Multi Band Antenna for Implantable Applications

BY

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RAWALPINDI, PAKISTAN

JUL 2019

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In The name of Allah the most Beneficent and the most Merciful

DEDICATION

Dedicated to my Parents and Soban who motivated me when I needed it the most and also to my Supervisor Dr Farooq Ahmed Bhatti for being forthcoming and helping in fulfillment of this research work.

ABSTRACT

Implantable antennas are topic of interest of researchers from last few decades. After the installment of first pacemaker in human body in late 1950’s a new era started for implantable devices and since then many advanced researches have been carried out. Implantable devices provide promising health care benefits. To monitor philological data like blood glucose from the inside of the human body these antennas are implanted inside the body. Concept of these is to provide maximum ease to the patient and to improve quality of life by timely determining the condition of patients. Efforts are being made to achieve high transmission data rate in these antennas.

Implantable antennas operate on following bands: medical implanted communication service band (MICS 402–405 MHz), midfield band (1.45–1.6 GHz) and ISM band (2.4–2.45 GHz). Main challenge faced by these devices is low gain and miniaturization. An improved and novel design is presented in this research which operates on three bands. Size of the antenna presented is compact and it operates on three bands. Antenna size is 9 mm ×9 mm × 0.25 mm or 20.25 mm^3. Roger RO3010 of permittivity 10.20 and loss tangent 0.0022 is chosen as a superstrate and substrate. Three bands on which antenna operate is 401 MHz, 940 MHz and 1400 MHz. To attain size reduction a shortening pin is used. HFSS 15 is used to design antenna and to calculate all the results attached in this research.

DECLERATION

No content of work presented in this thesis has been submitted in support of another award of qualification or degree either in this institution or anywhere else.

ACKNOWLEDGEMENTS

With profound humility, I pay my gratitude to Allah Almighty for blessing me with another dream achievement of mine. I would like to pay my regards to faculty and administration of Military College of Signals and NUST, for proffering a commendable research environment at the institute. This onerous work would have been impossible without the timely and proper guidance of my supervisor Dr. Farooq Ahmed Bhatti and co-supervisor Madam Marayam Rasool who not only provided me legitimate supervision, profound assistance and positive critique but also ensured that I complete the assigned tasks in given time. There affectionate and kind consideration towards my research helped me to carry on with my project in odd circumstances. I'm also very obliged to my committee members Dr Imran Rashid and Dr Zeeshan Zahid for their intimate help in fulfillment of this research work.

I am grateful of my parents and siblings who have been there when I was about to lose hope and motivation to go any further with this work. I am thankful of Aoosa and Soban who helped me with the problems I faced during this time. Without their continuous support and dialogues of encouragement this would not have been possible

List of ACRONYMS

HFSS	High-Frequency Structure Simulator
ISM	Industrial Scientific and Medical band
RF	Radio Frequency fields
AC	Alternating Current
VSWR	Voltage standing wave ratio
PIFA	Planner Inverted-F Antennas
VLP	Vertical Log Periodic
LP	Log Periodic
UHF	Ultra high frequency
NFC	Near Field Communication
COPD	Chronic Obstructive Pulmonary Disease
FCC	Federal Communications Commission
RFID	Radio Frequency Identification
IMD	Implantable Medical Devices
MHz	Mega Hertz
GHz	Giga Hertz
CP	Circularly Polarized
MICS	Medical implanted communication service band
AR	Axial Ratio
CSRR	Complementary split-ring resonator
PEC	Perfect Electric Conductor
TM	Transverse Mode

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CHAPTER 1

INTRODUCTION

1.1 Antenna

A metallic structure which converts Radio Frequency fields (RF) to Alternating currents (AC) and vice-versa is known as antenna. Antenna can be of both types: a transmitter or a receiver. If it is at transmitting end it will act as a transmitter and if it is at receiving end it will act as a receiver. Transmitter is the part which radiates power and receiver receives this power. Radiated or captured power by antenna is in the form of electromagnetic energy. Antenna is of different shapes, sizes and types. Every antenna has its own characteristics but basic parameters of all antennas are almost same.

1.2 Parameters of an Antenna

Different parameters of an antenna are defined below

1.2.1 Bandwidth and Wavelength

An important parameter of antenna is bandwidth which tells us spectrum of frequencies on which parameters such as gain, radiation pattern, beam width, side lobes and input impedance depends and shows if they are in acceptable range according to resonant or central frequency. Wavelength and frequency have an inverse relationship between them; if one increases the other one would decrease

1.2.2 Impedance Matching

When approximate values of impedances of receiver and transmitter matches, then impedance matching is achieved. In antenna designing impedance matching is important as it reduces power losses and gives maximum power transfer from one end to other. After proper matching with circuitry antennas give their maximum output. **Ohm** is the unit of impedance and its symbol is **Z.**

1.2.3 VSWR

VSWR is the abbreviation of voltage standing wave ratio. This ratio tells how much of incident wave or power is reflected back. When circuitry and antenna are not properly matched some of the power reflects back causing power loss. For maximum power radiation value of VSWR should be 1 or at least close to 1. Formula to calculate this ratio is

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

1.2.4 Return Loss

The proportion or ratio between incident power and reflected power is called return loss. Db is used to express return loss. Matching of any antenna can easily be judged from its return loss value. To calculate this parameter reflection coefficient Taw (Γ) is used as well. Formula to calculate return loss is

$$RL = -20 \log |\Gamma| (db)$$

1.2.5 Scattering Parameters

In an electrical system, relationship between input and output port is described as S-parameter. Reflected travelling waves and incident travelling waves define S-parameters. Place where input power or voltage is supplied is called port, voltage supplied here is then converted into electromagnetic energy. Vector based measurements such as magnitude, phase is used to measure S parameters but for some circuit elements Network Analyzer (software) is also used.

1.2.6 Radiation Pattern

Power emitted by antenna in open space is known as radiation, an imaginary figure drawn to show the shape and approximate distance to which emitted power reach, is called radian pattern. Radiation pattern can be of any type far field or near field. Different antennas have different radiation patterns. Radiation pattern can be omnidirectional, isotropic or can be directed in a specific direction. Radiation pattern has a major or fundamental, side lobes and small lobes at the back. Major lobe shows the area with maximum power radiation

1.2.7 Directivity and Gain

To understand the concept of directivity one should also know about isotropic antenna. An imaginary antenna which emits energy or radiation in all directions is known as isotropic antenna. Isotropic antenna has directivity equal to 1 and is of no good because it spread energy uniformly in all directions. An antenna must radiate maximum power in the desired direction. All the antennas are designed to radiate maximum energy in desired direction. Thus directivity is the numerical value which tells us in what direction an antenna radiate its maximum energy.

1.2.8 Polarization

While propagation of electrical signals the plane in which the wave vibrates. Simply the orientation of electric signal in a specific direction is known as polarization. It can be E-plane or H plane or an antenna can be in both. Polarization of an antenna can be of any type among vertical polarization, dual polarization, circular polarization, horizontal polarization and cross polarization. Left hand polarization and Right hand polarization are added types of Circular polarization.

1.3 Antennas Types

Various antennas types are there depending on their size, shape and properties. Following are the main categories antennas are divided in

i. Wire Antenna
ii. Travelling Wave Antenna
iii. Reflector Antenna
iv. Micro strip Antenna
v. Log Periodic Antenna
vi. Aperture antenna
vii. Other Antenna

1.3.1 Wire Antennas

As evident from name a wire act as antenna, it can be of multiple shapes. Properties of all the antennas very from each other due to the shape, thickness and length of wire used to make the antenna. These antennas have high performance. Various wire antennas are there some are listed below

i. Short dipole
ii. Dipole
iii. Broad band Dipoles
iv. Half wave Dipole
v. Monopole
vi. Folded Dipole
vii. Loop Antennas
viii. Clover Leaf Antennas

1.3.2 Travelling Wave Antennas

Antennas which have almost no standing wave in them while transmission of signal are known as travelling wave Antennas. Commonly antennas with traveling wave are of two types: fast wave and slow wave. Antennas which propagate a wave in free space with phase velocity less than light speed are slow wave and the ones which propagate wave with phase velocity more than light speed is fast wave. Following are the examples antenna with traveling wave

i. Spiral Antenna
ii. Yagi-Uda Antenna
iii. Helical Antenna

1.3.3 Reflector Antennas

For distance radio communication reflector antennas are used due to their high gain and better efficiency. Reflector antennas can gain more than 30 dB at higher frequencies easily. Due to this property reflector systems are widely used systems for long distances. A reflector system consists of a small feed antenna and a reflecting surface. Feed antenna is the point where signal leaves the system and reflecting surface then reflect the signal to long distances without much loss in the signal power. Area of reflecting surface is calculated for every frequency. Shape of reflecting surface can be varied according to the requirement. Following antennas fall under reflector antenna category

i. Corner Reflectors
ii. Parabolic Reflectors or dish antennas

1.3.4 Microstrip Antennas

A simple microstrip antenna comprises of dielectric material with thin layer of conductors on its both sides. A radiating patch of required shape is etched on the radiating side while ground can be plane or can have slots or any shape etched on it as per the requirement. Height of dielectric material can also be varied according to requirement. These antennas are popular due their compact size, easy installation and low cost. These are the topic of interest of many antenna researchers now a day. Following are the main types which belong to this category

i. Regular Microstrip Patch Antenna
ii. Planner Inverted-F Antenna (PIFA)

1.3.5 Log Periodic Antennas

An array of dipole antennas of periodically varying sizes attached and fed through a common transmission line. Due to the presence of different sizes of dipoles it operates on wide range of frequencies with high gain and directivity. Longest element gives the lowest usable frequency while shortest works for highest frequency present in the range the antenna operates on. Log periodic antennas are similar to Yagi-Uda antennas. Different periodic antennas are listed below

i. Bow Tie
ii. Log Periodic Antenna
iii. Zig-zag Periodic Antenna
iv. Slot Periodic
v. VLP
vi. dipole LP and trapezoidal Antennas

1.3.6 Aperture Antennas

Antennas in which electromagnetic waves are emitted through an aperture are aperture antennas. At UHF aperture antennas are commonly used and above where their size is reasonable. Their gain increases as f^2. To make aperture antennas more efficient and highly directive, its area should be less than λ^2. These antennas are impractical at low frequencies. Different aperture antennas are listed below

i. Slotted Antenna
ii. Cavity Backed Slotted Antennas
iii. Slotted Waveguide Antennas
iv. Vivaldi Antennas
v. Telescopes
vi. Horn Antennas
vii. Inverted-F Antennas

1.3.7 Other Antennas

Modern day antennas which are the topic of interest of researchers mainly fall in this category are

i. NFC Antenna
ii. Fractal Antenna
iii. Wearable Antenna
iv. Implantable antenna

1.4 Implantable antennas

1.4.1 Research Motivation

In last few years, with the advancement in technology for every application we prefer wireless systems to avoid complexity caused by wires. Implantable antennas are implanted in the body to observe necessary information about the patient like glucose, blood pressure etc. these antennas can enhance healthcare quality. Implantable devices are commonly used for therapeutic purposes such as pacemakers and for treatment of hyperthermia. Other purpose of these devices is to diagnose, detect and transmission of data. Importance of regular and repeated observation for many diseases such as blood pressure ,pulse, level of oxygenated blood in COPD, sugar levels in diabetic patients, and to note patient's condition after regular intervals of time is elaborated by medical researchers.

Mostly implantable antennas are operated on unlicensed FCC standardized industrial and medical band ISM (432–435 MHz) and Med Radio frequencies (400–405 MHz). In communication systems antenna design is properly understood, still for in-body communication implanted antennas face more challenges because of complicated in-body working surroundings, it’s utilization in medical systems comes with particular challenges like miniaturization of antenna, impedance matching due to very small size, limited bandwidth, requirement of multi-band operation, immense loses in body tissues, lesser power demands and safety when designing such an antenna..

1.4.2 Problem Statement

Implantable antenna is to be planted in tissues of host body; main challenge is to attain its miniaturization. For a length of 6 to 35.5 mm, implants should be in range 1 to 10mm in diameter, in order to facilitate the surgical [1]. Biological tissues surrounding the antenna also effect on antenna performance. Implantable antennas show good results when tested but when implanted, efficiency of these antennas decreases. Whenever the antenna is implanted in the body there is a notable decrease in the gain.

1.4.3 Objectives and Aims

Purpose of this research project is to achieve such design with following features.

i. Covers Med Radio bands.
ii. Provides Multiband antenna with Miniaturization
iii. Obtain high gain after implantation

1.4.4 Application

Wireless Medical Instruments are used to observe following

i. RFID Identification
ii. Sensing/monitoring systems.
iii. Positioning/localization systems.
iv. Bio-imaging systems.
v. With improvements it can be used to charge already implanted IMDs

CHAPTER 2

REFERECES AND PREVIOUS WORK

2.1 Background

Implantable devices are under observation since 1950's after the successful implant of first pacemaker in 1958, much advancement is attained in this field. The aspects of implantable pacemakers are to give proper power to heart, defibrillators to maintain heartbeat, glucose monitors for diabetic patients, cochlear implants to improve hearing, drug infusion pumps to control dosage of fluids to be given to body, intracranial pressure monitors to observe cerebrospinal fluids inside skull, neuro-stimulators implanted near spines are marked as appreciable examples [2]. It is admirable to acknowledge that designing of implantable antenna is one complex approach because there is risk of loss of power in body tissues. This prospect eventually diminishes the overall efficiency of antenna and the limited power deposition by RF safety regulations is also major concern. [3]-[7]. Size of the antenna is established as another major challenge concerning to the approach of implantation inside the body with consideration of battery pack [8][9]. For past few decades data transmission in the implantable devices is being tested. The broad perspective of biomedical telemetry indicates that data transmission is permitted concerning the perspective of implantable mechanisms and their receptors at a definite radius [10]. Limited bandwidth, substantial size, data rate less than required value and insufficient resoluteness of images obtained in MedRadio bands (903–929 MHz), ISM bands (2.40–2.484 GHz) are major reasons concerning to the idea of wireless medical implants [11] [12]. An implantable antenna with three bands with radiating patch of meandered shape was selected to assure better results [13]. Approach of multilayer CP helical antenna for gastro considerations was designed to ensure better application in the end [14]. It is observed that three opened-ended loops at various layers are interlinked via holes. A novel miniaturized implantable antenna encircling with the consideration of multiple communication channels [15] and the option of loaded patch antenna particularly for the sake of biomedical applications in [16] that were presented. A table from [17] with compares previous work with literature with some changes is given below, other than [18] every antenna contains a shortening pin to reduce the size. From

[19]-[26] no superstrate was used. From [27] and onwards superstrate layer was used and is preferred for every implantable antenna design.

Table 2.1 Comparison of previous work

Ref.	Frequency Bands (MHz)	Antenna to be implanted in	Permittivity of dielectric	Shape of Patch	Volume (mm^3)
18	400-406	Human skin	10.20	Coiled	10,241.2
19	400-406	2/3 muscle	2.941	Waffle	6,480.1
18	400-406	Human skin	10.20	Coiled	6,145.0
20	400-406	2/3 muscle	6.10	Coiled	3,458.3
21	400-406 2450-2850	Human skin	6.10	Coiled and coupled to SRR	1376.5
22	400–406 2450–2850	Human skin	10.20	Twisted	1264.6
23	400-406	Human skin	10.20	Coiled	1220.0
24	400-406	Human skin	10.20	Twisted	1220.0
25	400–406	2/3 muscle	9.40	Coiled	825.1
26	400–406	Deep in muscle	10.20	π Shaped	792.8
27	400–406	Inside body	6.70	Folded Square	449.1
28	400–406	Human skin	10.20	Curved slots	337.6
29	400–406	Gelatinous material in eye	10.20	Coiled	274.3
30	400–406 432–436 2450–2490	Human skin	10.20	Slotted and π shaped	255.4
31	400–406	Gelatinous material in eye	10.20	Coiled	253.9
32	400–406	Human skin	10.20	Twisted	204.1
33	400–406	Human skin	10.20	Coiled	192.3
34	400–406	Human skin	10.20	Curved Slots	150.1
35	400-406	Human skin	10.20	Curve Slots	122.0

2.2 SOME IMPLANTABLE ANTENNAS FROM LITTERATURE

Following are the papers which were used as reference work for this thesis

2.2.1 Dual Band Antenna for Implantable Wireless Communication with Miniaturization Achieved

An implantable antenna with dual-band and diminished size is discussed in [36]. A dipole operating on two bands i.e. Medical bands 400–406 MHz and ISM band (2.45–2.49 GHz) has been noticed. Substrate of loss tangent of 0.002, permittivity 10.20 and of thickness 20 µm was used. Rogers 3010 act as a biocompatible layer which isolates antenna from body environment. Antenna size achieved is 70.23 mm^3. At one dipole arm an inductive loop was added to achieve improved impedance matching with feed point.

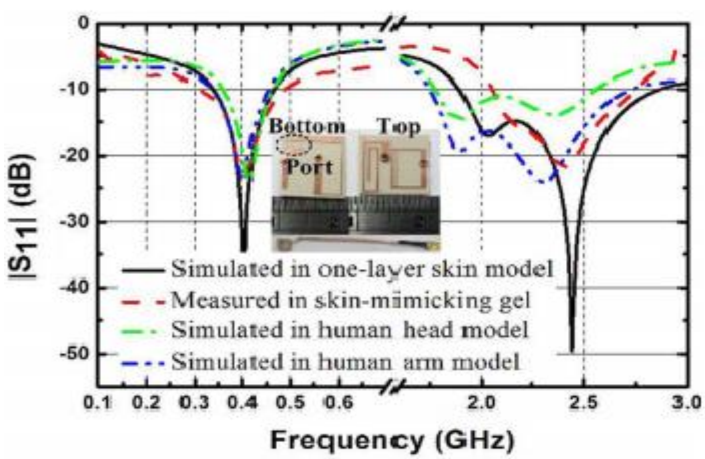
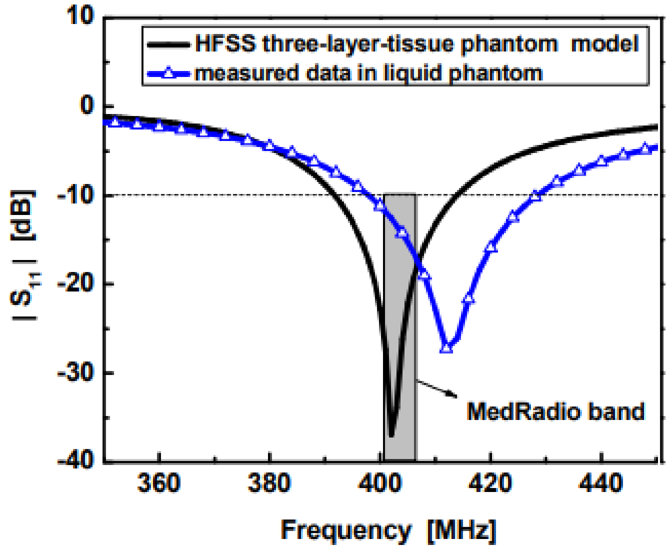


Fig 2.1 Compared measured and simulated S_{11} results of 2.2.1

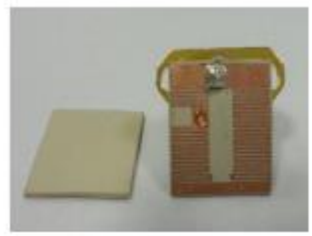
2.2.2 A Miniature Implantable Antenna operating on Med Radio Band for Biomedical Telemetry

For communication services and telemetry in med radio devices a compact antenna operating on Med Radio band of 400-406 MHz is presented in [37]. Size of the designed antenna is 12.5×12.5×1.27 mm^3 and this compact size is achieved by serpentine shaped patch and using shortening pin strategy. Proposed design is fabricated on substrate with a full ground plane and is single layered. Main features of the designed antenna are easy fabrication, small size, less weight and high compatibility with the environment.

Simulated bandwidth is 6.15% while measured bandwidth is 7.26%. Gain achieved at 402 MHz is -32.5 dBi.



(a)

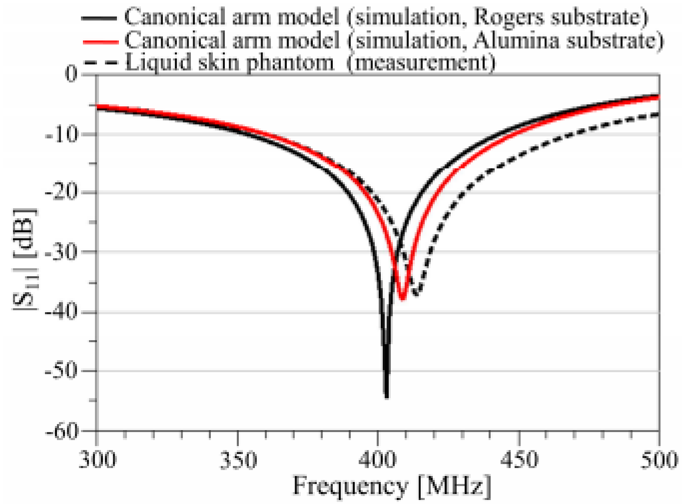


(b)

Fig 2.2 (a) Compared measured and simulated S_{11} results of 2.2.2 (b) photograph of fabricated antenna

2.2.3 A Dipole Implantable Planar Antenna for Wireless Biotelemetry Devices operating on Med Radio Band

In [38] a dipole implantable planar antenna operating on Med Devices and Radio communications Services band (400-406 MHz) is designed. Volume of antenna is approximately 18.1 mm^3 with dimensions $21 \times 2.5 \times 0.344$ mm^3. The objective of desired level of reduced size is established by eliminating intrinsic high capacitance and by introducing an L shaped reactive load on radiating patch.



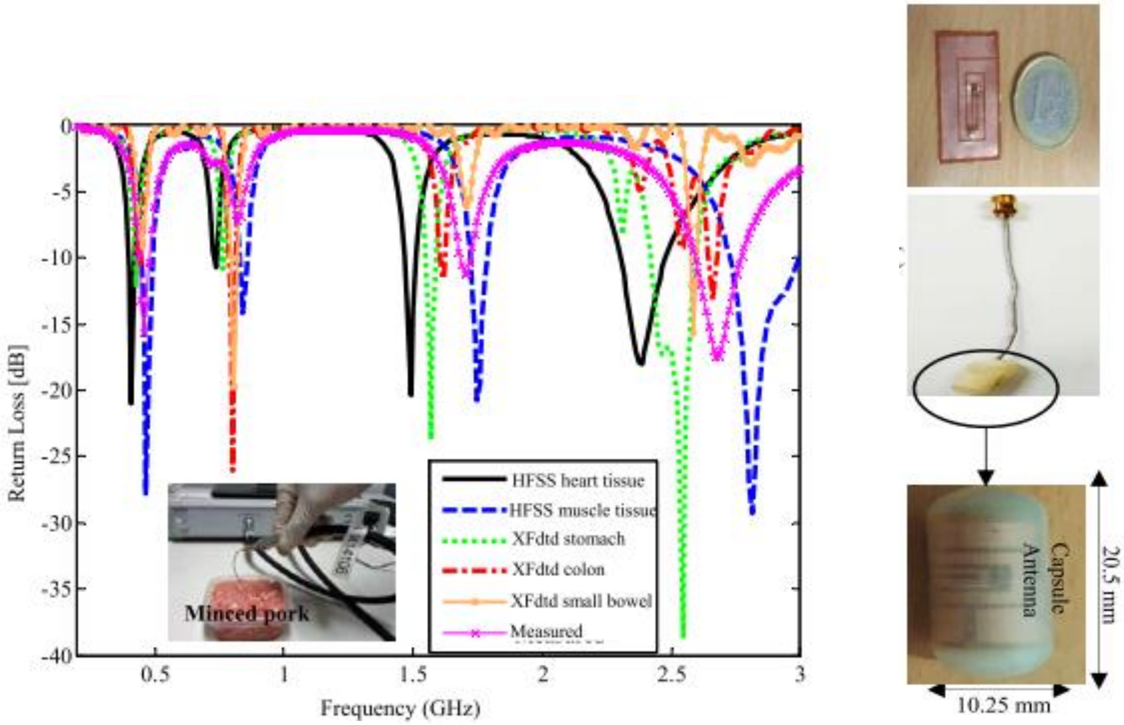
(a)

(b)

Fig 2.3 (a) Compared measured and simulated S_{11} of 2.2.3 (b) Picture of fabricated antenna

2.2.4 Multiband Antenna for Biomedical Implants Associating Non leaky Wireless Power Transfer System and Wireless Monitoring

An antenna wrapped in 3-D capsule model containing a slot of T shaped slot on ground plan is presented for different biotelemetry applications in [39]. A tri band antenna is designed in the research work. Antenna was placed in minced pork to acquire results.to attain the docility and biocompatibility polyamide was used as both superstrate and substrate. Volume of antenna is 31.78 mm^3. When flaccid, bands on which antenna operates is Med Radio devices communication service band (MICS 400–406 MHz), midfield band of frequency (1.46–1.61 GHz) and ISM band.

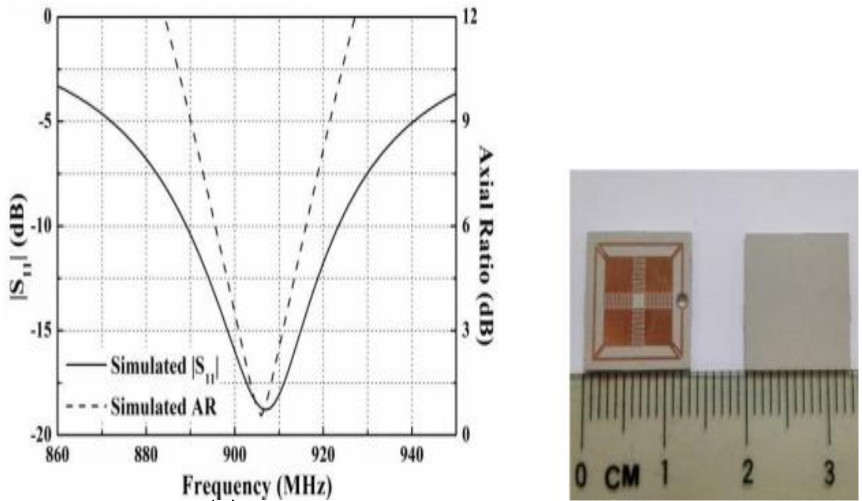


(a) **(b)**

Fig 2.4 (a) Compared measured and simulated S_{11} of 2.2.4 (b) Photograph of fabricated antenna

2.2.5 A CP Implantable Antenna for Far field Wireless Power Transmission operating at 916 MHz

A miniaturized CP implantable antenna is designed which operates on ISM band of 916 MHz in [40]. Miniaturization is obtained by capacitive coupling and stub loading between the stubs. Dimensions of design are 11×11×1.27 mm^3. A two layered Rogers 3010 of thickness 25 mm is used as superstrate and substrate. As compared to previous CP implants this antenna is small and has better radiation performance. Simulated S_{11} is less than -10.5 dBi for band width of 890 to 925 MHz. From 901 to 912 MHz is AR bandwidth. This design gives satisfactory results for far field wireless power transmission.

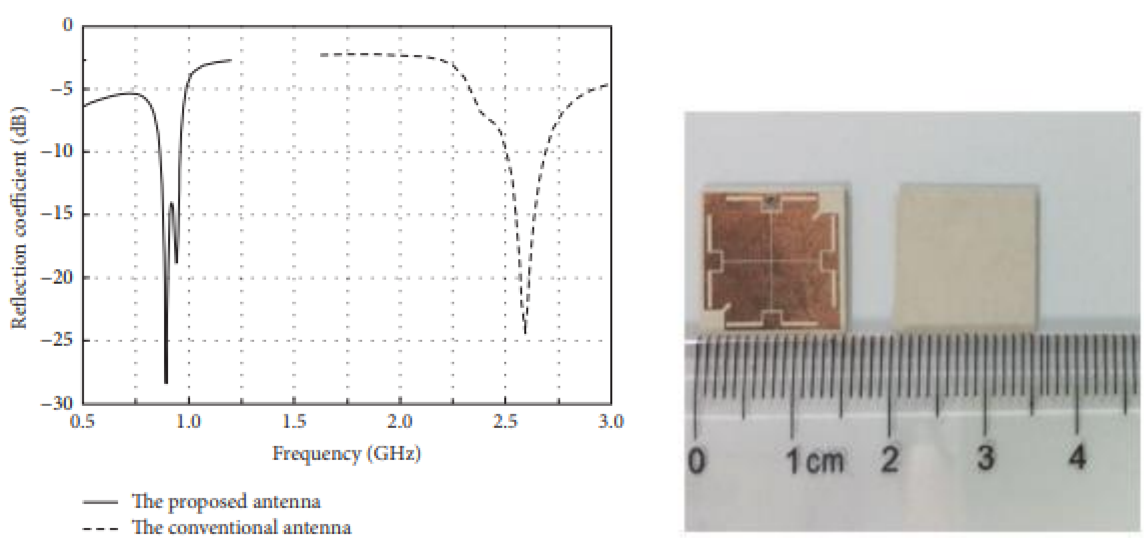


(a) **(b)**

Fig 2.5 (a) Compared measured and simulated results of 2.2.5 (b) Picture of fabricated antenna

2.2.6 Miniaturized CP Implantable Antenna Biomedical Devices operating on ISM band

A CP patch antenna operating at 915 MHz is proposed in [41]. To provide human subcutaneous surrounding a cube with similar properties as human skin and similar dielectric properties is used. Loop structured antenna is designed, which is a square radiating patch with two truncated corners in square shape with extra diagonal perturbed elements, a cross slot in center of radiating patch and a ground plane. Material used as superstrate and substrate is Rogers RO 3010.Size of proposed design is 15×15×1.27 mm^3.

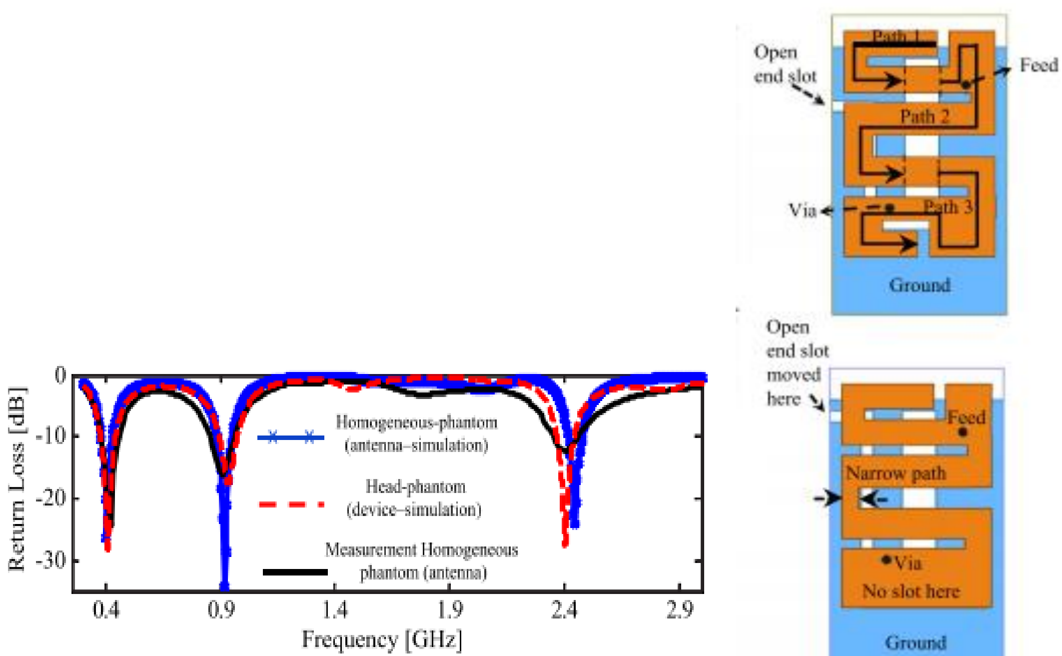


(a) **(b)**

Fig 2.6 (a) Compared measured and simulated S_{11} of 2.2.6 (b) Picture of fabricated antenna

2.2.7 Antenna System operating on Multi band for Skin Implant

In [42] an antenna system operating on five bands with two biotelemetry devices for skin implants is presented. Band on which antenna operates includes MICS Band (400–406 MHz) and ISM band of 434–439 MHz, 868.1–868.76 MHz, 902.5–929 MHz, 2450.0–2484.5 MHz. Total volume of system is 617mm^3 and 510 mm^3 respectively. Size of device 1 is 20 mm × 8.5 mm × 3.75 mm and device 2 is 20 mm × 8.5 mm × 3 mm. Rogers 6010 is used as both superstrate and substrate. For the 405 MHz operating frequency, data transmission occurs up to 5m away with a -30 dBi system limit for low gain value.



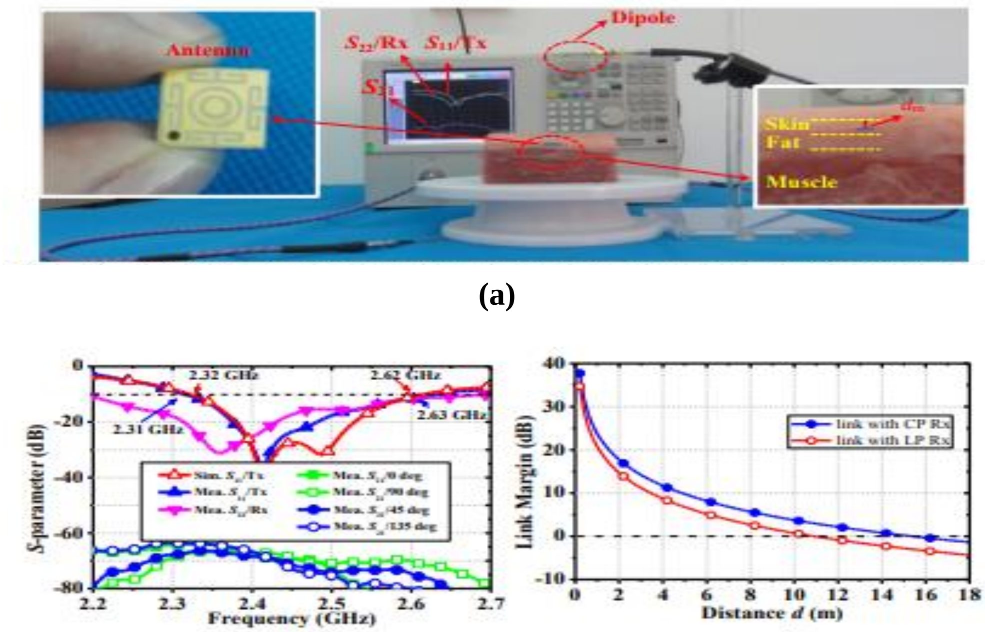
(a) (b)

Fig 2.7 (a) Compared measured and simulated results of 2.2.7 (b) Picture of fabricated antenna

2.2.8 A CSRR Loaded Wide Beam width CP Implantable Antenna for Continuous Subcutaneous Monitoring of Glucose

For subcutaneous glucose monitoring, a wide-beam width single fed CP implantable antenna operating on ISM band (2.45–2.49 GHz) is designed in [43]. Size achieved is

91.75 mm^3. Four slots of C shape and one CSRR is introduced to attain this compact size. By adjusting CSRR circular polarization (CP) is attained. Substrate used in this design is Rogers 3210 (ε_r = 10.20, tan δ = 0.0031). -17 dBi is the gain value and axial ratio (AR) of 3 dB is achieved in this design.



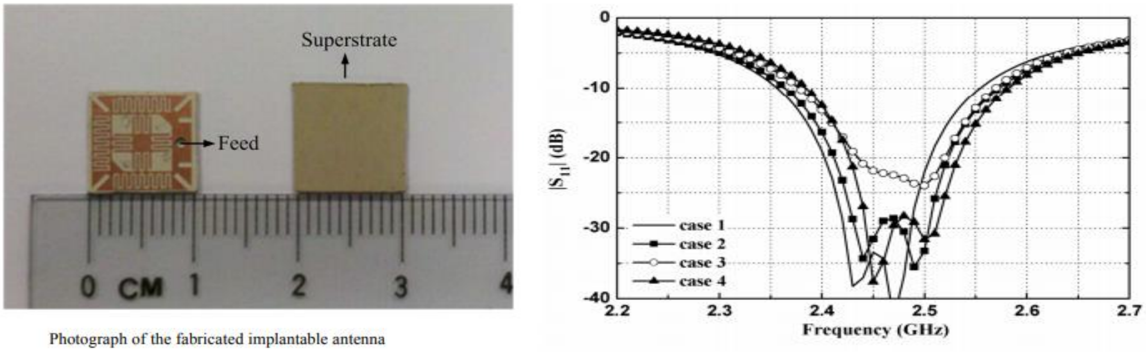
(a)

(b) (c)

Fig 2.8 (a) Photograph of fabricated antenna and measurement set up (b) measured S- parameters (c) Calculated link margin of the proposed

2.2.9 CP Implantable Patch Antenna with capacitive loading operating on ISM Band for Biomedical Applications

A CP patch antenna which operates on ISM band which is 2.45-2.49 GHz was designed for biomedical applications in [44]. On the radiator, capacitive loading is used. Size of the antenna is 10 × 10 ×1.27 mm^3. A two-layer Rogers 3010 is used as a superstrate and substrate. Thickness of each layer is 25 mm. Antenna was put in different cases of different materials to check its performance.

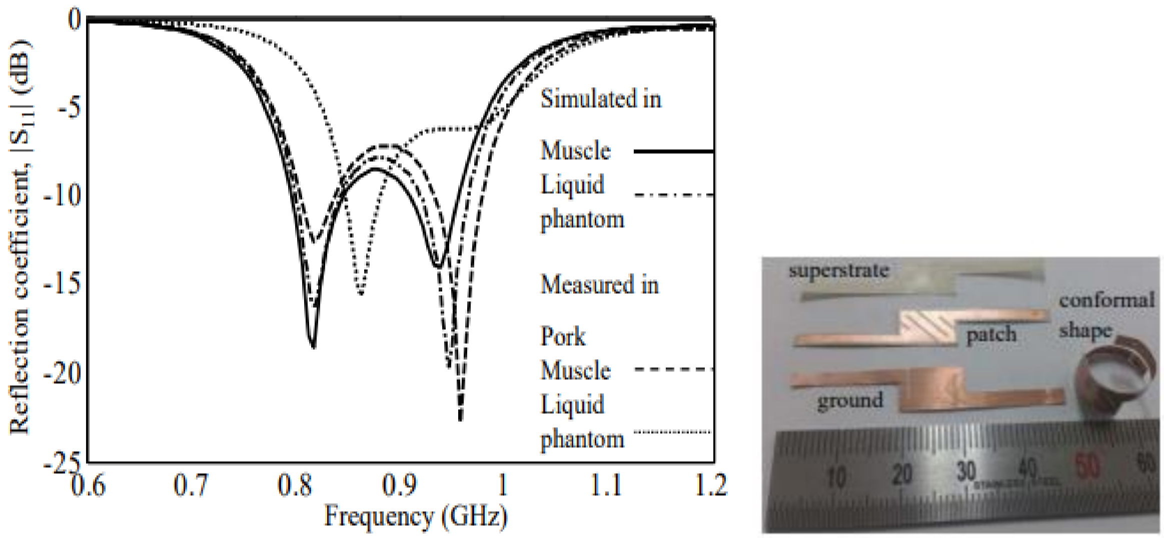


(a) (b)

Fig 2.9 (a) Picture of designed antenna (b) Compared measured and simulated S_{11} results of 2.2.9

2.2.10 Wideband CP Antenna for High-Speed Data Transfer in Conformal Endoscopic System

In [45] for endoscopic capsule application a CP antenna is designed for ISM band which is 903–929 MHz, Thickness of antenna is 0.2 mm. Compact size was achieved by etching open ended slots on ground plane and serpentine slots on radiating patch along two long arms. Volume of system is 66.7 mm^3 only. Rogers ULTRALAM 3850HT with permittivity of 3.14 is material used as superstrate and substrate and it is a liquid crystalline polymer. Antenna can transfer data up to 78 Mbps.



(a) (b)

Fig 2.10 (a) Compared measured and simulated S_{11} of 2.2.10 (b) Photograph of fabricated antenna

Chapter 3

Antenna Design discussion

3.1 Design of antenna

Presented antenna comprises of a substrate, a superstrate, microstrip radiating patch, ground plane and is fed by co-axial feed. To attain miniaturization shortening pin is used. This antenna is designed using HFSS15.

3.1.1 Substrate

Substrate is a dielectric material which provides mechanical support to antenna. Dispersion caused due to dielectric constant, Surface wave excitation, temperature effects, loss tangent, humidity, aging, conformability of availability, weight, solder ability, elasticity, machinability and expenditure are main criteria which are kept under observation during selection of a substrate. Substrate used in this design is RO 3010 having loss factor equal to 0.0023 and permittivity 10.20. Size of substrate is 9 mm ×9 mm and height used in this design is 0.25 mm.

3.1.2 Superstrate

The option of superstrate is generally considered to increase the overall efficiency level of antenna. Depending on the width of substrate and permittivity constant it plays its positive role in terms of antenna [46]. In this design however superstrate is used to cover radiating patch to avoid reaction of copper with skin tissues. RO 3010 of thickness 0.25 mm and of size 9 mm ×9 mm is used.

3.1.3 Coaxial feed

In Coaxial feeding method, radiating patch is soldered to inner conductor of coaxial cable while ground is attached to the outer conductor. Matching of such feed type is easy to fabricate and has less counterfeit radiations. To attain proper matching of 50 ohms the character impedance was calculated by the using the formula given below

$$Z_{O\infty} = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{D_e}{d_e} = \frac{138}{\sqrt{\varepsilon_r}} \, log_{10} \frac{D_e}{d_e} \; [\Omega]$$

d_e = inner diameter of coaxial cable

D_e =outer diameter of coaxial probe

ε_r= dielectric constant

$Z_{o\infty}$= characteristic impedance

3.1.4 Microstrip patch Antenna

A perfect electric conductor (PEC) which is mostly copper act as ground and radiating patch in a microstrip antenna, these two are separated by a dielectric of required permittivity and loss factor. They have a great characteristics of applications as they are low profile, has small weight, easily conformable with non-planar staging, simple and inexpensive to manufacture. Antenna's characteristics are dependent on ground plane as it plays important role in its functionality [47].

3.1.5 Shortening pin

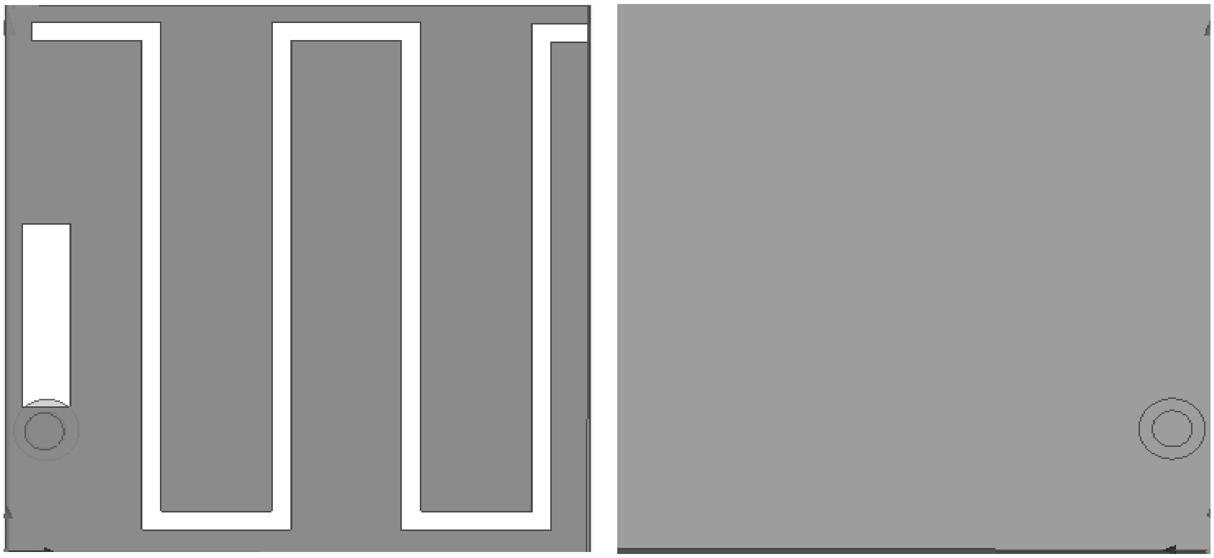
Resonant length of patch is related to ½ of its resonant frequency. This length is too large to be used in applications of which prefer patch antennas over other antennas due to is small size. It is critical to consider that resonant length can be decreased to half by considering the element of a shortening pin at the center of the TM01 where the electric field is identified as zero. Size achieved by this technique is one fourth of the regular patch. Shortening pins can sometimes decrease the size of patch up to one ninth of the original patch area [48]. This design also has a shortening pin for size reduction of antenna.

3.2 Evolution in design

Final design proposed in this thesis has undergone through many changes to get required shape and results.

A plane ground of 9 mm ×9 mm with no slots was initially selected. Rectangular patch of 9 mm × 9 mm with some slots was selected to be worked on. Formulas were used to calculate dimensions of radiating patch.

Following was the initial design



(a) **(b)**

Fig 3.1 (a) Radiating Patch (b) Ground Plane

Following was the S_{11} graph achieved

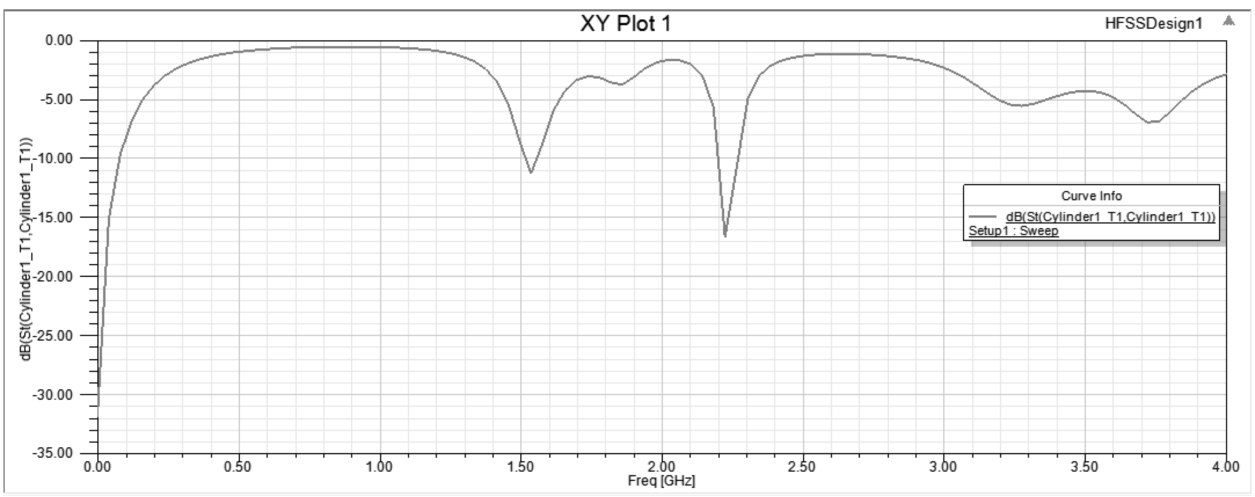


Fig 3.2 S-parameters of radiating Patch without slots

A shortening pin and slots in the radiation patch were added to get desired results. No changes in the ground plane were made.

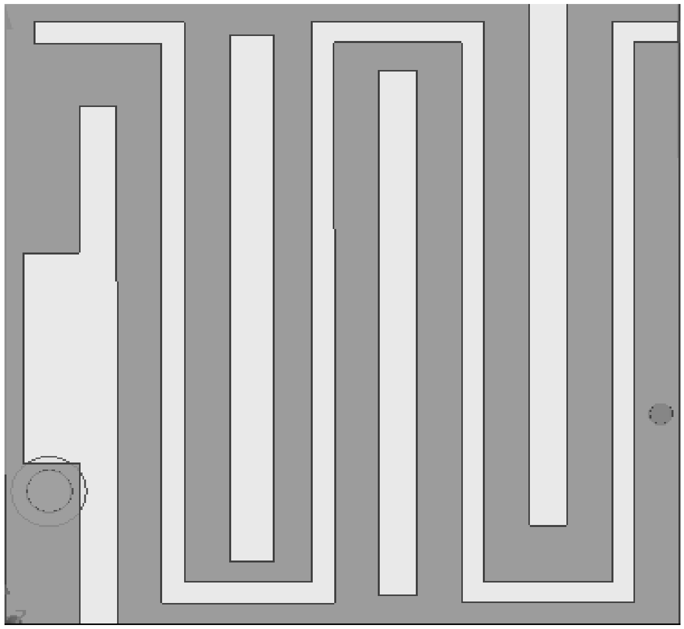


Fig 3.3 Radiating Patch with slots

Following was the S_{11} graph achieved after making changes

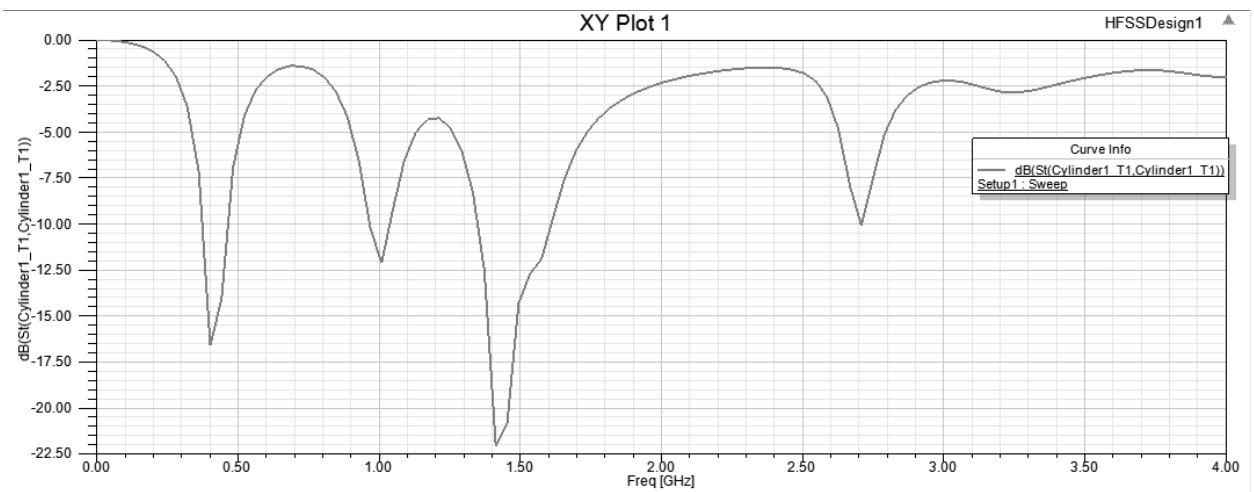


Fig 3.4 S-parameters with slots in patch

Slots in the ground plane were added to gain better values of S_{11}. Final design with measurements of radiating patch and ground plane is as followed

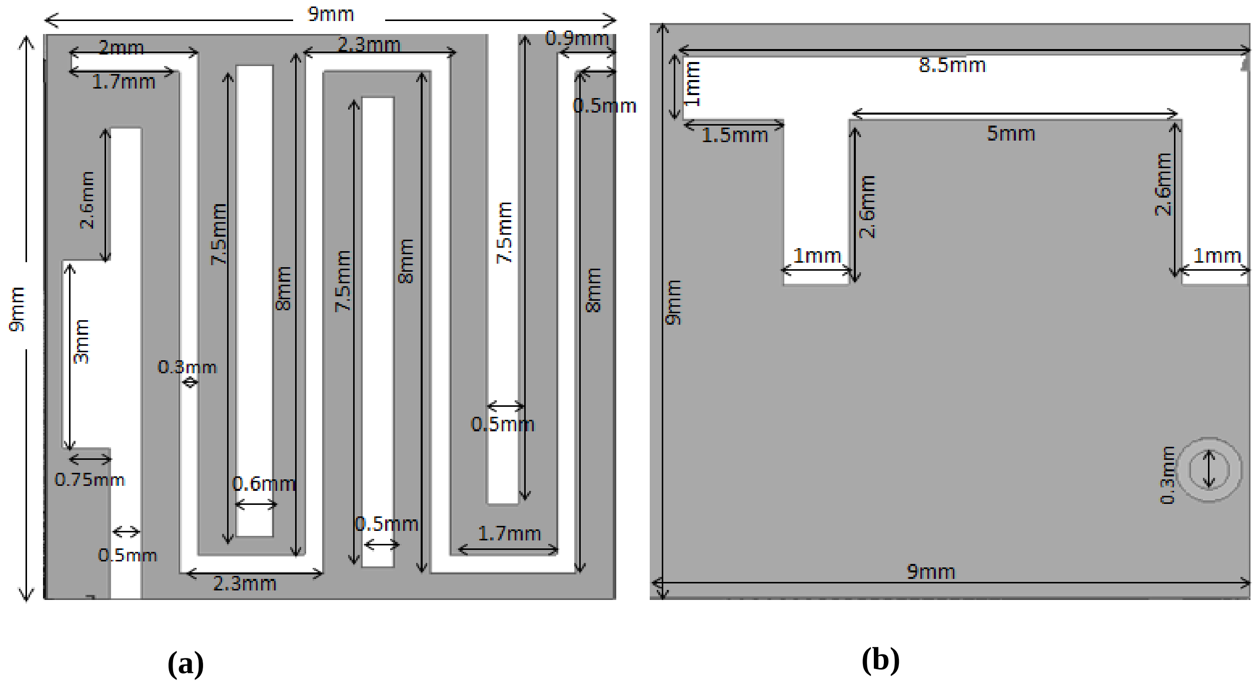


Fig 3.5 (a) Final Radiating Patch (b) Ground plane with slots

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Simulated Results

Simulated results and measured results of the design are compared in this chapter. S-Parameter graph at 0.4 GHz is given below shows that by adding slots in the ground plane the results were improved.

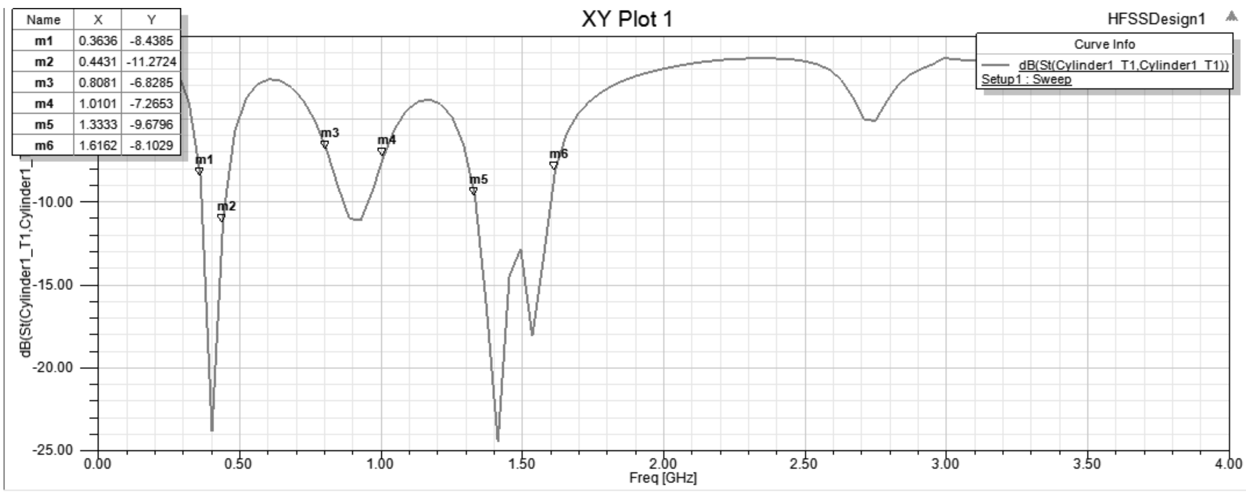


Fig 4.1 S_{11} at 0.4 GHz

The fig above shows that S_{11} for all three bands i-e 0.45 GHz, 0.94 GHz and 1.45 GHz is less than -10 dBi. Gain plot on 0.4 GHz calculated is

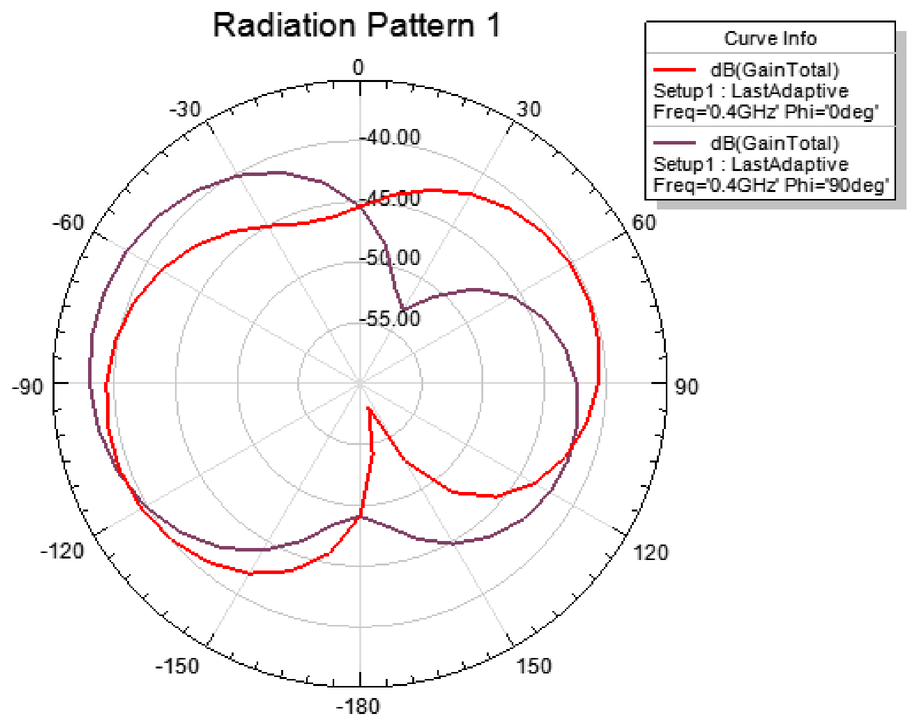


Fig 4.2 2D Radiation Pattern for E-Plane and H-Plane at 0.403 GHz

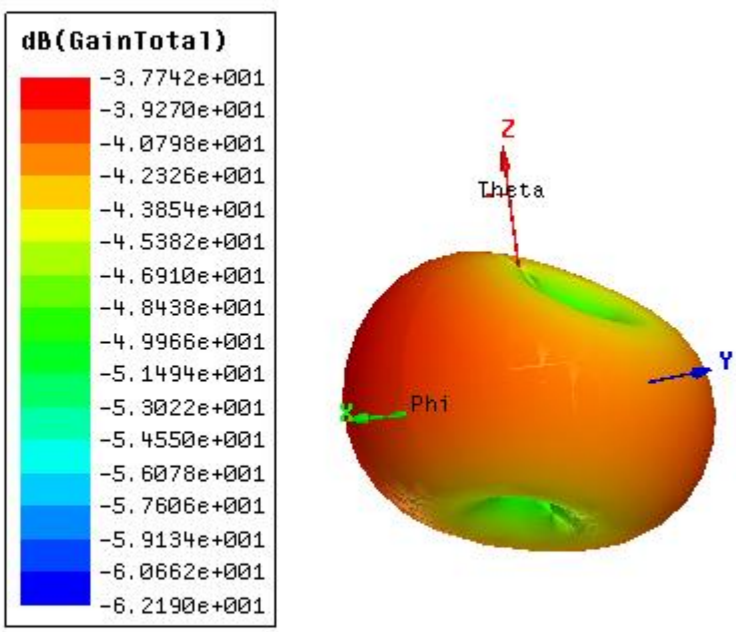


Fig 4.3 3D Gain Plot at 0.403 GHz

From Fig 4.2 the gain of the proposed antenna at 0.403 GHz is -37 dBi. Gain of implantable antenna at lower frequencies is negative because of antenna's small size. Gain at 0.904 GHz is -26 dBi.

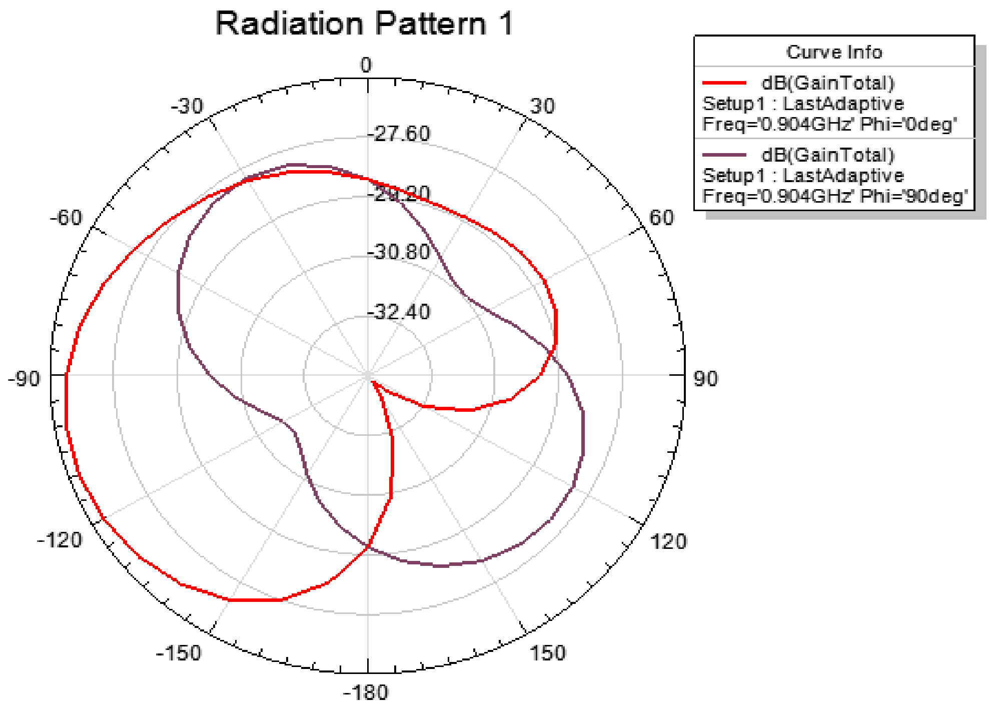


Fig 4.4 2D Radiation Pattern for E-Plane and H-Plane at 0.904 GHz

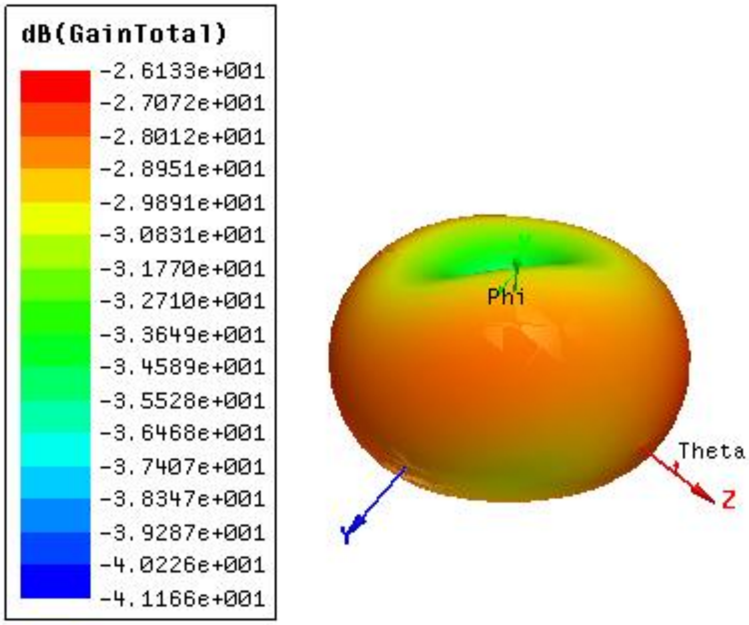


Fig 4.5 3D Gain Plot at 0.904 GHz

Fig 4.7 shows that gain at 1.4 GHz is -19dBi.

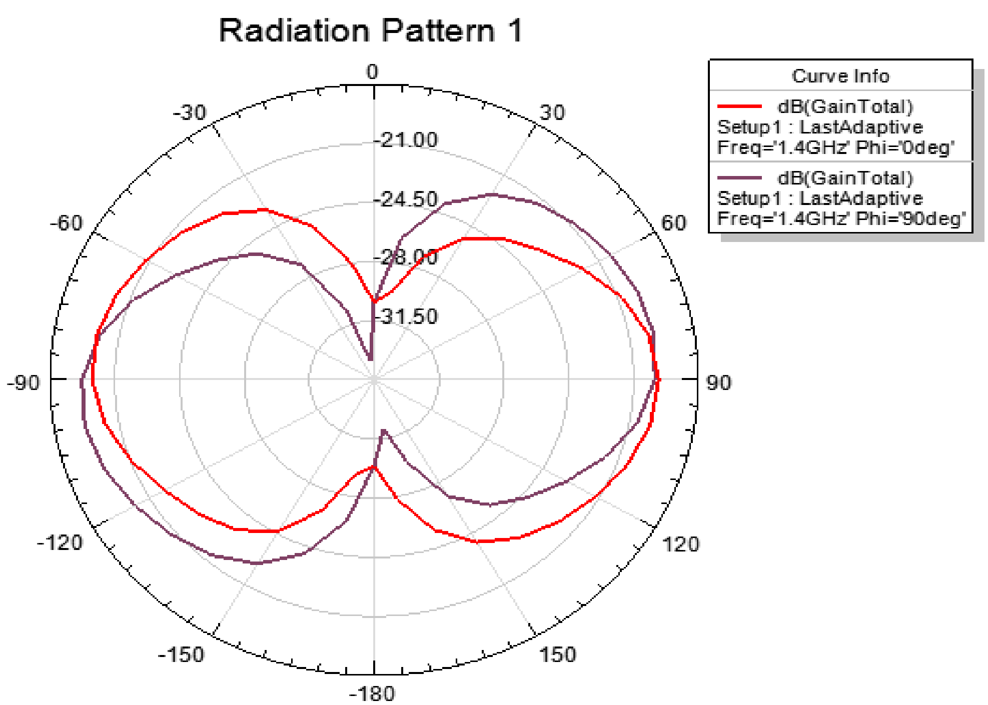


Fig 4.6 2D Radiation Pattern for E-plane and H-Plane at 1.4 GHz

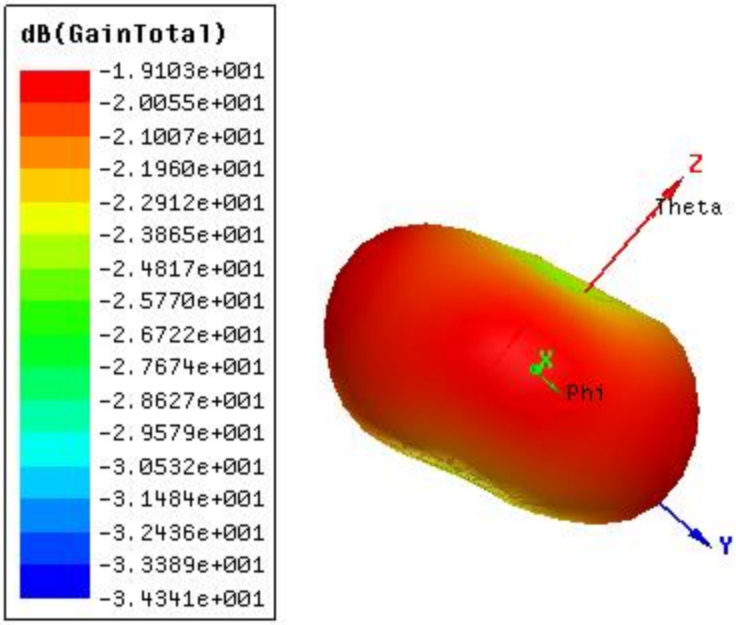


Fig 4.7 3D Gain Plot at 1.4GHz

Surface current of an antenna is calculated to see which element is radiating at what frequency or what resonance is achieved by what element.

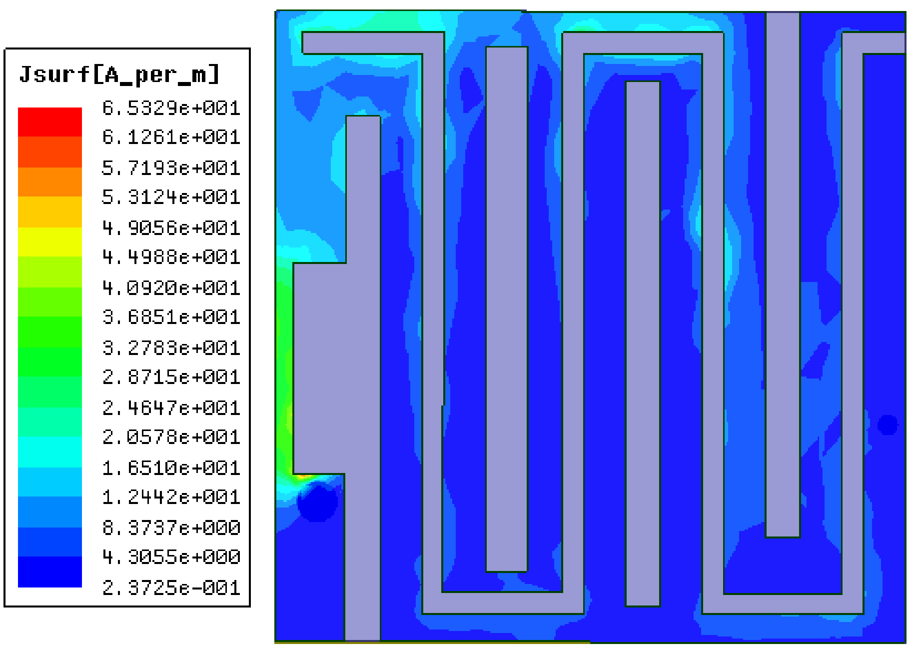


Fig 4.8 Surface Current Distribution at 0.403 GHz

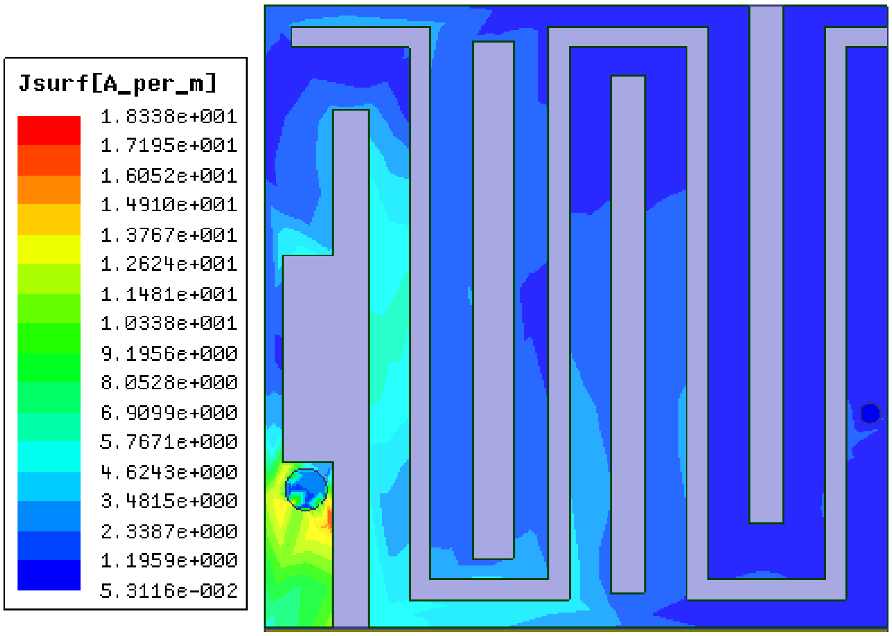


Fig 4.9 Surface Current Distribution at 0.904 GHz

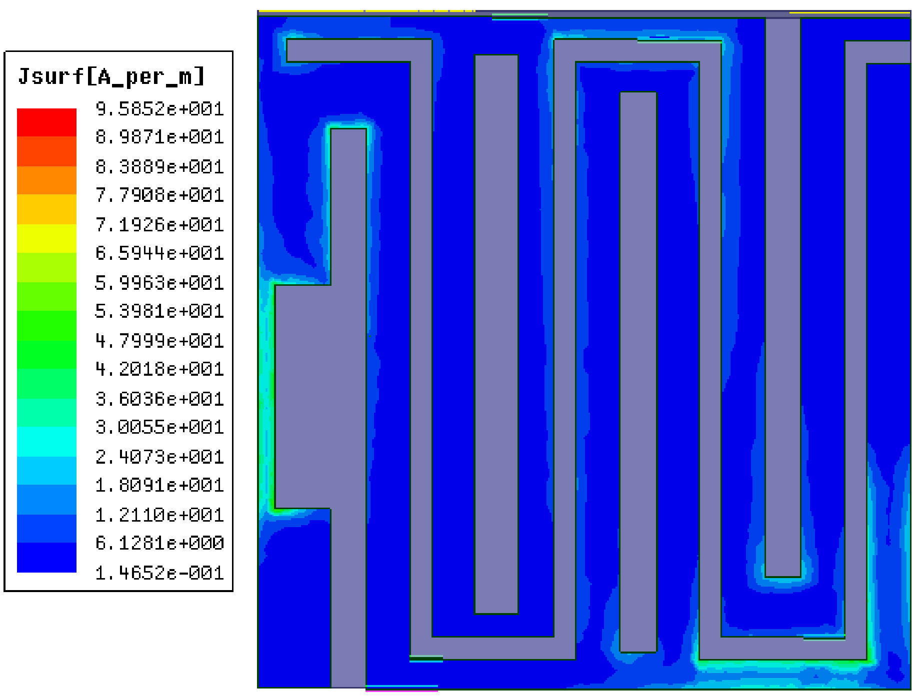


Fig 4.10 Surface Current Distribution at 1.4 GHz

Specific Absorption Rate (SAR) is a quantity which is defined as the rate of RF power absorbed per unit mass by any part of the body. SAR value commonly is determined either 1g or 10g of simulated biological tissue in the shape of a cube. SAR value normally specified at the maximum transmission power.

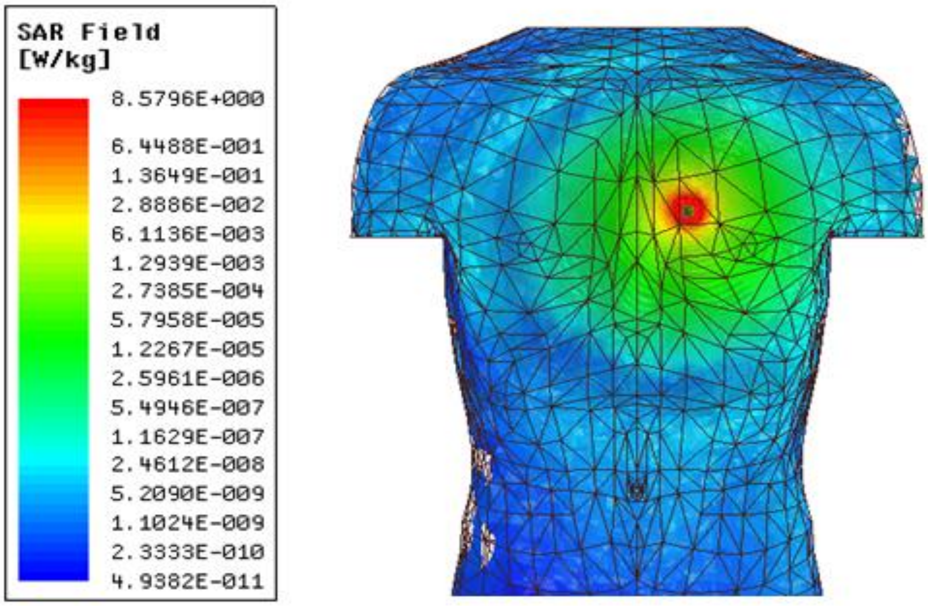


Fig 4.11 SAR Calculations at 0.403 GHz

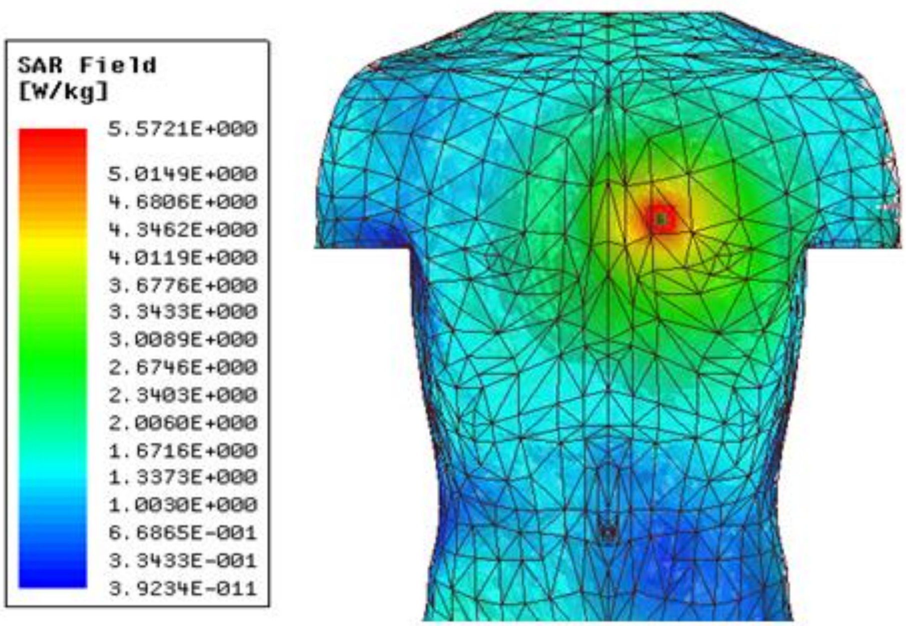


Fig 4.12 SAR Calculations at 0.94 GHz

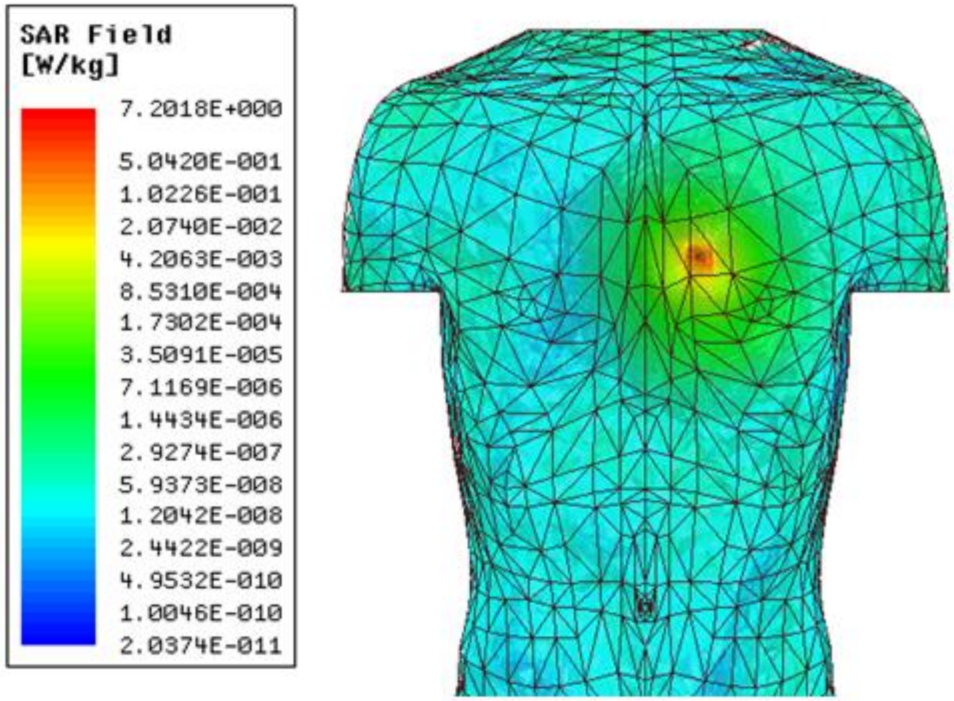


Fig 4.13 SAR Calculations at 1.4 GHz

Table 4.1 SAR Calculations

Frequency (MHz)	Max SAR Value (W/kg)		Max Input Power (mW)	
	Avg in 1g	Avg in 10g	SAR limit for 1g	SAR limit for 10g
403	207.49	38.217	7.71	39.4
904	237.49	34.863	6.7	39.91
1400	205.28	37.869	7.8	54.96

4.2 MEASURESD RESULTS

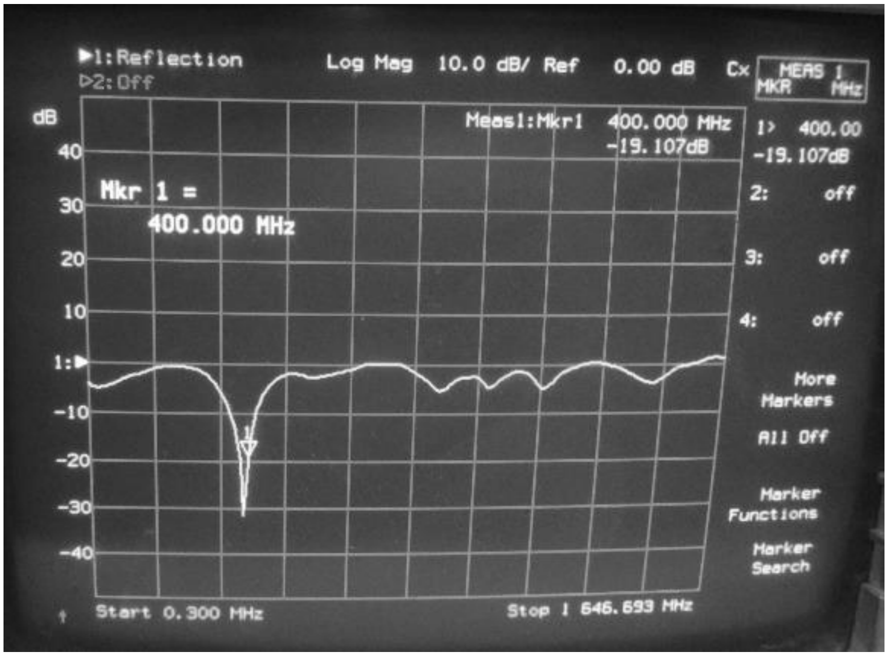


Fig 4.14 Measured S_{11} at 0.403 GHz

Fig 4.14 shows measured results at 0.403 GHz, dip obtained is at -30 dB

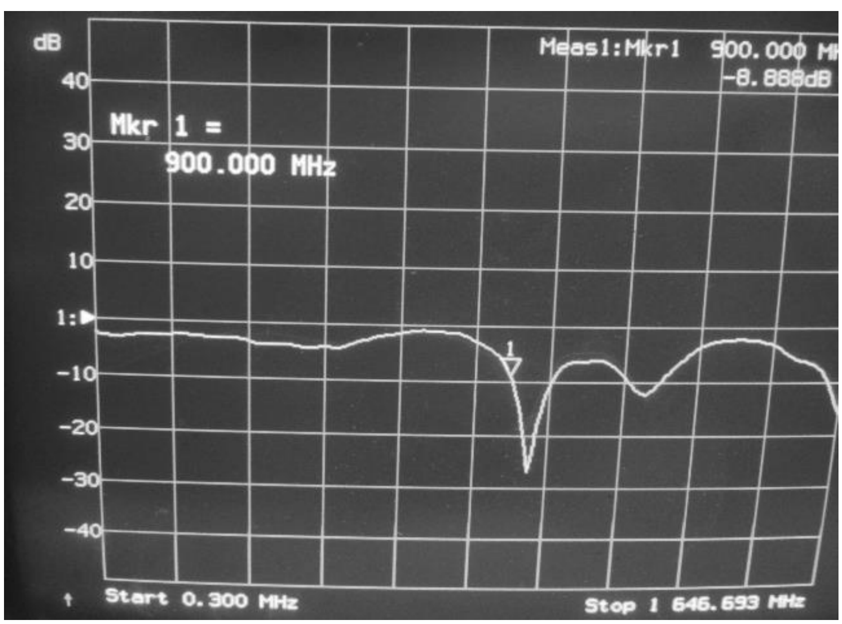


Fig 4.15 Measured S_{11} at 0.904 GHz

Fig 4.15 shows measured results at 0.904 GHz and dip obtained is at -26 dB

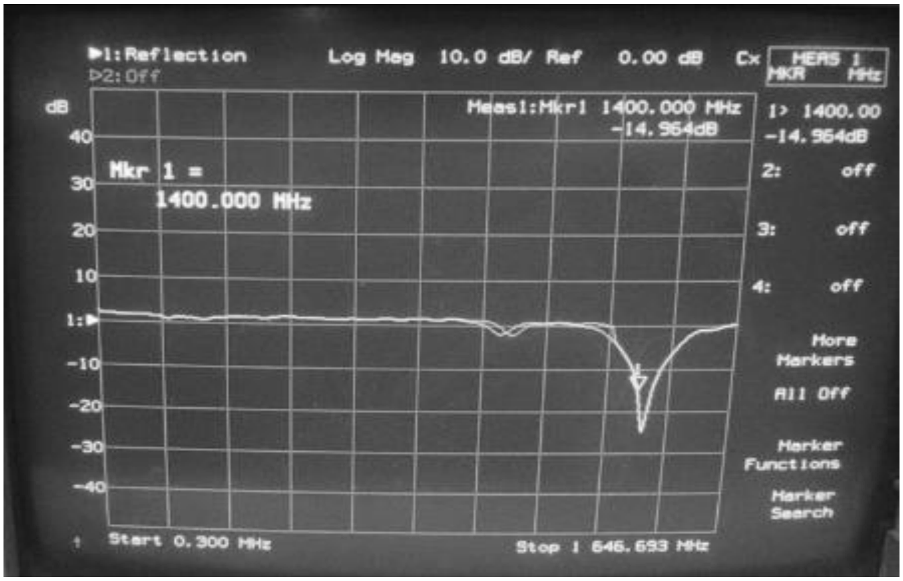
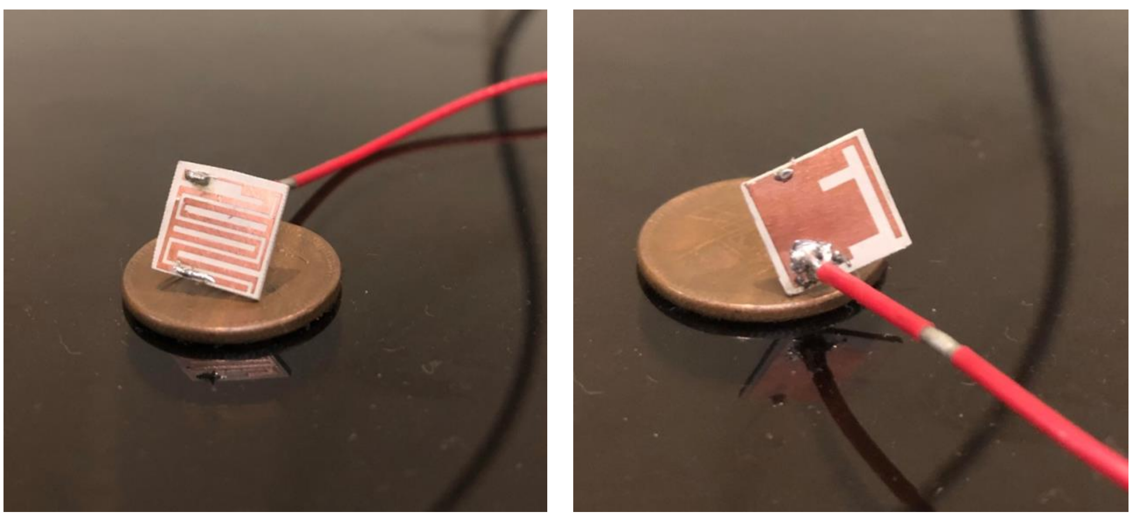


Fig 4.16 Measured S_{11} at 1.4 GHz

Fig 4.16 shows measured results at 1.4 GHz and dip obtained is at -23 dB



(a) **(b)**

Fig 4.17 picture of fabricated antenna (a) Front view (b) Rare view

CHAPTER 5

Future Work and Conclusion

5.1 Conclusion

Proposed antenna design in this thesis covers three bands 0.403 GHz, 0.904 GHz and 1.4 GHz. Fig 4.3 shows gain at 0.403 GHz which is approximately -37 dBi, Fig 4.5 shows total gain at 0.904 is -26 dBi and Fig 4.7 shows gain at 1.4 GHz is -19 dBi approx. Presented antenna is of compact size and operates on three bands. Size of presented antenna is 9 mm × 9 mm × 0.25 mm. This antenna has application in the medical field.

5.2 Contribution

The primary focus of this research was to obtain the approach of an implantable antenna with compact size and high Gain as compared to the previous work. After proper and thorough literature review on implantable antennas, by comparing the designs, results and efficiency it is concluded that proposed design has high gain, is tri band and has better performance.

Table 5.1 Comparison with previous work

Ref	No. of Bands	Frequency (MHz)	Gain dB	Phantom size	Volume mm^3	SAR value for 1g
[49]	Single band	920	-25	200×61×55	486.7	---
[50]	Dual band	928 2450	-28.75 -25.64	100×100×100	10.80	471
This work	Tri band	403 904 1400	-37 -29 -26	100×100×100	20.25	207

5.3 Future Work

- Design presented in this thesis is compact, operates on three bands and results obtained are quite satisfactory but evolution is always a perk.
- In future antenna can be made reconfigurable.
- A new band of 2.45 GHz can also be introduced in this design in future with some changes in the design.
- By making some modification data transmission can be achieved.
- Antenna size can be reduced more by using other techniques.
- Antenna can be made direction to lessen SAR value.
- Antenna efficiency can be improved by introducing some changes.

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