VISVESVARAYA TECHNOLOGICAL UNIVERSITY
Jnana Sangama, Belagavi-590018, Karnataka

PROJECT WORK (18ECP83) REPORT
ON
"WEARABLE ANTENNAS FOR REMOTE HEALTH CARE MONITORING"

Submitted in partial fulfilment of the requirements for the award of degree of
BACHELOR OF ENGINEERING
in
ELECTRONICS AND COMMUNICATION ENGINEERING
by

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Department of Electronics & Communication Engineering
2021 – 2022

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CERTIFICATE

Certified that the project work entitled **"WEARABLE ANTENNAS FOR REMOTE HEALTH CARE MONITORING"** carried out by **Shisheer S Koushik(1BG18EC127), Chidananda SP(1BG19EC403), Kiran B(),** and**,** bonafide students of **VIII semester** in partial fulfilment for the award of **Bachelor of Engineering** degree in **Electronics and Communication Engineering** of the Visvesvaraya Technological University, Belagavi during the year **2021-2022**. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the department library. The Project Phase II report has been approved as it satisfies the academic requirements in respect of Project work Phase II (18ECP83) prescribed for the said degree.

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ABSTRACT

Remote monitoring of the elderly in telehealth applications requires that the monitoring must not affect the elderly's regular habits.

To ensure this requirement, the components (i.e., sensor and antenna) necessary to carry out such monitoring should blend in with the elderly's daily routine. To this end, an effective strategy relies on employing wearable antennas that can be fully integrated with clothes and that can be used for remotely transmitting/receiving the sensor data. Starting from these considerations, in this work, two different methods for wearable antenna fabrication are described in detail: the first resorts to the combined use of nonwoven conductive fabrics and of a cutting plotter for shaping the fabric, whereas the second considered fabrication method resorts to the embroidery of conductive threads. To demonstrate the suitability of the considered fabrication techniques and to highlight their pros and cons, numerical and experimental results related to different wearable antennas are also reported and commented on.

Results demonstrate that the presented fabrication techniques and strategies are very flexible and can be used to obtain low-cost wearable antennas with performance tailored for the specific application at hand.

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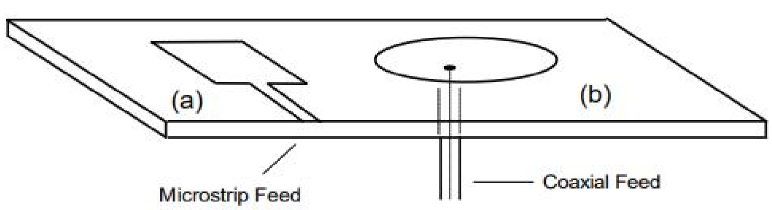
CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Health care is an inalienable human right and, as such, it should not be considered a privilege for the few. Nevertheless, budget cuts and spending reviews are seriously affecting public services in many sectors, including health care. In this scenario, the elderly population is often the category that is affected the most by this situation; in fact, hospitals are often unwilling to spend their budget on services for senior citizens. On the other hand, the increase of life expectancy, along with the elderly's undeniable right to live ageing as a positive experience, motivates the need to identify innovative and low-cost technological solutions that could make health care provision more cost-effective and efficient.

Applications that require low-profile, light weight, easily manufactured, inexpensive, conformable antennas often use some form of a microstrip radiator. The microstrip antenna (MSA) is a resonant structure that consists of a dielectric substrate sandwiched between a metallic conducting patch and a ground plane. The MSA is commonly excited using a microstrip edge feed or a coaxial probe. The canonical forms of the MSA are the rectangular and circular patch MSAs. The rectangular patch antenna in Figure 5.1 is fed using a microstrip edge feed and the circular patch antenna is fed using a coaxial probe.



(a) (b) Coaxial Feed Microstrip Feed Figure 5.1. (a) A rectangular patch microstrip antenna fed with a microstrip edge feed. (b) A circular patch microstrip antenna fed with a coaxial probe

feed. The patch shapes in Figure 5.1 are symmetric and their radiation is easy to model. However, application specific patch shapes are often used to optimize certain aspects of MSA performance.

A number of methods are used to model the performance of the MSA. The simplest model of the MSA is the transmission line model, developed in the 1970s by Munson. [1] The radiating edges of the patch, located at and opposite the feed edge, are modeled as a pair of transmission lines excited 180° out of phase. [1] This method neglects field variations along the radiating edge, and feed effects. Another disadvantage is that an empirically determined correction factor is required to account for fringing fields at the edges of the patch. [1] Despite these assumptions, the transmission line model provides a useful zeroth order approximation to the behavior of the rectangular patch MSA. However, it is not applicable to the circular patch MSA or patches of arbitrary shape. [1] A more rigorous solution to MSA behavior is the magnetic cavity model. The MSA is modeled as a resonant TMmn cavity with perfect electrically conducting (PEC) top and bottom surfaces and a perfectly magnetically conducting (PMC) ribbon around the edge. [4] The fields in the antenna are derived by solving for TMmn modes in the cavity. The radiation is accounted for using a loss tangent in the material, or a reflection coefficient at the PMC ribbon. Within the cavity, the TM00 mode represents static capacitance and loss in the conductors. The TM10 and higher modes are radiative. [1] The magnetic cavity model works well for cavities of simple shape, such as the rectangular and circular patch MSA. However, derivation of the TMmn modes in an arbitrarily shaped cavity is often tedious. For patch antennas of arbitrary shape, numerical methods are used to solve the integral equations. The Finite Difference Time Domain (FDTD) method and the Method of Moments (MoM) are both applied in practice.

One method commonly used to model microstrip antennas is the Magnetic Cavity Model. The cavity model of the MSA assumes that the patch and the ground plane are electric walls, and the periphery of the patch is a magnetic wall. [3] The fields in the resulting cavity are assumed to be the fields of the antenna and Huygen’s Principle is applied at the magnetic wall to determine radiation. [3] To determine the fields within the cavity, a solution of an inhomogeneous wave equation is required. Therefore, the Magnetic Cavity Model is most easily applied when the method of separation of variables is applicable. [3] The rectangular and circular patch MSAs are symmetric in two planes. Therefore, the cavity model is convenient in both cases. For arbitrarily shaped patches, application of the Method of Moments to the integral equation is necessary to

avoid tedious calculations. [3] The magnetic cavity model works best for a thin substrate. In this case the TM modes are superior in the cavity. The cavity model makes the following assumptions:

1. The electric field is z-directed, and the magnetic field has only a transverse component in the cavity. 2. Since the substrate is assumed thin, the fields in the cavity do not vary with z. 3. The tangential component of the magnetic field is negligible at the edge of the patch. 4. The existence of a fringing field can be accounted for by slightly extending the edges of the patch. An arbitrarily shaped microstrip patch is illustrated in Figure 5.2. The substrate thickness, t, is thin. The circumference of the patch is C and the area bounded by the circumference is S. The unit vector, n, is normal to the patch edge. The substrate has a dielectric constant Er.

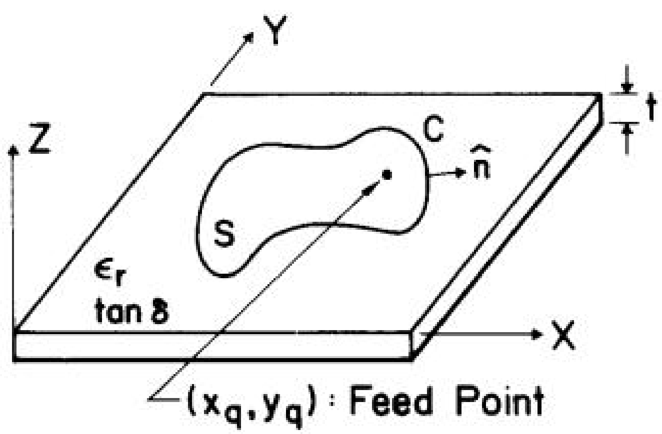


Figure 5.2. An arbitrarily shaped microstrip patch antenna

2. Figure 5.2. An arbitrarily shaped microstrip patch antenna If an e jwt time variation is assumed, the fields from a z-directed current source at the point (xq,yq) satisfy the following relations: [3]

$$\left(\nabla_T^2 + k^2\right)E_z = -j\omega\mu_o J_z(x_q, y_q)$$

$$\mathbf{H} = \frac{j}{\omega\mu_o}\nabla_T \times (\mathbf{a}_z E_z)$$

where ÑT is the transverse of the del operator with respect to the z-axis, and

$$k = k_o\sqrt{\varepsilon_r}$$

The solution of (5.5) for a rectangular conducting patch of length L and width W is [3]

$$\varphi_{mn}(x,y) = \frac{\delta_m \delta_n}{\sqrt{W_e L_e}}\cos\left(\frac{m\pi x}{W_e}\right)\cos\left(\frac{n\pi y}{L_e}\right) \tag{5.24}$$

$$\delta_l = \begin{cases} 1, & l = 0 \\ \sqrt{2}, & l \neq 0 \end{cases}$$

where m and n correspond to the mode indices in the x and y directions, We is the effective width including the extension used to simulate the fringing fields, and Le is the effective length. For the TM10 mode, the effective dimensions are found using [3]

$$W_e = W\left[1 + \Delta(W)\right]\frac{\sqrt{\varepsilon_e(W)\varepsilon_e(L)}}{\varepsilon_r} \tag{5.25}$$

$$L_e = L \tag{5.26}$$

and for the TM01 mode using [3]

$$W_e = W \tag{5.27}$$

$$L_e = L\left[1 + \Delta(L)\right]\frac{\sqrt{\varepsilon_e(W)\varepsilon_e(L)}}{\varepsilon_r} \tag{5.28}$$

Where

$$\varepsilon_e(x) = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 10\frac{t}{x}\right)^{-1/2} \tag{5.29}$$

In these expressions, the D function is a correction for the effect of the fringing field, and is given by [3]

$$\Delta(x) = \frac{t}{x}\left\{0.882 + \frac{0.164(\varepsilon_r - 1)}{\varepsilon_r} + \frac{\varepsilon_r + 1}{\pi\varepsilon_r}\left[0.758 + \ln\left(\frac{x}{t} + 1.88\right)\right]\right\} \tag{5.30}$$

The eigenvalues are found using [3]

$$k_{mn} = \sqrt{\left(\frac{m\pi}{W_e}\right)^2 + \left(\frac{n\pi}{L_e}\right)^2} \tag{5.31}$$

and are used to derive the resonant frequency with [3]

$$f_{mn} = \frac{k_{mn}}{2\pi\sqrt{\varepsilon_r\varepsilon_o\mu_o}} \tag{5.32}$$

The electric field in the cavity is found using (5.6), and is given by [3]

$$E_z(x,y) = \sum_m \sum_n \frac{V_{mn}}{t}\cos\left(\frac{m\pi x}{W_e}\right)\cos\left(\frac{n\pi y}{L_e}\right) \tag{5.33}$$

Where

$$V_{mn} = \frac{\sqrt{2}(\delta_m\delta_n)^2 I_q}{j\omega C + \frac{1}{j\omega L_{mn}} + g_{mn}}\cos\left(\frac{m\pi x}{W_e}\right)\cos\left(\frac{n\pi y}{L_e}\right) \tag{5.34}$$

The quantities C, Lmn, and gmn are derived using (5.7) through (5.11). The coordinates (xq, yq) give the location of the feed point, and Iq is the input current. For a rectangular patch with a single feed point, the input impedance is found using (5.11). The resulting expression is [3]

Finally, the radiating fields of the antenna are found by substituting (5.32) into (5.13) and (5.14). The resulting expressions for the radiation patterns of a rectangular MSA are [3]

$$E_\theta(\theta,\phi) = \frac{e^{-jk_oR}}{R}\frac{k_o^{\,2}}{2\pi}\left[\cos\left(\frac{k_o t}{2}\cos\theta\right)\right]\sin\phi\cos\phi\sin\theta \\ \cdot\sum_m\sum_n V_{mn}\left[1-(-1)^m e^{jk_oW_e\cos\phi\sin\theta}\right]\left[1-(-1)^n e^{jk_oL_e\sin\phi\sin\theta}\right] \\ \cdot\left\{\left[\frac{1}{k_o^{\,2}\cos^2\phi\sin^2\theta-\left(\frac{m\pi}{W_e}\right)^2}\right]+\left[\frac{1}{k_o^{\,2}\sin^2\phi\sin^2\theta-\left(\frac{n\pi}{L_e}\right)^2}\right]\right\} \tag{5.36}$$

And

$$E_\phi(\theta,\phi) = \frac{e^{-jk_oR}}{R}\frac{k_o^{\,2}}{2\pi}\left[\cos\left(\frac{k_o t}{2}\cos\theta\right)\right]\cos\theta\sin\theta \\ \cdot\sum_m\sum_n V_{mn}\left[1-(-1)^m e^{jk_oW_e\cos\phi\sin\theta}\right]\left[1-(-1)^n e^{jk_oL_e\sin\phi\sin\theta}\right] \\ \cdot\left\{\left[\frac{\sin^2\phi}{k_o^{\,2}\sin^2\phi\sin^2\theta-\left(\frac{n\pi}{L_e}\right)^2}\right]-\left[\frac{\cos^2\phi}{k_o^{\,2}\cos^2\phi\sin^2\theta-\left(\frac{m\pi}{W_e}\right)^2}\right]\right\} \tag{5.37}$$

This completes the application of the magnetic cavity model to a rectangular patch shape.

1.2. OVERVIEW OF THE PROJECT WORK

In this regard, telemedicine is regarded as one of the key strategies for a substantial reduction of the social costs related to health care, while still providing the necessary support to the elderly and guaranteeing a good quality of life [1]. Wireless technology is a key ally for remote health monitoring [2–10].

In fact, the combination of non-invasive wearable sensors and of information technologies can allow the elderly to receive the needed assistance, while continuing to live in their own homes, rather than in impersonal and expensive nursing homes [1].

Accordingly, at the state of the art, several solutions are available dedicated to activity recognition to extract information on habitat behaviour [2–6] and to detect possible anomalies in health parameters [7–10].

Among these, in [2], a system (consisting of a microwave radar sensor and a wirelessly connected base station for data processing) for remote fall detection in an indoor environment was presented.

Furthermore, in [9], a suite of home care sensor network system was proposed. It consists of biosensors placed on the body of the patient which transmit measured signals to the remote

wireless monitor for acquiring the observed human physiological signals. The monitoring platform was implemented by exploiting the ZigBee and the GSM technology.

1.3. PROBLEM STATEMENT

Statement:

Remote monitoring of the elderly in telehealth applications requires that the monitoring must not affect the elderly’s regular habits.

To Design:

wearable antennas that can be fully integrated with clothes and that can be used for remotely transmitting/receiving the sensor data

Project Focus:

- Obtain low-cost wearable antennas with performance tailored for the specific application at hand.
- Taking advantage of Nonwoven Conductive Fabrics (NWCFs)

CHAPTER 2

2.0. LITERATURE REVIEW

Title of the paper and year	Specifications & Methodology	Merits	Demerits	Applications
[1] "Wearable sensors for remote health monitoring," Sensors, vol. 17, no. 1, p. 130, 2017.	Uses Sensors that are interfaced with Bluetooth & ZigBee through the wireless Sensors and technology like wearable antenna, textile electrodes are used.	Helps in remotely monitoring the patient on telehealth application.	1. Suffers Low SNR 2. Lacks robust & effective algorithm 3. Privacy & security concerns	1. ECG's and EDA's 2. Proximity & activity monitoring 3. Blood Oxygen saturation
[2] "WSN for real-time localization and tracking of elderly people," in OASIS 1st International Conference, Florence, Italy, November 2014.	Uses RF module {wearable antenna}, consists of GPS system's, wireless sensors.	Apart from remotely monitoring telehealth application, it helps in detecting & positing of patients location.	1. Privacy & security concerns 2. Improvise in selection of sensing materials & embedded techniques.	1. Tracking & telemetry 2. Cardiovascular Monitoring system 3. Galvanic Skin Response
[3] Patch Array Antenna for Health Care and Monitoring System (ICICNIS) 2020.	The Swastik shaped antenna operating at a frequency of 3.5 GHz. The designed antenna shows efficiency of 93.8% with a simulated gain of 9.08 dB and a reflection coefficient of -23.50 dB	The results show a considerable increase in the gain of the overall antenna as compared to the right side or left side of the swastika design.	Hard to match the complete hardware setup results with the simulation results	This will be beneficial for different health applications i.e telehealth. The future scope of this work is to include metamaterial in the design.
[4] An Attempt to Develop an Logo antenna on textile materials 2014..	A novel Apple Inc. logo-shaped antenna is simulated and fabricated by using a conductive non-woven textile on a layer of jeans. Experimental data referring to a prototype working at 1.8 GHz with a radiation pattern greater than 2.2 dbi.	This fabric has non fraying problems thus allowing both: 1) a very simple design process 2) a time saving and cost-effective realization process based on the use of a common cutting plotter.	Special precautions needed during washing and ironing of the fabric.	Used as high performance RFID tags.

Title of the paper and year	Methodology	Merits	Demerits	Accuracy
[5] . A Wearable Wireless Energy Link for Thin-Film Batteries Charging.	A elliptical shaped concentric antenna ,it is demonstrated that, at 434 MHz, the RF-to-RF power transfer efficiency of the link is approximately 69.3%.	Experiments the time necessary for recharging the battery is lower than 50 minutes.	Need more improvisation to s demonstrate the feasibility of using the proposed wearable WPT link for implementing a wireless charger.	Wearable wireless Charger.

CHAPTER 3

SYSTEM DESIGN

3.1. Block diagram:

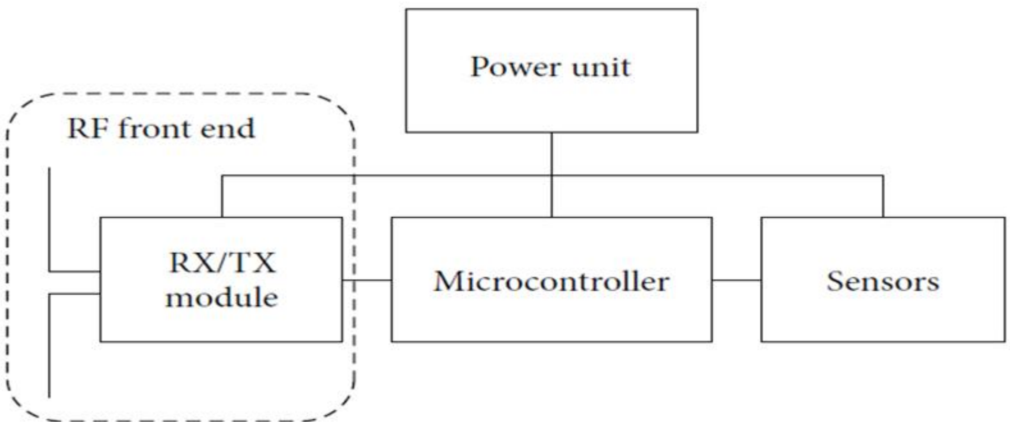


Figure 3.1: General block diagram of wireless monitoring systems

The general architecture of a wireless health care monitoring system is shown in Figure 3.1. Four major blocks can be identified: (i) The RF (radio frequency) front end, which comprises an antenna and an RX/TX (receiving/transmitting) module for receiving/transmitting data from/to the data monitoring unit (ii) A microcontroller for processing the data received from the sensors and sends them to block (i) (iii) The sensor (iv) The power supply unit necessary for operating all the previous blocks For an effective use of wearable wireless systems, all these four electronic blocks should be integrated into clothes or wearable accessories [10]. Hence, the use of nonconventional fabrication techniques and materials combined with customized design strategies is required. In this regard, the present paper focuses on fabrication techniques and materials which make the integration of the wireless monitoring platforms into garments easier. In particular, the present work addresses the fabrication of wearable antennas that can be fully integrated with clothes and that can be used for remotely transmitting/receiving the sensor data. The paper is structured as follows. In Section 2, the general requirements that should be guaranteed by wearable systems dedicated to the elderly's monitoring are discussed. Based on these requirements, in Section 3, two different fabrication techniques are investigated, namely, the use of nonwoven conductive fabrics in combination with a cutting plotter and the embroidery of conductive threads. Successively, Section 4 and Section 5 report the details on the design, fabrication, and characterization of different antenna prototypes using nonwoven conductive fabrics (NWCFs) or conductive threads, respectively. The reported numerical and experimental results demonstrate that the proposed fabrication techniques and strategies are very flexible and can allow obtaining low-cost wearable antennas with performance tailored according to the specific application requirements. Also, through an overview of different wearable antenna prototypes, it is shown that by selecting an appropriate fabrication technique, the antenna and the other blocks of a wireless health care monitoring system (Figure 3.1) can be successfully integrated with clothes.

General Requirements of Wearable Systems for Remote Health Care Monitoring

Before proceeding with the description of the investigated fabrication techniques, it is important to discuss some specific requirements that must be possessed by the wearable antennas to be effectively used for the intended monitoring purposes. As a matter of fact, these requirements motivate the choice of the most suitable technological solutions. First of all, wearable devices must be useful, comfortable, non-invasive, and unobtrusive to the users. This is particularly true for people who are affected by an illness such as the Alzheimer's disease; in this case, in fact, the ageing condition is usually aggravated by problems related to memory loss. It is not uncommon that people who suffer from Alzheimer's disease leave their homes without reason and start wandering around; in such cases, while they may probably forget their mobile phones or their identification documents, it is less likely that they do not wear their clothes, which are an inherent part of a person's everyday routine. Hence, wearable electronics embedded in clothes become the ideal means for implementing on one hand ubiquitous and continuous health monitoring [8] and on the other hand a tracking system which allows to locate the wandering person. By embedding it in the clothes, the components necessary for remotely monitoring the person and the use of the monitoring system would become an automatic action as getting dressed. To this purpose, textile materials could be exploited for both the conductive parts and the substrate. Additionally, the conductive parts should be fabricated with materials that allow tin soldering of the necessary electronics (electronic chips and, in general, surface mounted components). Other important requirements for wearable systems are related to the time and cost of the manufacturing process. In particular, in view of a large-scale production and cost containment, cost-effective and industrially scalable manufacturing techniques should be preferred. On the basis of these considerations, in the following section, two fabrication techniques and materials that can satisfy all the main requirements of a wearable monitoring system and which allow the fabrication of highly embeddable antennas are discussed in detail.

To test the performance of the manufacturing technique based on the combined use of NWCFs and the cutting plotter, an antenna mimicking the Levi's logo was designed and fabricated using a NWCF produced by Soliani EMC (model: RS CU C4) with surface resistivity approximately equal to 0.03 Ω/sq and thickness of 0.15 mm [35].

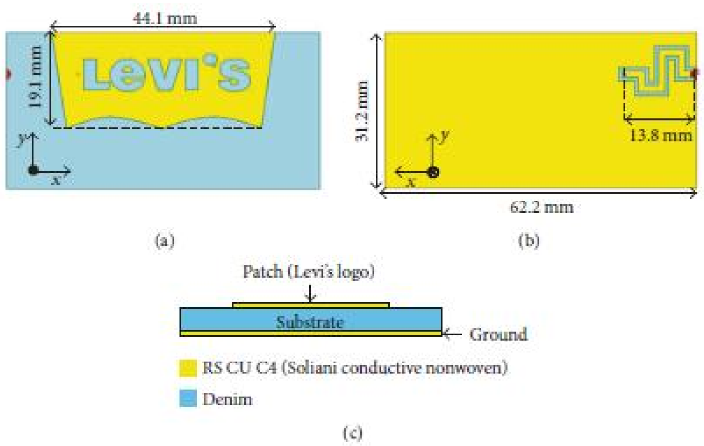
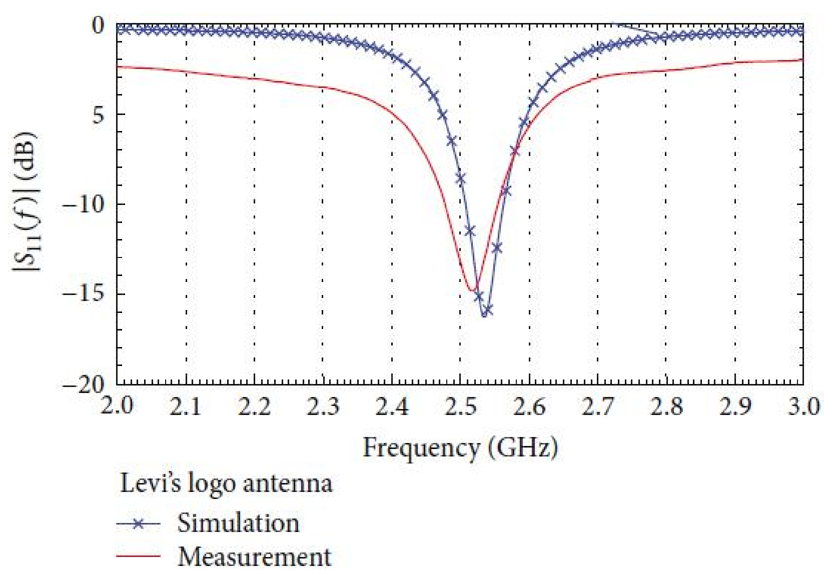


Figure 3.2: Levi's logo antenna design geometry: (a) front view; (b) back view; and (c) side view

Figure 3.3: Prototype of the proposed NCWF-based logo antenna: (a) front view and (b) back view.

A layer of denim, with relative dielectric permittivity εr= 1.67 and thickness of 0.5 mm, was used as a substrate. Generally, for wearable applications, an antenna with a patch-like radiation should be preferred; in fact, this configuration would allow not only to limit electromagnetic compatibility issues but also to achieve a platform-tolerant performance, thus enabling the operation in close proximity to the human body. In order to satisfy these requirements, the microstrip technology was chosen. The Levi's logo was recreated by appropriately shaping the edges of the patch and by using slots to reproduce the writing. To match the antenna impedance to 50Ω, a coplanar feed line slotted on the ground and shorted to the radiating element by means of a via hole was used. In order to obtain the desired behaviour, the dimensions of the antenna geometry were optimized by means of full-wave simulations carried out through the commercial software CST Microwave Studio (CST MWS) [36]. The optimized dimensions of the antenna are reported in Figure 2, which shows a sketch of the antenna geometry. As for the size of the coplanar feed line and via hole, the width of the line is equal to 1.35 mm, the gap between the feed line and the ground is equal to 0.7 mm, and the via hole has a diameter of 0.5 mm. Based on the simulation results, a prototype of the proposed antenna was fabricated by cutting the NWCF through a cutting plotter. Figures 3(a) and 3(b) show the pictures of the front and the back of the



fabricated prototype, respectively.

Figure 3.4: Comparison between the simulated and the measured reflection scattering parameter, |S11(f)|, for Levi's logo antenna.

The performance of the fabricated antenna was characterized through a vector network analyser (VNA R&S ZVA50). For the measurements, a 50 Ω SMA connector was tin soldered to the antenna, thus allowing the connection to the VNA. Figure 4 shows the comparison between experimental and numerical results obtained for the reflection coefficient, |S11(f)|; a good overall agreement can be noticed.

Microstrip patch antenna has many advantages as it is lighter in weight, low cost, low profile than the conventional microwave antenna. The planar structure of the antenna provides ease of fabrication [14]. Presently, it has been observed that the microstrip patch antenna become an ideal choice for the wearable healthcare applications. However, human body tissues can affect the performance and efficiency of the antenna, therefore, the selection of the material used to design such kind of antenna plays a significant role [15]. Also, the antenna performance and the radiation pattern are greatly influenced by the absorbed energy. The Specific Absorption Rate (SAR) is used to measure the amount of power absorbed by human body tissues. According to Federal Communication Commission (FCC), the SAR value should be below 1.6 W/Kg averaged over 1 gm of tissue and in European Standard, its value should be 2 W/Kg averaged over 10 gm of tissue [16]- [17]. An e-textile patch antenna was designed by the authors [18] for the frequency of 5.8 GHz using jeans as a substrate material. The measured return loss (S11), gain and SAR values are -21 dB, 3.05 dB, and 0.0111 W/Kg respectively. In [19], the authors have presented the flexible antenna design for the purpose of telemedicine applications. The authors used 2 substrate materials to design wearable antenna i.e., cotton and jeans. The jeans material has shown good results in terms of gain over cotton which is 5 dB compared to a gain of 3 dB for cotton. In [20], the authors have proposed a wearable patch antenna design using FR-4 as a substrate material covered by the jean's fabric as the outer layer. The measured antenna parameters such as return loss (S11) of -15.28 dB and a gain of 5.209 dBi at a frequency of 2.4 GHz. Similarly, in [21], the authors have designed and fabricated the wearable antenna on a flexible substrate material known as denim gens. This antenna can be used to operate in various frequency bands such as L, S, C, and X with both horizontal and vertical polarization

The proposed antenna is designed and simulated using the CST studio simulator. The suggested antenna is a microstrip patch antenna, therefore its design in CST needs some geometrical and simulation parameters. The geometrical parameters of the proposed antenna are calculated using microstrip equations discussed in Section IV. However, the major simulation parameter of an antenna is a frequency that can be defined according to the application of the proposed antenna [22]-[23]. After the computation of geometrical parameters, the design of the suggested antenna can be modeled in the CST Studio. The general methodology to model a patch antenna in CST Studio is explained in the flow chart given below in Fig. 1.

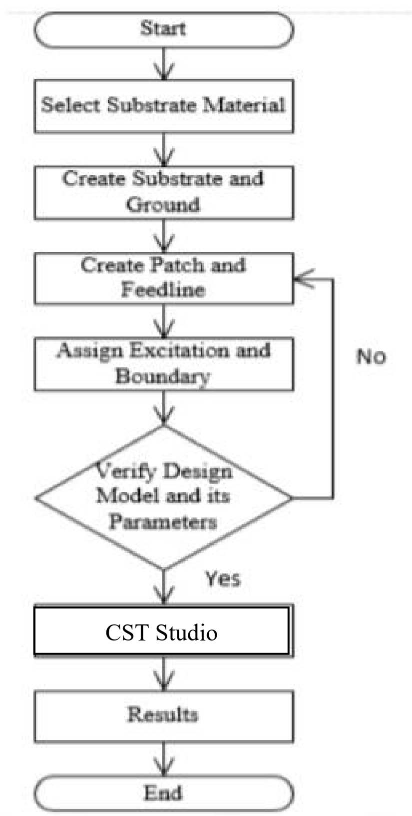
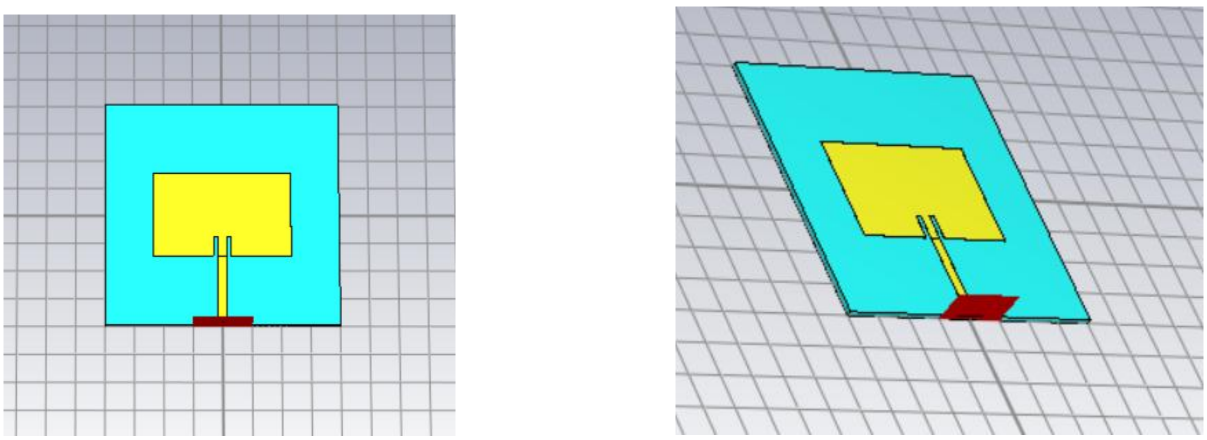


Figure 3.5: The Antenna simulation flowchart in CST studio

CHAPTER 4

4.1. TESTS AND RESULTS {Testing the Tool}:



(a) front view (b) side view.

Figure 3.6: Simulated Patch antenna design and Parameters

Parameters lists

Parameter List

Name	Expression	Value	Description
sbx	= 80	80	substrate dimension x
sby	= 80	80	substrate dimension y
sbh	= 1.5	1.5	dielectric height
antx	= 47	47	antenna dimension x
anty	= 30.2	30.2	antenna dimension y
trx	= 2.98	2.98	transmission line x
insx	= 1.5	1.5	inset dimension x
insy	= 7.16	7.16	inset dimension y

4.2 Results

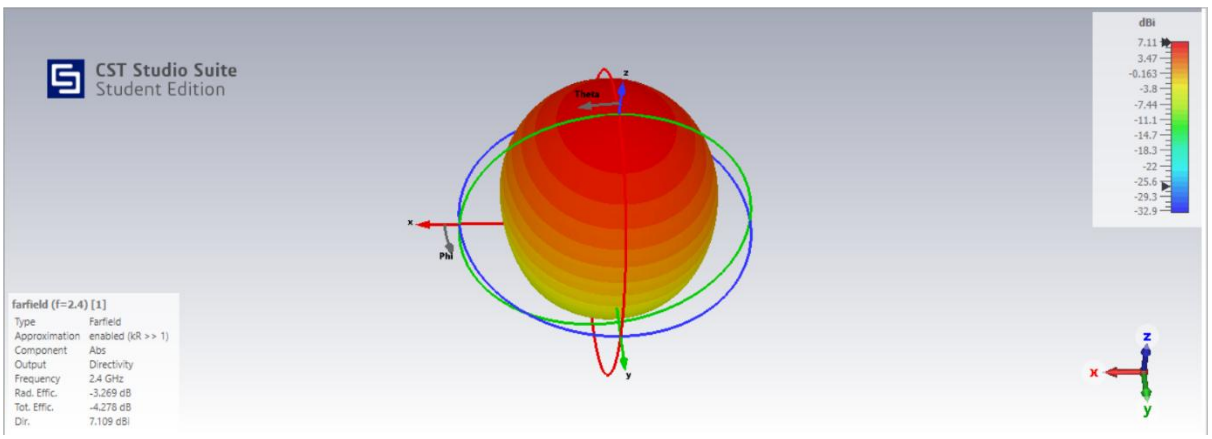


Figure 3.7: Far field cuts at f=2.4Ghz

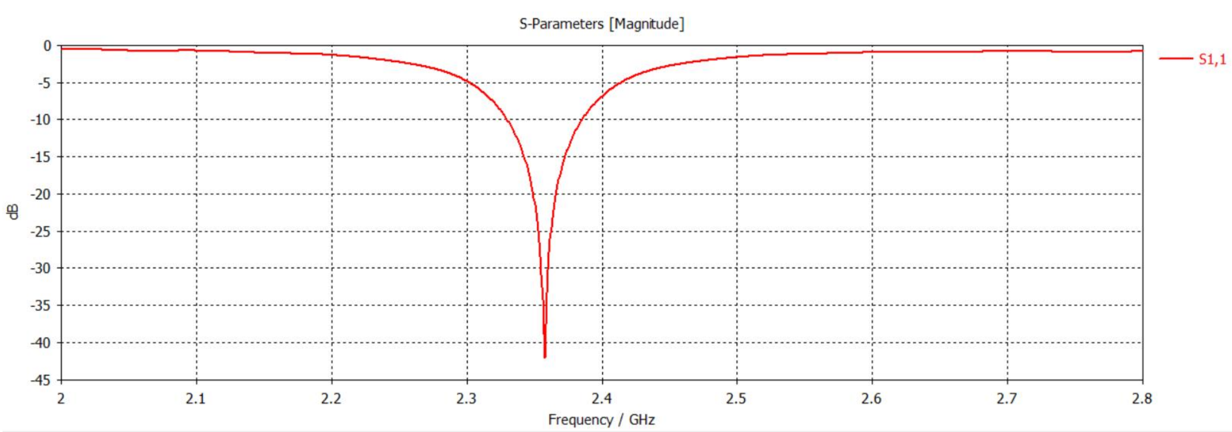


Figure 3.8: S-Parameter result

4.2. TESTS AND RESULTS {Exemplary Design}:

a] Front View

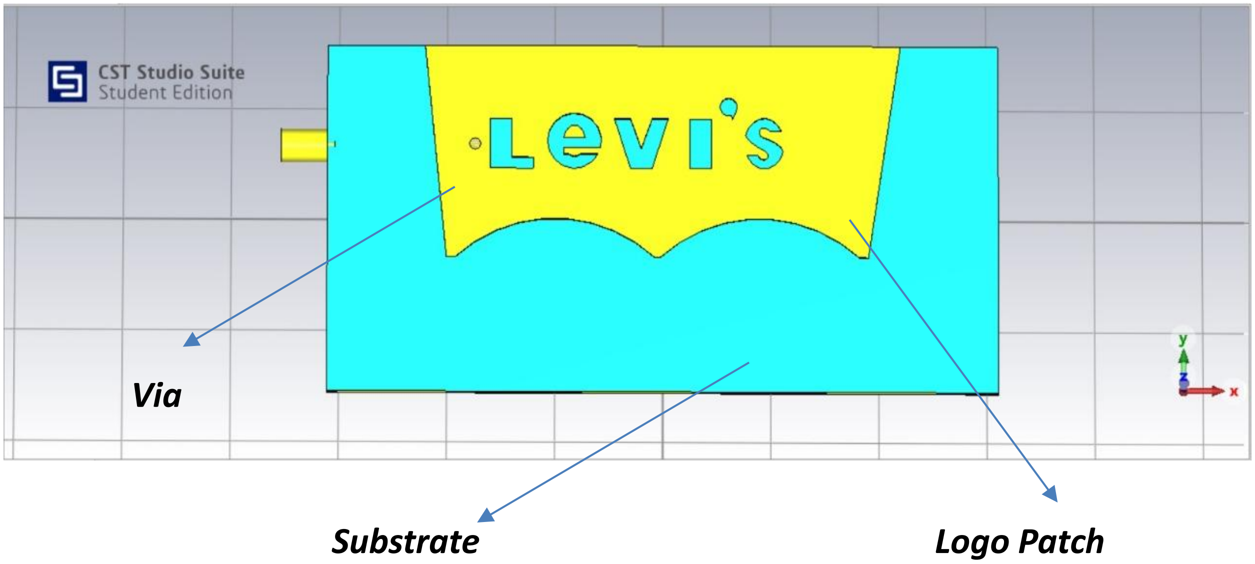


Figure 3.9: Front View

b] Back View

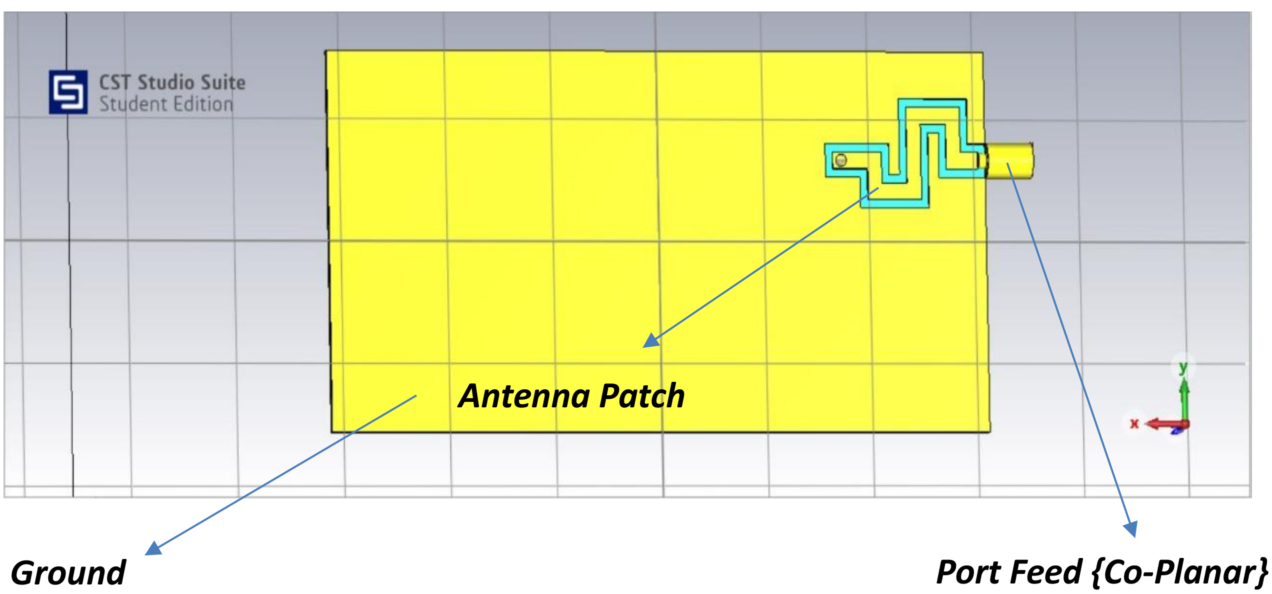


Figure 4.0: Back View

c] Antenna Design {Parameters}:

Parameter List

Name	Expression	Value	Description
subx	62.2	62.2	substrate L
suby	31.2	31.2	substrate W
h	0.15	0.15	copper H
h1	0.65	0.65	sub H
gndx	62.2	62.2	ground L
gndy	31.2	31.2	ground W
logox	44.1	44.1	logo L
<new parameter>			

Figure 4.1: Antenna Design Parameters

d] {Proposed Design} **with Same Parameters:**

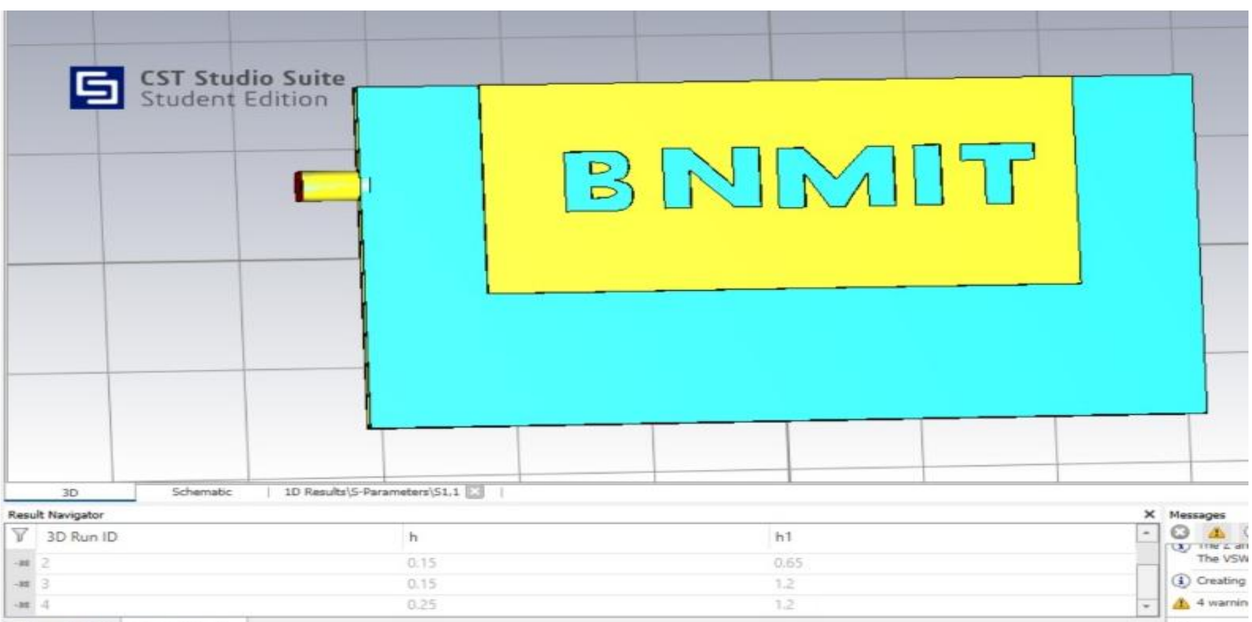


Figure 4.2: Our Design

e] Antenna Design Port {Coaxial Cable}:

Impedance Matching:

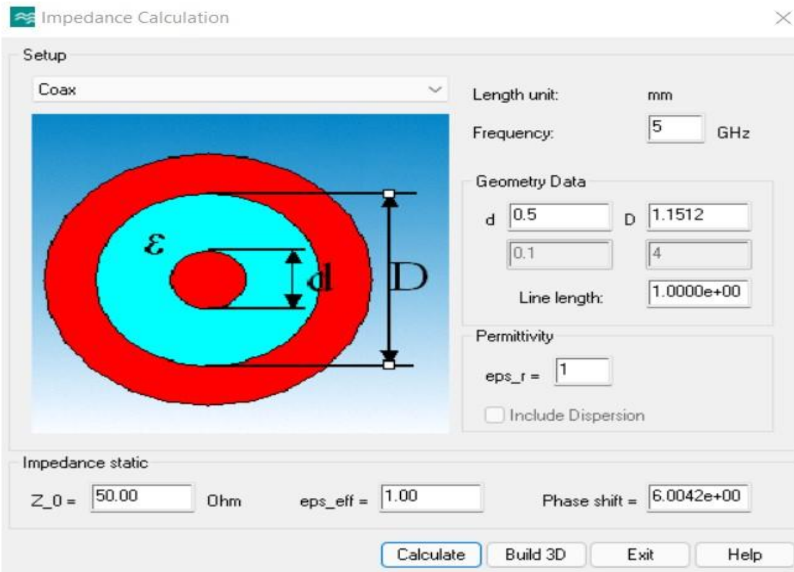


Figure 4.3: Impedance Matching

Coaxial Cable: {Design}:

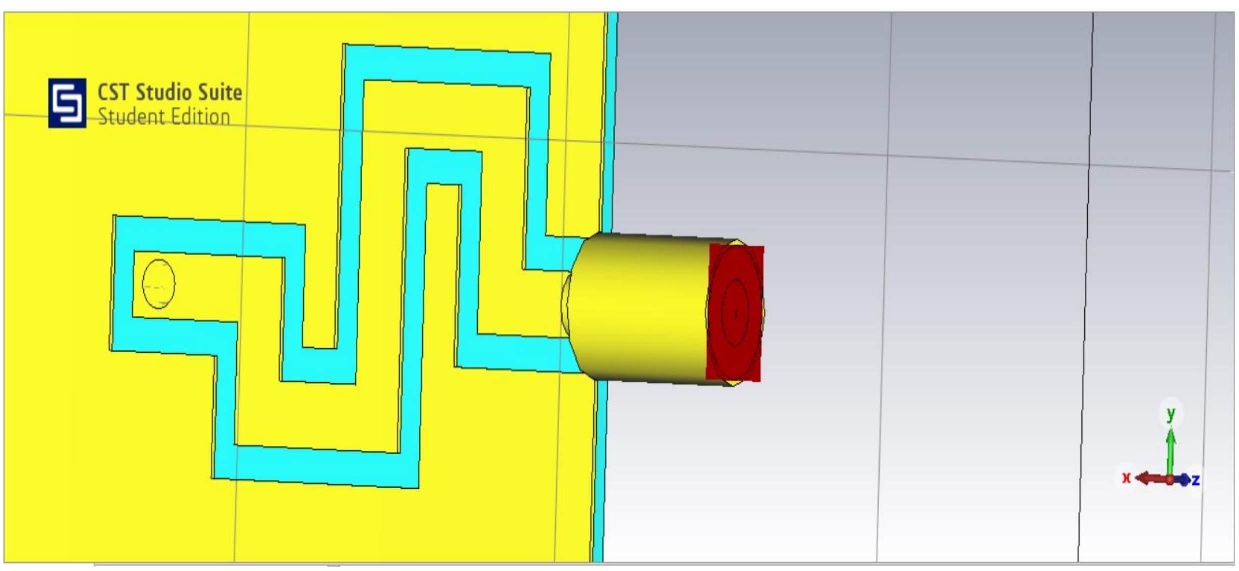


Figure 4.4: Coaxial Cable Design

4.3. Simulation & Observation:

a] S-Parameter [S11]-reflection coefficient:

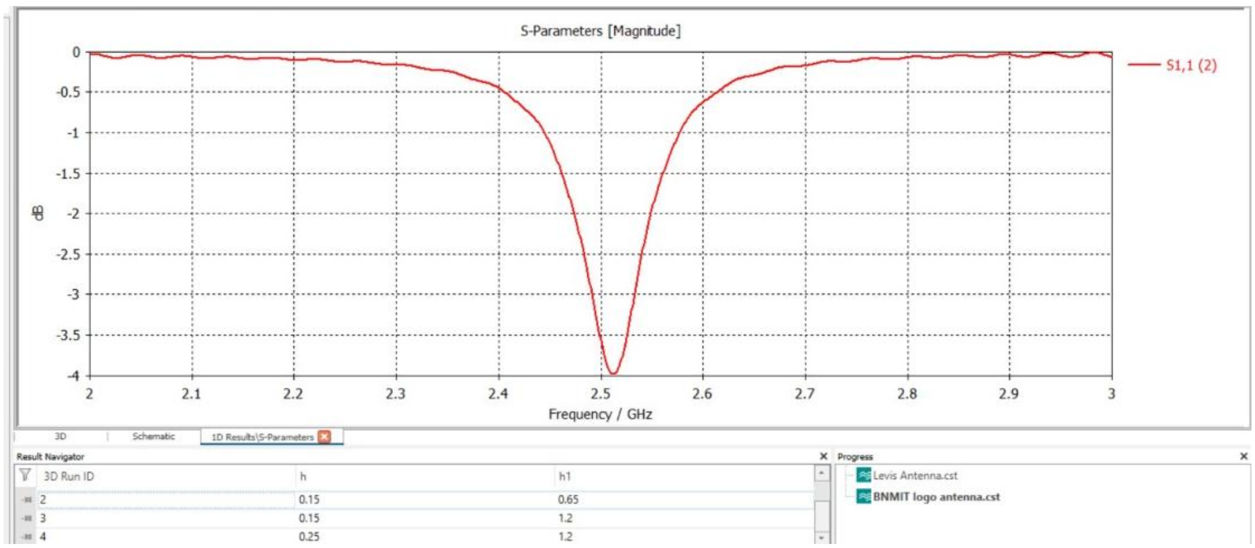


Figure 4.5: [S11] Parameter f=2.6Ghz

b] S11-Comaprison with respect to Modification in Dimension:

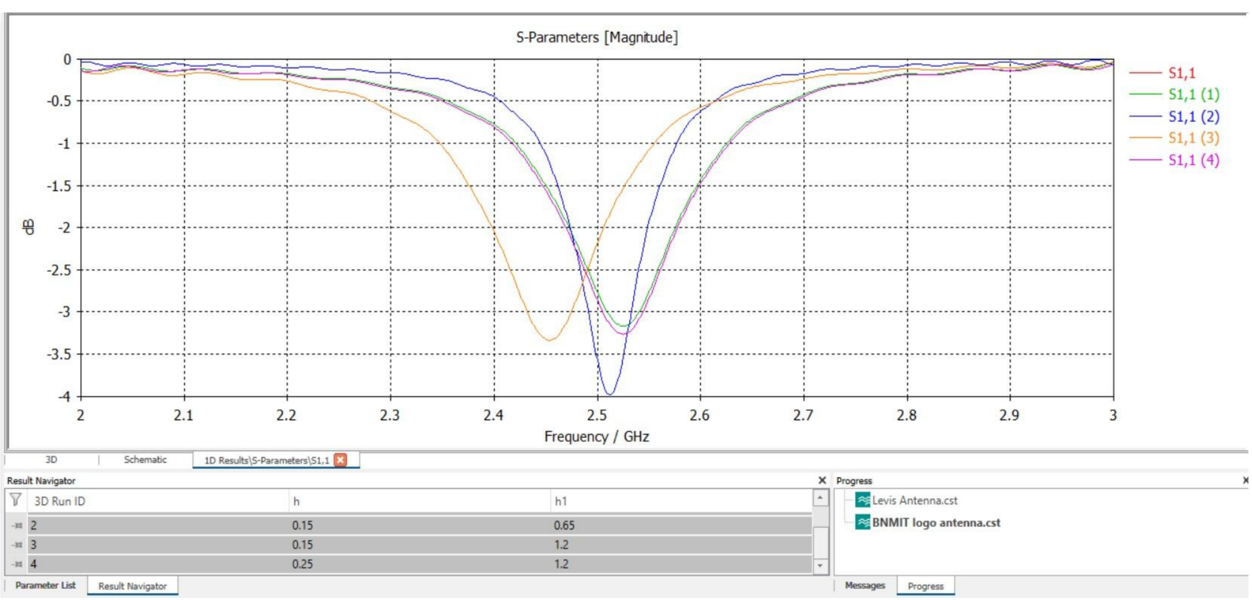


Figure 4.6: Comparison Results with varying {h,h1} parameters

c] Far-Field {f=2.5 GHZ}

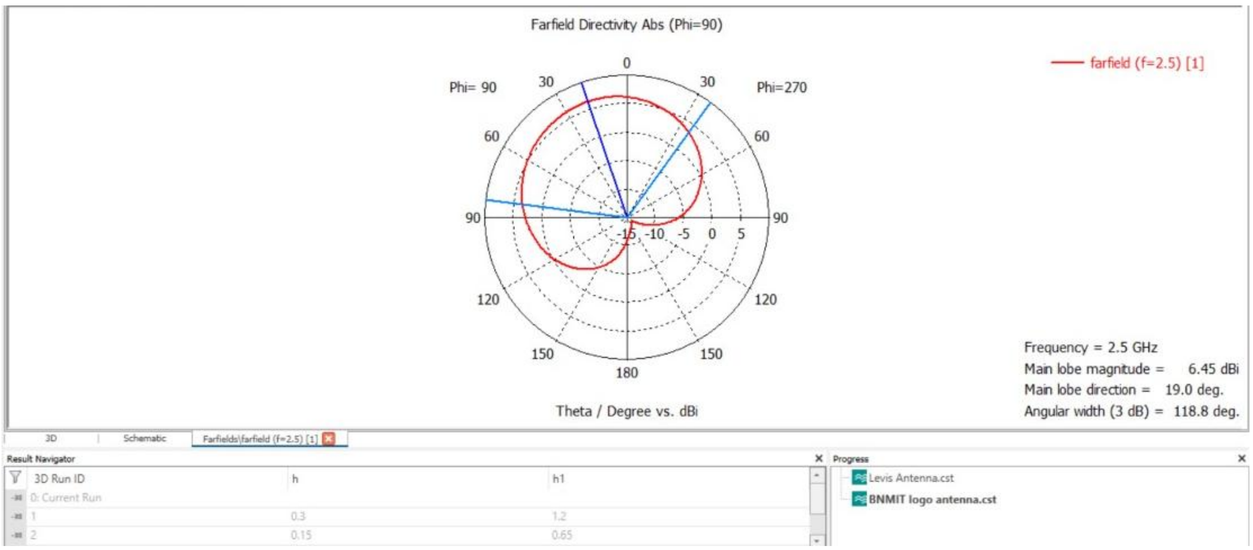
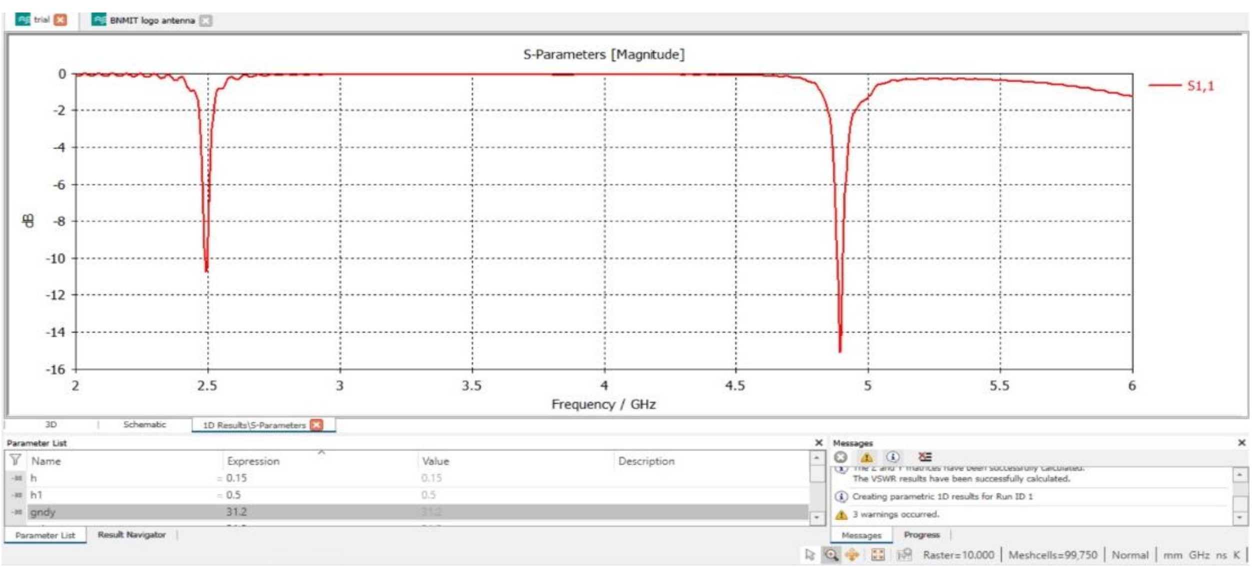


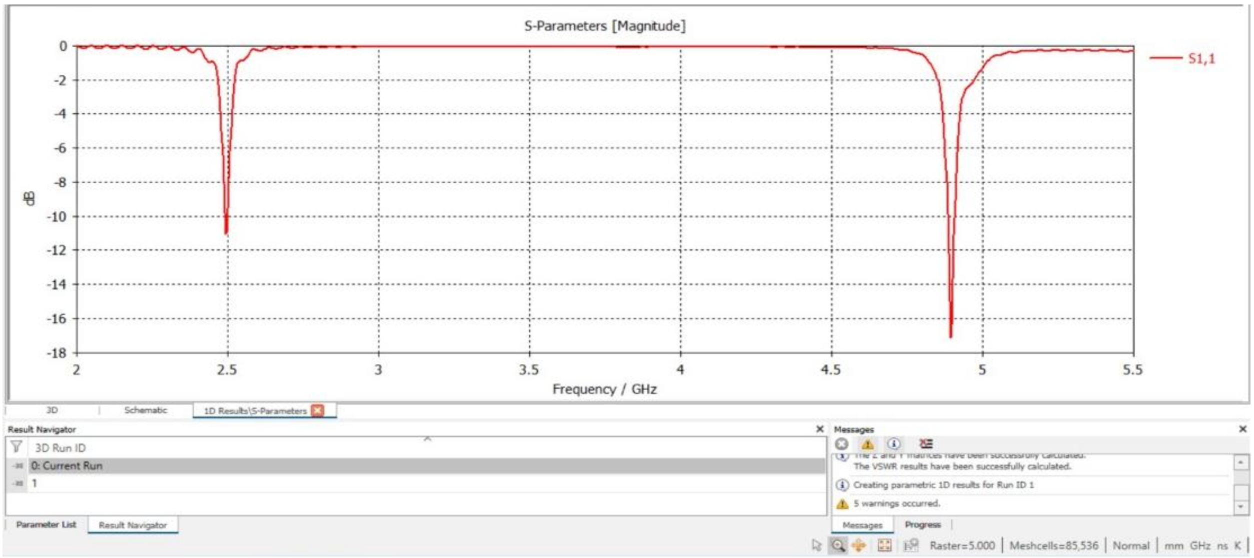
Figure 4.7: Far field cuts at f=2.5Ghz

S-Parameter{S11 for Denim}

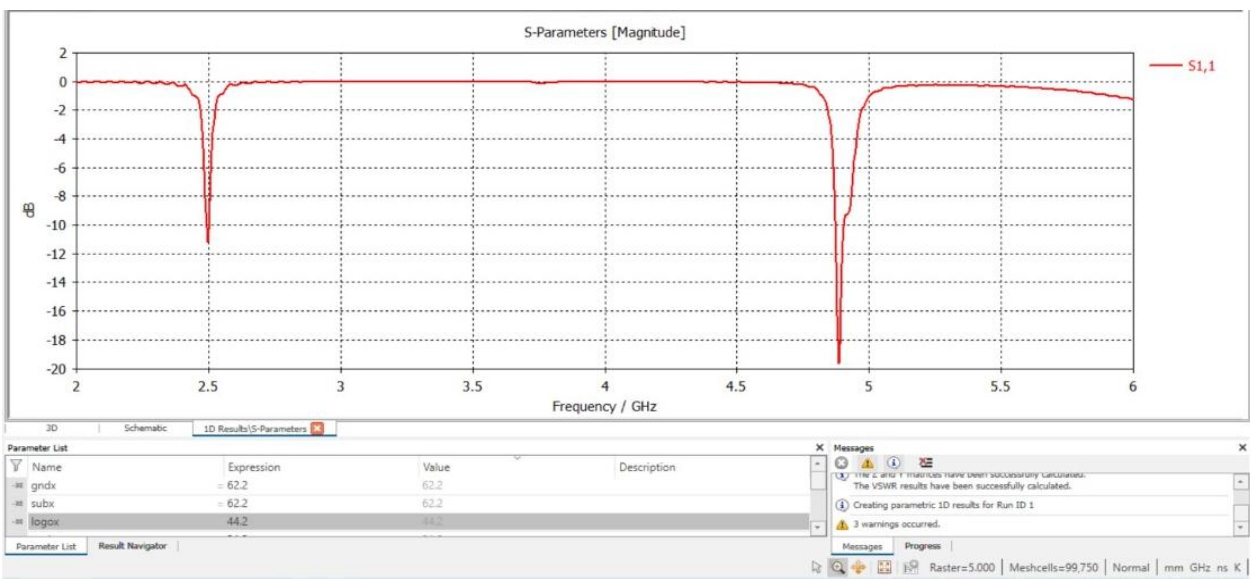
Result for Logox = 44.2 and Logoy = -3.6 parameter



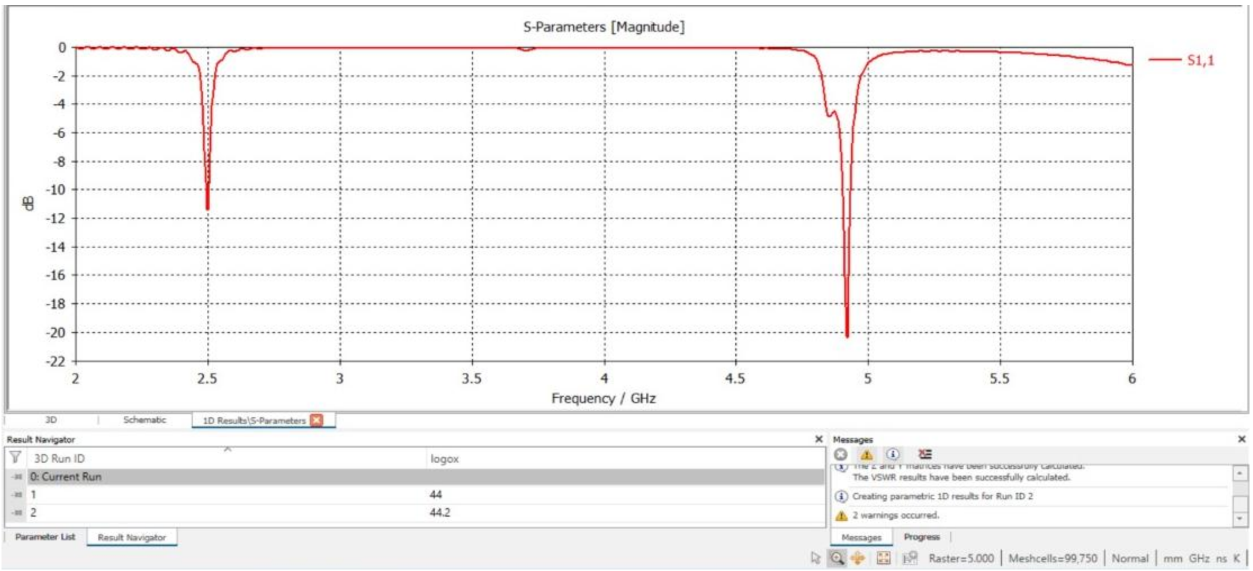
Result for Logox = 44.2 and Logoy = -4.8 parameter



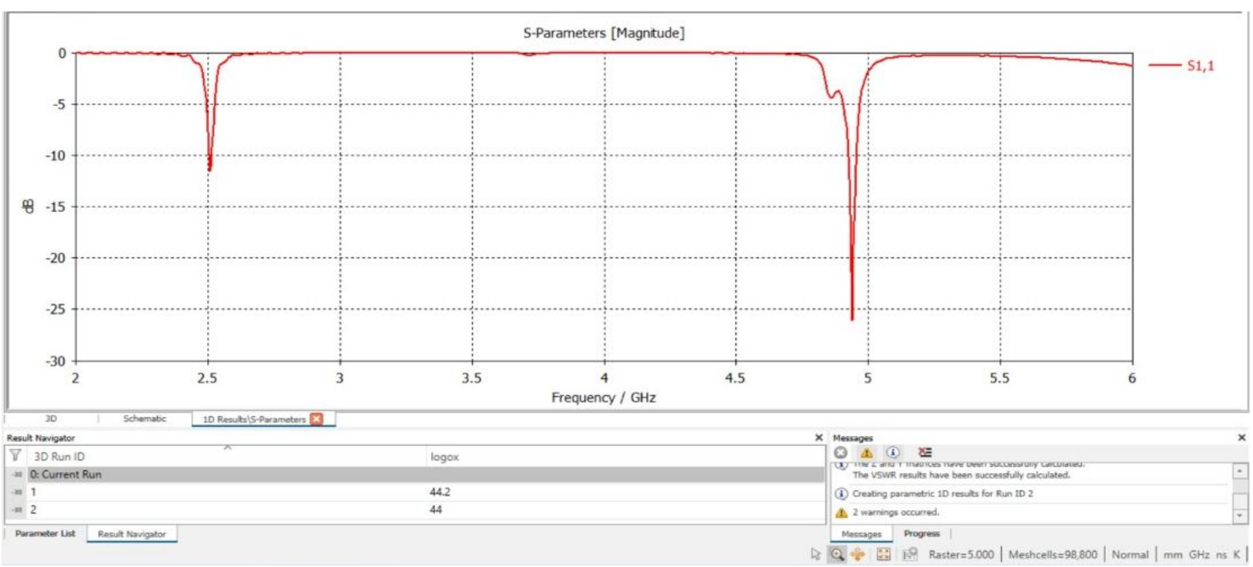
Result for Logox = 44.2 and Logoy = -4.5 parameter



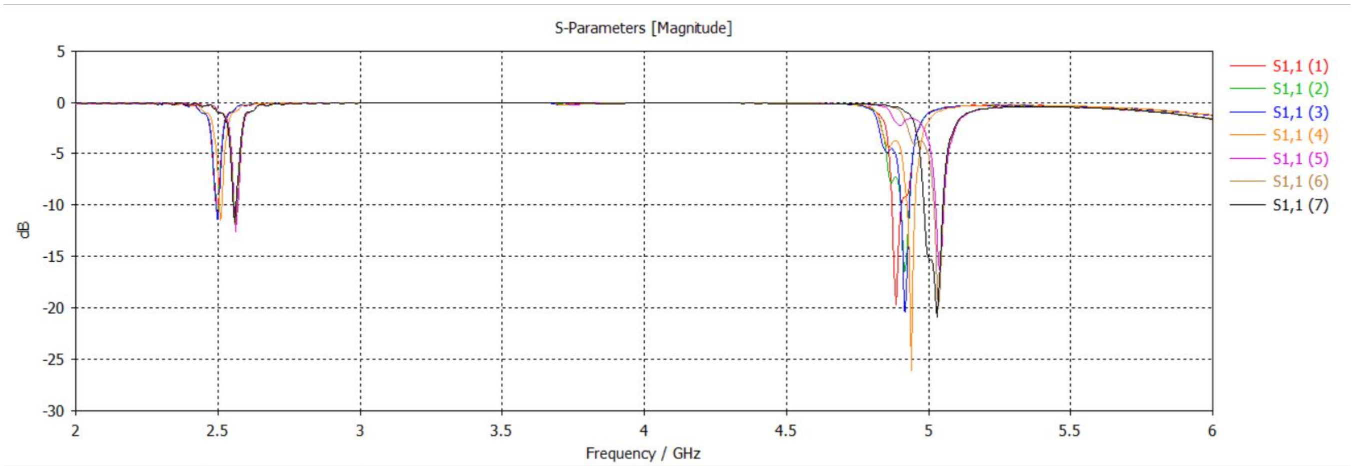
Result for Logox = 44.2 and Logoy = -5 parameter



Result for Logox = 44 and Logoy = -5 parameter



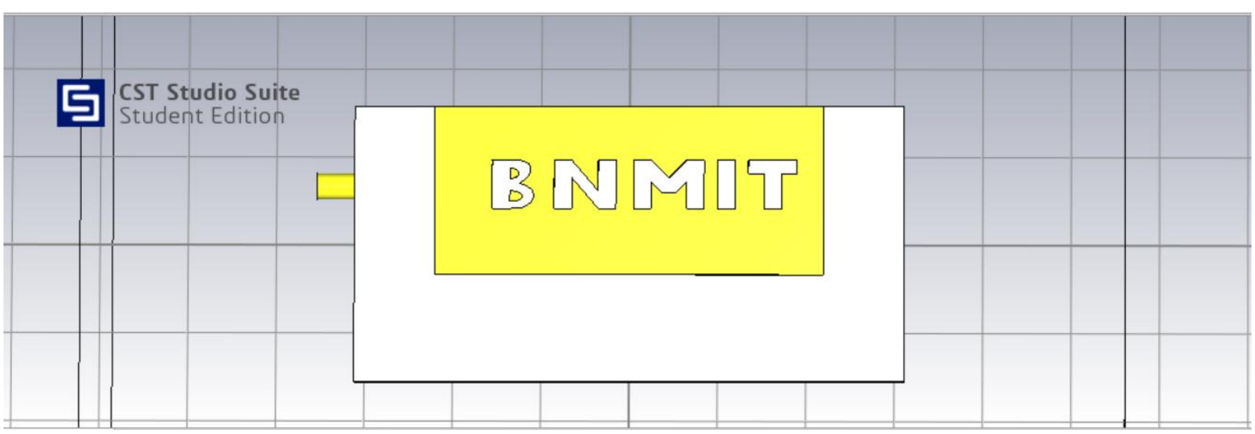
S11 parameters observation for various dimensions

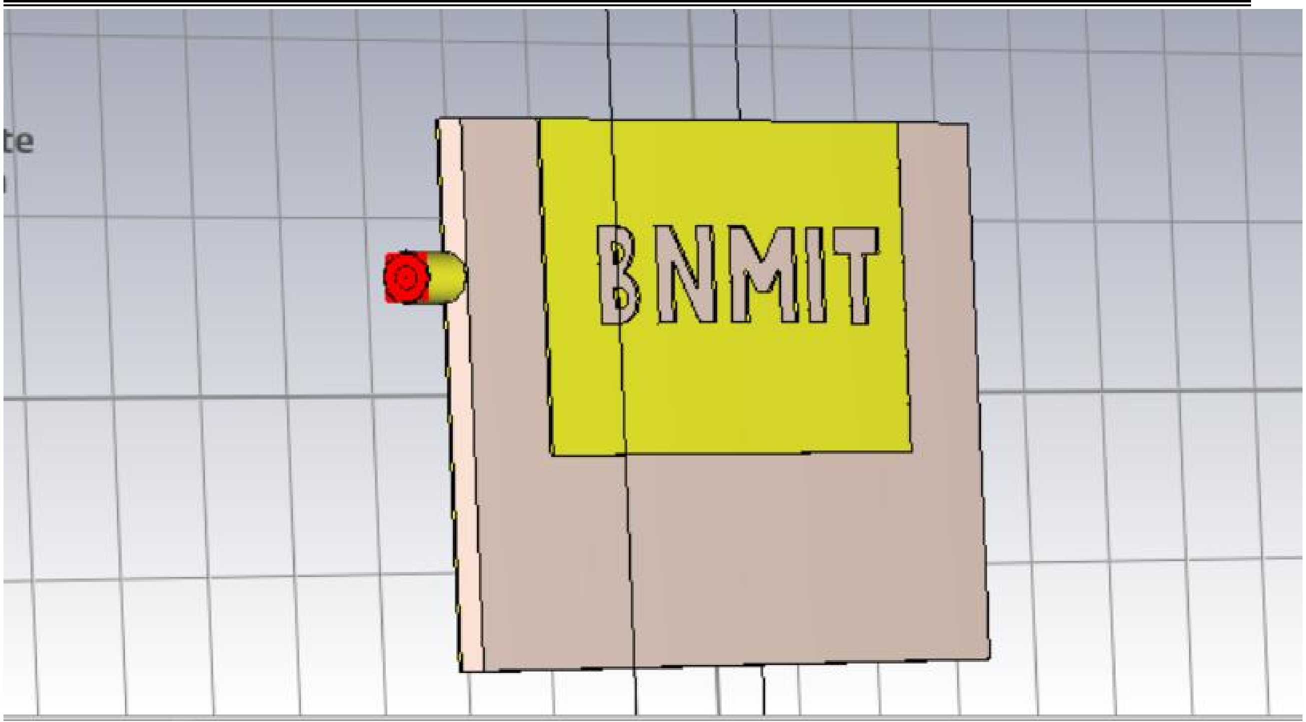


Result Navigator

3D Run ID	logoy	logox
0: Current Run		
1	-4.5	44.2
2	-4.8	44.2
3	-5	44.2
4	-5	44
5	-5	43
6	-4.5	43
7	-4	43

Design and result for FR4 material [Er=4.3]





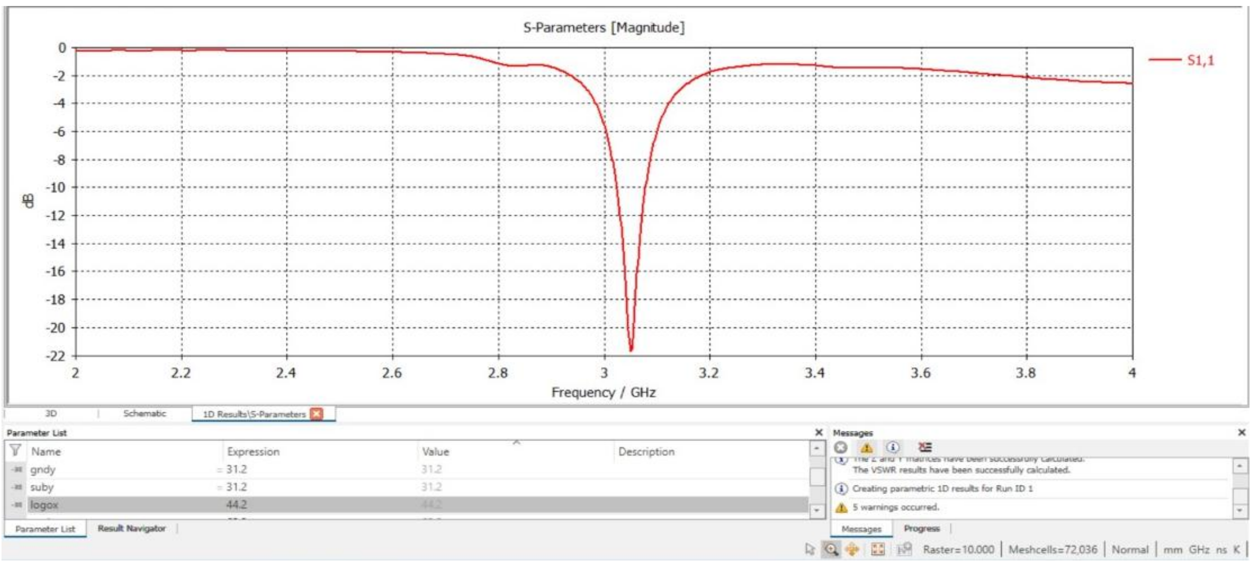
Parameter List

Name	Expression	Value	Description
h	= 0.15	0.15	Copper Thickness
gndy	= 31.2	31.2	Ground width
logoy	= -3.5	-3.5	Logo width
h1	= 1.57	1.57	Substrate Thickness
gndx	= 62.2	62.2	Ground length
logox	= 44	44	Logo length
subx	= 62.2	62.2	Substrate length
suby	31.2	31.2	Substrate width

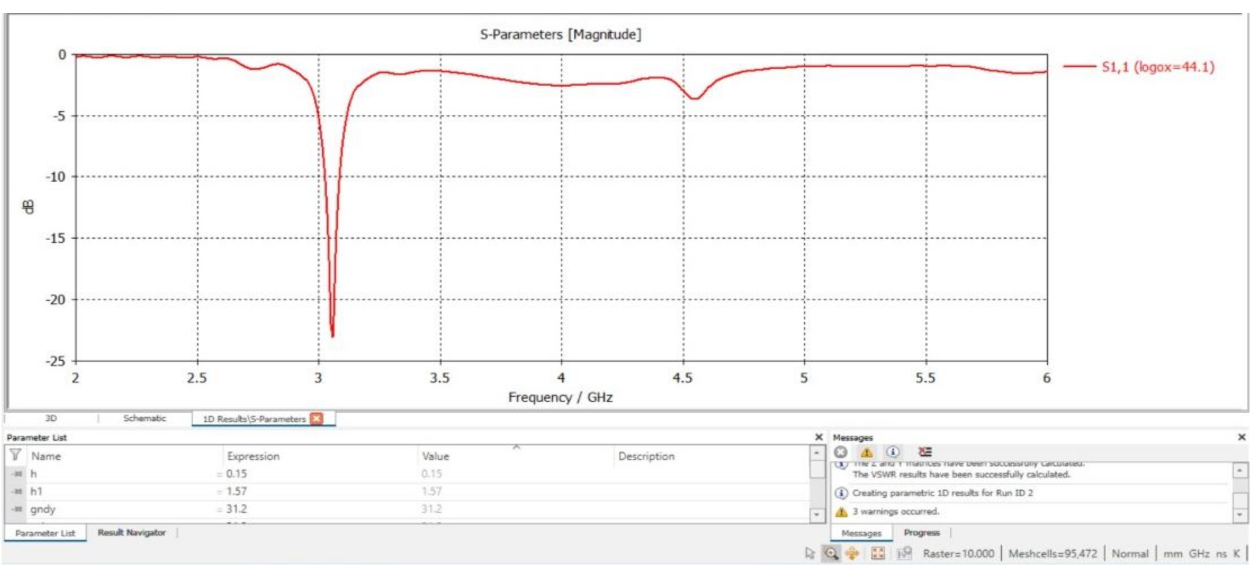
Parameter List | Result Navigator

S-Parameter {S11 for FR4}

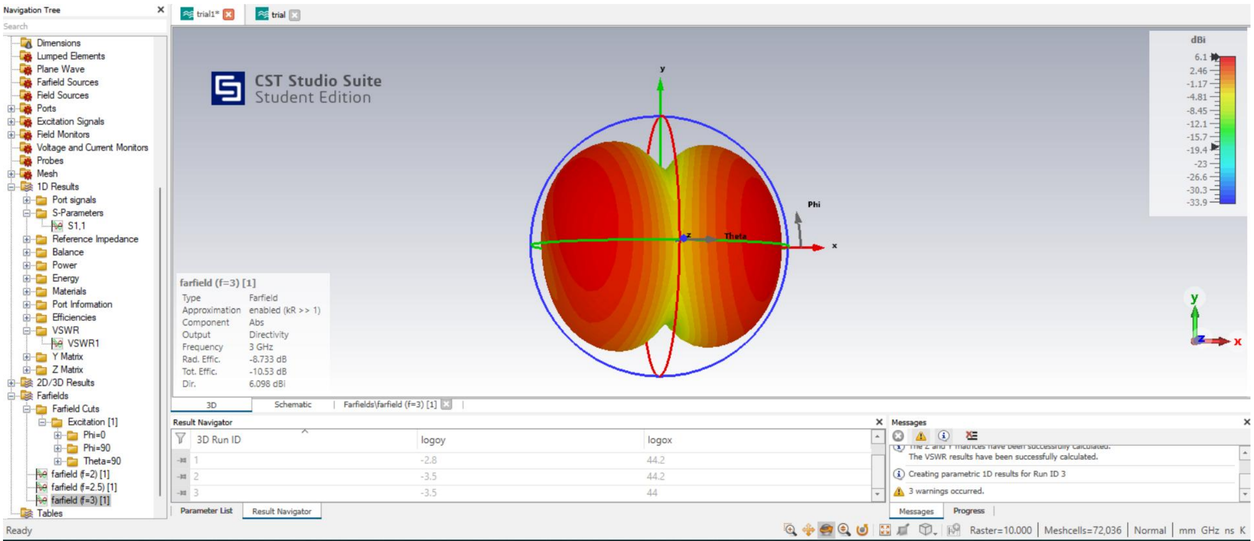
Result for Logox = 44.2 and Logoy = -2.8 parameter



Result for Logox = 44.1 and Logoy = -3.6 parameter



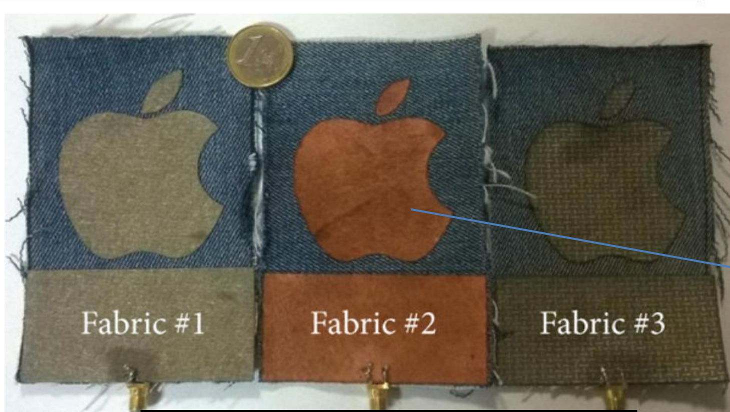
Farfield (f=3)



4.4. Fabrication Techniques {NWFC}

a] Comparison of Fabrics:

	NWCFs	Conductive material Threads	Electro-textiles	Inks
Conductivity	High	Low	High	Low
Spatial resolution	High	High	Low	Low
Fraying	No	No	Yes	No
Washability	Yes	Yes	Yes	Yes
Cost	Low	High	High	Low
Ref.	This work	[13]	[24, 25]	[26–29]



DENIM-*NWCF's*

Figure 4.8: Fabrication Technique

CHAPTER 5

5. CONCLUSION

In this work, the fabrication of wearable antennas that could be integrated with sensors for remote monitoring of elderly people was addressed. In particular, two different fabrication methods are described in detail: one resorts to the combined use of adhesive-backed nonwoven conductive fabrics and of a cutting plotter, whereas the other manufacturing technique resorts to the embroidery of conductive threads. Numerical and experimental results related to the design, fabrication, and characterization of wearable antennas obtained with the considered fabrication techniques were reported and commented on. Results demonstrated that the presented manufacturing methods are very flexible and can be effectively used to obtain a low-cost wearable antenna with performance tailored for the specific application at hand.

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