ. Many applications at around 1800 MHz require antennas in the order of 0.25 λ or less. Examples of antennas of a quarter-wavelength electrical size that are used include monopole antennas, slot antennas, helical antennas, and PIFAs (planar inverted-F antenna).

In the past few years, new designs of low-profile antennas for handheld wireless devices have been developed. The major drawback of many low-profile antenna designs is their narrow impedance bandwidth. Some designs can barely cover the bandwidth requirement and hence, may not be used because there is no margin in the bandwidth for potential detuning effects due, for example, to the presence of a human operator. Furthermore, the market trend of personal wireless devices is moving toward a universal system that can be used anywhere. The rapid expansion of the wireless communication industry has created a need for connectivity among various wireless devices using short-range wireless links in the Bluetooth operating band to get rid of the cable connections.

This requires, therefore multiple frequency band operation. A list of a few useful wireless applications and their operating frequencies is shown Table 1.1. Dual-band and tri-band compact antennas have been realized to help the transition of new wireless system generations go smoothly but the current market demand needs wireless systems to operate in more than three bands especially wide band. Hence it is concluded that the desired characteristics of antennas in wireless communication systems are physically small size, wide bandwidth, and high efficiency.

Table 1.1: Frequency Bands for a Few Popular Wireless Applications

Wireless Applications	Frequency Band (GHz)
Bluetooth	2.4
WLAN	5-5.8
WiFi	2.4 (or) 5
WiMAX	3.3-11

Some advantages of WiMAX application is that a single station can serve hundreds of users, much faster deployment of new users comparing to wired networks, speed of 10 Mbps at 10 kilometers with line-of-site, it is standardized, and same frequency equipment should work together and the advantages of WLAN are listed as below

- Flexibility: within radio coverage, nodes can communicate without further restriction, Radio waves can penetrate walls.
- Planning: wireless ad hoc networks allow for communication without planning. (Wired networks need wiring plans).
- Robustness: wireless networks can survive disasters; if the wireless devices survive people can still communicate.

WiFi routers operating on the traditional 2.4 GHz band reach up to 150 feet (46 m) indoors and 300 feet (92 m) outdoors. Older 802.11a routers that ran on 5 GHz bands reached approximately one-third of these distances. Newer 802.11n and 802.11ac routers that operate on both 2.4 GHz and 5 GHz bands vary in the reach similarly. Some advantages of 5GHz over 2.4GHz: 5GHz generally provides faster data rates, fewer disconnects, and a more enjoyable experience. Bluetooth and other wireless peripherals aren't bothered the 5GHz spectrum so there's less interference. Microwaves don't operate up there (not even newer ones), so that source of noise is eliminated, too.

In this project, a compact Hexagonal-slot microstrip patch antenna for wireless application such us WiFi using HFSS software will be described. This antenna design can produce the multiple resonant modes and a much narrow bandwidth. Circular polarization can be achieved where the polarization of the antenna will be following the direction of the maximum gain. For achieving the resonant frequency various slots are cut in the main patch. Various slots are shaped in the radiating patch to manage the current flow on the antenna surface. Slot dimensions are varied to improve the various parameters like gain, return loss. The detailed explanation of this project is described in the following chapters.

1.2 PROJECT OBJECTIVE

- Design, simulate and fabricate a compact hexagonal slot antenna for WiFi and wearable applications.
- Analyse the antenna parameters such as Gain, VSWR, Radiation pattern and SAR values by using human head and hand phantom. The proposed slot antenna will be validated using both simulated and experimental results.
- Basic design specifications for a slot are listed in Table 1.2.

Table 1.2: Antenna Specifications

FEATURE	VALUE OR TYPE
Frequency	5GHz
Return Loss	>-30dB
Characteristic Impedance	50Ω
Circuit Board Material	Conventional & Textile(FR4, RT/Duroid & Polyester, Jean, Cotton)
SAR value	10g(2W/Kg), 1g(1.6W/Kg)

CHAPTER 2
LITERATURE REVIEW

1) Pratap N. Shinde., Jayashree P. Shinde., **“Design of compact pentagonal slot antenna with bandwidth enhancement for multiband wireless applications,”** Int. J. Electron. Commun. (AEÜ) 69 (2015) 1489–1494.

The compact design of a microstrip feed pentagonal shaped slot antenna with electromagnetically coupled pentagon parasitic patch is proposed in this paper for bandwidth enhancement. A compact pentagonal slot antenna is designed on a commercially available FR4 substrate, 25 × 25 × 1.6 mm^3 in size, with dielectric constant $\varepsilon_r = 4.4$ and loss tangent tanδ=0.02. The electromagnetically coupled pentagonal parasitic patch located at centre and fed by microstrip line excites resonating frequencies. These resonating frequencies overlap each other to broaden the bandwidth by lowering the lower edge frequency f_l and increasing the upper edge frequency f_2. The vertex feed pentagonal slot antenna is analyzed for bandwidth enhancement. The proposed antenna gives a wide bandwidth of 4.17 GHz (3.281 GHz–7.45 GHz), which corresponds to FRB 77.72%. The parasitic patch improves the coupling between parasitic patch and ground plane, which result into decline of lower as well as upper resonating frequency. The improvement in coupling indicates good impedance matching across wide dual band. The rotational behavior of slot antenna illustrates good impedance matching over the wide bandwidth. The bandwidth is enhanced when the antenna is fed at the vertex by 8.09% more than that of the side feed configuration, with an increase in the upper edge frequency. The pentagonal slot antenna with the slot at the 0° position has three resonant frequencies at 3.5 GHz, 5 GHz and 6.81 GHz. Antenna design exhibits good phase linearity over the wide operating band with small variations in group delay. Over the entire operating bandwidth, the antenna gain remains constant about 4.24 dBi and group delay is less than 0.5 ns and the radiation efficiency is 85%.

2) Dastranj A, Abiri Habibollah,**“Bandwidth enhancement of printed E-shaped slot antennas fed by CPW and microstrip line,”** IEEE Transaction on Antennas & Propagation 2010; 58(4):1402–7.

Two printed wide-slot antennas with E-shaped patches and slots, for broadband applications, are proposed. They are fed by a coplanar waveguide (CPW) and a microstrip line with almost the same performances. Two printed E-shaped wide-slot antennas fed by 50Ω microstrip line and CPW are proposed which use round corners to increase the bandwidth. In both designs (microstrip line and CPW), the E-shaped radiating slot is etched on a square substrate with a size of 85 mm x 85 mm, thickness h= 1 mm, and a relative dielectric constant ε_r =4.4 and the substrate used as FR4 substrate. A substrate of low dielectric constant is selected to obtain a compact radiating structure that meets the demanding bandwidth specification. Varying the feed shape or slot shape will change the coupling property and consequently the operating bandwidth. On the other hand, for optimum performance the feed and slot shapes should be similar and the feed should occupy an area of about one third of the slot size. The impedance bandwidth are, determined by -10dB reflection coefficient, of the proposed slot antennas fed by microstrip line and CPW, from both measurement and simulation, are about 136% (2.85 to 15.12 GHz) and 146% (2.83 to 18.2 GHz), respectively. This large operating bandwidth is obtained by choosing suitable combinations of feed and slot shapes. In order to achieve wider operation bandwidth both of the designed antennas have round corners on the wide slot and patch. Meanwhile, the proposed antennas exhibit almost Omni-directional radiation patterns, relatively high gain, and low cross polarization. Based on these characteristics, the proposed wide-slot antennas can be useful for broadband direction finder systems, satellite and communication applications.

3) Kawshik Shikder, Farhadur Arifin. **"Extended UWB Wearable Logo Textile Antenna for Body Area Network Applications,"** IEEE 5th International Conference on Informatics, Electronics and Vision (ICIEV) 2016; 978-1-5090-1269-5/16.

In this paper, a novel extended Ultra Wide Band (UWB) wearable logo-type textile antenna for body area network applications is presented. The substrate of the proposed antenna is made of Fleece fabric with permittivity 1.17. The proposed antenna comprises of a hexagonal radiating patch and a partial ground plane. Ultra wide bandwidth is attained by optimizing the geometry, introducing a square notch in the partial ground plane and introducing novel slot pattern on the radiating patch of the antenna. This novel slot represents the logo of author's department name "Electrical and Electronic Engineering (EEE)". The dimension of the proposed antenna is 38 × 32 × 2.05 mm3 and the bandwidth is 27 GHz starting from 2.85 GHz to 29.85 GHz for return loss less than -10 dB. The proposed antenna design details and simulated results are presented by the Commercial electromagnetic simulation package CST Microwave Studio. The simulated S11 characteristics illustrates that it has good impedance matching between antenna and transmission line with all over its occupied bandwidth. The proposed antenna exhibits almost omni-directional radiation pattern but it has quite significant distortion from omni-directional pattern at higher frequencies. Antenna gain varies significantly with changing frequencies while the total efficiency varies slightly though it doesn't affect the performance. However, the gain variation of the antenna is 4.5 dBi and average total efficiency more than 93%. Thereby, conclusion can be drawn that the overall performance of the proposed antenna indicates the suitability for UWB wearable textile applications.

4) Alaa A. Yassin, Rashid A. Saeed, Rania A. Mokhtar, **“Dual-Band Microstrip Patch Antenna Design Using C-Slot for Wifi and Wimax Applications,”** IEEE 5th international conference on computer & communication Engineering 2014; 978-1-4799-7635-5/14.

In this paper, a dual-band microstrip patch antenna design for WiMax and WiFi implementation by mean of 3.5 GHz and 5.2 GHz central frequencies, respectively.. The antenna system is been designed anchored in adds C-slot design on the patch and two parallel slit on the ground plane. The microstrip patch antenna design use rectangular patch shape and content the FR-4 proxy in substrate with dielectric constant 4.3 of thickness 16 mm and size (49 x 53 x 1.67 mm3). It moreover contains a copper on patch and ground plane with thickness 0.035 mm. The favor of this technique is that it puts forward low profile, high gain and wide bandwidth for the entire frequencies. Computer Simulation Technology (CST) microwave studio simulator is exploited to analyze the performance of the antenna system. The dual-band antenna configuration by C- slot on the patch and enhancement of the antenna performance by using ground slits. The analysis and optimization results are simulated by Matlab and CST microwave studio simulators. The proposed dual-band antenna has been successfully give return loss (-18 & - 31dB), better bandwidth (42 &138MHz), better radiation patterns and high gains (5.8dB, 6.7dB) at 3.5GHz and 5.2GHz respectively.

5) Imran A, Islam M.R, Hassan M.N, Shiblu N.H, Ahmad S, Ali M.T, **"Absorption Rate Analysis of Cellular Phone Radiation on the Human Head,"** IEEE 5th International Conference on Informatics, Electronics and Vision 2016; 978-1-5090-1269-5/16.

In this paper, the effects of electromagnetic (EM) radiation of mobile phone on human head are analysed. The EM radiation is measured based on Specific Absorption Rate (SAR). The human head is generally exposed to mobile phones operating at communication (GSM, CDMA etc) frequency bands. The radiation absorption analyzed through simulations by applying frequency domain using Comsole Multiphysics software. The specific absorption rate (SAR) was measured for different positions of mobile phone. SARs exhibited in much lower values as the mobile phone held in far position from human brain. This measurement demonstrates SAR is high at close distance; effectively the temperature increase is also high as the distance reduces. Comparative analysis also shows that FR4 substrate demonstrates higher SAR and temp raise compared to Rogers RO3006 and Rogers RO4003 substrates. From the SAR distribution and temperature increase following findings can be summarized:

a. SAR is high at close distance; effectively the temperature increase is also high as the distance reduces. As for example with Rogers RO3006 at 9cm, the SAR is 837.5% higher (from 0.016 to 0.15) and the temperature raised 0.218K greater than 15cm radiation effects.

b. FR4 substrate demonstrates higher SAR and temp rise compared to Rogers RO3006 and Rogers RO4003 substrates. As for example with FR4 at 9cm, the SAR is 100% higher (from 0.15 to 0.3) and the temperature raised 63.63% higher (from 0.36K to 0.22K) greater than Rogers RO3006 radiation effects.

CHAPTER 3

PROPOSED METHODOLOGY

3.1 INTRODUCTION TO ANTENNAS

An antenna is a device that provides a transition between electric currents on a conductor and electromagnetic waves in space. A transmitting antenna transforms electric currents into radio waves and a receiving antenna transforms an electromagnetic field back into electric current. The main property of the antenna is reciprocity. Reciprocity means that the antenna's electrical characteristics are the same whether it is used for transmitting or receiving. Because this is always true the antenna is a transitional structure between free-space and a guiding device. The guiding device or transmission line may take the form of a coaxial line or a hollow pipe (waveguide), and it is used to transport electromagnetic energy from the transmitting source to the antenna or from the antenna to the receiver. In the former case, they have a transmitting antenna and in the latter a receiving antenna.

Thevenin equivalent of the antenna system in transmitting mode is shown in Figure 3.1. In this transmitting mode, the source is represented by an ideal generator, the transmission line is represented by a line with characteristic impedance Z_c, and the antenna is represented by a load Z_A [$Z_A = (R_L + R_r) + jX_A$] connected to the transmission line.

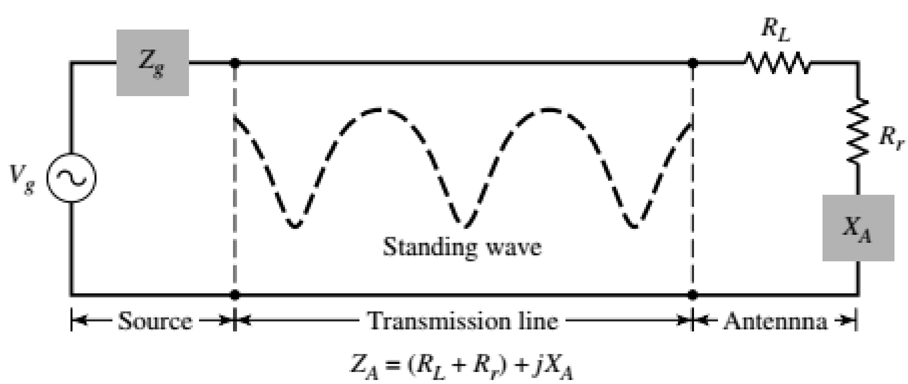


Figure 3.1: Thevenin Equivalent of Antenna in Transmitting Mode

The antennas are used in systems such as radio broadcasting, broadcast television, two-way radio, communications receivers, radar, cell phones, and satellite communications, as well as other devices such as garage door openers, wireless microphones Bluetooth-enabled devices, wireless computer networks, baby monitors, RFID tags on merchandise, etc.

3.1.1 Basic Concept of Microstrip Patch Antenna

A microstrip patch antenna has been one of the most innovative topics in antenna theory and design. Microstrip antennas are designed to have many geometrical shapes and dimensions but rectangular and circular microstrip patches have been used in many applications. They are used in wide range of modern microwave applications because of their simplicity and compatibility with printed-circuit technology.

A microstrip patch antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side as shown in Figure 3.2. The bottom surface of a thin dielectric substrate is completely covered with metallization that serves as a ground plane. The rectangular microstrip patch antenna is made up of a rectangular patch with dimensions width (W) and length (L) over a ground plane with a substrate thickness (h) and permittivity (ε_r). The length (L) of the patch is usually $\lambda_O/3 < L < \lambda_O/2$ and the thickness of the patch is very thin ($t \ll \lambda_O$).

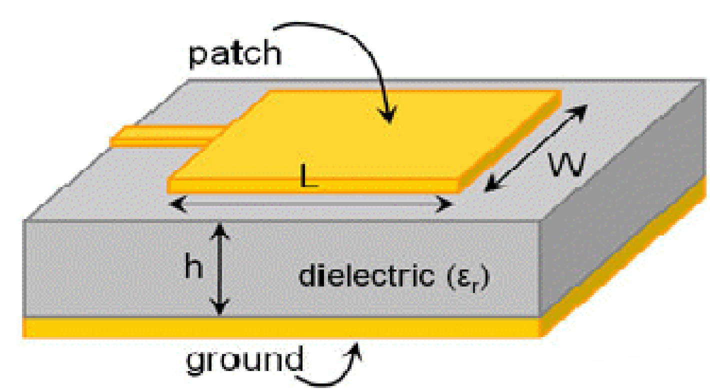


Figure 3.2: The Simplest Microstrip Patch Antenna

The patch is generally made up of a conducting material like gold or copper. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edges by variety of methods. The patch is in fact electrically a bit larger than its physical dimensions due to its fringing fields.

3.1.2 Types of Microstrip Patch Antenna

There are different types of microstrip patch antennas which can be classified based on their physical parameters. The patch may be square, rectangular, dipole, circular, triangular, circular ring, elliptical or any other configuration. These are illustrated in Figure 3.3. The rectangular microstrip patch antenna is the widely used because of ease of fabrication and analysis. This type is also robust to design and very ease to handle.

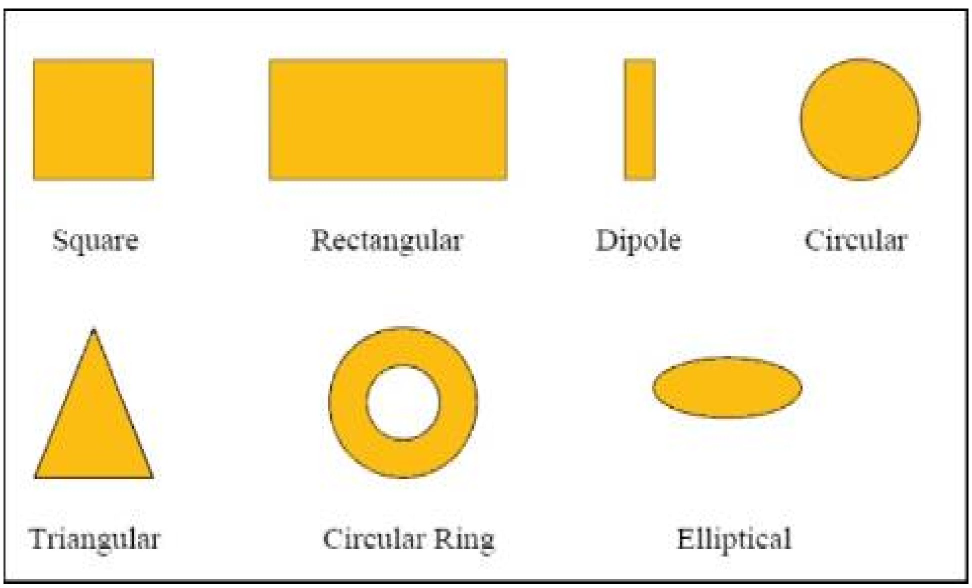


Figure 3.3: Common Shapes of Microstrip Patch Antenna

3.1.3 Feeding Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories, contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coxial probe, aperture coupling and proximity coupling.

3.1.4 Return Loss

Return loss is an important parameter when connecting an antenna. It is a way to characterize the input and output of signal sources. The return loss is related to impedance matching and the maximum transfer of power theory. When the load is mismatched, not all the available power from generator is delivered to the load. This return loss is also a measure of the effectiveness of an antenna to deliver power from the source to the antenna. The return loss, R_L shows the level of the reflected signal with respect to the incident signal in dB. It is defined by the ratio of the incident power of the antenna P_{in} to the power reflected back from the antenna of the source P_{ref}.

The mathematical expression is:

$$R_L = -20 \log_{10}|\Gamma| \text{ (dB)} \qquad \text{-------- (1)}$$

Where $|\Gamma|$ is determined by:

$$|\Gamma| = \frac{P_{in}}{P_{ref}} = \frac{Z_L - Z_O}{Z_L + Z_O} \qquad \text{-------- (2)}$$

The Z_L and Z_O are the load and characteristic impedance.

For effective power transfer, the ratio P_{in}/P_{ref} should be high. If the return loss is low, the standing wave phenomena's or resonances might occur, and it will end up in the frequency ripple or gain. During the process of the design of microstrip patch antenna there is a response taken from the magnitude of S_{11} versus the frequency which is known as return loss. In most practical circuits a return loss value of -10 dB is good enough.

3.1.5 Gain

Gain is a useful measurement describing the antenna performance. Although the gain of the antenna is closely related to directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Antenna gain is usually expressed in dB, simply refers to the direction of maximum radiation. Mathematically the maximum gain, G is obtained by

$$G = \eta D \qquad \text{-------- (3)}$$

Where, η = efficiency and D = directivity

3.1.6 Directivity

It is desirable to maximize the radiation pattern of the antenna response in a fixed direction to transmit or receive power. Likewise, the directivity is dependent only on the shape of radiation pattern. It is always referenced to an isotropic point source as in Figure 3.4. A quantitative measure of this response is the directive gain of the antenna for a given direction.

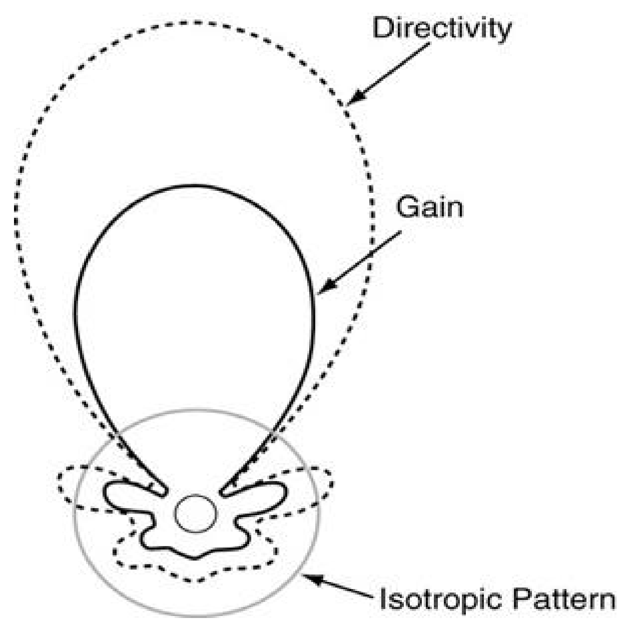


Figure 3.4: Directivity of an Antenna

3.1.7 Radiation Pattern

The power radiated or received by an antenna is a function of the angular position and radial distance from the antenna. The radiation pattern is represented in the form of a three dimensional graph of power versus elevation and azimuth angles but more commonly represented by E-plane or H-plane where one angle is held fixed while the other is varied.

3.1.8 Bandwidth

The bandwidth of an antenna is defined as the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The bandwidth can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency. The bandwidth is given by the expression:

$$\text{Bandwidth}_{\text{narrow band}} (\%) = [\frac{f_H - f_L}{f_c}] \text{ x } 100\% \qquad \text{--------} (4)$$

Where,

f_H = upper frequency

f_L = lower frequency

f_C = center frequency

3.1.9 Antenna Efficiency

The antenna efficiency is defined as the ratio of total power radiated by the antenna to the input of the antenna. The total antenna efficiency is used to take into account losses at the input terminals and within the structure of the antenna. An antenna may dissipate power due to conductor loss or dielectric loss. A high efficiency antenna has most of the power present at the antenna's input radiated away. A low efficiency antenna has most of the power absorbed as losses within the antenna, or reflected away due to impedance mismatch.

3.1.10 Polarization

The polarization of an antenna is defined as the polarization of the wave transmitted or radiated by the antenna. Whenever, the direction is not stated, the polarization of the antenna will be following the direction of the maximum gain. It is known that a rectangular patch with a conventional feeding will radiate linearly. However, with some modifications on the feeding techniques or the patch itself can turns to a circular polarization. The main advantage of using circular polarization is because of it as a receiver orientation so that it can always receive a signal even from different axis of transmission.

3.1.11 Substrate

There are numerous substrates that can be used for the design of microstrip patch antenna. Their dielectric constants are usually in the range of $2.2 < \varepsilon_r < 12$. The microstrip patch antenna radiates primarily because of the fringing fields between the patch edge and the ground plane. Therefore, the effective dielectric constant (ε_{reff}) must be obtained. The dielectric constants play a major role in the overall performance of the antenna. When a dielectric substrate is selected, the material with the lowest tangent ($\tan \delta$) is preferred. The loss tangent is a metric of the quantity of electrical energy, which is converted to heat by a dielectric. The lowest possible loss tangent maximizes the antenna efficiency.

The relative dielectric constant, ε_r of the substrate determines the physical size of a patch antenna. The larger the dielectric constant the smaller the element size, but also the smaller the impedance, bandwidth and directivity and the surface wave loss increases. If the material has high dielectric constant, it reflects more RF energy and detunes the antenna more, which makes it harder to tag. The materials that are most desirable for antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size. Thin substrate with higher dielectric constants is desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element sizes. However, they are less efficient and have relatively smaller bandwidth because of their greater losses. Since microstrip antennas are often integrated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design. Table 3.1 shows types of dielectric constant for different materials.

Table 3.1: Dielectric and Loss Tangent for Different Materials

Substrates	Material	ε_r	tan δ
Conventional	Teflon (PTFE)	2.1	0.0005
	RT/Duroid(5880)	2.55	0.0007
	FR4	4.4	0.02
	Alumina	9.8	0.0003
Textile	Polyester	3.2	0.003
	Silk	2.5	0.0005

3.1.12 Fringing Effects

Fringing fields have a great effect on the performance of a microstrip antenna. In microstrip patch antennas, the electric field in the center of the patch is zero. The radiation is due to the fringing field between the periphery of the patch and the ground plane. Higher the substrate, the greater is the fringing field. Due to the fringing effect, the microstrip patch antenna looks greater than its physical dimension. Thus, an effective dielectric constant is to be introduced. The effective dielectric constant takes in account both the fringing and the propagation in the line. Hence, when designing a patch antenna it is typically trimmed by 2-4% to achieve at the desired resonance frequency.

3.2 WEARABLE ANTENNAS

Wearable Antennas are essentially any antenna that is specifically designed to function while being worn. Examples include smart watches glasses, textiles. Utilization of wearable textiles in the antenna segment has been seen on the rise due to the recent miniaturization of wireless devices. The characteristics of wearable antennas are compact size, light weight, flexible, cost effective and robust. A wearable antenna is meant to be a part of the clothing used for communication purposes, which includes tracking and navigation, mobile computing and public safety. The operation of wearable patch antenna is illustrated at Figure 3.5.

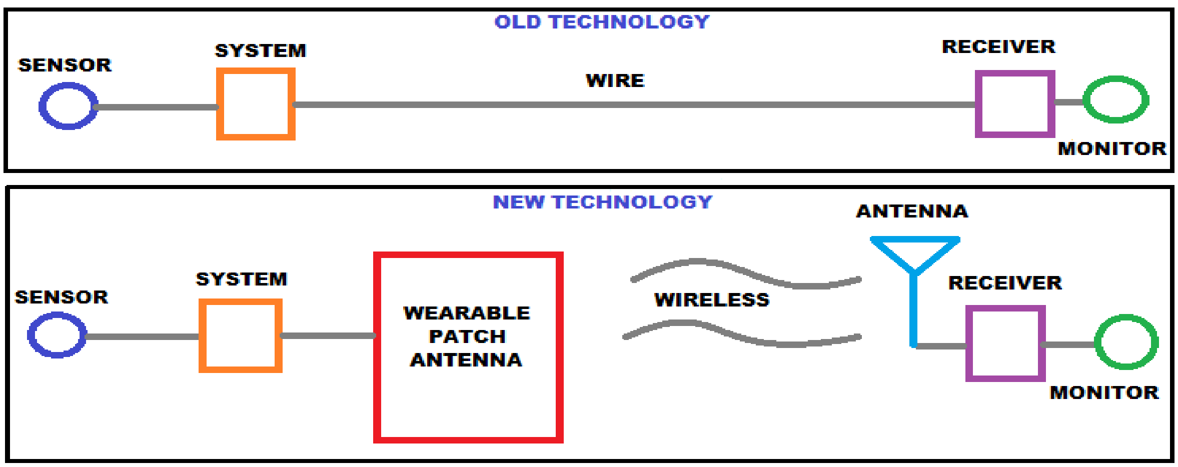


Figure 3.5: Operation of Wearable Patch Antenna

3.2.1 Body Area Networks

A BAN system consists of various nodes attached to different body parts. These nodes are responsible for communicating with each other and transmitting the data to any remote server. A node is subdivided into a sensor, an actuator and a Personal Digital Assistant (PDA). The sensor is the most important part and it includes a memory unit for data storage and an antenna for transmitting and receiving the collected data. The antennas used in BAN systems must fulfill the following conditions: 1. Compact and light weight. 2. Flexible and retain their shape. 3. Radiation away from the human body. 4. Stable characteristics in the human body vicinity.

3.2.2 Need of On-Body Measurements

In WBAN applications, single or multiple antennas are mounted as transceiver nodes on human body. The transceiver nodes may communicate with one another or some remote server for sending data depending on the application. The problem arises when the antenna is placed on human body as not all parts of the human body are flat. The antennas are designed to operate on the bent body parts like arm and leg, and their performance are checked in real time environment.

3.2.3 Effects on Antenna due to Human Body

The wearable antenna operates near human body vicinity. Water constitutes two-thirds of human body and it is attributed as polar in nature, the antenna property changes in the vicinity of human body due to the polarization of water molecules in the presence of electromagnetic radiations. This phenomenon is known as dielectric loading. The electrical properties of human body change with frequency. All the commonly used antenna parameters, such as resonant frequency, bandwidth, radiation pattern, and particularly efficiency are likely to change radically as an antenna moves closer to the body and therefore a free space design may only be a rough approximation of antenna suitability.

3.3 SAR (SPECIFIC ABSORPTION RATE)

Specific absorption rate (SAR) is a measure of the rate at which energy is absorbed by the human body when exposed to radio frequency (RF). It is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg).

SAR for electromagnetic energy can be calculated from the electric field within the tissue as:

$$\text{SAR}=\frac{1}{V}\int\frac{\sigma(r)|E(r)|\hat{}2}{\rho(r)}dr \qquad \text{-------- (5)}$$

$\sigma =$ is the sample electrical conductivity

E = is the RMS electric field

ρ = is the sample density

V= is the volume of the sample

3.3.1 Mobile Phone SAR Testing

When measuring the SAR due to a mobile phone the phone is placed against a representation of a human head (a "SAR Phantom") in a talk position. The SAR value is then measured at the location that has the highest absorption rate in the entire head, which in the case of a mobile phone is often as close to the phone's antenna as possible. Measurements are made for different positions on both sides of the head and at different frequencies representing the frequency bands at which the device can transmit. Depending on the size and capabilities of the phone, additional testing may also be required to represent usage of the device while placed close to the user's body and/or extremities. Various governments have defined maximum SAR levels for RF energy emitted by mobile devices:

- United States: The FCC requires that phones should have a SAR level at or below 1.6 watts per kilogram (W/kg) taken over the volume containing a mass of 1 gram of tissue that is absorbing the most signal.
- European Union: CENELEC specify SAR limits within the EU, following IEC standards. For mobile phones, and other such hand-held devices, the SAR limit is 2 W/kg averaged over the 10 g of tissue absorbing the most signal.
- India: Follows both US limits and EU limits for mobile handsets from 2012 onwards.

3.4 PROJECT FLOW

The project starts with the research project background and problem statement definition. Theories and previous research have been the basic reference in order to define the logic specification to achieve for the microstrip slot antenna. Figure 3.6 shows the flow of steps required in designing the microstrip slot antenna.

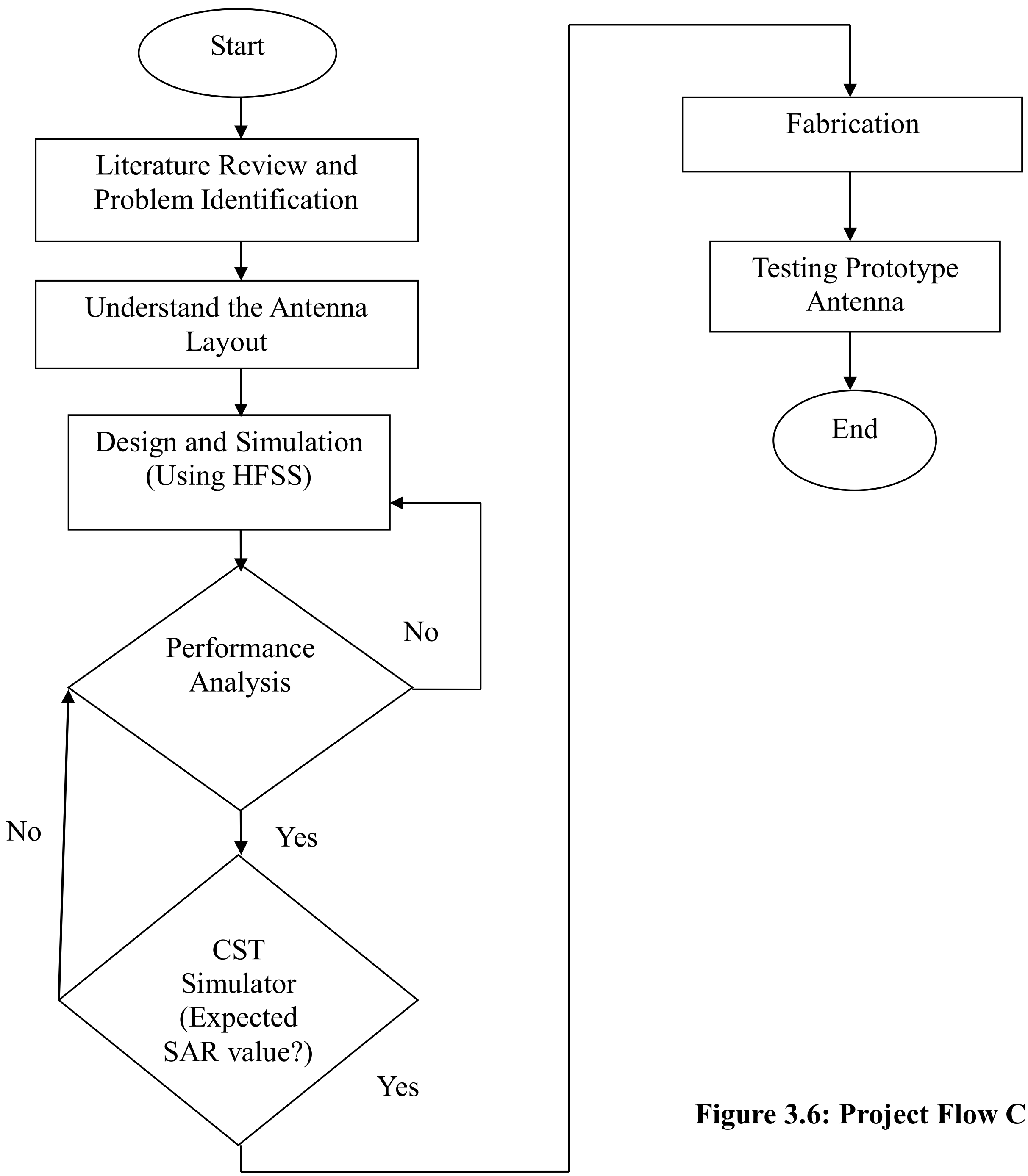


Figure 3.6: Project Flow Chart

3.5 ANTENNA SPECIFICATION

Basically, the performance of the antenna depends on its resonant frequency, dimension, operating frequency, radiation efficiency, directivity, and return loss. The characteristics of the antenna are defined mainly by their geometries and the material properties. The design of slot antenna requires precise physical dimensions and power feeding method for the antenna.

The Hexagonal-slot microstrip patch antenna is designed based on three parameters. The substrate used here is conventional substrates like FR4, RT/Duroid and textile substrates like Polyester, Jean and Cotton. The properties of different substrates are given in Table 3.2. The patch is considered to be fed by a 50Ω microstrip feed line. The predefined specification is shown in Table 3.3.

Table 3.2: Substrates Properties

Substrate	Dielectric Constant(εr)	Height(mm)	Tangent Loss(tanδ)
FR4	4.4	1.6	0.02
RT/Duroid	2.2	2.2	0.009
Polyester	3.2	1.2	0.003
Jeans	1.7	3.5	0.025
Cotton	1.51	3.2	0.02

Table 3.3: Antenna Specifications

Parameters	Specifications
Operating Frequency	5 GHz
Gain	> 3 dB
Return Loss	< -10 dB
Polarization	Circular
SAR value (Measured at human head and hand)	10g(2W/Kg), 1g(1.6W/Kg)

A low dielectric constant of the substrate material is used in the prototype design because it gives better efficiency and higher bandwidth. The low value of the dielectric constant will increase the radiated power. The design has a patch size independent of the dielectric constant. Therefore, the reduction in the patch size is accomplished by using higher dielectric constant. Thus, FR4 and cotton is good in this agreement. Another important design parameter is the substrate thickness, h. The thickness of the substrate increases the fringing field at the patch periphery. Therefore, for each substrate the appropriate height has been chosen. Typically, gain is a useful measurement describing the performance of the antenna. Although the gain of the antenna is closely related to the directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. In this design, it is a requirement to obtain more than 3dB gain as the antenna is expected to transmit the signal at the microwave frequency of 5GHz.

The return loss is required to be less than -10 dB. Lesser the return loss value more will be the reflected power. This can be achieved by providing a appropriate geometrical parameters and transmission line system. For the bandwidth, it is defined as 3-5% for a greater path of the transmission signal.

In a microstrip feed line, the conducting strip is connected directly to the edge of the microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. Patch antennas are widely used semi-directional and a patch antenna can have a beam width between 30 to 180 degrees and a typical gain of 9 dB. Microstrip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be considered as an extension of patch. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13), due to overall increase in the thickness of the microstrip patch antenna.

The Hexagonal-slot antenna design needs to have a circular polarization for the WiFi application. Circular polarization is more practical compared to the linear polarization. The signal can be transmitted and received for not only in single direction.

There are many ways to obtain the circular polarization for example, modification on the patch or the feed arrangement. Due to the advanced signal propagation properties, CP antenna technology offers numerous performance advantages over traditional linear technologies. When implemented as a central component within a Wi-Fi network, CP delivers better connectivity with both fixed and mobile devices and ultimately leads to a superior user experience. The SAR value is measured for how much the human body absorbs the radiation. Here, the conventional substrates are used in mobile phones and the textile substrates are used for biomedical applications. The human phantom models are used for measuring the SAR value.

3.6 ANTENNA DESIGN WITH THEIR DIMENSION

The proposed antenna is designed on a commercially available conventional and textile substrate whose dielectric constant, thickness and loss tangent are tabulated in Table3.2. The proposed slot antenna has a compact size of 25x25mm^2 and is fed by 50Ω transmission line using the microstrip feed. Geometrical configuration of the proposed antenna is shown in Figure 3.7.

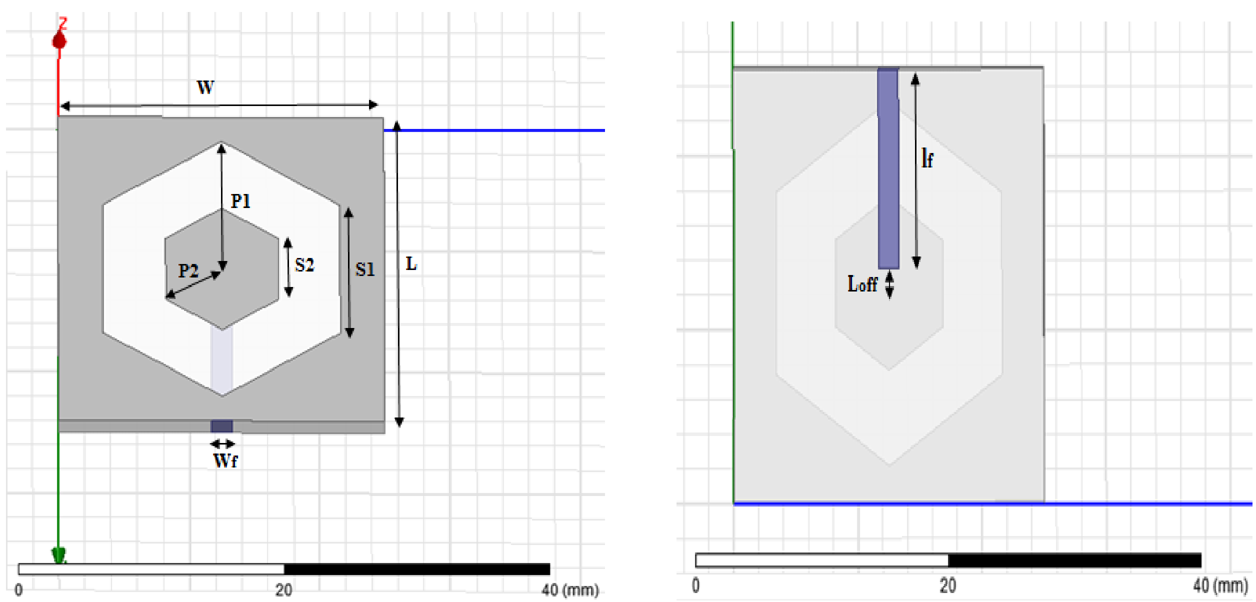


Figure 3.7: Hexagonal Slot Antenna Configuration

Table 3.4: Antenna Dimensions for both Conventional and Textile Substrates

S.NO	Dimensions	Values (mm)
1	L	25
2	W	25
3	P1	10.7
4	P2	4
5	S1	10.5
6	S2	5
7	W_f	1.6
8	L_f	9.75
9	L_{off}	2.75

The antenna comprises of ground plane of length L and width W with the hexagonal shaped slot cut from the ground plane. Table 3.4 shows the antenna dimensions of the proposed antenna. The hexagonal slot has a side length of S1 and the distance from its centre to the vertex of the slot is P1. There is a electromagnetically coupled hexagonal parasitic patch of side length S2 with distance from its centre to the vertex being P2 printed on the same substrate .The parasitic patch is positioned at the point of origin, which is surrounded by a wide hexagonal shaped slot. The area of this slot is controlled by either variation in P1 or P2.The hexagonal slot antenna is excited from a microstrip line placed beneath it, l_f in length and W_f in width. The gap between the centre of the parasitic hexagonal patch and upper end of the projected microstrip feeding line is termed as L_{off}. The microstrip feeding line excites the parasitic patch electromagnetically through the hexagonal shaped slot. The impedance matching condition for the maximum transmission of signals from the feed line to the parasitic patch is achieved by optimization of the parameters P2, feed length lf and gap L_{off}.

3.7 ANTENNA SIMULATION TOOL

3.7.1 HFSS (High Frequency Structural Simulator)

The software used to model and simulate the Hexagonal-slot microstrip antenna by HFSS (High Frequency Structural Simulator). This software provides a user-friendly interface to handle multiple projects and views at the same time. Modeling with HFSS allows the use of an interactive mouse for data input, design capture, template assistance for specific applications and fully parametric 3D modeling. The navigation tree is an essential part of the user interface where the structural elements and simulation results may be accessed.The block diagram of the HFSS design steps as shown in the Figure 3.8.

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for 3D volume and it employs the Finite Element Method (FEM), adaptive meshing, tetrahedron & brilliant graphics. The software also has advanced solid modelling features and Boolean operations such as adding and subtracting solid objects from existing structures. Simulation materials can be arranged in layers, whether they are isotropic or anisotropic, linear or non-linear, magnetic or nonmagnetic. RF energy excitation sources include waveguide ports, lumped ports, and discrete voltage and current sources. Figure 3.9 shows a screenshot of Ansoft-HFSS main window.

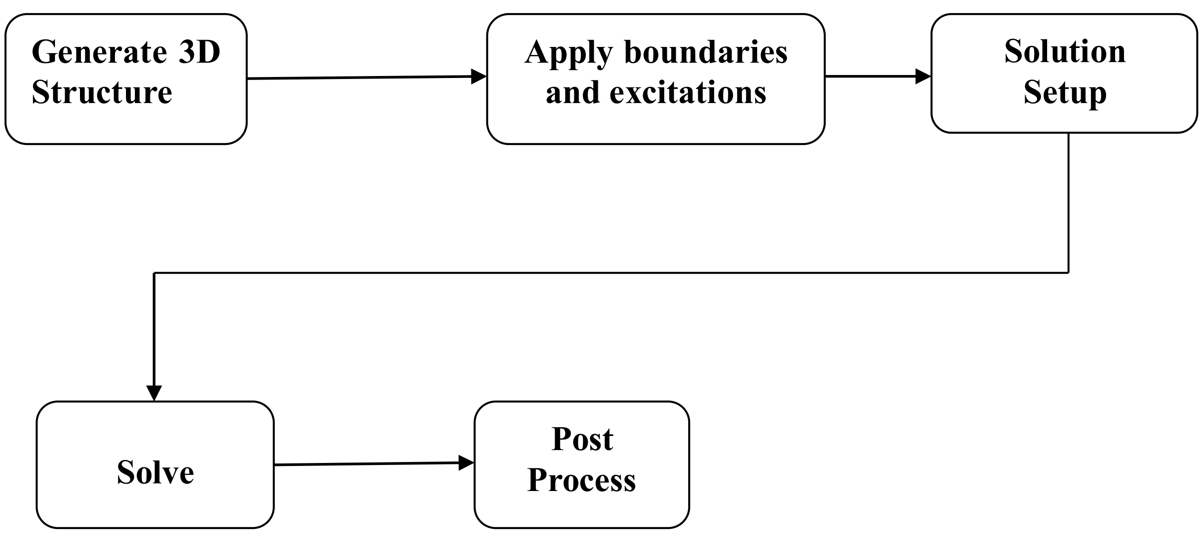


Figure 3.8: General Steps in HFSS Simulation

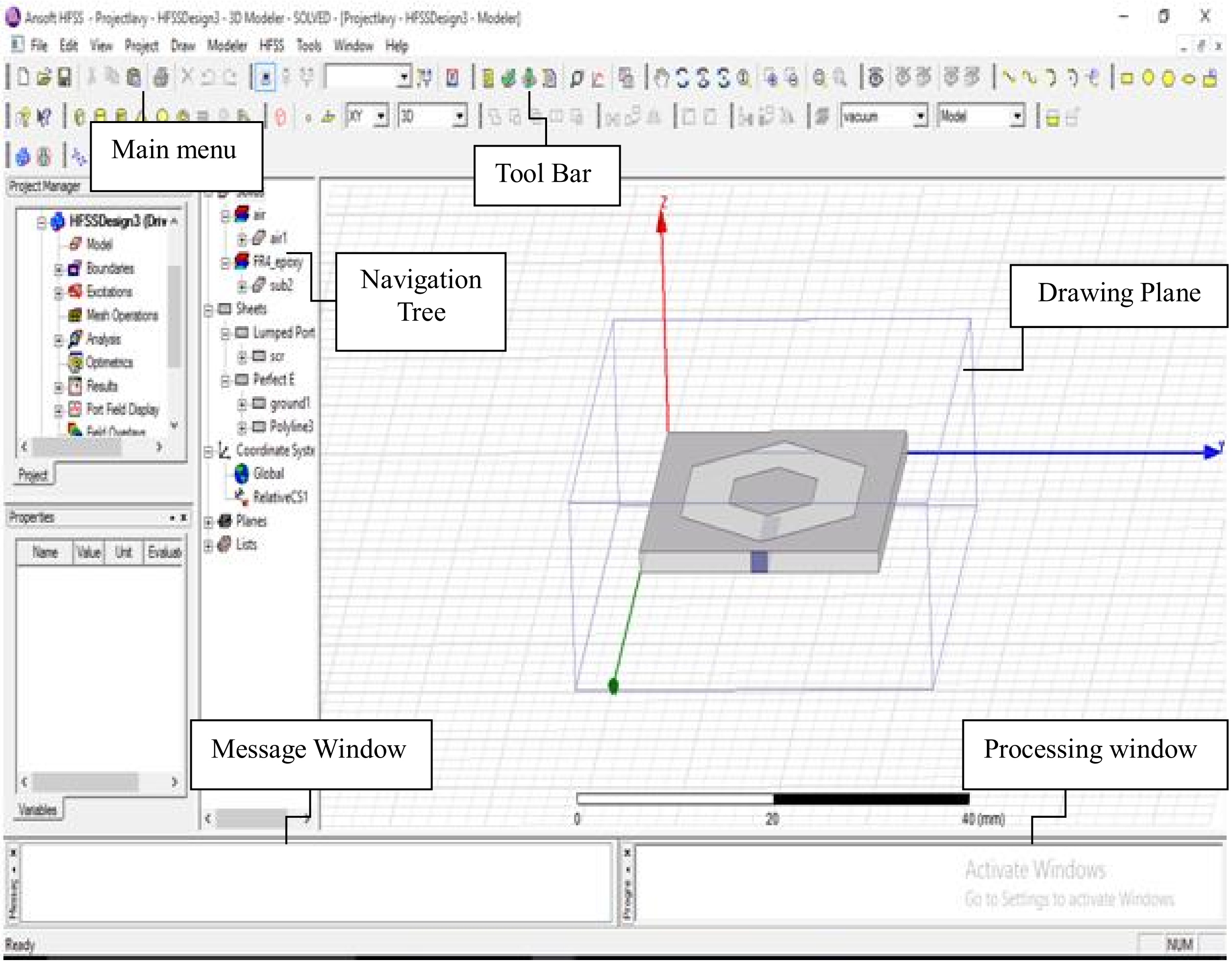


Figure 3.9: A Screenshot of HFSS Main Window

The post-processing includes the VSWR and Smith chart plots, port signal plots, polar radiation pattern plots, and 2D and 3D field plots. The software can also calculate and plot the antenna axial ratio, which is important for circularly and elliptically polarized antennas. The first step in the antenna design processes is determining the criteria to use in selecting an optimal antenna. The first criterion is to achieve power transfer from the feed transmission line to the antenna. This is accomplished by matching the antenna input impedance to the characteristic impedance of the transmission line. The post process step describes the analyses of antenna parameter like reflection coefficient, antenna gain, VSWR, radiation pattern etc.,

3.7.2 CST (Computer Simulation Technology)

The CST can also be used to model and simulate the antenna design. But, here the CST is mainly used for calculating the SAR value. The CST Microwave Studio (MWS) provides the human head and hand phantom for SAR calculation. Generally, CST MWS is the leading edge tool for the fast and accurate 3D simulation of high frequency devices and market leader in Time Domain simulation. It enables the fast and accurate analysis of antennas, filters, couplers, planar and multi-layer structures and SI and EMC effects etc. Beside the flagship module, the broadly applicable Time Domain solver and the Frequency Domain solver, CST MWS offers further solver modules for specific applications. Filters for the import of specific CAD files and the extraction of SPICE parameters enhance design possibilities and save time. The post processing is similar to the HFSS. In CST the SAR values are measured in terms of point, average, 10g and 1g of SAR values by the standards of IEEE/IEC 62704-1, IEEE C95.3, CST C95.3 and CST Legacy. Figure 3.10 shows a screenshot of CST MWS main window with head and hand phantom model.

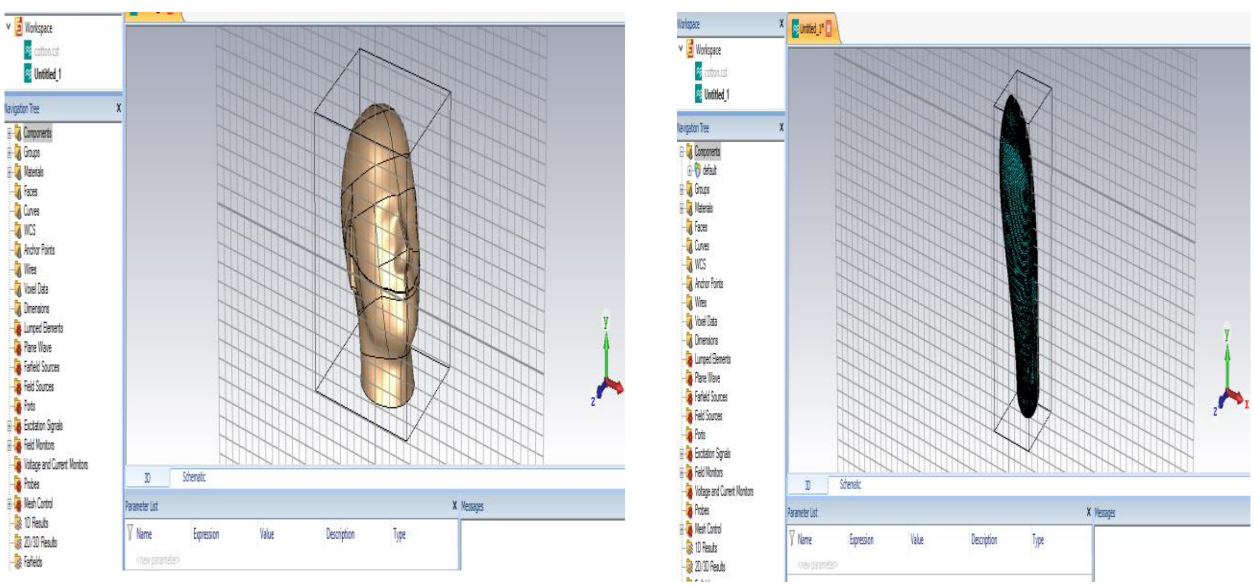


Figure 3.10: A Screenshot of CST MWS Main Window with Head and Hand Mode

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter analyzes the performance of the proposed hexagonal slot antenna in terms of Return loss (S_{11}), VSWR, Radiation Patterns, Antenna Gain and Efficiency. The performance is measured over both frequency and SAR values for both conventional and textile antennas.

4.1 RETURN LOSS ANALYSIS OF BOTH CONVENTIONAL AND TEXTILE SUBSTRATES

The simulated S_{11} plot over frequency of the proposed Hexagonal slot antenna with conventional substrates is shown in Figure 4.1. Here, the conventional substrates are FR4 and RT/Duroid-5880 with the thickness of about 1.6mm and 2.2mm respectively.

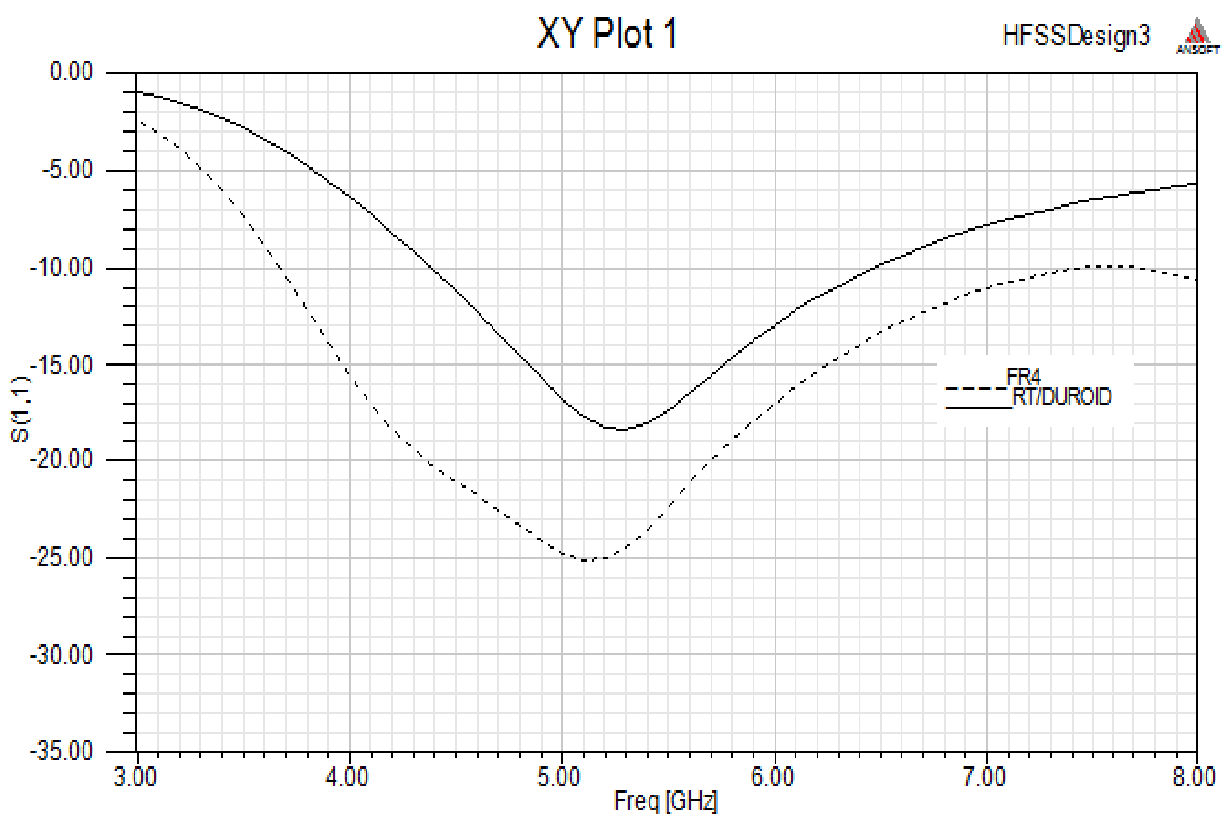


Figure 4.1: Simulated Return Loss for the Conventional Patch Antenna

The FR4 substrate covers the bandwidth of about 4GHz (3.6GHz-7.6GHz) and it provides a return loss of about -25 dB for a frequency of 5GHz. The RT/Duroid (5880) covers the bandwidth of 2GHz (4.4GHz-6.4GHz) and this substrate gives a return loss of about -18 dB for a frequency of 5GHz. The simulated return loss plot over frequency of the proposed hexagonal slot antenna with textile substrates is shown in Figure 4.2. Here, the textile substrates are Polyester, Jean and Cotton with the thickness of about 3.2mm, 1.7mm and 1.51mm respectively.

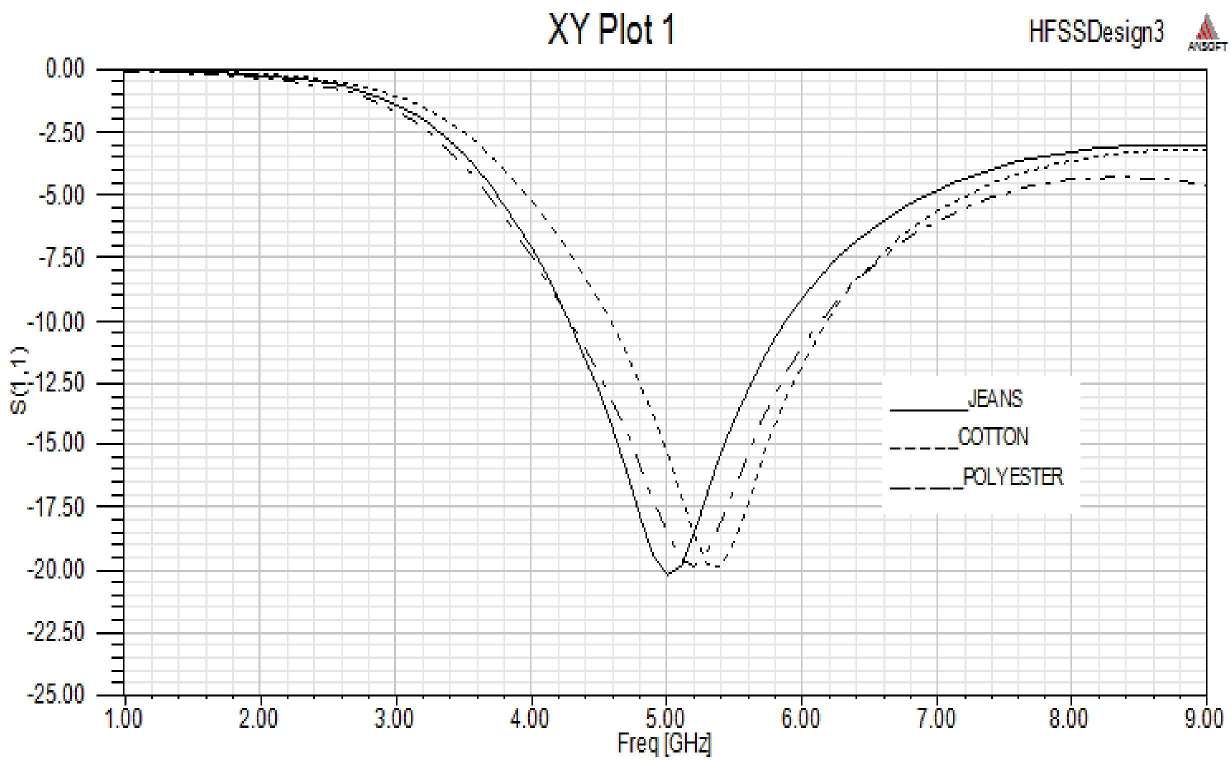


Figure 4.2: Simulated Return Loss for the Textile Patch Antenna

The Polyester substrate covers the bandwidth of about 2GHz (4.2GHz-6.2GHz) and it provides a return loss of about -18 dB for a frequency of 5GHz. The Jean covers the bandwidth of 1.6GHz (4.2GHz-5.8GHz) and this substrate gives a return loss of about -20 dB for a frequency of 5GHz. The return loss of the resonant frequency 5GHz of Cotton substrate is -18dB and it covers the bandwidth of about 1.6GHz (4.6GHz-6.2GHz). When compared with other substrates FR4 substrate covers the higher bandwidth ant the jean substrate gives the perfect notch point at 5GHz.

4.2 VSWR (VOLTAGE STANDING WAVE RATIO) MEASUREMENT FOR BOTH CONVENTIONAL AND TEXTILE SUBSTRATES

The simulated Voltage Standing Wave Ratio (VSWR) over frequency plot of the proposed hexagonal slot antenna for conventional and textile substrates are shown in Figure 4.3 and 4.4 respectively.

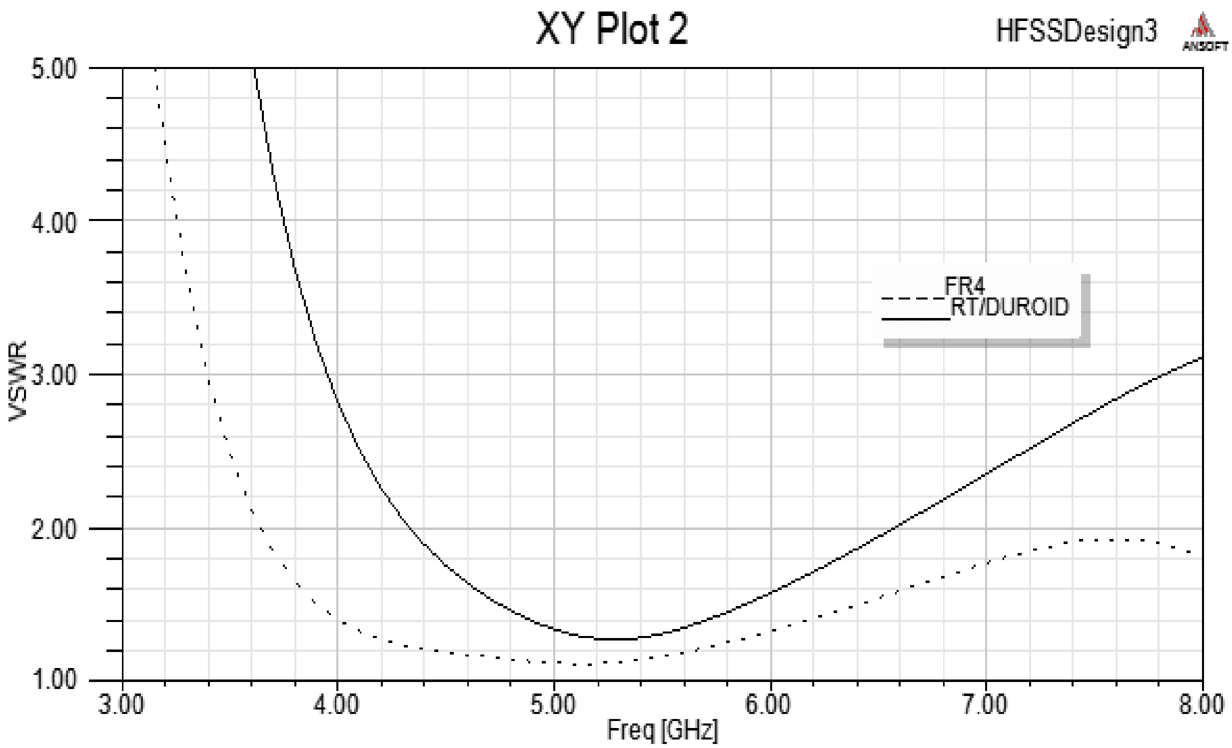


Figure 4.3: VSWR Plot of Conventional Patch Antenna

With the 2:1 VSWR impedance bandwidth, this is acceptable for practical application. From the Figure 4.3 and 4.4 it can be seen that simulated VSWR of the hexagonal slot antenna is less than 1.5 for both conventional and textile substrates which indicates a good impedance matching between the antenna and transmission line with all over its occupied bandwidth. In this proposed antenna both conventional and textile substrates have good impedance matching because for all different substrates the VSWR range is less than 2 for most of the operating bandwidth.

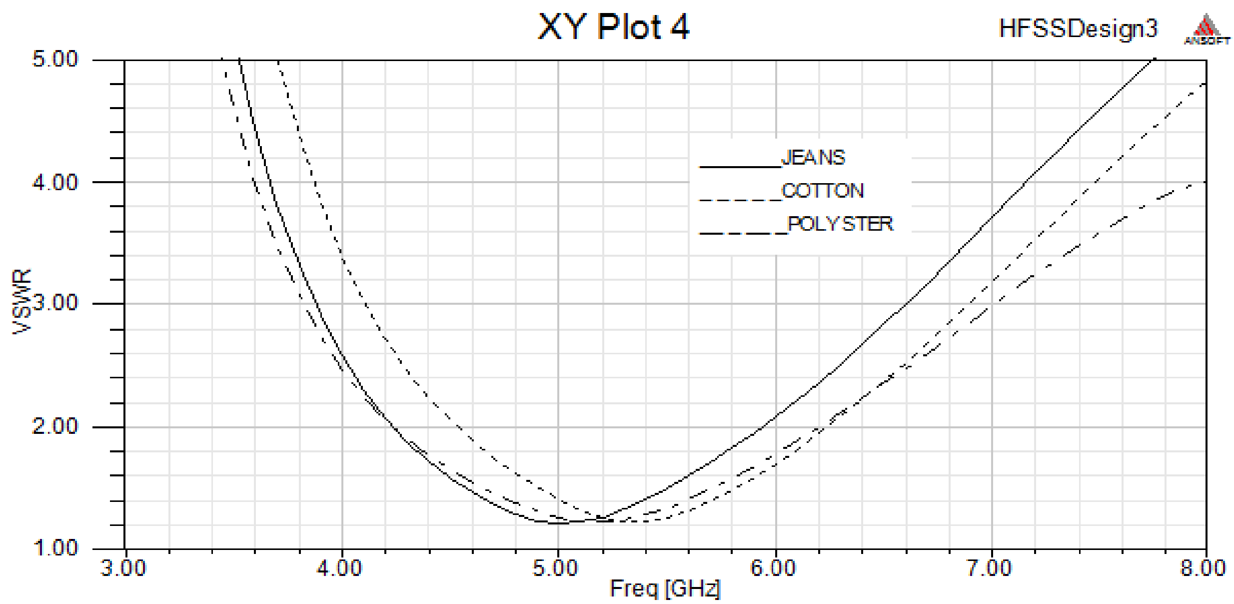
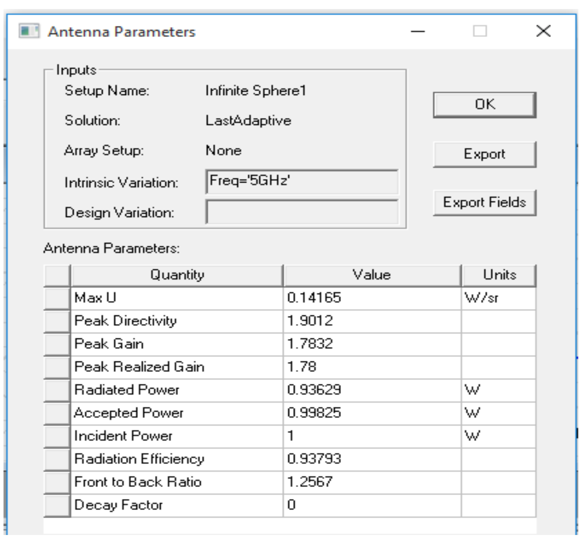


Figure 4.4: VSWR Plot of Textile Patch Antenna

4.3 GAIN AND EFFICIENCY OF BOTH CONVENTIONAL AND TEXTILE SUBSTRATES

Figure 4.5 and 4.6 show the simulated antenna parameters for substrates like FR4 and Jeans respectively.



Antenna Parameters

Inputs

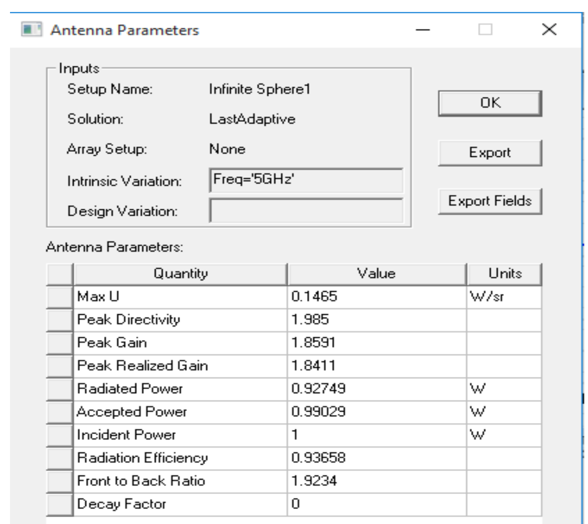
Setup Name:	Infinite Sphere1
Solution:	LastAdaptive
Array Setup:	None
Intrinsic Variation:	Freq='5GHz'
Design Variation:	

OK | Export | Export Fields

Antenna Parameters:

Quantity	Value	Units
Max U	0.14165	W/sr
Peak Directivity	1.9012	
Peak Gain	1.7832	
Peak Realized Gain	1.78	
Radiated Power	0.93629	W
Accepted Power	0.99825	W
Incident Power	1	W
Radiation Efficiency	0.93793	
Front to Back Ratio	1.2567	
Decay Factor	0	

Figure 4.5: Antenna Parameters for FR4 substrate



Antenna Parameters

Inputs

Setup Name:	Infinite Sphere1
Solution:	LastAdaptive
Array Setup:	None
Intrinsic Variation:	Freq='5GHz'
Design Variation:	

OK | Export | Export Fields

Antenna Parameters:

Quantity	Value	Units
Max U	0.1465	W/sr
Peak Directivity	1.985	
Peak Gain	1.8591	
Peak Realized Gain	1.8411	
Radiated Power	0.92749	W
Accepted Power	0.99029	W
Incident Power	1	W
Radiation Efficiency	0.93658	
Front to Back Ratio	1.9234	
Decay Factor	0	

Figure 4.6: Antenna Parameters for Jeans substrate

For other substrates like RT/Duroid, Polyester, Cotton, the important antenna parameters like gain and efficiency are tabulated below. Table 4.1 shows the simulated gain and efficiency of the conventional and textile substrates.

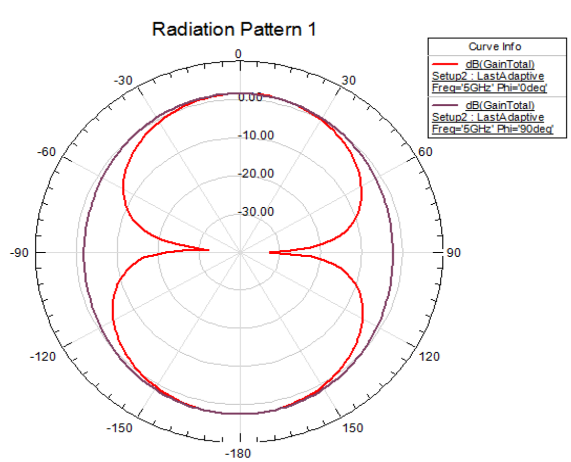
Table 4.1:Simulated Gain and Efficiency of the Conventional and Textile Substrates

Substrates	Gain(dB) at 5GHz	Efficiency at 5GHz
FR4	1.78	0.937
RT/Duroid	1.7	0.93
Polyester	1.72	0.931
Jeans	1.85	0.936
Cotton	1.82	0.935

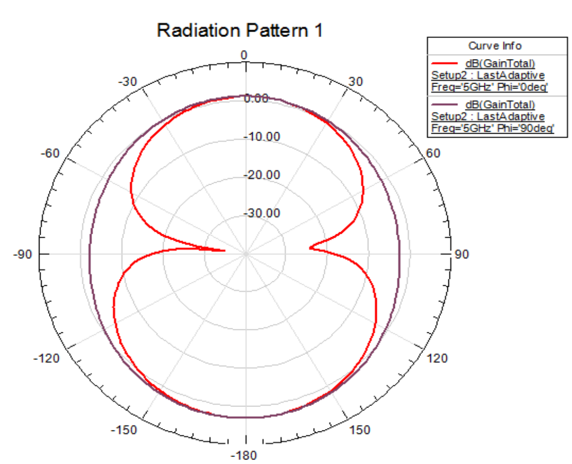
The Jeans, Cotton and FR4 substrates have maximum gain when compared to the other substrates.

4.4 RADIATION PATTERNS OF THE CONVENTIONAL AND TEXTILE PATCH ANTENNA

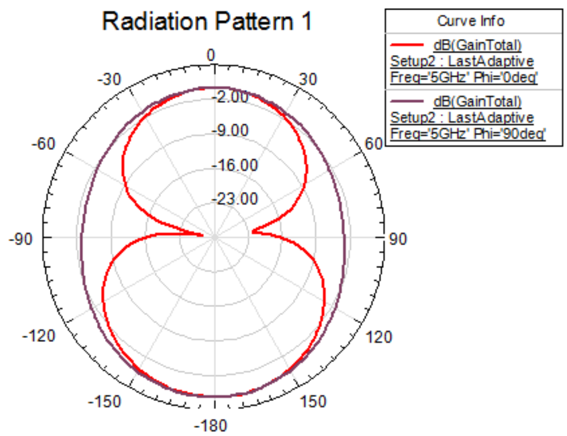
The simulated elevation radiation patterns at resonant frequency of the proposed hexagonal slot antenna of conventional and textile substrates are shown in Figure 4.7.



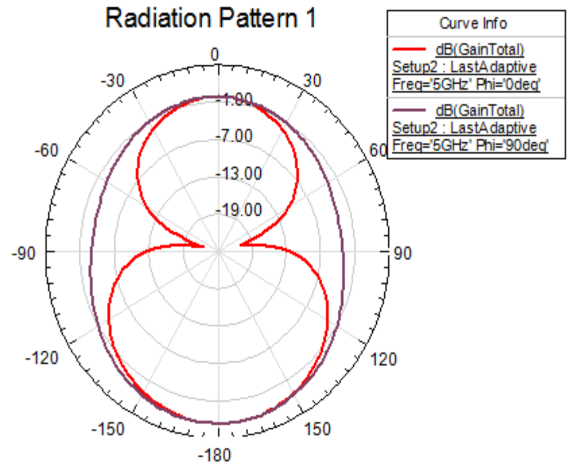
(a) FR4-Theta/deg vs. dBi (phi=0˚ & 90˚)



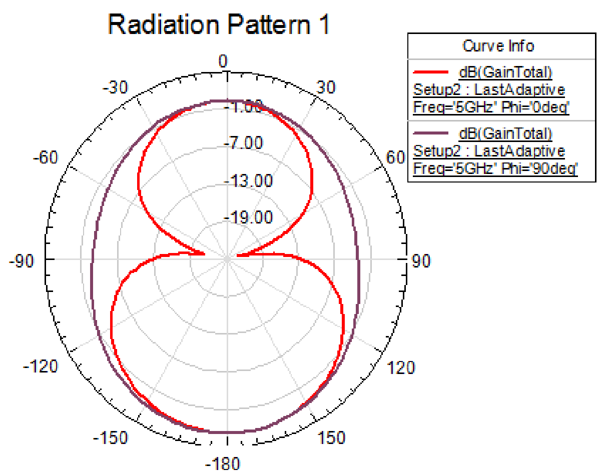
(b) RT/D-Theta/deg vs. dBi (phi=0˚ & 90˚)



(c) Polyester-Theta/deg vs. dBi (phi=0˚ & 90˚)



(d) Jeans-Theta/deg vs. dBi (phi=0˚ & 90˚)



(e) Cotton-Theta/deg vs. dBi (phi=0˚ & 90˚)

Figure 4.7: Elevation Radiation Patterns at 5GHz - (a) & (b) are Conventional Substrates and (c), (d) & (e) are Textile Substrates

Here, the elevation pattern is observed, for that phi (φ) has been set to 0 and 90 degree for all values of theta (θ). The elevation radiation patterns of the hexagonal slot conventional and textile antenna at resonant frequency such as 5GHz have been shown in Figure 4.7. At 5 GHz, it exhibits almost omni-directional radiation pattern for both conventional and textile substrates whereas there is no deformation or deviation of radiation pattern observed at resonant frequency. There is a good impedance matching because of no deviation in radiation pattern.

4.5 SAR (SPECIFIC ABSORPTION RATE) ANALYSIS

For calculating S_{11} parameter, Gain, Efficiency and Radiation Patten the HFSS software is used and for calculating the SAR value CST MWS is used. To determine the interaction between EM sources and the cell phone user, the dielectric properties of human body tissues should be set carefully. In this project, a numerical specific anthropomorphic mannequin (SAM) head model and a hand phantom are used. The SAM phantom consists of shell and brain simulating liquid. As the human tissue parameters are frequency dependent, the dispersive material model considered in the simulation is head and hand phantom. Table 4.2 indicates the dielectric properties of head and hand phantom at 5GHz.

Table 4.2: Properties of Human Head and Hand Models

Materials	Relative permittivity (εr)	Conductivity (σ)S/m
	5GHz	5GHZ
SAM shell	3.5	0.0016
SAM liquid	40	1.42
Hand	32.6	1.26

The CST MWS based on finite-integral time-domain technique is utilized in this investigation. The simulation is carried out using time-domain solver considering hexahedral mesh with adaptive meshing scheme. The SAM head and hand phantom model is taken from the CST MWS example and it's considered for the SAR calculation. Figure 4.8 indicates the head and hand model. The antenna having conventional substrates (FR4 & RT/Duroid) is placed near the ear position in the head model which is a hearing mode. The antenna having textile substrates (Polyester, Cotton, and Jeans) is placed near the arm position in the hand model. The textile substrates are mainly used for biomedical applications. The conventional antenna is placed near the ear position in the head model for measuring the mobile phone radiation in the human head. The textile antenna is placed near the arm position in the hand model for measuring the radiation at the time getting biomedical information. The power absorption by the mobile phone user can be evaluated from the induced electric field (E) in the human biological tissue. SAR for electromagnetic energy can be calculated from the electric field within the tissue as:

$$\text{SAR}=\frac{1}{V}\int\frac{\sigma(r)|E(r)|\hat{}2}{\rho(r)}dr \qquad \text{---------- (6)}$$

σ is the sample electrical conductivity, E is the RMS electric field, ρ is the sample density, V is the volume of the sample. The SAR values are calculated in the post-possessing phase of simulation according to the IEEE standard algorithm. The peak SAR values (spatial-peak SAR [IEEE-1529]) are averaged over 1 and 10 g of human tissues by setting excitation equal to 0.6 W.SAR is usually averaged either over the whole body, or over a small sample volume (SAR value of 2 W/kg (SAR) absorbed per 10 g and 1.6 W/kg per 1 g of body tissue).

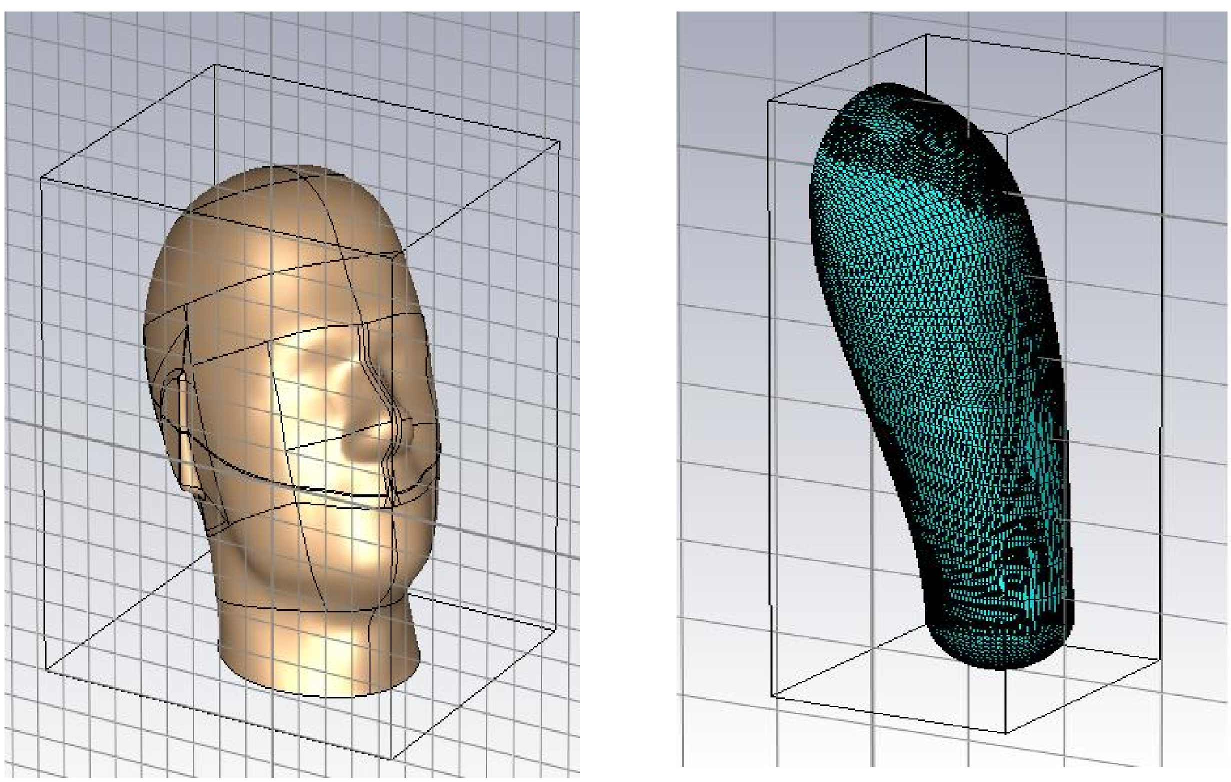
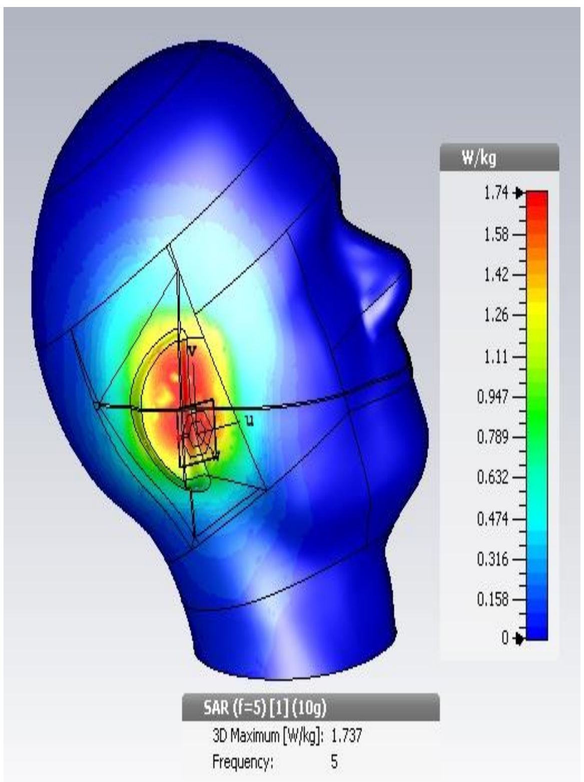
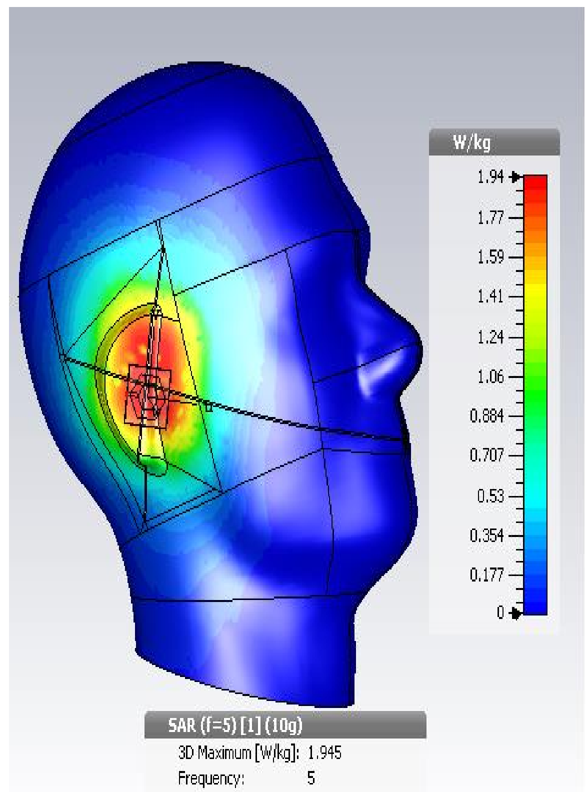


Figure 4.8 Head and Hand Model

The slot antenna resonated at 5GHz. Each substrate used to build an antenna has its own dielectric properties and thus has the specific potential of absorbing and depositing the radiation from the mobile phone onto a human head. Generally, the substrate with higher conductivity deposits higher radiation towards the head or hand rather than the substrate of lower conductivity. The head phantom model is made of human shell and brain liquid and the hand model is made of skin and the blood flow. SAR effect onto the user's head is observed at a distance of 3cm and 4cm from the head model for the conventional substrates (FR4 & RT/Duroid). Figure 4.9 shows the radiation effects on head with conventional substrates.

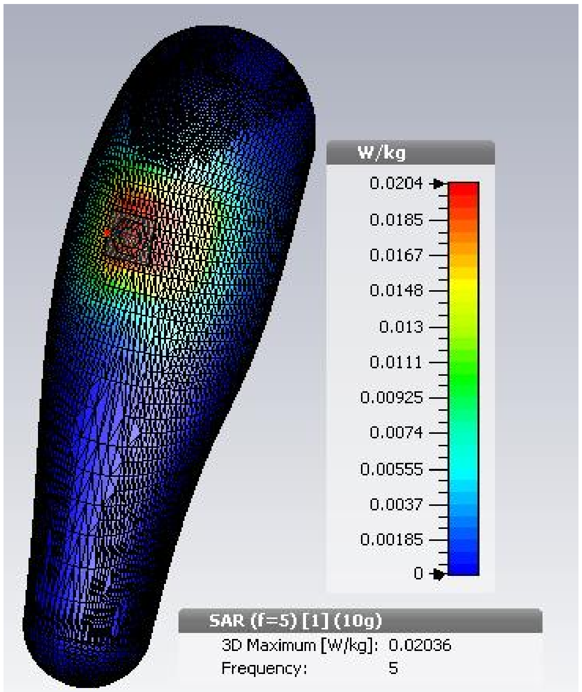


(a) FR4 Substrate (3cm from head)

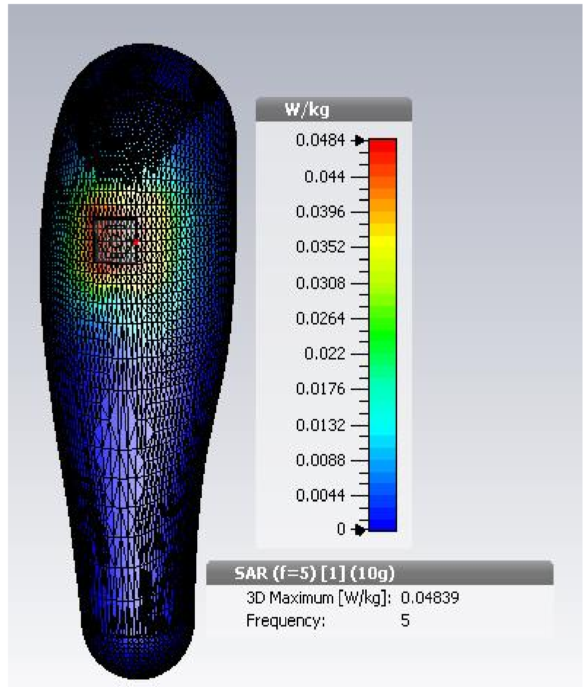


(b) RT/D Substrate (3cm from head)

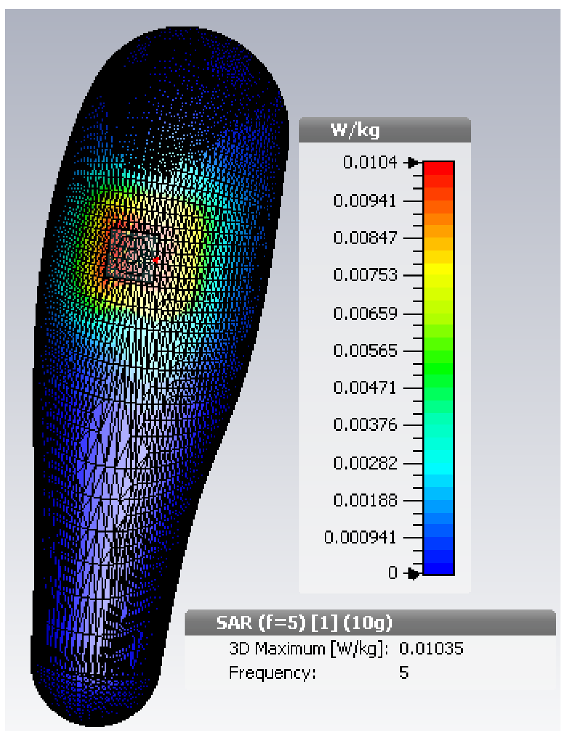
Figure 4.9: Radiation Effects on Human Head with Conventional Substrate at 5GHz



(a) Polyester (1cm from hand)



(b) Jeans (1cm from hand)



(c) Cotton (1cm from hand)

Figure 4.10: Radiation Effects on Human Head with Textile Substrate at 5GHz

In FR4 and RT/D (RT/Duroid) the maximum SAR value at 10g of body tissue is 1.737 W/kg and 1.945 W/kg respectively. SAR effect onto the user's hand is observed at a distance of 1cm and 1.5cm from the hand model for textile substrates (Polyester, Jeans & Cotton). Figure 4.10 shows the radiation effects on hand with textile substrates. In Polyester, Jeans and Cotton the maximum SAR value at 10g of body tissue is 0.02036 W/kg, 0.04839 W/kg and 0.01035 W/kg respectively. Table 4.3 and 4.4 show the average SAR values for the proposed antenna with conventional substrate at a distance of 3cm and 4cm from the head model and also the textile substrate at a distance of 1cm and 1.5cm from the hand model by the standard the ICNIRP (SAR<2mw/kg) (10g).

Table 4.3: SAR Values of Conventional Substrates

Substrate	SAR(W/kg)-10g of body tissue	
	3cm from head	4cm from head
FR4	1.74	1.59
RT/Duroid	1.94	1.75

Table 4.4: SAR Values of Textile Substrates

Substrate	SAR(W/kg)-10g of body tissue	
	1cm from hand	1.5cm from hand
Polyester	0.0204	0.0185
Jeans	0.0484	0.0450
Cotton	0.0104	0.0100

From the above SAR analysis while increasing the distance from the antenna to the human head or hand the radiation absorbed by the human body is decreased. In this proposed work, the antenna with cotton substrate gives very low SAR value. The proposed antenna meets the SAR limits recommended by the ICNIRP, which is 2 W/kg averaged over 10 g of tissue.

CHAPTER 5

EXPERIMENTAL RESULTS OF FABRICATED ANTENNA

The design of the proposed conventional and textile antenna was validated by simulating the antenna reflection coefficient against frequency. Two different full wave simulators were employed; the commercial software ANSYS-HFSS is used for measuring S_{11}, VSWR etc., and commercial software CST microwave studio is used for calculating the SAR. Then the simulated results are compared with the experimental results using Agilent Technologies Microwave Vector Network Analyzer.

For the fabrication process the FR4 and Cotton substrate are considered. The Figure 5.1 & 5.2 shows the front and back side of the fabricated conventional and textile antenna respectively.

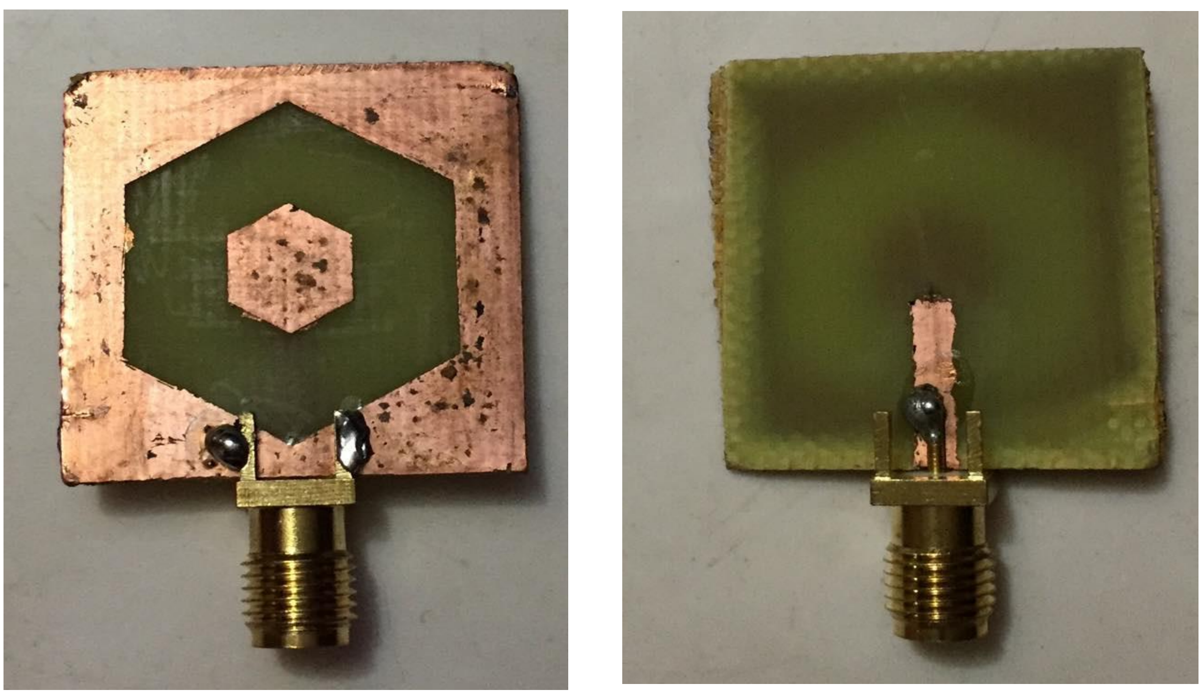


Figure 5.1: Front and back Side of the Conventional Prototype antenna (FR4 substrate)

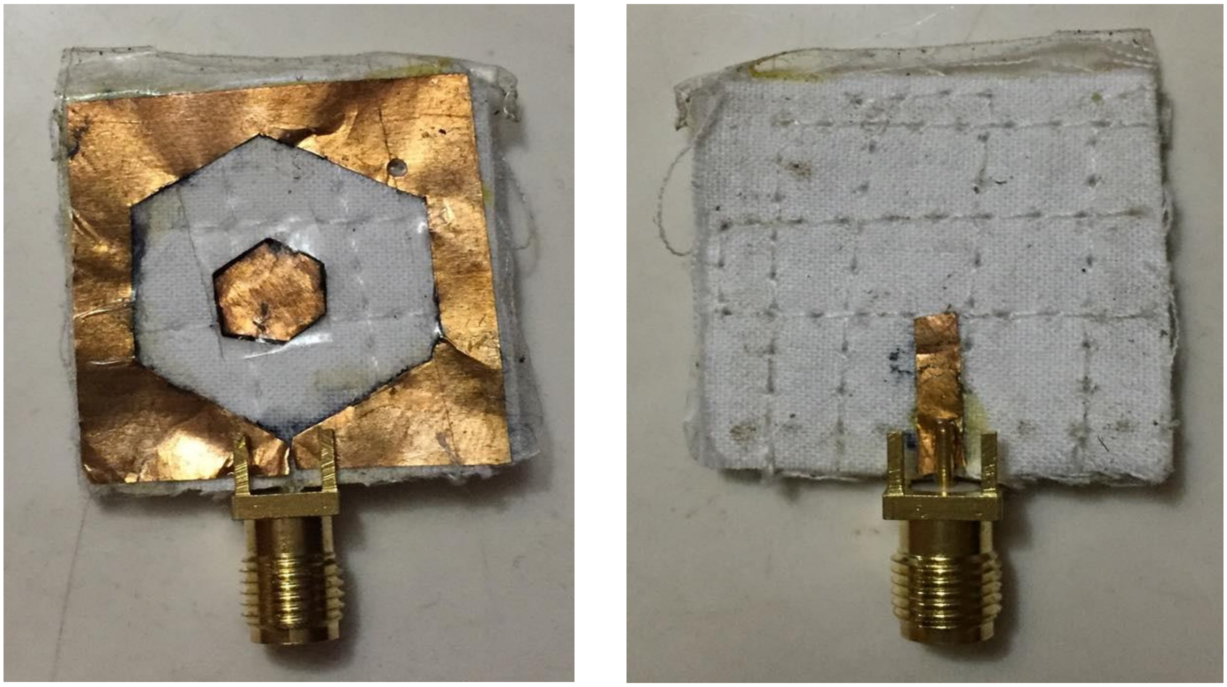


Figure 5.2: Front and back Side of Prototype Textile antenna (Cotton Substrate)

The conventional antenna having FR4 substrate covers the bandwidth of about 4GHz (3.6GHz-7.6GHz) and it provides a return loss of about -25 dB for a frequency of 5GHz and the textile antenna having cotton substrate covers the bandwidth of about 1.6GHz (4.6GHz-6.2GHz) and it provides a return loss of about -18 dB for a frequency of 5GHz. Figure 5.3 shows the experimental return loss plot of antenna with FR4 substrate. It covers the bandwidth of about 4.1GHZ (3.7GHz- 7.8GHz) and it provides a return loss of about -36 dB for a frequency of 5GHz. The experimental setup gives better output results compared to the simulated results. The impedance matching is perfect in this fabricated antenna because the return loss at 5GHz is very less when compared to the simulated results. Figure 5.4 shows the experimental return loss plot of antenna with Cotton substrate. It covers the bandwidth of about 2.6GHZ (3.9GHz- 6.5GHz) and it provides a return loss of about -32 dB at a frequency of 5GHz. Cotton Substrate also provides good impedance matching.

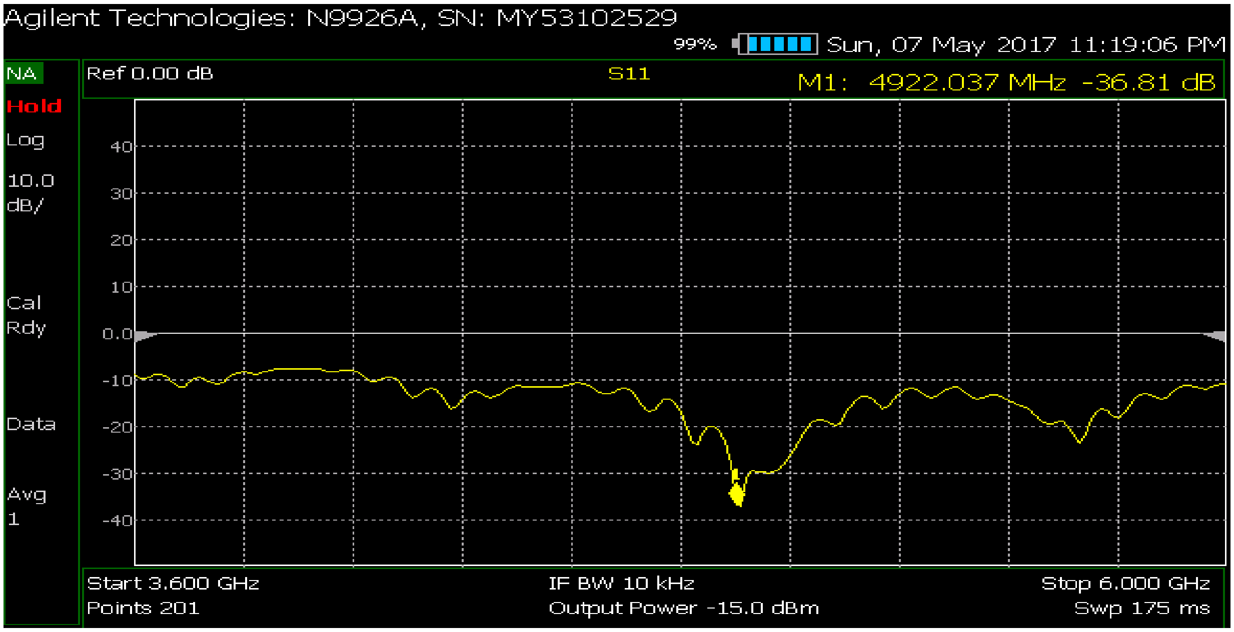


Figure 5.3: Reflection Coefficient of the Fabricated Antenna with FR4 Substrate

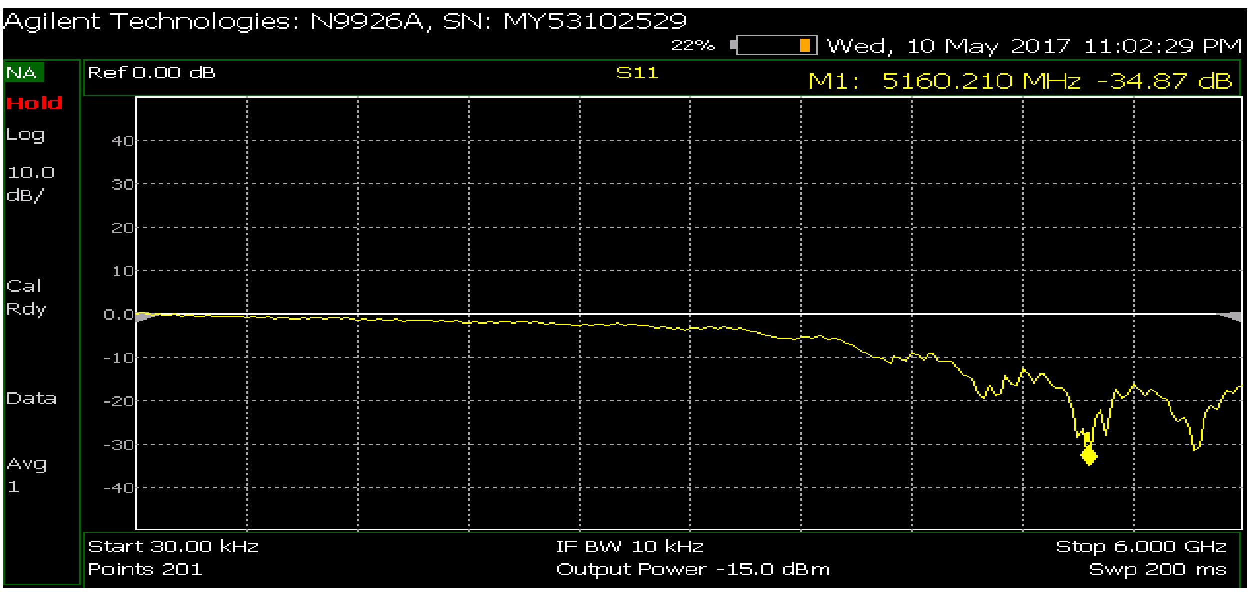
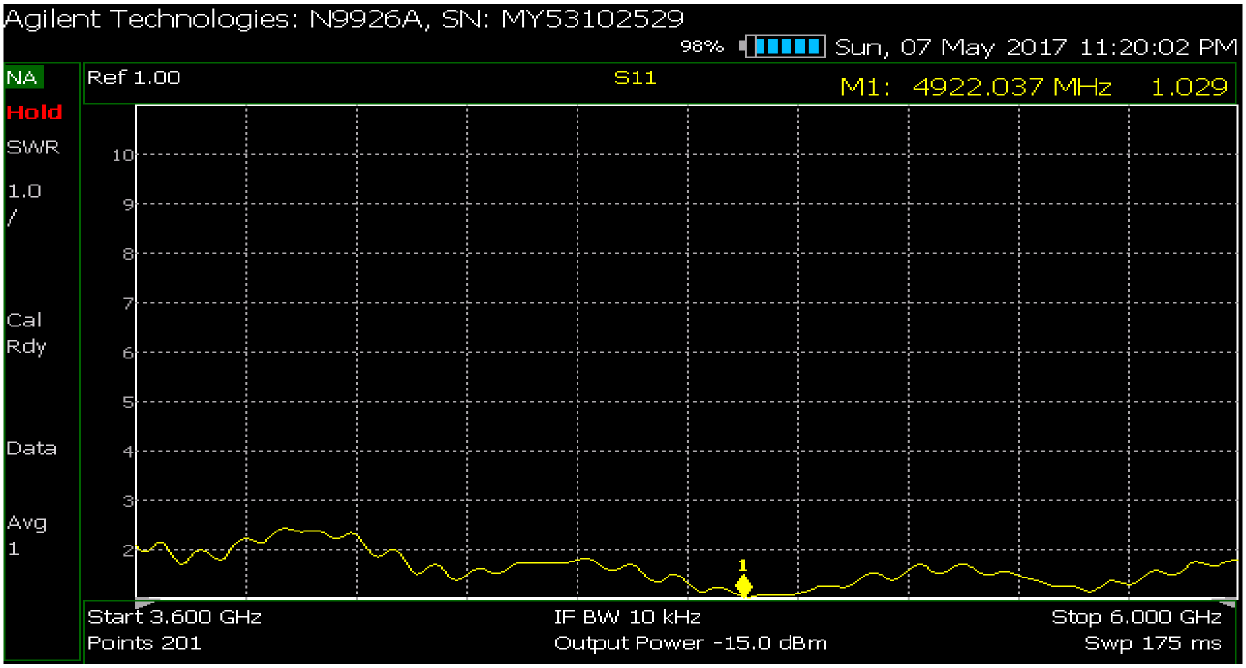
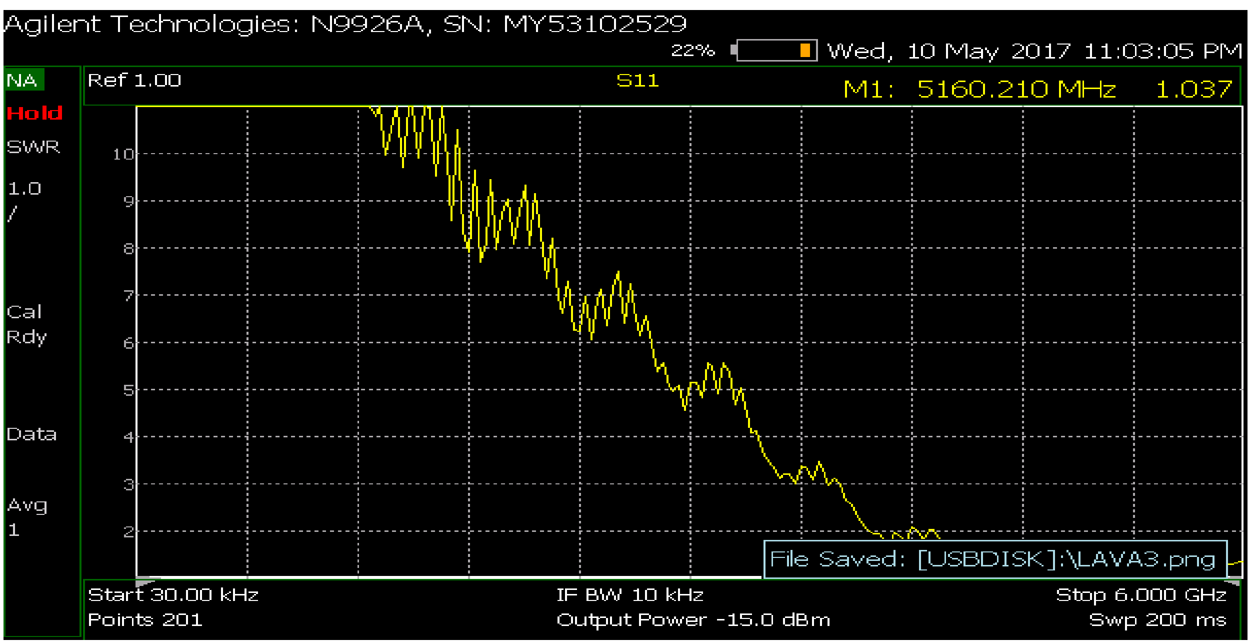


Figure 5.4: Reflection Coefficient of the Fabricated Antenna with Cotton Substrate

Figure 5.5 shows the experimental VSWR plot of both FR4 and Cotton substrate. At 5GHz the VSWR values for FR4 and Cotton substrates are 1.029 and 1.037 respectively.



(a)



(b)

Figure 5.5: VSWR of the Fabricated Antenna with (a) FR4 Substrate (b) Cotton Substrate

CHAPTER 6
CONCLUSION

6.1 CONCLUSION

This proposed work presents a compact hexagonal slot antenna for WiFi and wearable applications. This slot antenna is designed by using conventional substrates like FR4, RT/Duroid-5880 and textile substrates like Polyester, Jean and Cotton. The dimension of the proposed antenna is 25×25 mm^2 and is powered by micro strip line feed structure. The proposed antenna with conventional and textile substrates structure resonates at 5GHz. Over the resonating frequency the maximum antenna gain is 3dBi and the radiation efficiency of about 87%. Hence it is concluded that the proposed antenna is suitable for wireless device applications. The proposed slot antenna is validated using both simulated and experimental results, the experimental results are better compared to the simulation results. This proposed work also analyzed the effects of EM radiation on the human head and hand. The specific absorption rate (SAR) was measured at different distances from the antenna to the human head and hand. The average SAR values of FR4 and RT/D (RT/Duroid) are 1.737 W/kg and 1.945 W/kg respectively and for Polyester, Jeans and Cotton the SAR values are 0.02036 W/kg, 0.04839 W/kg and 0.01035 W/kg. Because of the low SAR values the proposed antenna can be used for communications and biomedical applications.

REFERENCES

[1] Pratap N. Shinde., Jayashree P. Shinde ., "Design of compact pentagonal slot antenna with bandwidth enhancement for multiband wireless applications," Int. J. Electron. Commun. (AEÜ) 2015 : 69-1489–1494

[2] Sze Jia-Yi, Wong Kin-Lu. "Bandwidth enhancement of a microstrip-line-fed printed wide-slot antenna," IEEE Trans Antennas Propag 2001; 49(7):1020–4.

[3] Horng-Dean Chen. "Broadband CPW-fed square slot antennas with a widened tuning stub," IEEE Trans Antennas Propag 2003; 51(8):1982–6.

[4] A.Dastranj , Imani Ali, Mohammad. "Printed wide-slot antenna for wideband applications," IEEE Trans Antennas Propag 2008; 56(10):3097–102.

[5] Dastranj A, Abiri Habibollah. "Bandwidth enhancement of printed E-shaped slot antennas fed by CPW and microstrip line," IEEE Trans Antennas Propag 2010; 58(4):1402–7.

[6] Chiou Jyh-Ying, Sze Jia-Yi, Kin-Lu Wong. "A broad-band CPW-fed strip-loaded square slot antenna," IEEE Trans Antennas Propag 2003; 51(4):719–21.

[7] Jan Jen-Yea, Jia-Wei Su. "Bandwidth enhancement of a printed wide-slot antenna with a rotated slot," IEEE Trans Antennas Propag 2005; 53(6):2111–4.

[8] Sung Y. "Bandwidth enhancement of a microstrip line-fed printed wide-slot antenna with a parasitic centre patch," IEEE Trans Antennas Propag 2012; 60(4):1712–6.

[9] Cheng S, Hallbjörner P, Rydberg "A. Printed slot planar inverted cone antenna for ultra wideband applications," IEEE Antennas Wirel Propag Lett 2008; 7:18–21.

[10] Li P, Liang J, Chen X."Study of printed elliptical/circular slot antenna for ultra wideband applications," IEEE Trans Antennas Propag 2006; 54(6): 1670–2.

[11] A Amsaveni, Ántennas and Wave Propagation. Anuradha Publications, Chennai,2015

[12] Sze J-Y, Hsu C-IG, Chen Z-W, Chang C-C. "Broadband CPW-fed circularly polarized square slot antenna with lightening-shaped feedline and inverted-L grounded strips", IEEE Trans Antennas Propag 2010; 58(3):973–7.

[13] Chen Q, Zheng H-L, Quan T, Li X. "Broadband CPW-fed circularly polarizedantenna with equiangular tapered-shaped feedline for ultra-wideband applications", Prog Electromagn Res C 2012; 26:83–95.

[14] Yahya R, Denidni TA. "Design of a new dual-polarized ultra-wideband planar CPW fed antenna", IEEE Int. Symposium on Antennas and Propag 2011; p. 1770–2.

[15] Lee KF, Luk KM."Microstrip patch antennas", London: Imperial College Press; 2011.

[16] Sze J-Y, Pan S-P. "Design of CPW-fed circularly polarized slot antenna with a miniature configuration", IEEE Antennas Wireless Propag Lett 2011; 10:1465–8.

[17] Jeevanandham N, Nasimuddin, Agarwal K, Alphones A. "Dual-band circularly polarized hexagonal-slot antenna", Int. 42nd European microwave conference (EuMC) 2012; p. 834–7.

[18] Joseph S. Paul B. Mridula S. Mohanan P. "CPW-fed UWB compact antenna for multiband application", Prog Electromagn Res C 2015; 56:29-38

[19] Kawshik Shikder, Farhadur Arifin. "Extended UWB wearable logo textile antenna for body area network applications," IEEE 5th Int. Conference on Informatics, Electronics and Vision (ICIEV) 2016; 978-1-5090-1269-5/16

[20] Alaa A. Yassin, Rashid A. Saeed, Rania A. Mokhtar, "Dual-Band microstrip patch antenna design using C-slot for Wifi and Wimax applications," IEEE 5th Int. Conference on Computer & Commun Engg 2014; 978-1-4799-7635-5/14

[21] Imran A, Islam M.R, Hassan M.N, Shiblu N.H, Ahmad S, Ali M.T, "Absorption rate analysis of cellular phone radiation on the human head," IEEE 5th Int. Conference on Informatics, Electronics and Vision 2016; 978-1-5090-1269-5/16.

[22] Mohammad Rashed Iqbal Faruque, Md Ikbal Hossain, Mohammad Tariqul, "Low specific absorption rate microstrip patch antenna for cellular phone applications," IET Microw. Antennas Propag 2015, vol. 9, Iss, 14, pp. 1540-1