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A 2 x 2 antenna with vary DGS Microstrip for brain tumor detection with high sensitivity

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ABSTRACT

This paper presents a design of four defective ground surface (DGS) - based patch antennas for early detection of stage 0 brain tumours. The four antennas form a 2 x 2 antenna design and are attached to a dielectric ring suitable for being mounted on the head. The proposed 2 x 2 design is composed of four antenna, two of them having an elliptical DGS, while the other two patches have circular DGS. This system is characterized by comprising compact and highly isolated elements. It operates at a frequency of 2.45 GHz and has a wide bandwidth. The antenna's compact dimensions of 50 x 40 x 1.13 mm3 are achieved by employing a meandering geometry, a defective ground structure, and a high permittivity substrate. It is feasible to obtain a bandwidth wider frequency range of 700 MHz (2.38–2.45) GHz. Furthermore, the defects in the ground construction result in a compact size. The performance of the proposed design is demonstrated through simulated and other parameters results using a brain phantom, including the effects of the tumour and without tumour.

1. Introduction

Cancer has overtaken cardiovascular disease as it is the second leading cause of death worldwide, according to the WHO, every year, cancer kills 9.6 million individuals. Brain and central nervous system tumors are diverse malignancies. These tumors account for 3% of all cancer cases and are more common in men than women [1]. Cancerous cells form a malignant tumor, the most serious, unexpected, and possibly life-threatening medical illness.

The severity and appearance of cancer determine its stage. There are four stages of cancer. Stage 0 identifies abnormal cells on the surface of the tissue. These rare cells may infect healthy tissue and become malignant. Stage I is comprised of IA and IB. Stage IA refers to a tumor that is less than 5 cm in size. Stage IB refers to cancer that has grown larger than 5 cm. Tumor dispersion or brain neuron invasion indicate Stage II. Both qualities are present in Stage III, which is divided into phases IIIA and IIIB. A stage IIIA tumor has spread to brain neuronal tissue. At stage IIIB, the cancer has spread to other brain layers or neurons. Stage IV is advanced cancer with metastases to distant organs or systemic nervous system damage [2].

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The importance of early detection of cancer comes from better treatment results, as detecting the tumor early usually decreases its size and prevents it from spreading, making treatment simpler. This leads to improved outcomes and a greater likelihood of eradication [3]. Smaller tumors may need less aggressive therapy, resulting in fewer side effects [4]. People with early-stage cancer have a higher chance of survival. Hence, finding a growth early provides additional therapy choices in addition to improving the prognosis [5]. Also, finding the tumor in an early stage aids with symptom management, minimizing the chance of neurological damage, and improving brain function [6]. There are various methods to detect brain tumors or malignant cells, such as X-ray mammography, MRI, ultrasound, radiography, and CT scans [7]. However, these approaches expose patients to high amounts of ionizing radiation and cannot discriminate between benign and malignant tumors, and they are also costly. Microwave head imaging is another approach to brain tumor detection. Therefore, the antenna used has an impact on the system's picture quality and performance. The antenna is tiny, easy to integrate, has a basic geometric architecture, and has a broad frequency range. Thus, microstrip patch antennas (MPAs) satisfy these criteria. Planar arrangement, compact design [8], lightweight construction, minuscule size, and low production cost define these antennas [9] [10] [11].

The author in [12] proposed a symmetrical Defected Ground Structure (DGS) design in order to improve tumor detection, as brain tumors may disrupt antenna function. An antenna may diagnose cancer by monitoring radiation properties, impedance, and return loss. The antenna is ideal for a multilayer brain phantom model to correctly simulate brain tissue. However, the tumor's detectable size was not mentioned. The author in [13] proposed a design that is used to detect brain tumors, including design, construction, and experimental validation of the system. The data allowed for an accurate and complete cancer diagnosis. The study lacks a significant sample size for validation, limiting its usefulness. Additionally, sensor system integration with current medical imaging approaches remains a challenge. The author in [8] proposed a broadband microstrip antenna with DGS. The study focuses on antenna design and execution to improve brain tumor detection sensitivity and accuracy. The authors discuss how DGS improves antenna performance by optimizing impedance matching and reducing radiation. The study examines the possible applicability. Unfortunately, there is no clinical or scientific evidence of the antenna's effectiveness in real life. Experimental validation, comparison with current brain tumor detection methods, and address any implementation issues for the suggested antenna are recommended. The effort will be more effective. This would greatly enhance brain tumor detection, especially with broadband microstrip antennas and DGS. The author in [14] researched brain tumor detection using a DGS broadband microstrip antenna. The antenna design and simulation results are examined in this work. Microstrip patch antennas are examined in this context, and brain cancer detection is stressed. No clinical studies or experimental validations have been done to assess the antenna's effectiveness in this work.

The paper discusses antenna designs for brain tumor detection. Section 2 covers the design specifics and essential features of the 2 x 2 antenna system. This section provides a detailed description of the antenna arrangement. At the beginning, we build and simulate a single microstrip patch antenna using CST. Then, we improve the antenna's effectiveness for its intended purpose by considering factors such as frequency range and radiation pattern. Section 3 offers comprehensive guidance on creating a six-layer head phantom, both with and without a tumor, ensuring accurate dimensioning [4]. This section outlines the procedure for creating a phantom that correctly resembles the brain, cerebrospinal fluid (CSF), dura, skull, fat, and skin layers. The antenna undergoes extensive testing using phantoms. Section 4 focuses on calculating Specific Absorption Rate (SAR) to ensure the safety and effectiveness of the proposed antenna design. SAR values were measured in various situations to better understand how head phantom models absorb electromagnetic radiation. Then, in Section 5, the antenna sensitivity, the surface current distribution, and the radiation of the far-field are simulated in two scenarios: healthy and defected with 1.5 mm and 1 mm radius tumors. Then, in Section 6, a comparison between this work and other related work in this topic is presented. Then, Section 7 summarizes this paper.

2. The geometry and the configuration of the proposed design

This section articulates the architectural process of the proposed construction. We thoroughly inspect fundamental components to verify the antenna's functionality and optimize it to operate at a frequency of 2.4 GHz inside the ISM band. However, the primary objective is to create an antenna that aids in the early detection of stage 0 brain tumors.

2.1 Single Element Antenna Design

The suggested antenna is a single element, which is shown in Figure 1 and includes a representation of its spatial configuration. The physical dimension of the antenna element is 40 × 50 mm². To complete the antenna element, a rectangular patch antenna and a ground plane that has been modified with the use of DGS technology are also included. The DGS is offered in a multitude of forms. However, the circular and elliptical shapes were used due to multiple features. The first feature is compact dimensions. Circular DGS antennas may be designed to have a small and streamlined shape, making them ideal for incorporation into various biomedical devices and implants where limited space is a significant limitation [15]. The DGS's circular shape allows for the creation of antennas with customized radiation patterns, such as omnidirectional or directional characteristics, to meet the unique requirements of biomedical applications [16]. Enhanced impedance matching: The circular DGS structure may be used to improve the impedance matching between the antenna and the feeder network, which is crucial for efficient power transmission and minimizing reflections [17]. Reduced mutual coupling: The circular DGS design may help minimize the impact of mutual coupling between the antenna and adjacent components or structures, which is vital in highly populated biomedical systems [18]. Also, conformal integration: The DGS antenna's round design allows it to be seamlessly integrated with curved or irregular surfaces, making it suitable for biomedical equipment that is needed to match the curvature of the human body [19]. The Rogers RT 5880 substrate material is used with 1.575 mm thickness. The CST software is used to perform simulations of the proposed antenna. Figure 1 shows the antenna element in action, which consists of a ground plane and a rectangle patch attached to the dielectric substrate on opposite sides. Table 1 displays the dimensions. The equations presented in were utilized to perform the calculations [20].

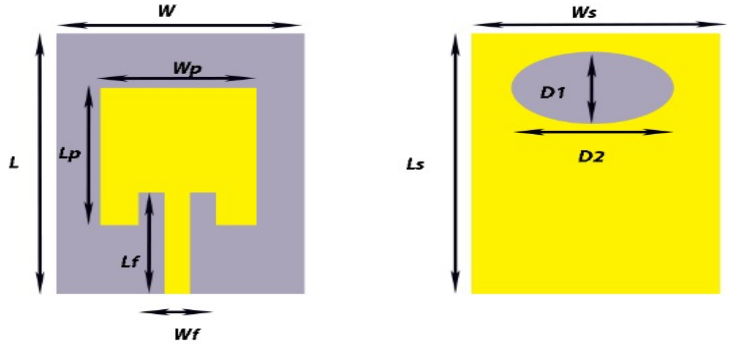

Fig. 1. An elliptical DGS antenna design (a) front view (b) back view

Table 1
Dimension of the rectangular microstrip patch with elliptical dgs

Parameter	Dimension (mm)
W = Ws	50
L = Ls	40
Lf	14.2
D1	20
D2	30
Wp	2.3
Lp	4.5
Wf	6.32

2.2 A Proposed Design of 2 X 2 Antenna

For diagnosing brain cancer, it is essential to make use of several antennas that are positioned around the human head, as stated in [21] [22] [23] [24] [25] [26] [27] [28]. This is mostly because it increases sensitivity and gives wider spatial coverage. The use of this multiple antennas structure makes it possible to collect a greater quantity of data, which in turn makes it possible to identify minute electromagnetic changes that are associated with different phases of the disease [29]. Initially, it is necessary for the antennas to encompass the entire brain. This research started with four identical antenna elements; the four elements are connected with the FR-4 ring. The structure of the ring consists of an inner radius of 95 mm and an outer radius of 110 mm. The average radius of the head ranges from 19.5 cm to 29.1 cm [30]. Figure 2 depicts the establishment of the antenna design, which consists of four antennas with a 12 mm gap between each. However, this design was unable to function in the ISM band. Figure 3 shows the reflection coefficient (S11) results, which prove that the proposed design is having a problem with coupling and could not operate at 2.4 GHz.

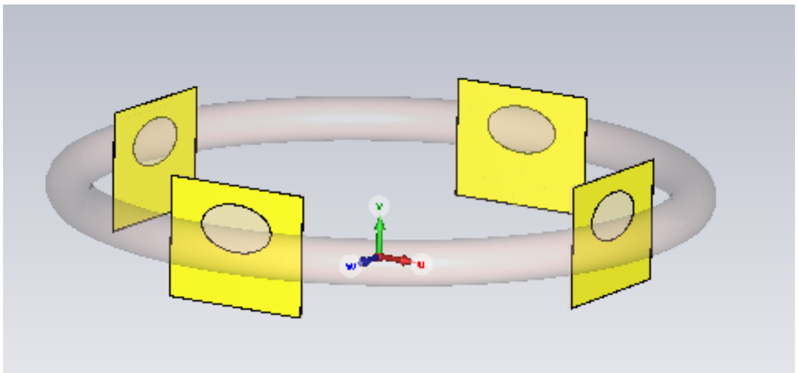

Fig. 2. Configuration of 2 X 2 proposed design with ellipse DGS in all the four antennas

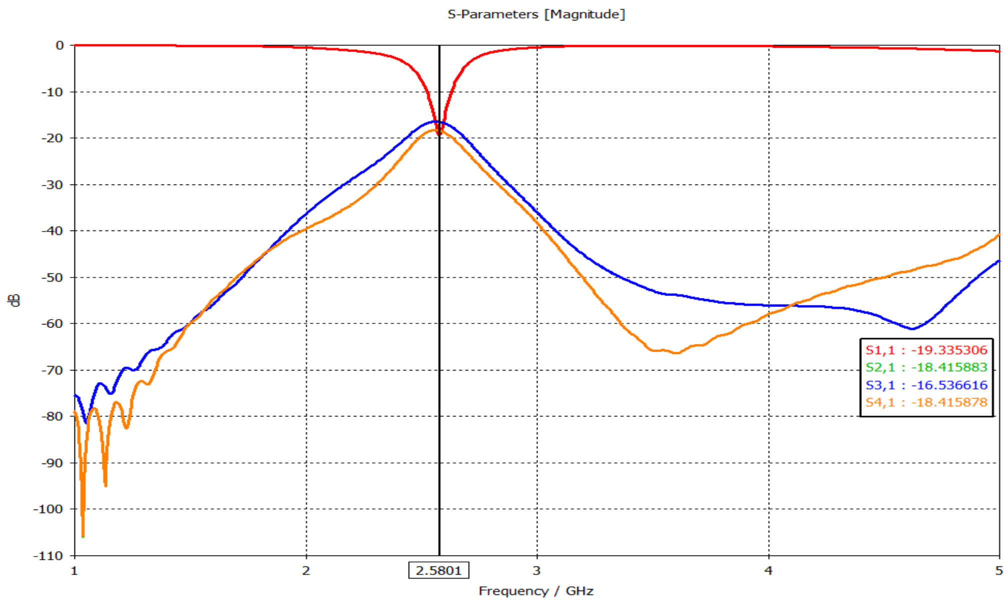

Fig. 3. S11 results of 2 X 2 proposed antenna design with ellipse DGS for all the four antenna

The Fleet material is utilized in the construction of the substrate antenna. It was utilized in the fabrication of both the radiating patch and the ground plane structures. Figure 4 depicts the antenna with a circular DGS and table 2 displays the dimensions. Then the installation of the suggested antenna of four MPA with circular DGS has been made and it can be shown in figure 5. The dimensions had been calculated using [20].

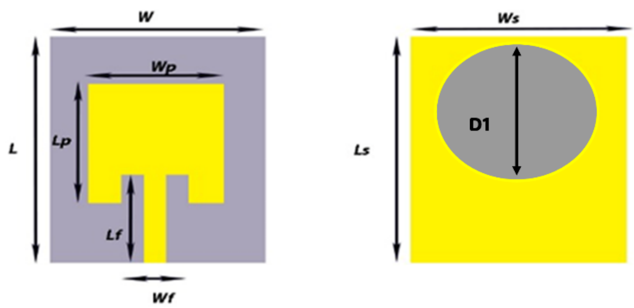

Fig. 4. Configuration of 2 X 2 proposed design with circular DGS in all the four antenna

Table 2
Dimension of the rectangular microstrip patch with circular dgs

Parameter	Dimension (mm)
W = Ws	50
L = Ls	40
Lf	14.2
D1	33.5
Wp	2.3
Lp	4.5
Wf	6.32

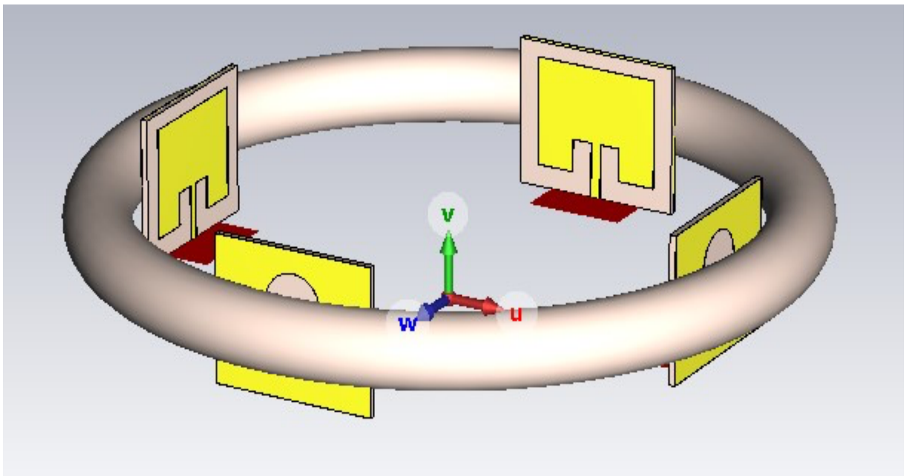

Fig. 5. Configuration of 2 X 2 proposed design with circular DGS in all the four antenna

Nevertheless, this design was incapable of operating within the ISM band. Next, we started the process by implementing a 2 X 2 element system with two circular DGS Structure and 2 elliptical DGS. Figure 6 displays results of the reflection coefficient (S11) which show a problem in coupling.

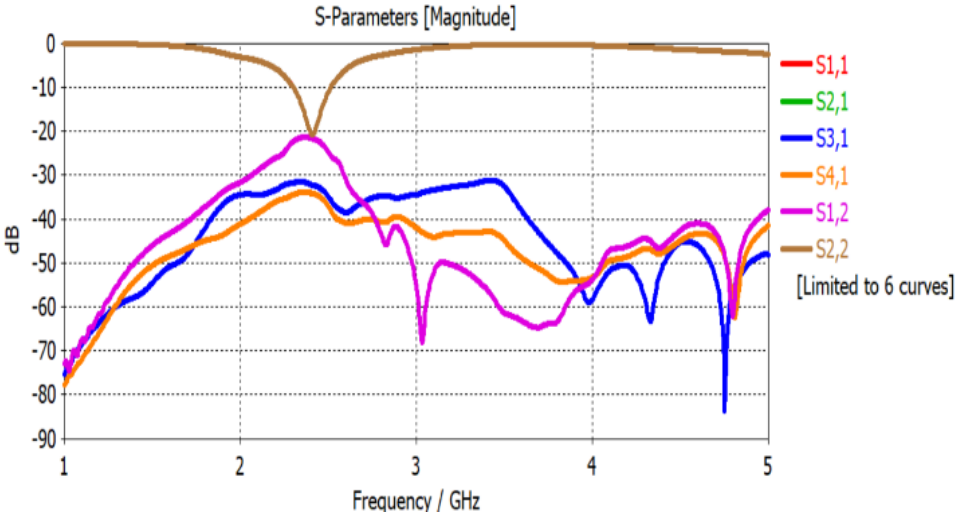

Fig. 6. S11 results of 2 X 2 antenna design with circular DGS to all the four element

Finally, a 2 X 2 antenna was proposed which comprised of four elements, with two elliptical DGS and two circular DGS. Figure 6 depicts the arrangement of the suggested design. The proposed design succeeded in working on ISM band. Figure 7 shows the configuration and the four antennas with different DGS (elliptical and circular). Figure 8 shows the reflection coefficient S11 results concerning the proposed design. The results shows that the resonating frequency was 2.4 GHz the antenna's dimensions, while simultaneously improving the matching impedance and protecting the antenna from the effects of the coupling [31].

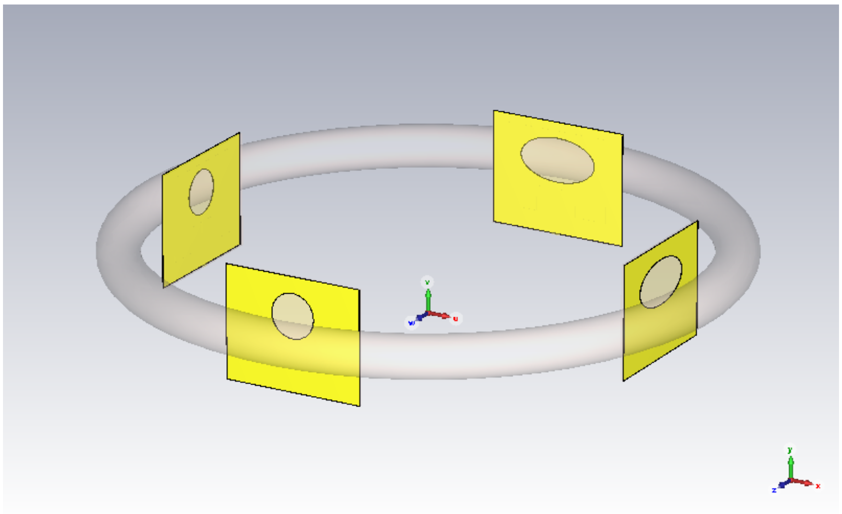

Fig. 7. Configuration 2 X 2 antenna design with two circular DGS and two elliptical DGS

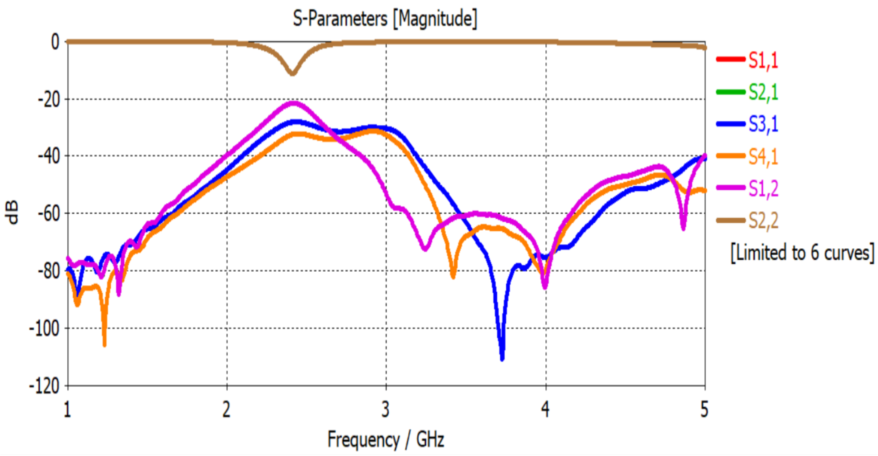

Fig. 8. S11 results of 2 X 2 antenna design with two of circular DGS and two of elliptical DGS in all the four element

3. The human brain in phantasmal model

The demand for creating human body phantoms to investigate the impact of radiation on different tissues has increased in parallel with the expansion of biotechnology applications. The CST was being used to construct the phantom model, which consists of six layers: dura, skin, brain, cerebrospinal fluid, and brain. Each Phantom Layer has a spherical geometry. The capacity to detect cancerous brain cells is improved by the variation in electrical properties, such as permittivity (ε) and conductivity (σ), as one transitions between different layers. The human brain model is described in depth in Table 3. The information provided includes the measurements of the tumor's thickness, permittivity, and conductivity, as well as the corresponding values for its layers [32]. The tumor exhibits distinct traits because of its electrical properties, when compared to healthy cells. Models for antennas and brain phantoms are currently in development.

Figure 9 shows the configuration of the proposed design, featuring four antenna components located 10 mm from the skin layer and surrounding the six-layer cranial tissues. The details of each layer of the brain phantom which had been constructed can be seen in table 3.

Table 3
Phantom Information of each layer of the brain phantom

Tissue	Permittivity	Conductivity	Density	Thickness(mm)
Skin	42.85	1.59	1090	1.50
Fat	10.82	0.26	910	0.15
Skull	14.96	0.59	1850	0.60
Dura	42.03	1.66	1130	0.40
CSF	66.24	3.45	1005.9	0.50
Brain	42.53	1.5	1030	82.25
Tumour	55.8	4.2	1070	--

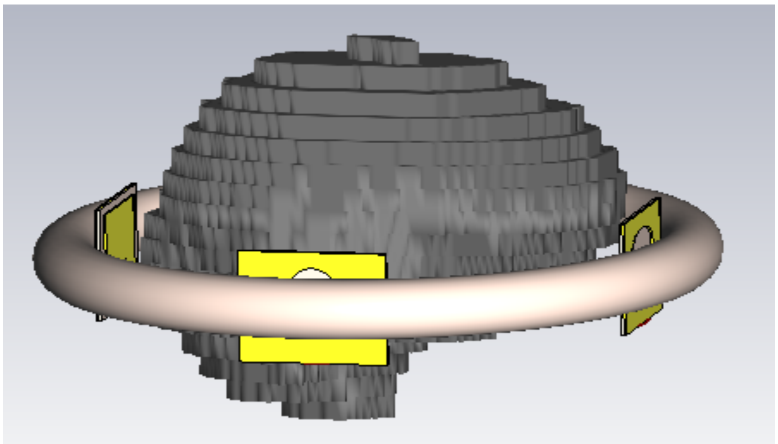

Fig. 9. Phantom brain, with its six distinct layers

4. Evaluation of Specific Absorption Rate (SAR).

Ensuring the safety criteria of the proposed brain imaging system are given utmost importance is crucial, as even a short exposure to radiation could potentially result in adverse health effects. This can be achieved by meticulously assessing the Specific Absorption Rate (SAR). SAR is determined by the progressive buildup of electromagnetic radiation within the tissues of the human body as can be seen in equation 1. The mathematical representation of SAR is as follows:

$$SAR = \frac{J^2}{\rho\sigma} \qquad (1)$$

The current density is denoted by J in this equation, while the conductivity of the head tissue is denoted by π, and the density of the head tissue is defined by [33]. The amount of electromagnetic energy that is absorbed by the body can be measured using a technique known as the Specific Absorption Rate (SAR). Typically, it is expressed in terms of watts per kilogram. Quantification of SAR in bodily tissue can be accomplished in a variety of ways. In the process of calculating SAR, there are a number of factors that might have an impact. These factors include the working frequency, the type of antenna that is utilized, and the distance that exists between the body surface and the scanning antenna. There is a possibility that SAR restrictions will vary from country to country because of variations in the manner in which they report, test, and utilize network bands. According to the rules of the United States and the European Union, the specified limitations for Specific Absorption Rate (SAR) are 1.6 W/kg and 2 W/kg for 1 gram and 10 grams, respectively. These constraints adhere to global standards. The mean Specific Absorption Rate (SAR) for a mass of 10 grams is 1 w/kg. Figure 11 shows the values of the SAR of the four elements of the 2 X 2 antenna design which is 1.24, 0.186, 0.883 and 0.871 for the first, the second, third and fourth respectively. The SAR values have been measured at 2.4 GHz, to ensure the patient’s safety.

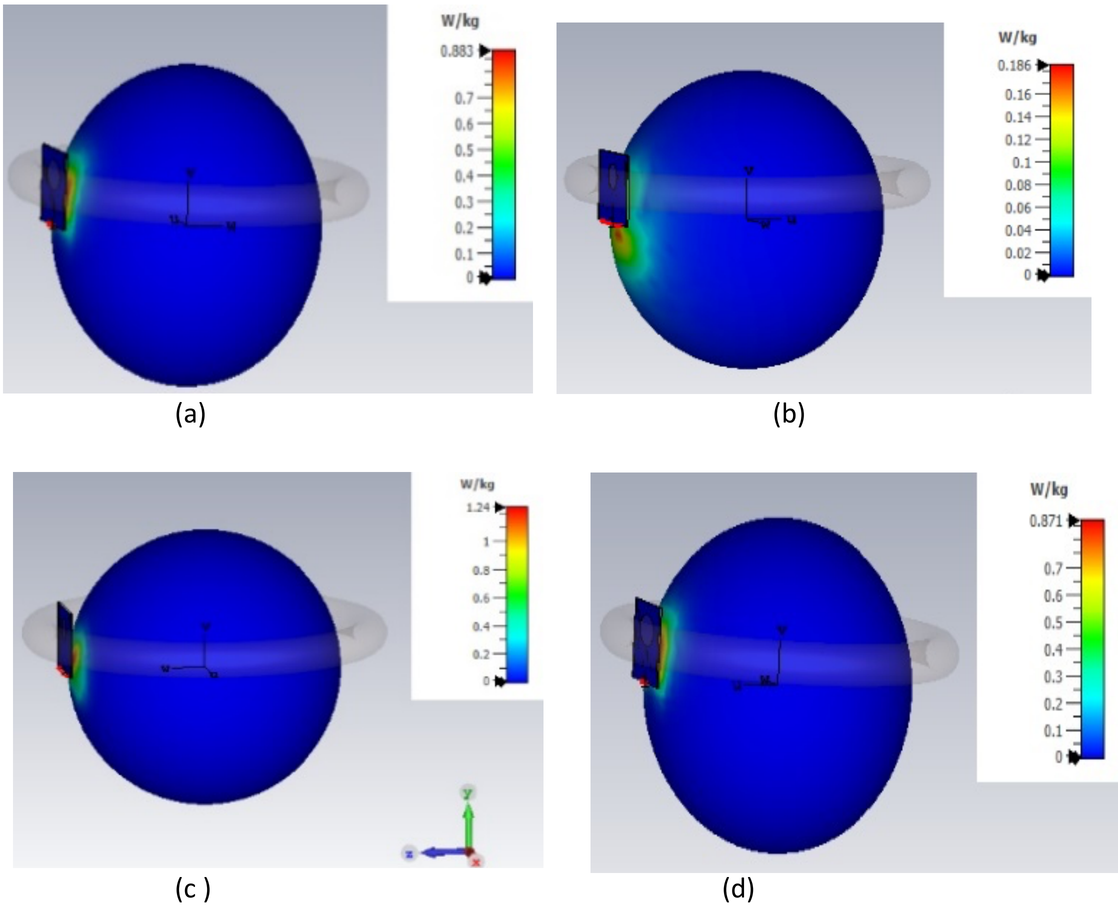

Fig. 11. Healthy brain's surface current of the first antenna of the suggested 2 X 2 proposed antenna design. (a) the first antenna. (b) the second antenna. (c) the third antenna. (d) the fourth antenna

5. Results analysis

The proposed 2 X 2 design is utilizing the Brain Phantom in two scenarios: one with a tumor and one without. The subsequent section presents a comprehensive analysis of the simulation's conclusive findings which are antenna sensitivity, surface current and farfield.

5.1 Antenna sensitivity

Applying a tumor with 1.5 mm radius. As can be seen in Figure 12, the change in the results of the reflection coefficient (S11) is predominantly associated with the presence of a tumor, which has the effect of causing a noticeable frequency shift from 2.2 GHz to 2.3 GHz. A shift occurred in the reflection coefficient value from -10.597 to -12.139, -48.083 to -47.501, -57.102 to -55.637, - 46.324 to -47.372 that is for the 2 X 2 proposed antenna design S11, S12, S13 and S14 respectively as you can see from figure 12. In order to test the antenna sensitivity, a 1 mm tumor radius is tested and a shift in the frequency from 2.2 GHz to 2.3 GHz is noticed. There was a change in the reflection coefficient values for the 2 X 2 proposed antenna design. Specifically, the values shifted from -10.626 to -13.676, -48.019 to -46.665, -57.096 to -54.340, and -46.324 to -46.372 for S11, S12, S13, and S14 respectively, as figure 13 is showing.

This change in frequency and reflection coefficient values is a remarkable discovery that provides clear confirmation of the tumor's influence on the electromagnetic properties of brain tissue. It is a discovery that presents a large amount of evidence. The frequency shift is successfully proved with graphical representations, which highlights the significance of this phenomenon in terms of comprehending how the tumor influences the reflection coefficient. In addition, the graphical representation illustrates the significance of this frequency-domain shift, which provides an understanding of the changed electromagnetic response that occurs when a brain tumor is present.

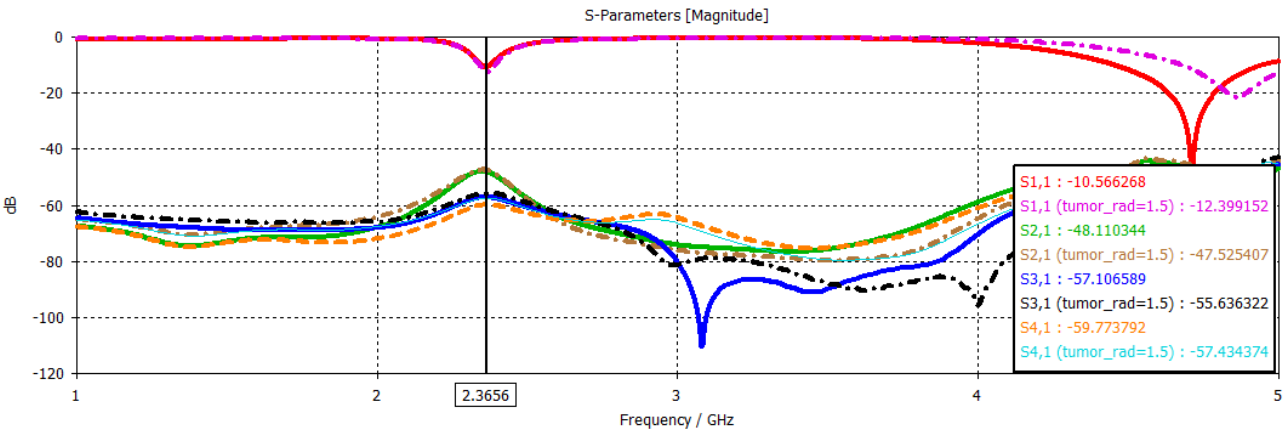

Fig. 12. Reflection coefficient of the healthy brain and the defective brain with a 1.5 mm tumor using the suggested 2 X 2 proposed antenna design. (a) the first antenna. (b)second antenna. (c) the third antenna. (d)the fourth antenna

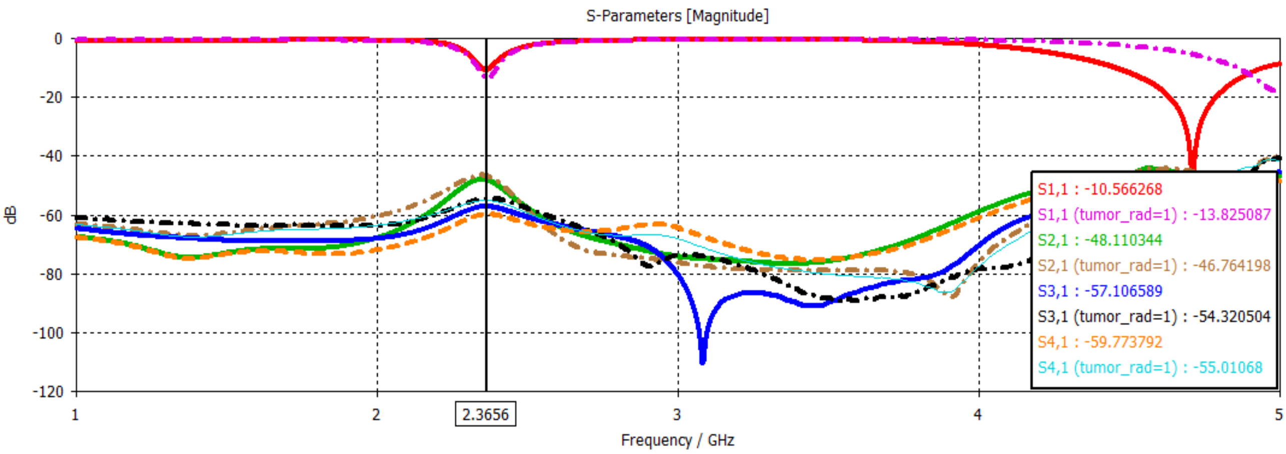

Fig.13. Reflection coefficient with a 1mm tumor in the suggested 2 X 2 proposed antenna design. (a) the first antenna. (b)second antenna. (c) the third antenna. (d)the fourth antenna

5.2 Surface current distribution

When an electromagnetic field is put on something, it makes an electric current run. This current is called surface current and is most common in metallic antennas. When the suggested antenna model was used on the Brain Phantom (which has a tumor), an amazing result was seen: a

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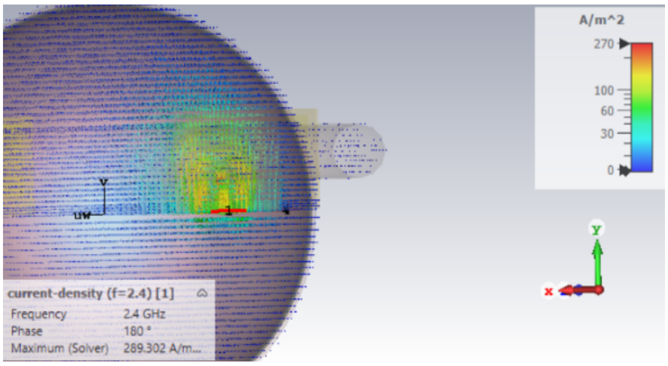
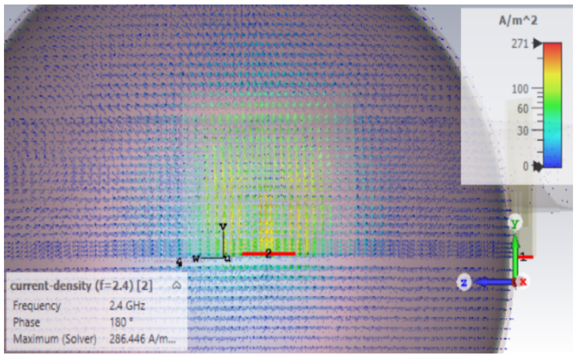
virtual Surface Current of 39.1 A/m. This result displays the flow of electricity across the metallic parts of the phantom's surface. Figure 14 shows Surface Current of has been spread cross the healthy brain phantom. While Figure 15 shows how the surface current is spread out across the brain phantom, which gives a thorough understanding of how cancer cells affect the brain's electromagnetic response. Findings from this simulation give us a better idea of how surface current changes when there is disease and help us understand how electromagnetic fields affect brain tissue, especially when there are tumors. The simulated results show a symmetrical nature of the configuration of the antennas. Consequently, it may be concluded that there is minimal current leakage between the four antenna components, indicating excellent isolation performance. The picture shows both the general strength and the changes in the shape of the surface.



(a)



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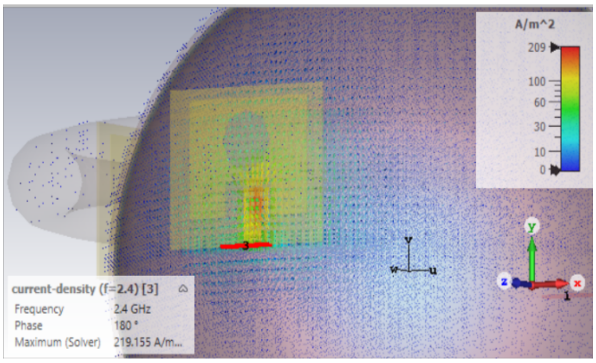
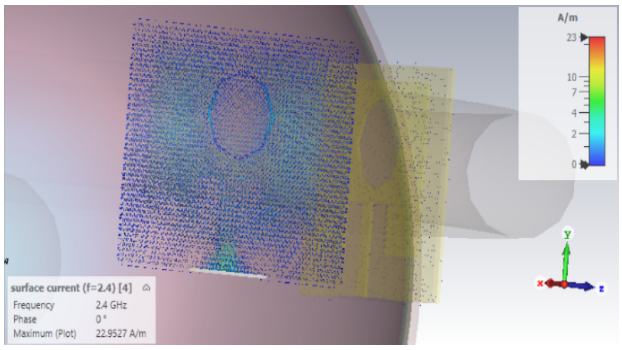
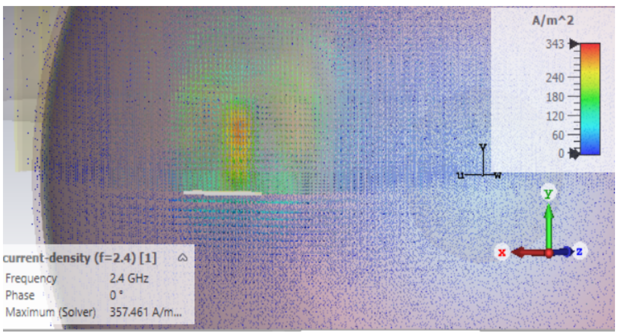


(c)

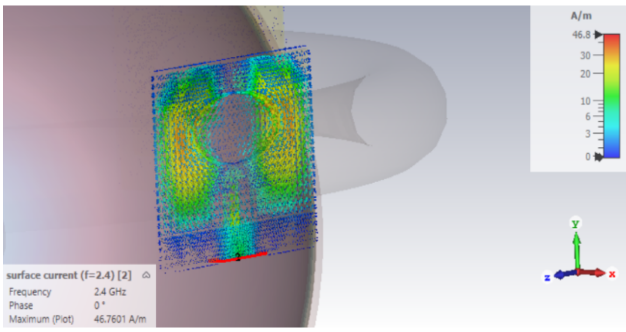


(d)

Fig. 14. Surface current of the healthy brain using the suggested 2 X 2 proposed antenna design. (a) the first antenna. (b)second antenna. (c) the third antenna. (d)the fourth antenna



(a)



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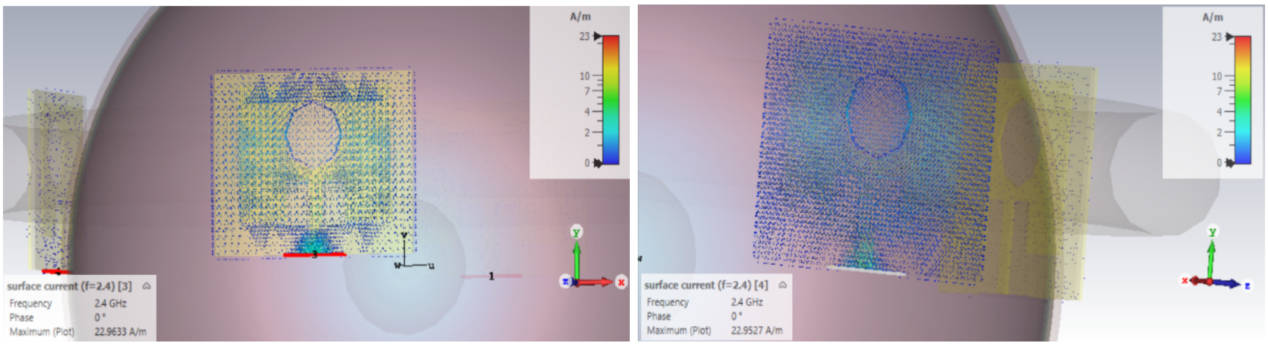


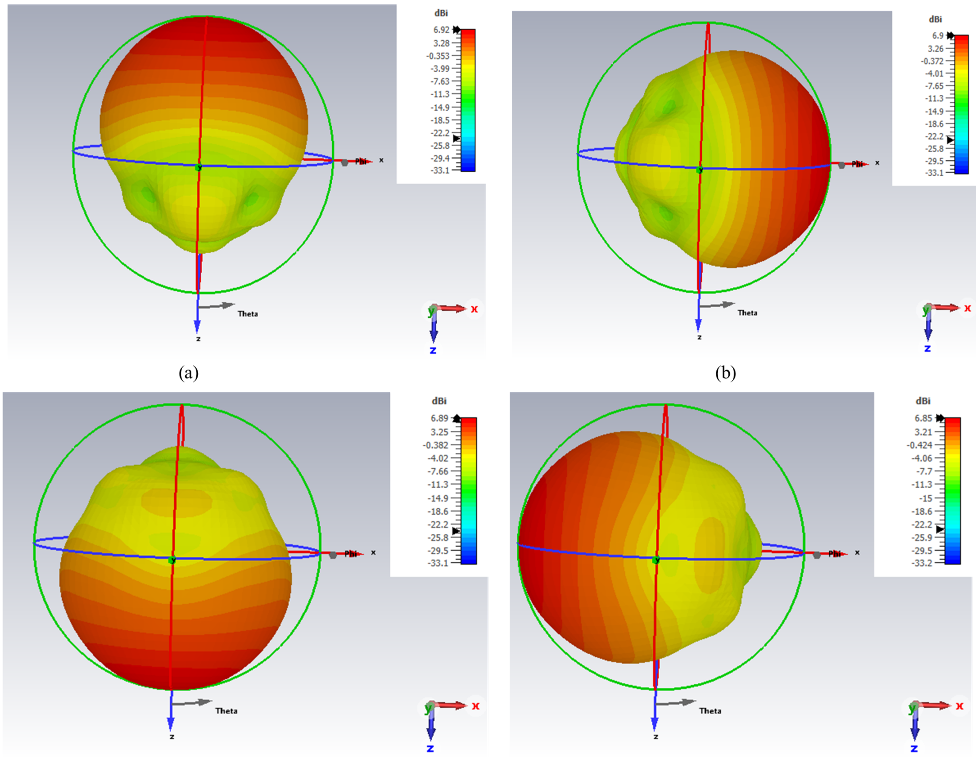
(c) (d)

Fig.15. Surface current of the defective brain with a mm tumor in the suggested 2 X 2 proposed antenna design. (a) the first antenna. (b)second antenna. (c) the third antenna. (d)the fourth antenna

5.3 The Radiation of the Farfield

The farfield is utilized to evaluate the performance of an antenna, understand how it will operate in real-world circumstances, and optimize its design and to Ensure that an antenna satisfies these requirements is required for legal compliance and to avoid detrimental interference with other systems.

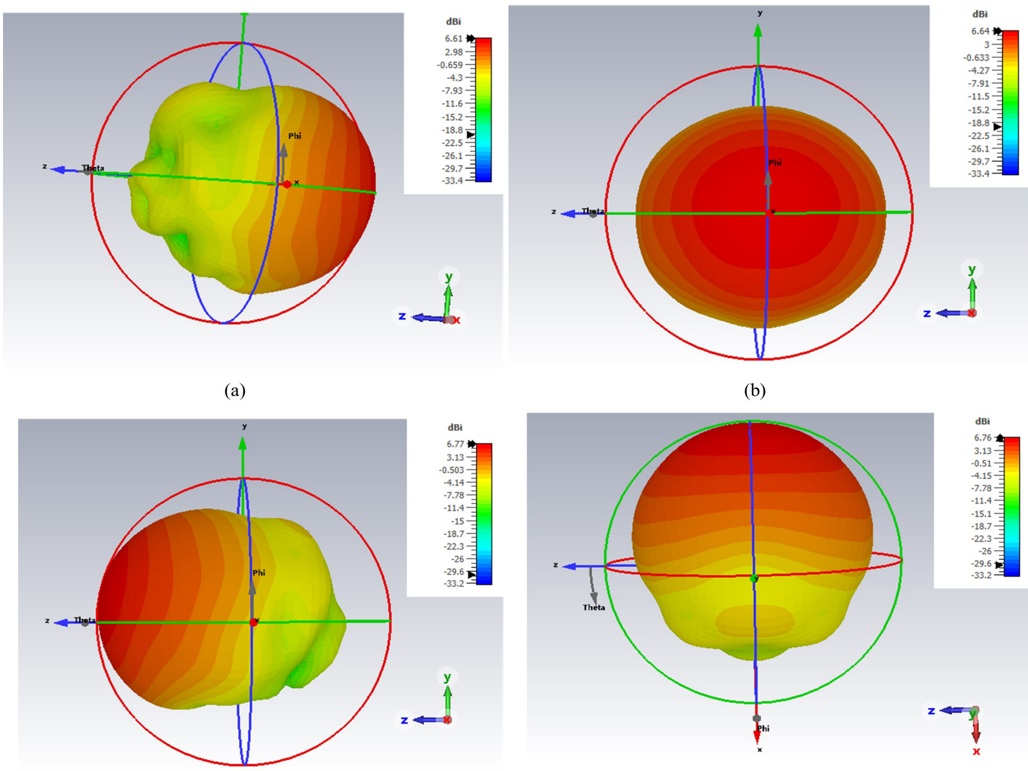
The antenna model was positioned on top of the Brain Phantom, which was designed to contain a tumor. The Farfield Radiation has been estimated during the simulation in 3D format. The cst. Farfield Radiation of the Brain Phantom is depicted in Figure 16 and figure 17, which illustrates both the presence and absence of a tumor in the brain. The data is presented in three-dimensional format. When used on a healthy brain phantom, the antenna displayed a Reflection Factor of -6.61dB, -6.64dB, -6.77dB and -6.74 for the first, second, third and fourth antenna respectively, figure 16 depicts the values of the farfield. Figure 17 displays the farfield radiation of the brain phantom including a brain with 1.5 mm radius tumor, For the first, second, third, and fourth antennas, the antenna displayed reflection factors of -6.61dB, -6.64dB, -6.77dB, and -6.74dB, respectively. The farfield values shows that are shows that the measured of the radiation patterns has a consistent behaviour in all directions and closely match the forecasts. In both major planes, the radiation patterns show virtually isotropic properties. Because isotropic radiation patterns may send and receive information waves from all directions, they are highly attractive for biomedical implanted devices.



(a) (b)

(c) (d)

Fig. 16. Farfield of the proposed antenna with the healthy brain phantom (a) the first antenna. (b)the second antenna. (c) the third antenna. (d) the forth antenna



(a) (b)

(c) (d)

Fig. 17. Farfield of the proposed antenna with the defective brain phantom with a mm tumor (a) the first antenna. (b)the second antenna. (c) the third antenna. (d) the forth antenna

6. Related work

The following table 4 provides a comparative study of a number of studies that concentrate on the detection of brain tumors through the use of antenna design. A component of this procedure involves conducting an analysis of many parameters, including gain, operating frequency, size of the antenna, and SAR values. A condensed summary of each study is provided, focusing on the methodology, findings, and any distinctive characteristics of the study.

The suggested study outperforms past attempts by adopting a more effective methodology, which results in higher -detection accuracy and perhaps addresses specific challenges mentioned in earlier research. Moreover, the proposed study is more successful than previous efforts.

Table 4
The Related Work

Ref.	Dimension (mm3)	Tumor radius	Operating frequency (GHz)	Gain (dBi)	SAR (W/Kg)	Overall observation
(Alazemi and Iqbal, [34])	5 × 4.2 × 0.12 mm^3	Different values of tumor radius	2.15–2.77 GHz	−20.6 dBi	198.5 W/Kg	Significant low dimension, an acceptable range of BW, minimum value of the gain, large value of SAR.
(Rokunuzzaman et al., [35])	0.23 × 0.23 × 0.04 λ in size with respect to the lowest operating frequency	5 mm	1-1.7 GHz	Not reported	0.0147 W/kg	Compact dimensions (the dimension changes according to the operating frequency), limited BW, the gain is not reported and There is no SAR calculation,
(Zhang et al., [36])	.4x 41.9x1.7 mm^3	5 mm	5– 10 GHz	3.1 dBi	NA	Large dimension, very low BW, low gain and SAR is not reported.
(Elkorany et al., [37])	0× 50 ×1.5 mm^3	35 mm	3.9GHz	Not reported	0.435 W/kg	Large dimensions, gain is not reported and low antenna sensitivity.
(Hossain et al., [38])	50 × 40 × 8.66 mm^3	4 mm	1.69 GHz	6.67 dBi	0.0018 W/kg	Compact size and reasonable SAR
(Sinha et al., [23])	33 × 23 × 1 mm^3	5 mm	l-2.4835 GHz	Not reported	)3101 W/kg	Compact size but the gain is not reported
Proposed work	40x50x mm^3	1 mm	2.45 GHz	7.7 dBi	1.5 W/kg	Compact dimension, good BW, high gain and high SAR

7. Conclusions

In The investigation of microstrip patch antennas (MPAs) with defect ground structures (DGS) for the purpose of microwave imaging (MI) in the identification of brain tumors stands for a significant advancement in the realm of medical diagnosis. This study utilizes the 2 X 2 proposed antenna design which consists of four antennas, two with circular DGS and the other two with elliptical DGS to detect brain cancers in their early stages. Several modifications have been implemented in the design to reduce its size and enhance its sensitivity. The antenna was designed to oscillate at a frequency of 2.4 GHz, within a bandwidth of 700 MHz. The recommended antenna maintained its high gain and efficiency in the vacant area. In addition, SAR of the antenna, measured at 10 grams of tissue, is below the maximum thresholds established by the regulation of IEEE, which is set at less than 2 Watts per kilogram for an input power of less than 265 milliwatts. This antenna has the potential to be highly beneficial in the early detection of brain cancer. The CT and MRI scans were unable to detect stage 0 of the brain tumor due to its small size of 1 mm, which falls below the minimum detectable radius of 3 mm for both imaging techniques. The subsequent objective is to develop the design, conduct human testing, and thereafter fabricate the proposed antenna and precisely determine their location within the brain. Furthermore, the defects in the ground construction result in a compact size. The performance of the proposed design is demonstrated through simulated and measured results using a brain phantom, including the effects of the device and other components, while also considering the overall system setup.

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