Performance analysis of compact E-Shaped Microstrip Patch Antenna for Wireless Body Area Network

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ABSTRACT

With the recent development of Wireless Body Area Networks (WBAN), wearable antennas have become a interesting topic for academics. WBAN makes it possible to monitor and identify physical changes in the human body and its surroundings through the integration of contemporary technology, electronics downsizing, and low-power sensor nodes inside and outside the body. Nonetheless, there are significant design issues with body worn antennas because the majority of applications require low-profile, dependable, and lightweight antennas. Wearable technology has also benefited greatly from the microstrip patch antenna. An E-shaped slotted microstrip wearable antenna is presented in this research. The substrate material is FR-4, which is 1.7 mm thick and has a relative permittivity of 4.3. The developed antenna features a decreased Specific Absorption Rate (SAR) of 0.383 W/Kg, a 224 MHz bandwidth, 4.83 dB directivity, and a return loss of -28.7 dB. Therefore, using this antenna on the body is permitted. Using CST Microwave Studio, the suggested 2.45 GHz rectangular patch antenna is designed. At 2.45 GHz, the VSWR of 1.01 is appropriate for matching impedances. The dimensions of the antenna are 21 mm x 31 mm x 1.7 mm. The developed antenna is perfect for health monitoring applications since it is flexible, small in size, and offers superior performance parameters than the current antennas.

Keyword—*WBAN, SAR, Wearable antenna, FR-4, ISM band*

1. Design of compact E-Shaped Microstrip Patch Antenna for Wireless Body Area Network

WBAN has grown tremendously during the past few years. WBAN is a recently developed wireless technology that is used for wireless communication inside or on the body for applications such emergency rescue systems, physical training, tracking, and health monitoring for people of various ages. Wearable antennas are those that operate in close proximity to a person's body, absorbing specific transmitted energy and decreasing the antenna's efficiency. An external antenna or other wearable antennas on the body can communicate with one another. This type of network is known as WBAN. Because the microstrip patch antenna may be conformably incorporated into clothing, it is a great option for wearable technology. When there is a broad ground plane present, it may provide excellent directivity. Microstrip patch antennas provide significant advantages in portable and medical monitoring applications. Among the many benefits of microstrip patch antennas are their small size and great degree of flexibility. Wearable antennas for networking applications like mobile computing, public safety, tracking, and navigation would be included into clothes. A variety of wearable sensors are implanted or applied to the human body to collect data on vital signs like blood sugar, temperature, and pulse. Data on various physiological markers is gathered by wearing sensors and transmitted to wearable devices. The medical data is subsequently sent via sensors at a lower frequency to the receiving antenna. After obtaining medical data, all sensor data from the human body is collected and sent to an external computer. In order to improve treatment standards, a physician will assess each patient's condition whether they are in a hospital or a remote location and promptly prescribe medication .Microstrip patch antennas are currently the most often used in wireless transmission technology, especially in microwave systems, due to their appealing qualities. The microstrip patch antenna is lightweight, compact, and easy to make. It is inexpensive to produce and features top-notch performances. This slotted microstrip is easier to design as it has ground on one end and a patch on the other. The SAR value should be appropriate for wearable antennas under conventional limits. According to IEEE C95.1: 1999, the threshold value for 1 gram of tissue mass is 1.6 W/Kg.

1.1 PROBLEM DEFINITION

Significant challenge in the design and implementation of body wearable antennas is the interference and signal degradation caused by the human body itself. The human body, being a complex and dynamic environment, introduces various obstacles and changes in the radio frequency (RF) signal propagation, leading to degradation in communication performance. This issue is particularly critical in applications such as smart clothing, health monitoring devices, and communication wearable. Many researchers have been attracted to the topic of the wearable antenna as a result of the recent advent of Wireless Body Area Networks (WBAN). WBAN enables modern technological integration, miniaturization in electronics, and low power sensor nodes in and around the body to monitor and recognize physical changes in the human body and the surrounding environment. Body wearable antennas, however, have certain design problems because most applications demand antennas to have been lightweight, reliable, and low-profile. The microstrip patch antenna has also made a significant contribution to wearable technology. The challenges posed by the human body in wearable antenna design require an approach.

1.2 AIM AND OBJECTIVES

Recently, a variety of antennas have already been proposed to be used with WBAN. The proposed antenna is being designed with the goal of achieving the lower human body SAR models while taking into account both the electromagnetic impact and the human tissue shell model. The antenna is based on the FR4 substrate at 2.45 GHz. This antenna is appropriate for ISM bands for its frequency. The substrate is FR-4, which is an excellent low-frequency choice and a commercially available manufacturing material. The return loss and gain of the antenna are enhanced by employing slots.

The ground plane, dielectric substrate, and microstrip patch are all part of the antenna design. Because of its lower weight, easy processing, and ability to transmit data at fast speeds, the microstrip patch antenna is utilized. The substrate thickness, dielectric constant, and operational frequency are taken into consideration while estimating the antenna dimensions. In antenna design, patch width, patch length, ground width, and ground length must all be calculated.

For the WBAN application, the proposed antenna has better performance parameters. The designed antenna has a uniquely compacted structure. Compared to existing biomedical antennas, the designed antenna is smaller. Because of its compact size, suitable radiation & performance, the presented antenna is a good contender for ISM applications. As a result, biomedical applications such as tumor and disease detection, real-time patient tracking can benefit from this antenna.

2. Methods that aim to Design of Compact E-Shaped Microstrip Patch Antenna for Wireless Body Area Network.

[1] For WBAN applications, an on-body circular-ring patch antenna with a shorting via is suggested. In the 2.45 GHz industrial, scientific, and medical (ISM) band, the suggested circular-ring patch antenna offers the highest radiation direction along the body surface for on-body communication. The suggested antenna excited TM 31 mode at ISM 2.45 GHz using shorting vias in order to obtain a low profile. An annular ring with shorting via is placed closely around a circular patch to improve bandwidth performance. The proposed antenna is fed through a microstrip line that is coupled to a via. The suggested antenna's overall dimensions are 60 mm x 65 mm × 3.15 mm.

[2] The body area networks (BAN) paradigm is one of the innovative advancements in health monitoring technologies brought about by the sharp rise in healthcare demand. The goal of BAN technology is to create a network of constantly functioning sensors that monitor vital physiological and physical characteristics including heart rate, glucose levels, and mobility. The popularity of BAN technology is largely due to wireless networking, which gives users mobility and flexibility. Although most BAN implementations have successfully incorporated radio frequency (RF) wireless technology, these systems have security flaws, high battery consumption, and are

vulnerable to electromagnetic interference. An alternative wireless communication technique called intrabody communication (IBC) employs the human body as a medium for signal propagation.

[3] Due to the need for flexible, durable, and low-profile antennas in the majority of applications, body worn antennas are facing some design challenges. This study describes the design and fabrication of a wearable U-shaped slot dual-band microstrip feed antenna. It has been noted that another mode originates when a U-shaped slot of order λ/2 is cut. The antenna that is being proposed has a gain of 8.29 dB at 2.425 GHz and 7.442 dB at 5.75 GHz. This antenna can be utilized for WLAN/Wi-Fi and WBAN (wireless body area network) applications because of its great gain and directional pattern.

[4] An important area of research focus is the proper narrowband antenna design for wearable devices in the biomedical application. This paper proposes a microstrip patch antenna based on a defective ground construction that may be used in narrowband applications. The suggested antenna is ideal for a single ISM band channel. The antenna's resonance frequency is 2.45 GHz, and its return loss is about -30 dB. The antenna's -10dB impedance bandwidth is 20 MHz (2.442-2.462 GHz), or the bandwidth of ISM band channel 9.

[5] Due to the growing use of wireless networks and other electrical equipment, wireless body area networks are being utilized extensively. WBAN applications can be improved by using a wearable patch antenna. In this research, a low profile wearable microstrip patch antenna is constructed and proposed to use wireless body area network (WBAN) technology for continuous monitoring of human vital signs, including blood pressure, pulse rate, and body temperature.

[6] The globe is currently struggling with the innovative technology of wireless communication. The increasing use of electrical devices and wireless networks has led to the widespread adoption of wireless body area networks. WBAN has connected various devices to the human body by placing them on the body. Several WBAN applications are enhanced by the wearable antenna. This work presents a low-profile wearable antenna using WBAN for continuous human indicator monitoring, including skin temperature, blood pressure, and pulse rate. FR-4 material is used to create a tiny, flexible antenna with a low profile. Operational frequency of the antenna is 2.45 GHz; return loss is less than -10dB.

[7] We design and demonstrate a miniature textile antenna for 2.4 GHz ISM band applications. The suggested antenna creates an inverted E-shaped antenna by appropriately loading a rectangular slot or notch and inserting a strip line. The construction is straightforward, small, and simple to assemble from fabric alone. The antenna is 75% smaller than a typical antenna in size. The antenna's performance remains stable even with distortion when it is bent. To create the whole equivalent circuit of the suggested antenna, each slot, notch, and strip line is converted to its corresponding circuit and then integrated.

3. ANTENNA DESIGN

3.1 Antenna Specifications

The antenna design includes the dielectric substrate, microstrip patch, and ground plane. The microstrip patch antenna is used because it is lightweight, simple to manufacture, and has a high data transmission rate. When determining the antenna dimensions, the operational frequency, dielectric constant, and substrate thickness are taken into account. When developing an antenna, it is necessary to first choose the resonant frequency and the antenna's dielectric material.4.3 is the substrate's dielectric constant. It is also 1.7 mm thick. Calculations are required for antenna design in relation to patch width, patch length, ground width, and ground length. This formula can be used to find the patch width (W).

$$W = \frac{Co}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where, εr= Dielectric constant of the substrate, co = Light velocity, and fr is the frequency of resonance.

There are several ways to compute the patch's length, L. The first unknown to be found is the effective dielectric constant. The real dielectric constant of the substrate would have been more closely matched by the effective dielectric constant. The effective dielectric constant can be found in the following equation.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{1}{2}}$$

Therefore, the real length increment (ΔL) of the patch needs to be calculated using the following formula (3). This might be used to find the resonance frequency of the microstrip antenna.

$$\Delta L = 0.412\, h \frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

The patch's actual length (L) will now be determined using the actual length increase.

$$L = \frac{Co}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L$$

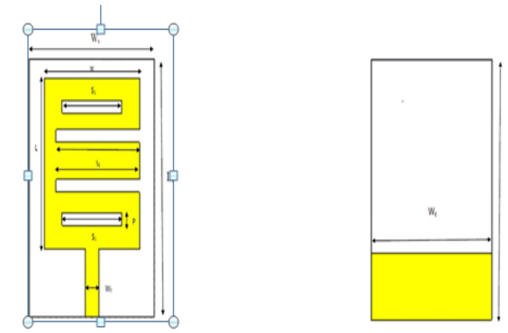
Regardless of the material, a patch antenna design requires a defined ground plane. The ground's length (Lg) and width (Wg) are calculated using this method. Lg = 6h + L & Wg = 6h + W

To calculate the breadth and length of the ground, one must know the patch’s width and length. The substrate height is considered in every scenario.

Parameters	Values (mm)
Ground width, Wg	21
Ground length, Lg	8
Substrate width, Ws	21
Substrate length, Ls	31
Patch width, W	16
Feed-line Width, Wf	2.3
Patch Length, L	22
Feed-line Length, Fi	7
Width of Slot, S1	10
Width of Slot, S2	14.5
Length of slot, P	1.5

TABLE I. Design elements & values of the antenna

Following optimization, Table I displays the design parameter values in a tabular style. The patch now has slots in order to enhance the performance metrics. The length and breadth of the antenna feed line are 7 and 2.3 mm, respectively. Fi represents the feed-line length that is used to build ports. The thicknesses of the substrate and conductor are 1.7 and 0.7 mm, respectively.



The proposed antenna from (a) the top (b) the bottom view.

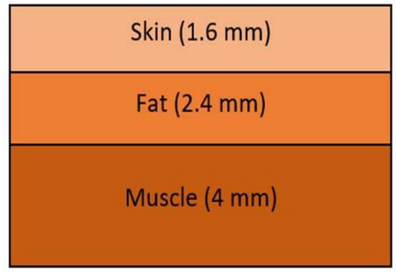


Fig. 1.The proposed antenna (a) the top (b) the bottom view. Fig. 2. Three-layered human phantom model.

Fig. 1 shows the antenna from both the top and bottom views after the ground and patch have been optimized. The antenna patch has an E shape to it. Copper is used for the patch and ground material. This antenna is constructed from the FR-4 substrate, which was selected due to its availability and flexibility.

A human phantom model with three layers is developed in order to calculate the specific absorption rate (SAR). A phantom model of the proposed microstrip antenna is used to study the SAR influence around an individual's body. The effectiveness of the antenna as a biomedical antenna is assessed using a three-layer human phantom model.
Skin, muscle, and fat are the human body tissues represented in the three-layered human phantom model. Skin, muscle, and fat in Fig-2 demonstrates respective diameters of 1.6 mm, 4 mm, and 2.4 mm.

The permittivity, density, conductivity, and loss tangent of human skin, fat, and muscle tissues are displayed in TABLE II. National and international organizations recommend values for the maximum allowed SAR provided by antennas in wireless devices. According to IEEE C95.3-1999, the maximum SAR in 1g of tissue mass cannot be greater than 1.6 W/kg.

Tissue	**Permittivity (εr)**	**Density(kg/m^3)**	**Conductivity (S/m)**	**Loss Tangent**
Skin	31.29	1100	5.0138	0.2835
Fat	5.28	1100	0.1	0.19382
Muscle	52.79	1060	1.705	0.24191

TABLE II. THE HUMAN BODY'S TISSUE PROPERTIES

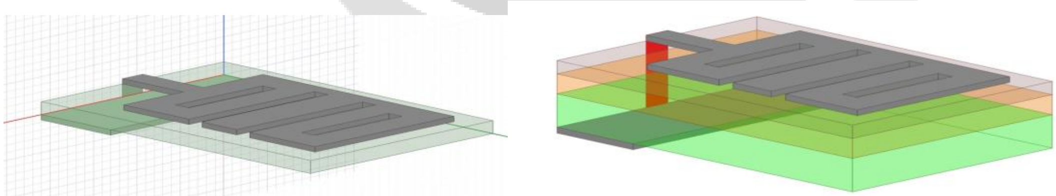


Fig 3 (a): E-shaped patch antenna design in HFSS without Phantom & (b) With Phantom

Antenna design without phantom and with phantom are presented in Fig 3 (a) and 3(b) respectively

4. Simulation & Results

4.1 Return loss

The S11 parameter, also known as return loss, is the most fundamental measure used to assess an antenna's performance. Return loss is a measure of reflected energy from an antenna. The power relationship between the input port and the output port is described by the scattering parameter. It varies with frequency and is frequency-dependent. There is no power radiated if S11 is 0. The return loss of the suggested antenna, both with and without phantom, is shown in Figs. 4 and 5.

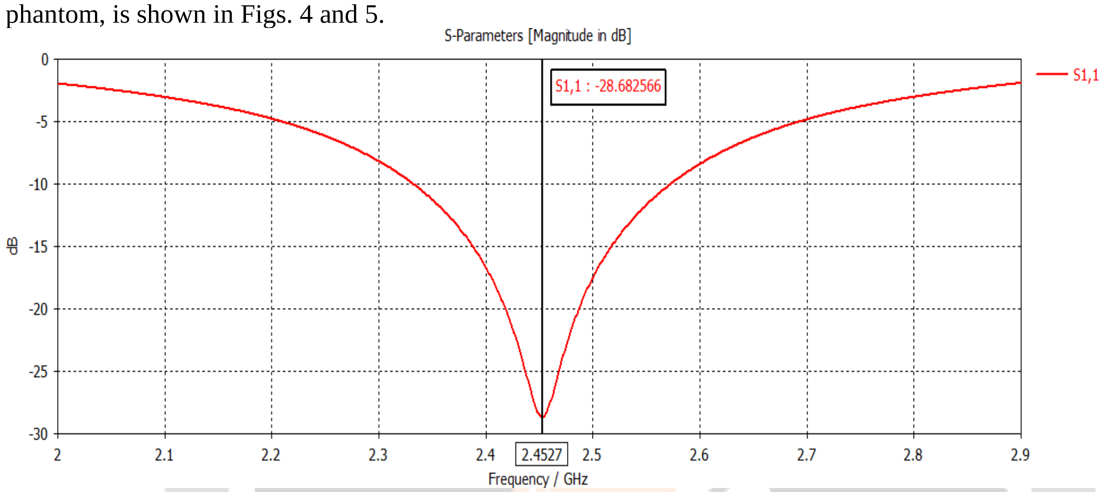


Fig. 4. The proposed antenna's return loss without phantom.

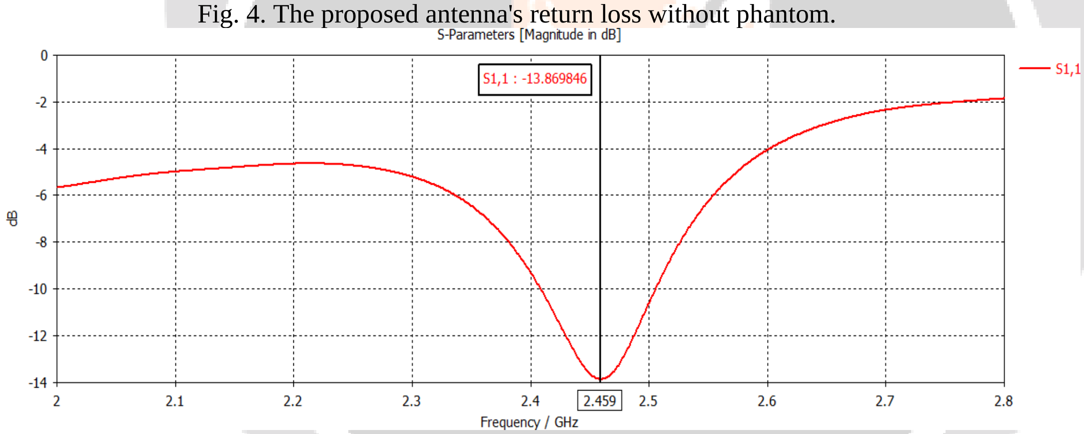


Fig. 5. The proposed antenna's return loss with phantom.

4.2 Antenna Bandwidth & VSWR:

The antenna bandwidth is defined as the frequency range where return loss is more than 10 dB. The bandwidth of an antenna is the range of frequencies over which it can operate as intended. The anticipated antenna bandwidth is 2.45 GHz, with a central frequency of 244 MHz without phantom and 98 MHz with phantom.

The standing wave ratio of voltage measures the relationship between the highest voltage amplitude and the lowest voltage amplitude in a standing wave. This parameter is used to match and tune the transmitting antenna. The amount of energy returned to the source is shown by the antenna's VSWR. When the number is 1, the antenna transmits all the power transmitted through it.

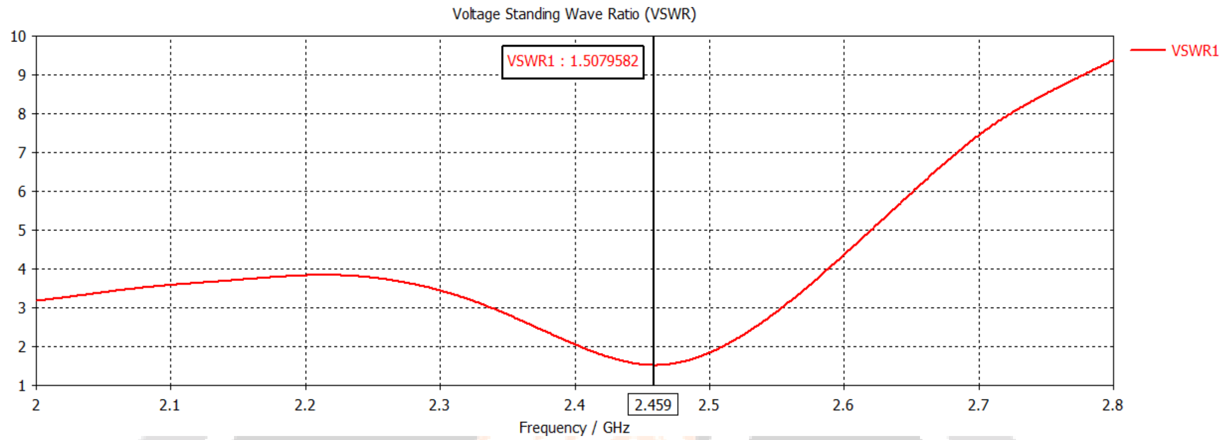


Fig. 6. The designed antenna's VSWR without phantom.

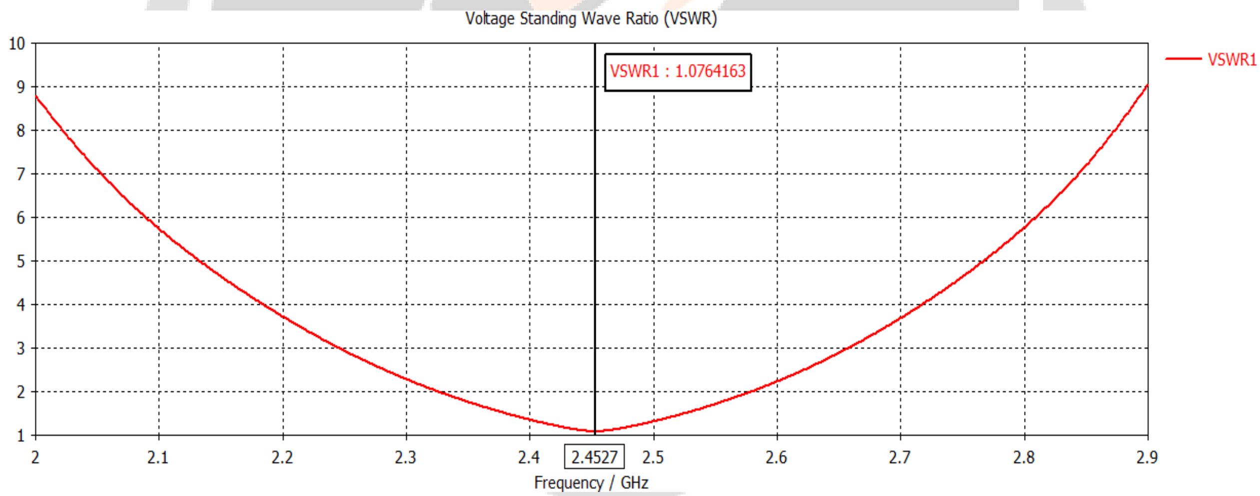


Fig. 7. The designed antenna's VSWR with phantom.

4.3 Radiation Pattern & Transmitted Power:

The antenna's radiation pattern represents the energy emitted by the antenna. A 3D radiation pattern represents a three-dimensional illustration of how an antenna radiates power through free space. Directivity is the quantity of energyradiated in a specific direction, usually the maximum energy.

The power transmitted to a particular direction from a 3Dradiation pattern is relatively simple to analyze. Fig. 8 and Fig. 9 describe the designed antenna's 3D radiation pattern for 2.45 GHz. Without phantom, the antenna's directivity is 2.03dB, while with phantom, it is 4.83 dB.

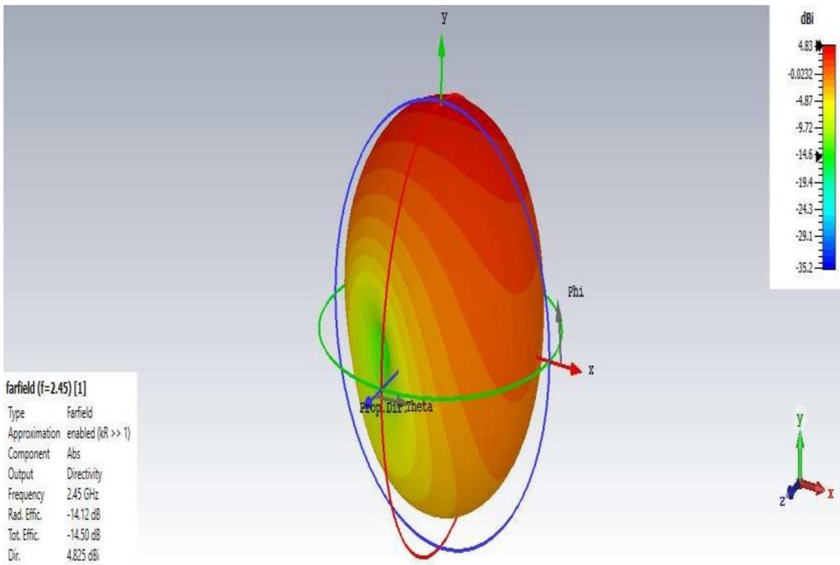


Fig. 8. The radiation pattern in 3D far-field view without phantom.

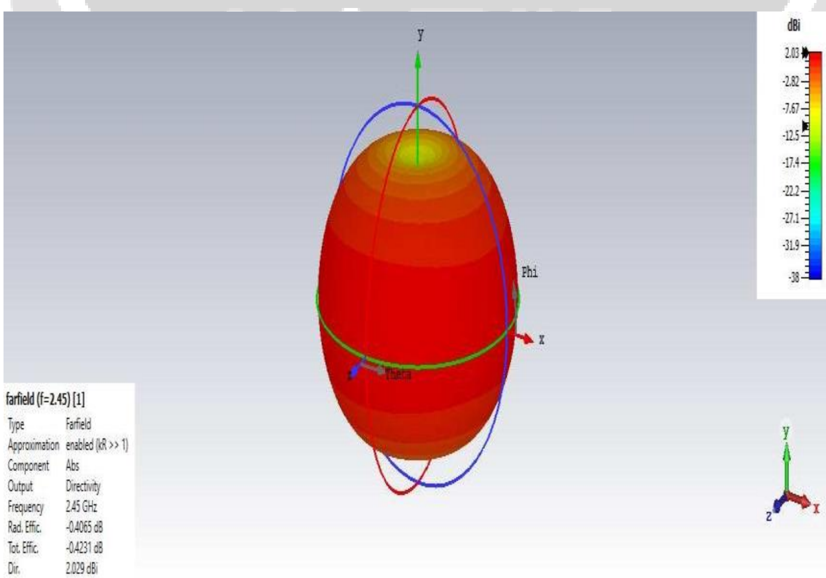


Fig. 9. The radiation pattern in 3D far-field view with phantom.

4.4: Polar Plot for far field

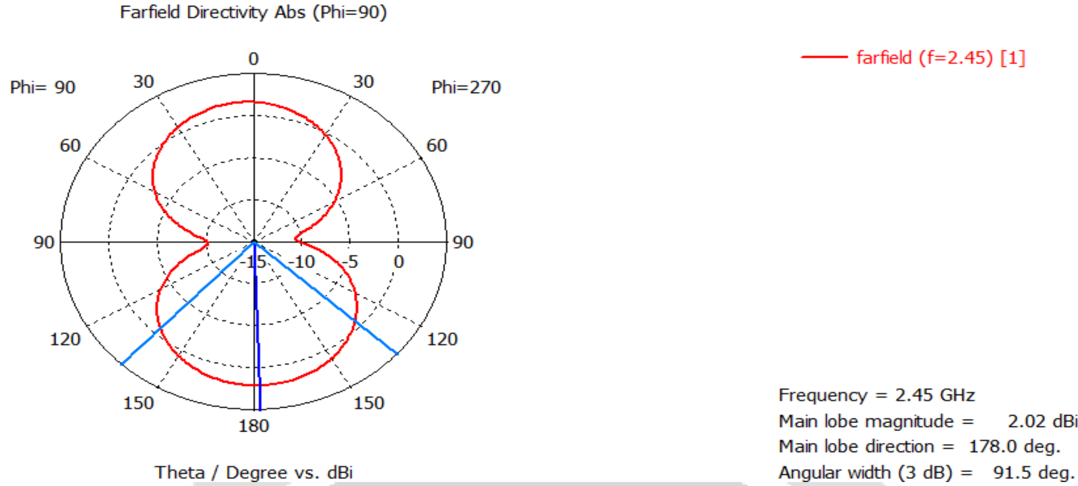


Fig 10. The designed antenna's 2-dimensional radiation pattern without phantom.

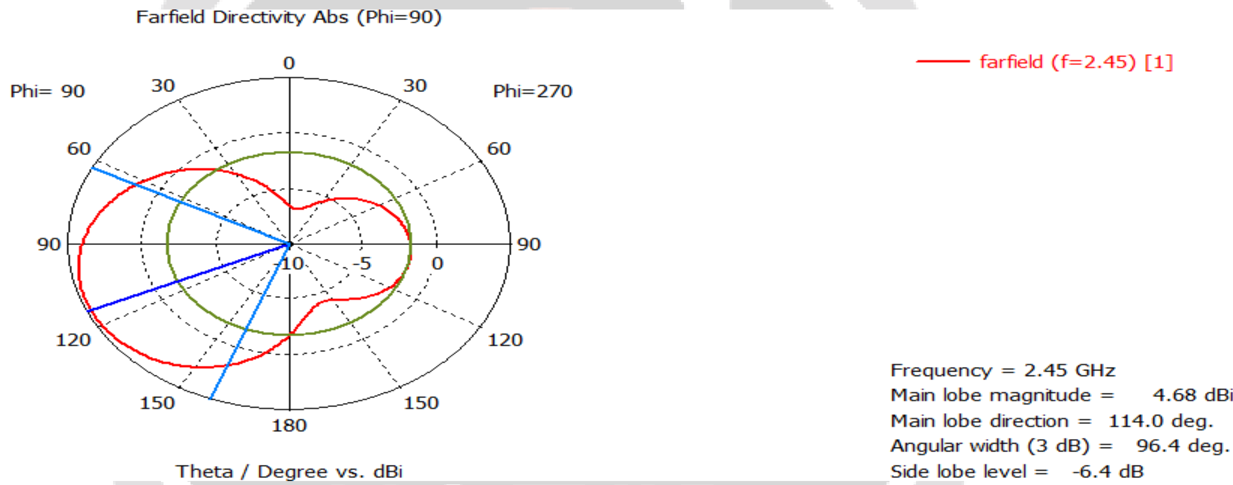


Fig. 11. The designed antenna's 2-dimensional radiation pattern with phantom.

Fig. 10 and Fig. 11 depict the polar representation of the far-field. Without phantom, the major lobe magnitude is 2.02dB, whereas with phantom, it is 4.68 dB.

4.5: Surface current distribution

By applying an electromagnetic field, a real electric current is induced. The electric field causes charges to move around.

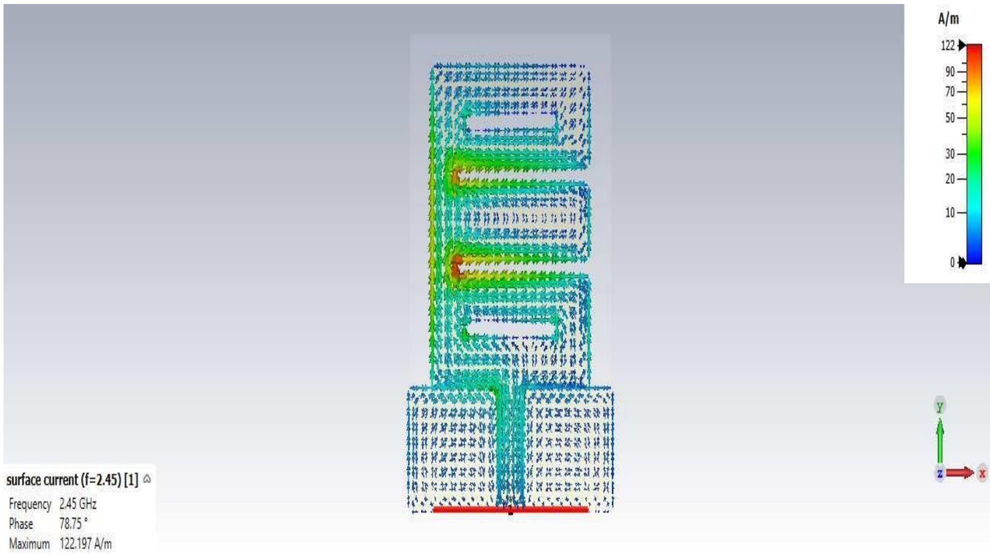


Fig. 12**.** Surface current of the antenna without phantom.

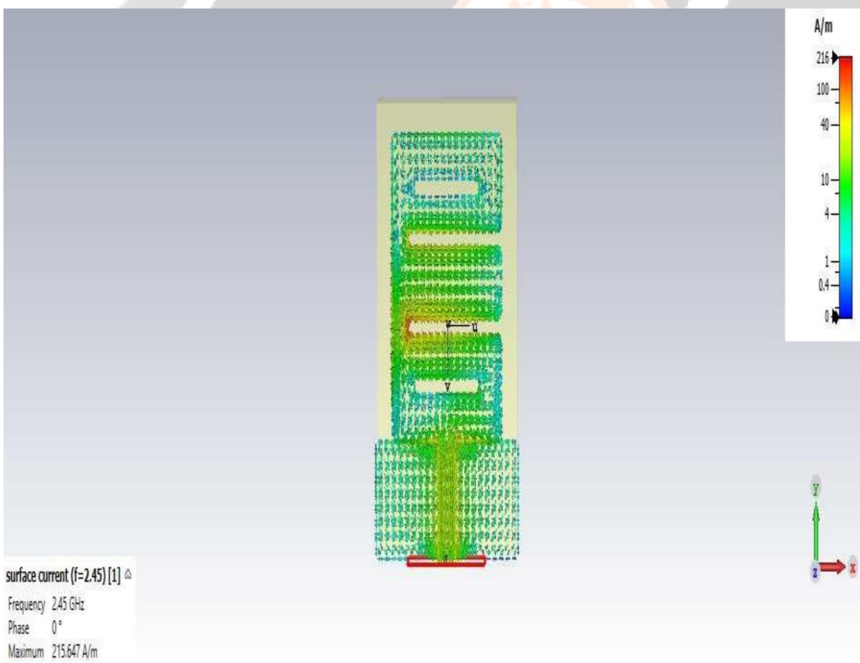


Fig. 13. Surface current of the antenna with phantom.

Fig. 12 and Fig. 13 illustrate the surface current distribution of this antenna.It has a surface current of 122 A/m without phantom and 216 A/m with phantom.

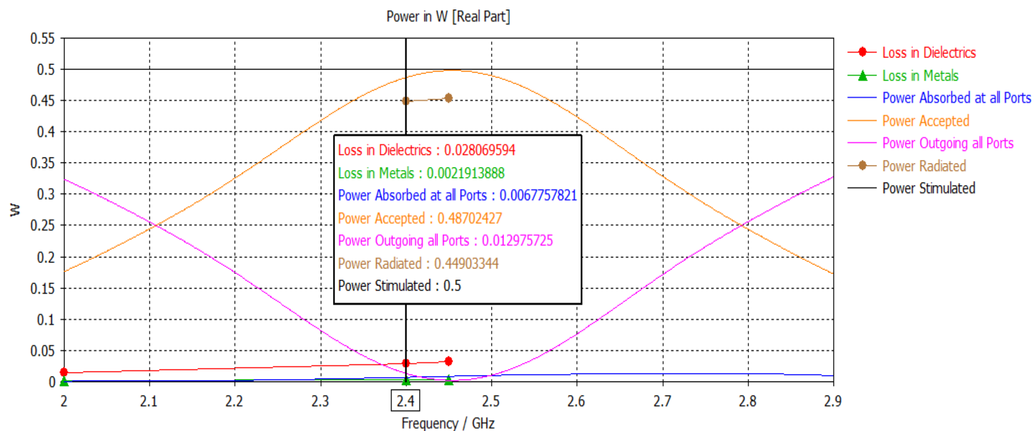
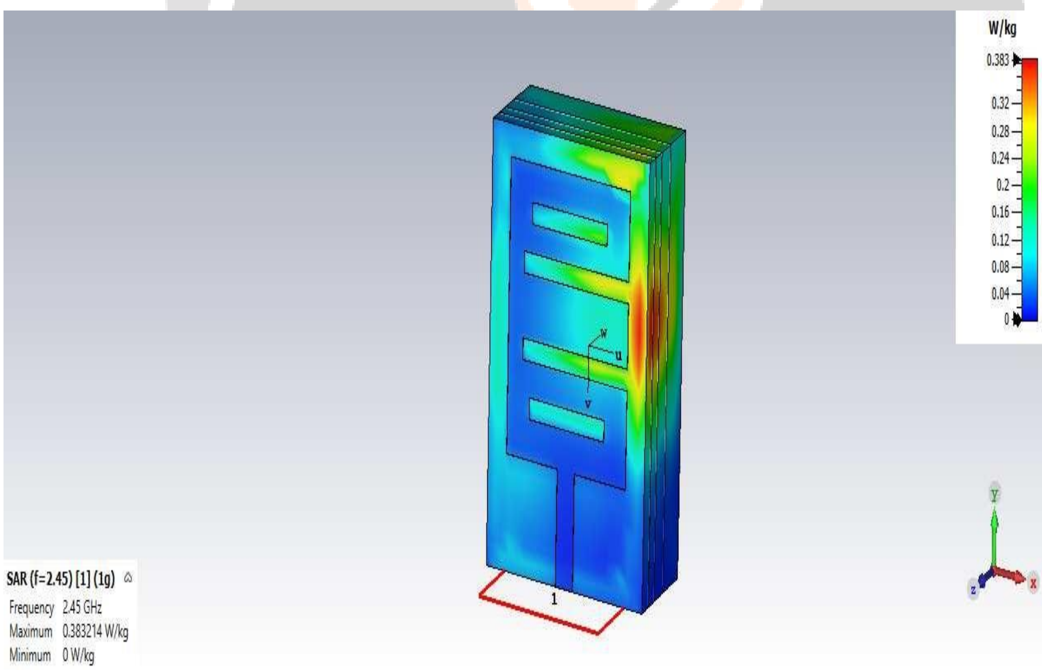


Fig. 14. Analyzing the proposed antenna's power for 2.45GHz.

Figure 14 displays the power lost in metal and dielectric material at 2.45GHz together with the power accepted, radiated, and other relevant parameters. The efficiency can be computed using the accepted and radiated power. The antenna has a 92% overall efficiency.

This work uses a simplified human phantom model to predict the SAR. This model is composed of three layers. For human tissue to be safe, consideration must be given to its basic absorption rate (SAR).



The SAR of 0.383 W/kg does not cause any damage to human tissue. The antenna's SAR is demonstrated using a human phantom in Fig. 15. SAR for 1g tissue in the planned antenna is 0.383 W/kg, below the maximum limit and appropriate for on-body applications.

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