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Wideband Fabric Antenna for Ultra Wideband Applications using for Medical Applications

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ABSTRACT

Traditional cancer detection imaging techniques suffer high costs, high false negatives, high false positives, and pain. The microwave imaging techniques overcome the limitations, which depend primarily on antenna design. If an antenna is wearable and implantable, the imaging system gives better results with less pain and cost. A wide band fabric antenna that operates at the ultra-wideband frequency with a low specific absorption rate (SAR) on breast phantom is verified. The proposed design has Jeans material as a substrate and the copper patch as a radiating element. The patch is designed in a circular shape with an M-type slot to suppress the spurious modes. The designed antenna model is commonly used for monitoring microwave imaging and has dimensions of 28X30X1.6 mm^3. The proposed antenna design covers 2.3-8 GHz frequency with a broadside radiation pattern. The gain over the operating frequency is about 2.3-4.5 dB, and the efficiency is 55 %–79 %. The antenna model was designed and simulated in CST microwave studio. The performance of an antenna is tested on breast cancer to detect the presence of tumor cells in the breast. The antenna analysis on the phantom was done by considering the tumor location and corresponding results are presented. By varying the sizes of the tumor the antenna performance is analysed. The simulated SAR values of the proposed antenna design on breast phantom are under the limits of FCC.

Keywords: Breast cancer; CST; Textile antenna; UWB

1. INTRODUCTION

The developing area in communication systems is body-centric wireless communication, which has applications in public safety, sports, defense, and healthcare.[1] The personal digital assistant (PDA) is used to monitor the functions of the human body with the entourage environment in a wireless body area network (WBAN). In a wireless body area network, the personal digital assistant (PDA) is to monitor bodily functions in conjunction with the surrounding environment (WBAN). In tracking individual data and physiological activities of people, WBAN plays a significant role in the medical sector and has stimulated current research.[2]

Wearable technology makes it easier to monitor human parameters.[3] Wearable antennas are crucial for body sensing applications, such as a bra that can detect a woman's breast tumor. Using this wearable bra as a part of the sensing system eliminates the need for patients to consult their doctors for minute changes in the tissues. Due to the loss and permittivity of tissues, there are many difficulties when designing antennas to test biomedical applications on the human body.[4] The circular monopole antenna with huge dimensions that Adel Alomairi designed operates between 1.6 and 10 GHz.[5] A piece of Cotton fabric is the substrate in the large-scale implementation of textile sensor-shaped rectangular and circular monopole antennas by NMK Elsheakh,[6] which operates in the 2–6 GHz frequency range[7] presents a hexagonal-shaped antenna with RTDuroid that operates at 1.11-5.47 GHz. Mehdi Mehranpour presents a low-profile aperture stacked patch antenna.[8]

To detect breast cancer at frequencies between 3.1-6.8 GHz, Praveen Kumar built a resonator-based antenna using a Fr-4 substrate.[9] An antenna with dimensions of 40X45x1.5 mm3 with a polyester substrate has produced a gain of 2.9 dB.[10] A UWB tiny slotted monopole antenna for the detection of breast cancer is presented by[11] using two notches. Several reports on wearable antennas have been published recently.[13-14] Different antenna designs are available for ultra-wideband frequencies.[16–21] This paper has four sections. Firstly, the first section contains an introduction and a literature review of antennas for UWB applications. A design requirements analysis and an outcome analysis are presented in sections two and three, respectively. In the fourth section, there is a conclusion.

2. MATERIALS & METHODS

2.1 Materials

Textile materials are conductive materials or substrate materials for garment integration applications. It has a low relative permittivity, a low loss tangent, and a thinner thickness (h), all of which help to reduce surface wave losses and improve antenna performance. The microstrip patch antenna was created and simulated with Computer Simulation Technology (CST). Copper material is the ground and patch in antenna design. In antenna design, the substrate is crucial. Wearable antennas must be compatible with human clothing to suit human needs. The

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antenna design is made with various substrates to see which one is best for wearing. The most commonly used substrates for antenna design are RT Duroid, GML, RO4003, and FR-4. Due to the development of wearable antennas, Cotton, Quartzel fabric, curtain cotton, Jeans, Lycra, Rubber, Polyester, Wash cotton, Resin, and Teflon substrates are employed. Taconic TLC, Bakelite, and Arlon AD 250 substrates are also suitable in antenna design based on the application. It has recommended using UWB antennas constructed from cotton or denim (jeans) material due to their low impact on the human body. The fundamental feature of this paper is on low profile wearable UWB antenna with jeans fabric and partial ground structure.

2.2 Basic Equations used for the Design of an Antenna

Microwave imaging works based on sending microwave impulses into a human body and observing any variances in tissue electrical characteristics due to back-scattered signal variations. The identification of cancerous tumor cells in the breast depends on the fluctuations in the back-scattered signal. The effective dielectric constant of tumor tissue is from the Maxwell Garnett equation (Eq.(1)).[15]

$$e_{ff} = e_m + 3\phi e_m \frac{(e_p - e_m)}{(2e_m + e_p - \phi(e_p - e_m))} \quad (1)$$

where e_m and e_p are the phantom Permittivity and tumor permittivity, φ is the tumor cell inclusion fraction. The important factor in the microwave imaging technique is the phantom's changing permittivity when the tumour is present. As a result, a sensor sensitive enough to detect permittivity variations is essential.

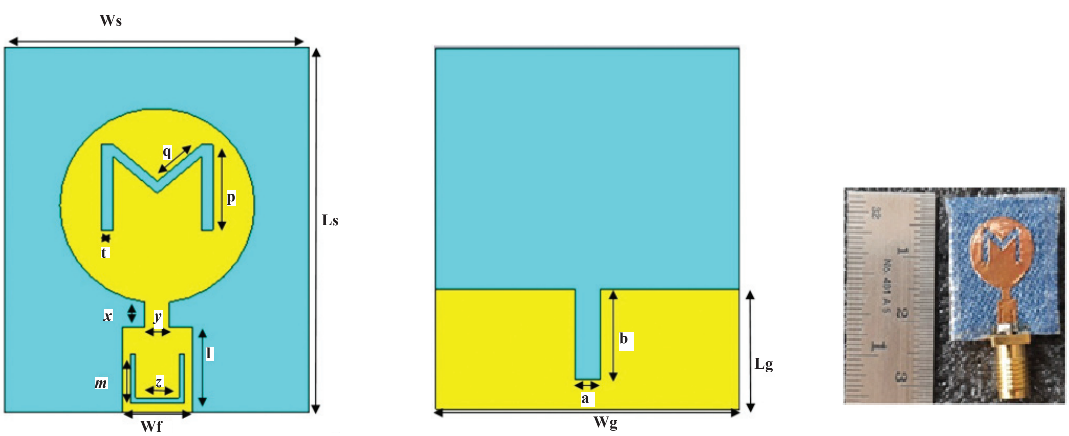
Another metric to consider when using microwave imaging is the depth of penetration in the breast phantom in Eqn (2). A breast phantom's frequency and dielectric characteristics influence its attenuation coefficient.

$$\delta = \frac{1}{\alpha} \quad (2)$$

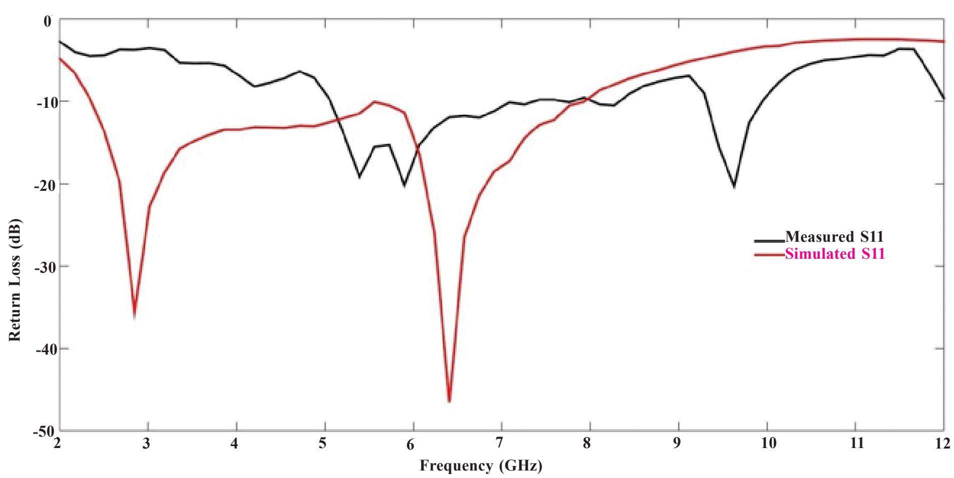
R is the radius of the circular patch and is from the following Eqn (3).

$$R = \frac{F}{\sqrt{\left\{1 + \frac{2h}{\pi F e_r}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}}} \quad (3)$$

where, F is given by



(a) (b)



(c)

Figure 1. (a) Geometry of proposed antenna, (b) Measured Vs simulated S11, and (c) Fabricated antenna.

$$F = \frac{8.79X10^9}{f_r\sqrt{e_r}} \qquad (4)$$

The resonance frequency is f_r, the substrate's relative permittivity is e_r, and the height is h An antenna's operational bandwidth needs to be as large as possible to provide high resolution for detecting small tumors.

2.3 Configuration and Performance of Proposed Antenna Design

A low profile ultra wideband antenna with a jeans substrate is proposed and the geometry with a fabricated prototype is in Figs. 1(a) and (c). Slots in the patch enable us to design smaller microstrip antennas with improved bandwidth and efficiency. It may also be necessary to add a slot to adjust the antenna impedance if it is far from the cable impedance and the reflection loss is too high. In this study, two slots, one in the patch and

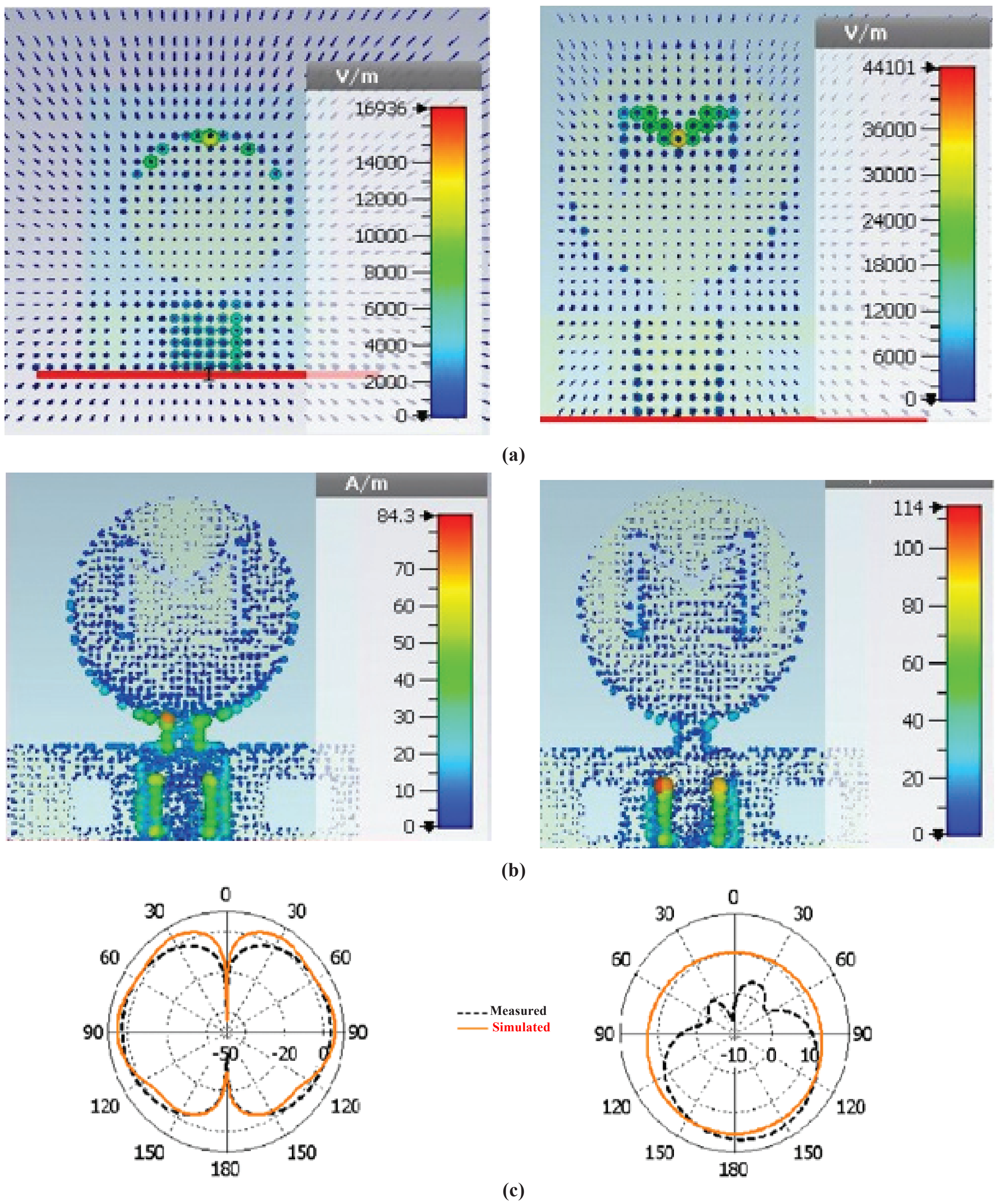


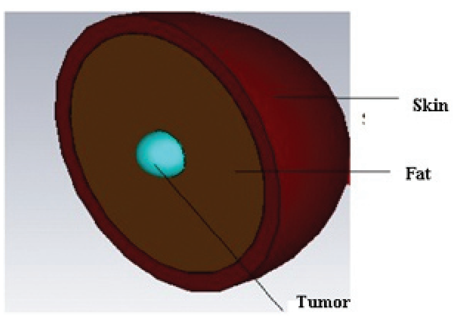
Figure 2. (a) & (b) E-field, Surface current distribution of antenna at 2.8 & 6.2 GHz, and (c) Radiation pattern of antenna at 6.2 GHz (90^0)

the other in the feed, are to increase the proposed antenna design's bandwidth and gain. The M-shaped slot is responsible for the resonances and the ground slot aids the creation of a constructive current interface. The proposed antenna design has a circular shaped patch with M shaped slot, and the radius of a circle is calculated for the resonant frequency of 6GHz with h=1.6 mm. All calculations are from the Eqns. (3) & (4). The simulated and measured S11 values of the proposed antenna design are in Fig. 1(b). Design and simulations are done using CST microwave studio and the fabricated antenna is tested using a network analyzer. Simulated results show that the antenna covers the frequency range from 2.3-8GHz with a maximum peak of -37 dB at 2.8 GHz and -48 dB at 6.2 GHz. The measured results indicate that the antenna has a maximum S11 of -38 dB for the frequencies mentioned above.

Figure 2 (a)&(b) depicts the patterns of Electric field and surface currents at resonance frequencies of 2.8 and 6.2 GHz. The ground slot and plane can be seen in the figure, and the M-shaped slot is responsible for the resonances. The ground slot aids in the creation of a constructive current interface. In addition, at lower frequencies, the patch with a slot forms a constructive interface at the margins of the frames. Figure 2(c) gives the antenna's radiation patterns in the phi 90^0 and theta 90^0 planes. In an anechoic room, the proposed antenna's radiation patterns were measured. The antenna's radiation patterns were well-measured, and it was clear that the antenna has an Omnidirectional response. The radiation patterns are steady across the whole bandwidth, as can be seen in the image. The modest differences between the simulated and measured findings could be attributable to measurement setup mistakes. The antenna has a directed response in the phi 900 planes at specific frequency points.

3. RESULTS & DISCUSSION

An understanding of the dielectric characteristics of human breast tissue is required for the antenna design for microwave imaging systems. To identify the type of cancer one can observe the differences in permittivity and conductivity of healthy tissue and cancerous tissue. The various ratios of water content present in the breast cause differences in the dielectric properties. The suggested antenna is intended for use in microwave imaging, to detect malignant cells in the breast. The phantom with its dielectric properties is mentioned in Figs. 3 (a)& (b). Figure 3(c) shows the S11 parameters analysis of the antenna with and without tumor and in free space at ultra-wideband frequencies. In free space antenna results maximum



(a)

Tissue	Permittivity F/m	Electrical Conductance (S/m)
Skin	36.7	2.34
Fibro-glandular fatty tissue	22.57	0.31
Tumor	54.9	4

(b)

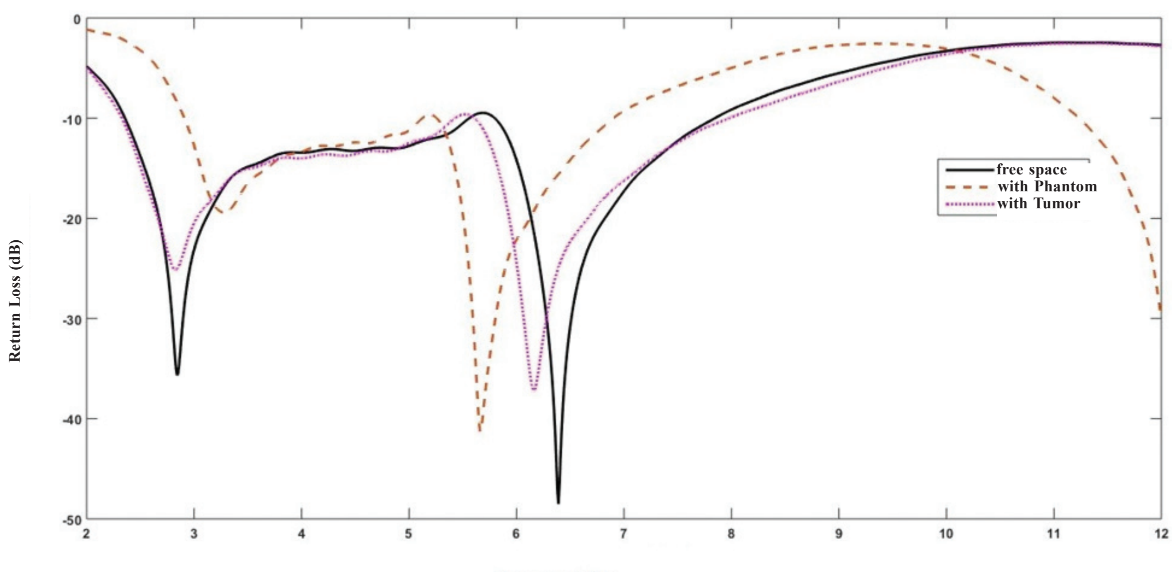


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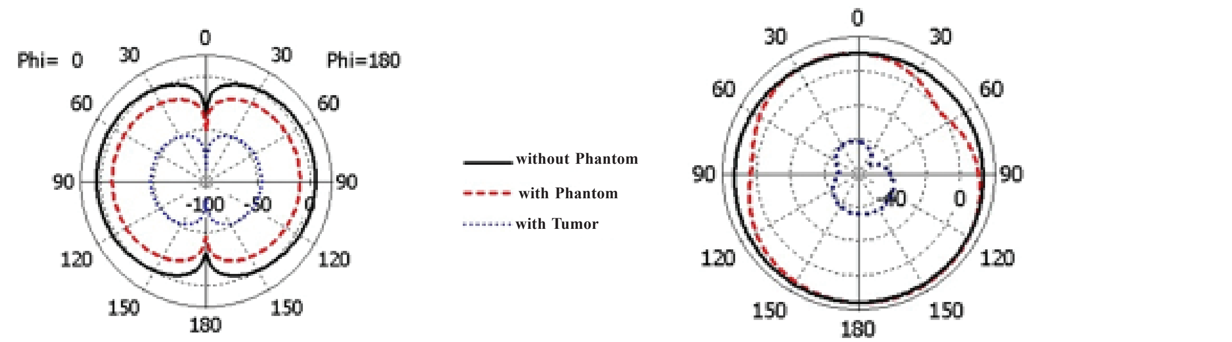
Figure 3. (a) Breast phantom, (b) Dielectric properties of phantom, and (c) S11 parameter analysis.

of -48 dB at 6.2 GHz, while testing on phantom without tumor results in S11 of -40.15 dB at 6.05 GHz and S11 of -37.5 dB at 6.12GHz in the presence of the tumor. Thus, since the tumor has high dielectric properties, S11 values decrease, indicating that it is a tumor. At 6.2 GHz, the radiation patterns of the antenna with and without tumor are shown in Fig. 4(a).



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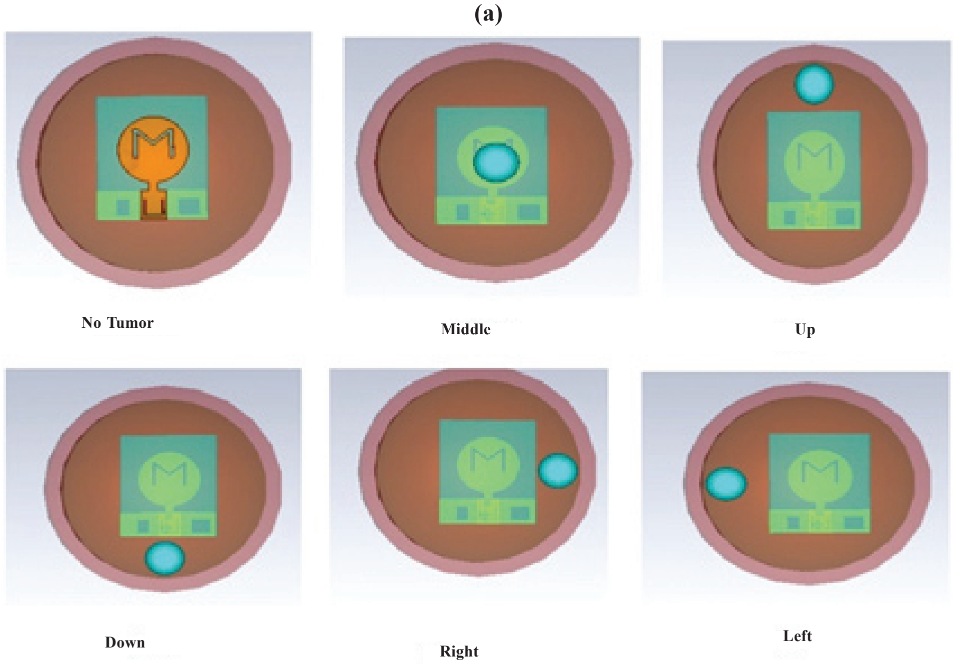

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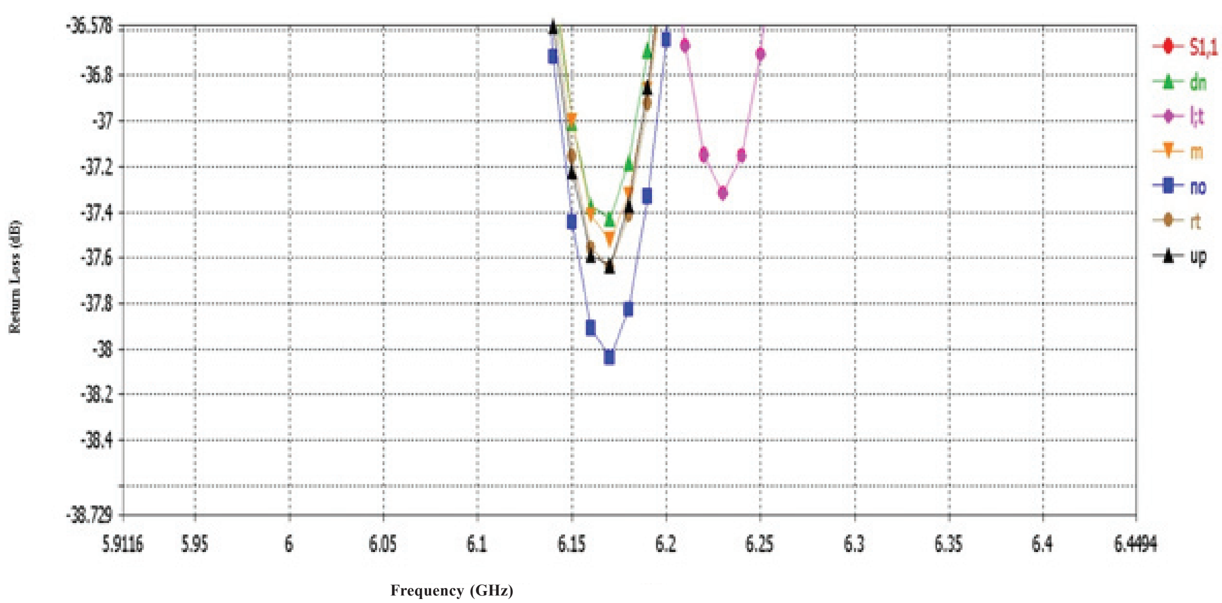


(c)

Figure 4. (a) Radiation pattern at 6.2 GHz (phi= 0^0 & 90^0), (b) Various positions of tumor, and (c) S11 parameter analysis.

Any antenna must be able to find cancer, no matter where it is. The tumor is positioned inside the breast at various locations, as shown in Fig. 4(b), to analyze those conditions and evaluate the performance of the antenna. Based on the position of the tumor antenna results in different S11 values, without tumor case results -37.3 dB while tumor at left and right positions result in -37.6 dB are shown in Fig. 4(c). The tumor at up and down positions resulted from return loss of -37.6 dB and -37.4 dB respectively. According to all of these findings, the suggested antenna is ideally suited to finding the tumor in any location and covers UWB frequency with a VSWR of less than 2, SAR within FCC-specified limitations, and UWB frequency under -10 dB as shown in Fig. 5(a).

The antenna's performance is also observed by positioning it at a distance of 40 mm from various tumor radii; the associated parametric findings are provided in Fig. 5(b). From this, -39.18 dB return loss for tumor of radius 3 mm, -37.9 dB for 10 mm, -37.5 dB for 15 mm, while for 20 mm radius it is -36.13dB. The antenna has a gain of 0 dBi, indicating that it has an Omnidirectional radiation pattern. On the one hand, the shape of the pattern changes to directional as the gain increases in positive values. When the gain is less than 0 dBi or shows negative values, this indicates that the radiation pattern is changing shape owing to back lobe variation. The gain of the antenna at a 3 mm radius is 5.2 dB, at a 10 mm radius is 4.8 dB, at a 15 mm radius is 4.72 dB and at 20 mm is 4.24 dB. The efficiency of the antenna also decreases from 78.10 to 69.14 as the radius increases which indicates the tumor is detected more accurately if it is at earlier stages.

In the case of any wearable application, SAR is the main parameter for testing the device. If it is under 2W/Kg then it is preferable to use on the human body. Figure 5(c) shows the different SAR values of the antenna at different frequencies by changing the distance between the antenna and phantom. From the figure, it was observed that the SAR value increases as the distance between the antenna and phantom increases. So the implantations of the antenna in wearable cloths become more important while considering the radiation effect.

For microwave imaging, two antennas are for transmitting and receiving. The phantom is placed in between antennas as shown in Fig. 6(a) and input, output signals are shown in Fig. 6(b). It shows that the delay is less than 1ns within the

Position of the tumor	S11(dB)	VSWR	Impedance (ohm)	SAR (W/Kg)
No tumor	-42.34	1.1	50.24	1.28
Right	-35.2	1.21	50.134	1.341
Left	-35.01	1.212	49.56	1.346
Up	-3529	1.19	48.75	1.335
Down	-35.26	1.25	49.99	1.345
Middle	-35.98	1.18	50.1	1.3

(a)

Radius of the tumor	S11(dB)	SAR (W/Kg)
3	-36.12	1.28
10	-34.12	1.486
15	-33.01	1.659
20	-31.95	1.956

(b)

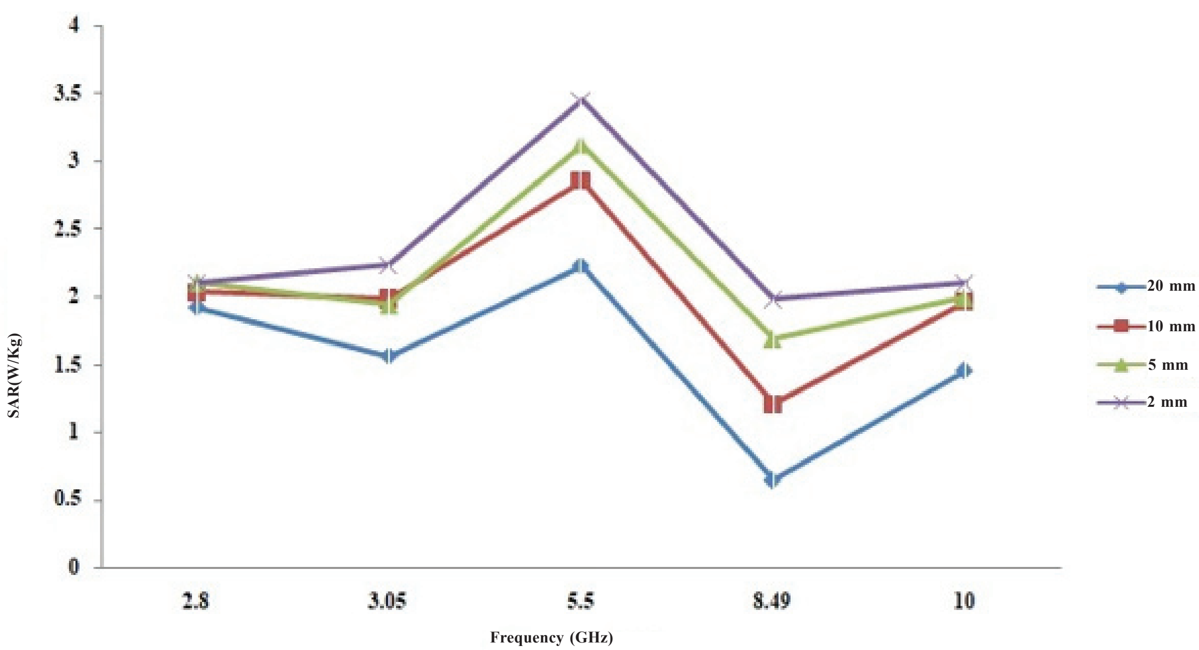
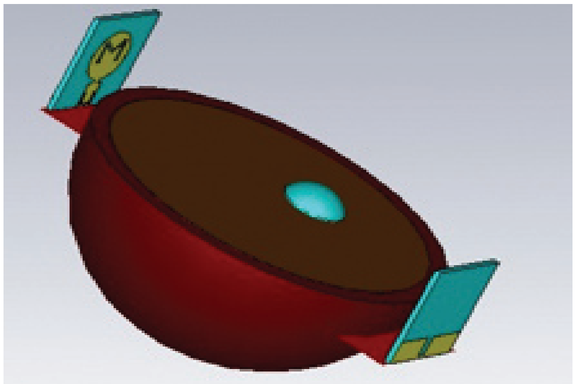


Figure 5. (a) SAR Values of the antenna with various tumor positions, (b) SAR Values Vs Distance, and (c) S11 results at different radii of the tumor.

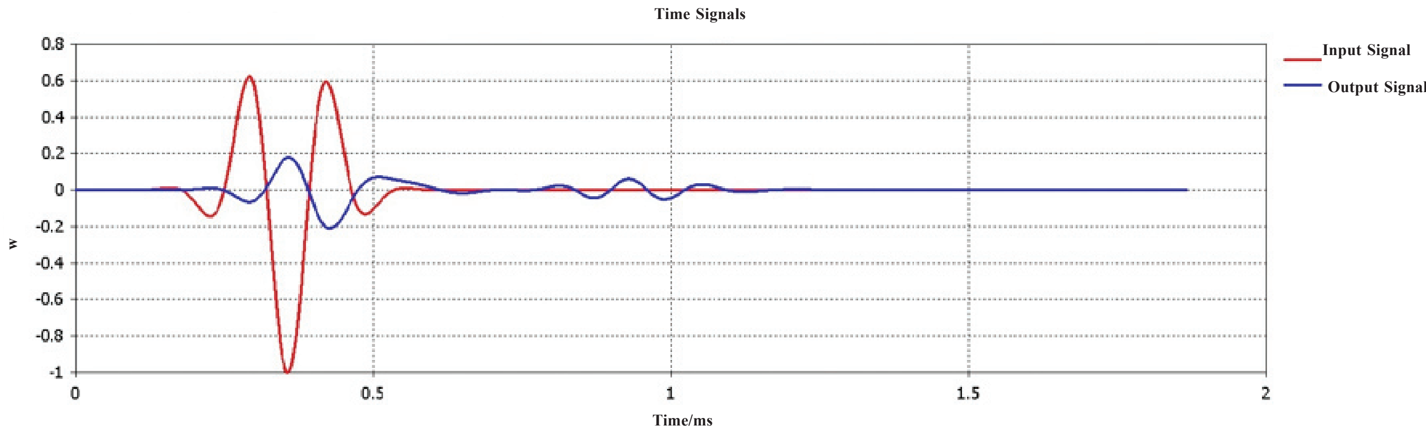
operating frequency of the antenna. The output signals with and without tumor are shown in Fig. 6(c). Whenever the tumor is present then results in a deviation in the output signal. A comparison between the proposed antenna and existing models is summarized in Table 1. As can be seen, the proposed antenna has a low profile, high return loss and lowest SAR compare to most of the existing models.

In contrast to other antennas, the following are the results of this antenna:

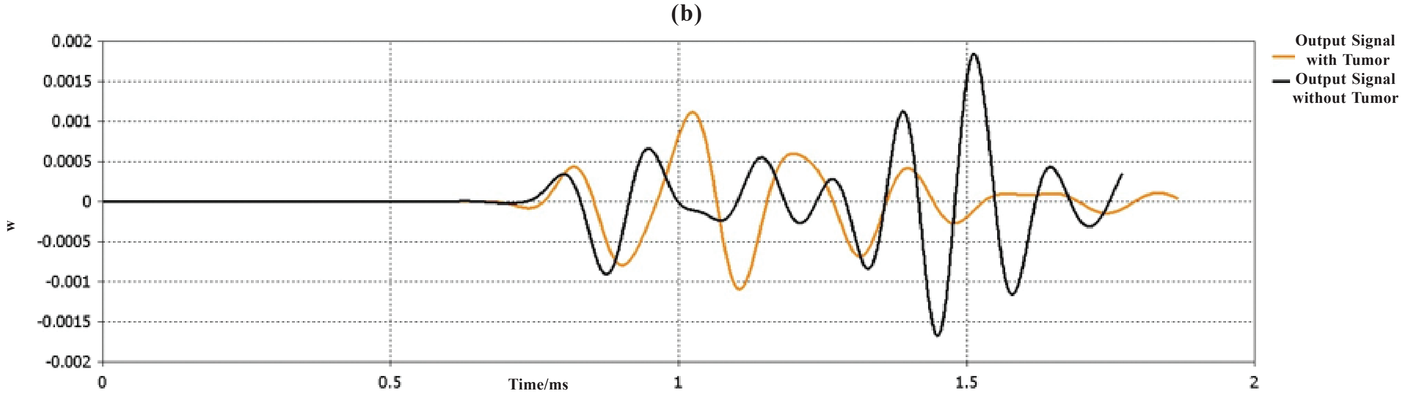
1. The suggested research introduces a textile antenna that can be integrated into the human body.
2. It requires less power and exhibits harmless radiation.



(a)



(b)



(c)

Figure 6. (a) Microwave imaging setup, (b) Input & output signals, and (c) Output signals with and without tumor.

Table 1. Comparison of the proposed antenna with literature

Antenna model	Size (mm3)	Substrate	Gain (dB)	Operating frequency (GHz)	Lowest SAR (W/Kg)	Return oss (dB)
[5]	60X70X1.6	FR-4	4.431	1.6−10	0.692	-34
[6]	50X50X1.6	Cotton	5	2.5-9	3	-20
[7]	50X50X3	Felt	NA	2.38 to 2.58	0.23	-25.4
[8]	10 × 10 × 3.475	Jeans, Cotton	NA	2.5–15	NA	-30
[9]	20X30X1.6	FR-4	4.8	3.1-6.8	1.02	-25
[10]	40X45X1.5	Polyster	2.9	1.198–4.055	0.0014	-32.2
[11]	52X42X1.6	FR-4	4.2	3.4&5.5	1.09	NA
[12]	48.46X42.4X1.6	FR-4	NA	2.465	NA	-31.9
Proposed	28X30X1.6	Jeans	4.5	2.3-8	0.46	-48

3. The proposed antenna can be used to transport high-speed data across small distances.
4. This antenna features a revolutionary compact design that adds to the structure's originality.

4. CONCLUSIONS

A Microstrip antenna with a circular patch including M shaped slot was developed in this paper to detect breast tumors at an early stage. After using the Antenna on breast phantom with and without tumor, this article shows a precise approach for defining different tissues in various simulated circumstances. In the CST Microwave Studio, a human breast phantom model was created and the developed Antenna was mounted on the phantom. As a result, the antenna detects the tumor irrespective of its position. The S11 values of the antenna with and without tumor are -40.15 dB at 6.05 GHz and -37.5 dB at 6.12 GHz. The proposed antenna model is to be capable of diagnosing breast cancer from the cancer-affected breast based on all of the collected data. After examining the performance parameters of the Antenna with and without tumours and tumours with different radii, the proposed antenna with a low profile is suitable for microwave imaging applications.

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Her area of Interest are: Image processing and antenna engineering
In the present work, she developed the design and prepared the initial draft of the manuscript.

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In the present work, he provided the conceptual framework, and supervised the work.