Design of RF sensors for Biomedical and Security Applications

An OELP Project

Bachelor of Technology

by

Aryan Mathur
(122201017)

Gaurav Nagar
(102201026)

Under the esteemed guidance of
Dr. Sukomal Dey

INDIAN INSTITUTE OF TECHNOLOGY PALAKKAD

Department of Electrical Engineering

INDIAN INSTITUTE OF TECHNOLOGY PALAKKAD

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Chapter 1

Introduction

In a world where disasters disrupt and health monitoring remains overlooked, emerges a pioneering project poised to redefine the essence of wearable or implantable technology.

Our mission is clear: to craft a micro device that seamlessly monitors nutrient levels within the human body and transforms into hope for precise human tracking during calamities. Powered by RF metamaterial-based sensors and electromagnetic waves, this project safeguards lives and reshapes the boundaries of health and safety.

1.1 Objectives

Develop a compact device that can stay on human body without bothering daily activities i.e. being implantable. This device should monitor actual nutritional levels (like proteins, carbohydrates, etc.) inside human body and not just the vitals like oxygen level.

Enable Human Tracking during Disastrous Situations: Design the device to double as a precise human tracking system during natural disasters, utilizing RadioFrequency wave technology for efficient location monitoring.

1.2 Problem Statement

Addressing the dual challenge of inadequate health tracking and efficient disaster response, this project aims to develop a device utilizing RF metamaterial-based sensors to monitor nutrient levels and enable precise human tracking during emergencies. All this while the device being compact and always in/on body.

Chapter 2

Methodology

2.1 Research Phase

Literature Review:

The project began with an extensive exploration of existing theses, and reports related to wearable health monitoring devices and disaster tracking systems. We could gain a lot of new insights on the domain of RF Technology and it's various applications. Out here metamaterials, RF Sensors, RF Antennas are primary areas of concern. About these we understood:

2.1.1 Metamaterials

Metamaterials are artificially built structures with enhanced electromagnetic properties, normally constituted by periodically organized metallic elements [20]. The size of these elements is less than the incident EM wavelength. The behavior of these materials can be different from any natural component, and the exhibited properties are very different depending on the geometry, shape or size of the structures. For instance, fields can be strongly enhanced or localized, improving the transducer's selectivity and sensitivity. Typical applications of metamaterial-based sensors are, for example, biosensing devices and super lenses for optical engineering.

2.1.2 RF Technology

RF technology is based on radio waves. The main properties of oscillating waves are the frequency, amplitude and wavelength. The amplitude refers to the peak-to-peak value of the signal. The frequency is the number of cycles of a periodic wave per unit of time. The wavelength is the distance between two equivalent points of two consecutive cycles, given by: = (13) where is the wavelength, f is the frequency and c is the speed of light in free space (300,000,000 m/s). When referring to RF, the frequency range of the electromagnetic waves is from 20 kHz to 300 GHz. This means the wavelength range is from 15,000 m to 1 mm. In electromagnetic antenna theory, the length of a dipole antenna is half the wavelength of the signal, so this parameter is relevant to the form factor of a transmitting or receiving device.

2.2 RF Sensor

The sensor is based in the dielectric layer response to different foods. This active layer is embedded between two Split Ring Resonators (SRR), forming an RF tri-layer sensor. This metamaterial has the SRRs reverse-facing each other, forming a Broadside Coupled SRR (BC-SRR), which has a lower resonant frequency (appropriate for RF instrumentation) and confines the electric field to reduce the external influence, important in an in-vivo biomedical device.

2.3 Development Phase:

2.3.1 Gaining a Hold of the Topics and its' applications

We first got hands on the software HFSS for designing such a material. We then switched over to CST since it provided better simulation environment and accessibility. We simulated and replicated scenarios to test and refine the nutrient tracking aspects of the device which provided a controlled environment to fine-tune and validate the accuracy of the nutrient monitoring system before real-life implementation.

2.3.2 Development phase and Objectiives

We then started designing based on our yet known knowledge and required outputs. We modulated a lot of parameters and design parameters to get the desired set of outputs which we observed on S-11 parameters.

2.4 Testing and Iteration:

Once the newly made designed behaved properly on the given set of frequency-power parameters, we implanted it inside a muscle cell. Now since the medium for muscle cell was not available, we further researched on properties of muscle like tissues and then made such a material to enclose the metamaterial based antenna that recieves all RF Signals and behaves differently for each frequency.

2.5 Structures made and Results observed

2.5.1 Square RF Chip for Nutrient Monitoring Performance

We made the following design referring to the reference [1] The observations

Fig. 2.1 Structure

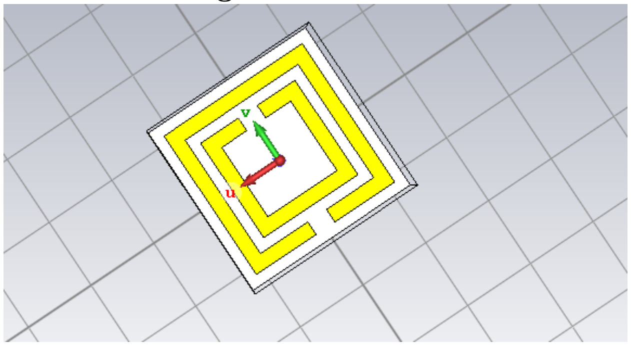


Fig. 2.2 Microstrip Line

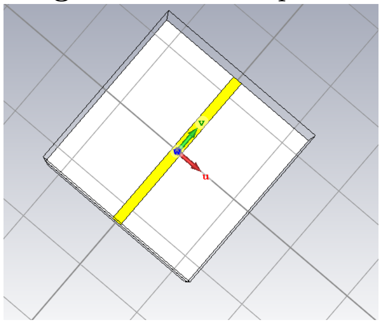
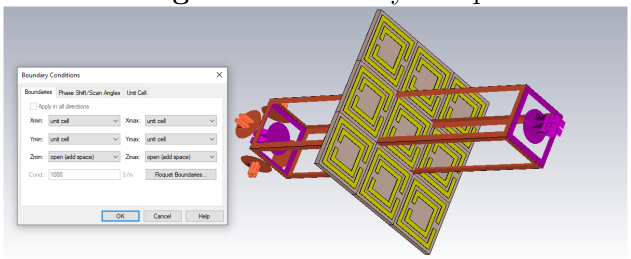


Fig. 2.3 Boundary Setup



were as follows:

2.5.2 Antenna for RF Detection and Human Tracking

For this we made this antenna using CST and following were its' observation parameters The following were observed:

Fig. 2.4 Design Parameters

phaseX	= Choose(Fix(PathPara)+1, PathPara*18...	180	phase difference between periodic x-...
phaseY	= Choose(Fix(PathPara)+1, 0, (PathPara...	0	phase difference between periodic y-...
ls	= 2.5	2.5	
l1	= 2.2	2.2	
PathPara	= 1	1	Master Parameter, sweeping from 0.1 ...
g	= 0.3	0.3	
h	= 0.25	0.25	
w	= 0.2	0.2	
s	= 0.15	0.15	
lw	= 0.14	0.14	
t	= 0.017	0.017	

Fig. 2.5 Excitation Diagram

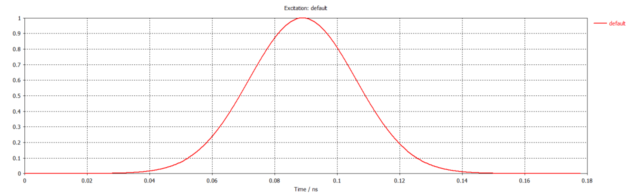


Fig. 2.6 Excitation Diagram

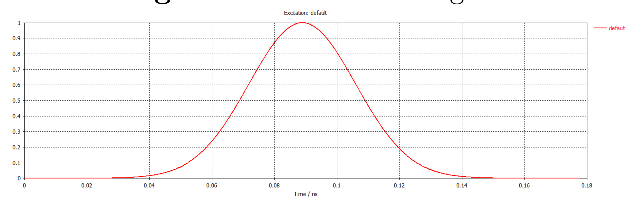


Fig. 2.7 Excitation Diagram

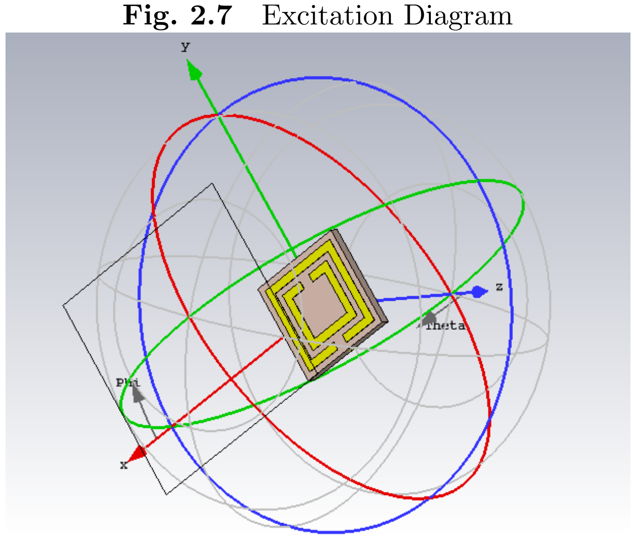


Fig. 2.8 S11 Observations

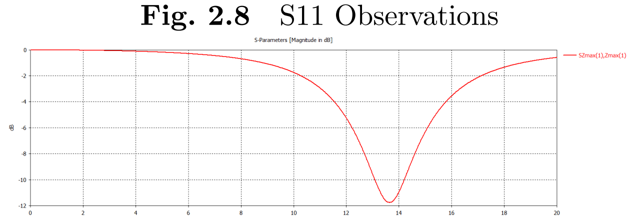


Fig. 2.9 Antenna View

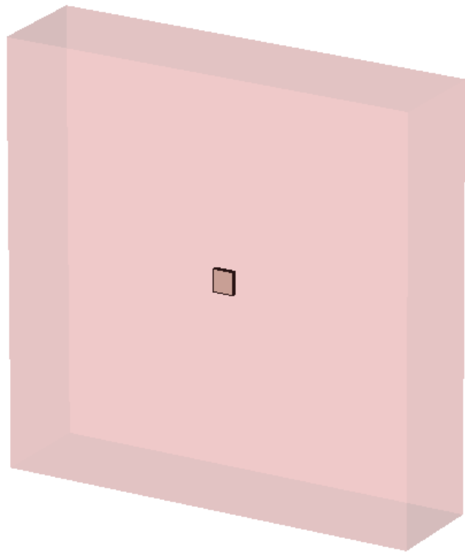


Fig. 2.10 Antenna back

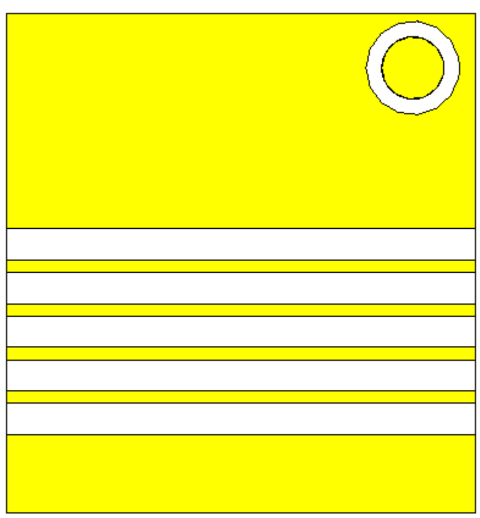


Fig. 2.11 Antenna front

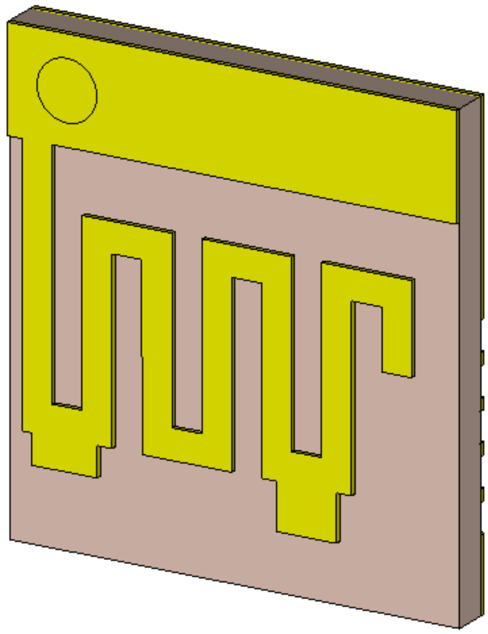


Fig. 2.12 Muscle Layer's Dielectric Properties

Three layer tissues	Dielectric properties	Loss tangents
Skin	7.98	1.37
Fat	3.13	0.27
Muscle	12.86	0.0012

Dielectric properties and loss tangents of skin, fat and muscle

Fig. 2.13 3D Radiation Patterns

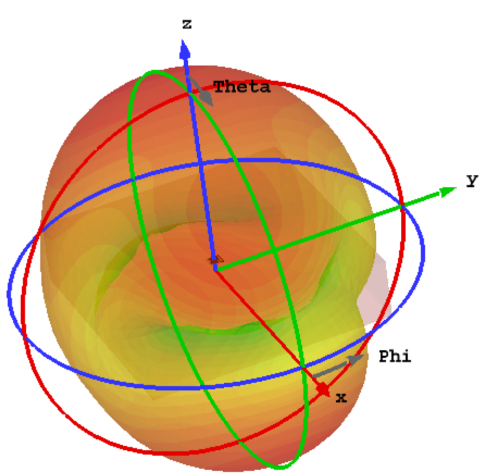


Fig. 2.14 2D Radiation Patterns

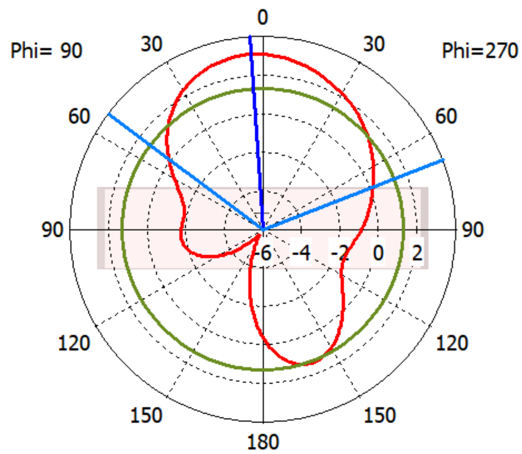


Fig. 2.15 Surface Current Distribution Diagram (5 GHz)

Fig. 2.16 S11 parameters

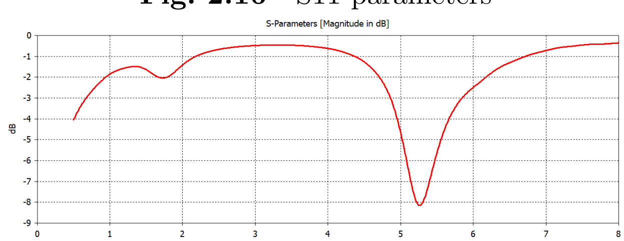
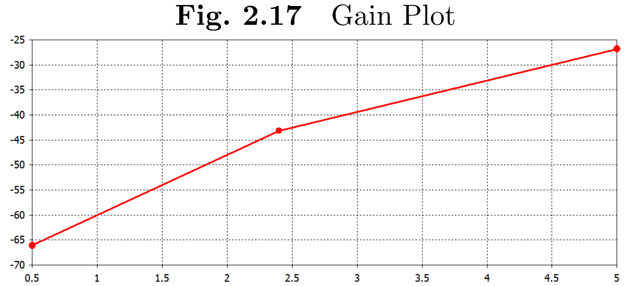


Fig. 2.17 Gain Plot



Chapter 3

Challenges

3.0.1 Designing Software compatibility and simulation environment

We first started with HFSS, got an idea of how things work but simulations were becoming a tidious task, we then switched over to CST to get better results in a lesser amount of time.

3.0.2 Finding Enough systems with CST installed

The next challenge seemed to be finding enough available systems which had CST installed. Under the advice of sir we then started working on the same system (Table 24) everytime. Untill the last phase when we contacted Research scholars for a faster system.

3.0.3 Muscle Material

We could not find the required muscle material in the pre installed library of CST. For which we refered to quite a few research papers mentioned in the references and ultimately created such a material on our own based on the electrical and magnetic properties and dimensions. For the same we referred refereence [6].

3.0.4 Incorrect Power-Frequency response

After everything was set and we were about to get the product fabricated, we had this one serious challenge of not getting the desired outputs after enclosing the antenna in the muscle material. We explored different options like refering alternate frequencies to get similar outputs and even altering the design to get the desired outputs. Optimisation is what came to our rescue for the same.

3.0.5 Structure disorientation

The expected outputs were now in sync with the ones we observed, but a lot of design attributes had changed by then . For the same, we sought to changing the port orientation to test the given material on different observatory parameters.

Chapter 4

Future Work

4.0.1 Fabrication

Our Next plan is to fabricate this and measure the real life observations.

4.0.2 Converting into Dual Band

Making it possible to work for dual band frequencies of 2.4 and 5.7 GHz.

4.0.3 Exploring further more biomedical applications in different implantable devices

4.0.4 Sensors Integration

We will be integrating both of these sensors in one in future.

4.0.5 Making it work for ISM Industrial bands of 5.2, 5.7 GHz

Further advancements in algorithm development will target more sophisticated human tracking methodologies. Exploring machine learning techniques to...

4.0.6 Enhanced Wireless Communication

To ensure seamless and robust data transfer, future work will investigate advanced wireless communication protocols or technologies. The goal is to...

Chapter 5

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