Design and Fabrication of a Simple Microstrip Patch Antenna for Brain Tumor Detection with Low Sar

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Abstract: Brain tumors are a significant global health concern, with early detection delayed by their small size and limitations in current diagnostic methods. This study introduces a new rectangular microstrip patch antenna featuring a Defect Ground Structure (DGS) for brain tumor detection. Operating within the Industrial, Scientific, and Medical (ISM) frequency band of 2.4 to 2.48 GHz, the antenna has compact dimensions of 39 x 47 x 1.6 mm. It is constructed using a 1.6 mm thick FR-4 lossy dielectric substrate and 0.1 mm thick copper for both the patch and ground layers.To evaluate its effectiveness, a human head phantom model comprising six layers—skin, fat, skull, dura, cerebrospinal fluid (CSF), and brain—was developed. A simulated 10 mm benign tumor with a relative permittivity of 50 and conductivity of 1.58 S/m was incorporated into the model. The antenna's performance was assessed by analysing its radiation pattern, Voltage Standing Wave Ratio (VSWR), and return loss in both normal and tumor-affected head models. Safety considerations were paramount; the antenna operates within the ISM band and follows to IEEE safety standards for Specific Absorption Rate (SAR). With an SAR value of 0.36 W/kg—well below the safety threshold of 1.6 W/kg—the device is deemed safe for human use. This innovative antenna design offers a promising approach for the early detection of brain tumors.

Keywords*:* Patch Antenna, Simulation, Optimisation, HFSS, VSWR,

How to cite this article: Kumar R, Sayeed M, Namdev A, Sharma A, Sah S, Pathani A. Design and Fabrication of a Simple Microstrip Patch Antenna for Brain Tumor Detection with Low SAR. Int J Drug Deliv Technol. 2026;16(51s): 462-469. DOI: 10.25258/ijddt.16.51s.33

INTRODUCTION

A brain tumor is a serious condition that significantly impacts a person’s life. Tumors can start in the brain or spread there from other parts of the body. Symptoms often include persistent or severe headaches, vision problems, loss of balance, confusion, and seizures.

To detect brain tumors, many advanced technologies have been developed. Microwave-based methods are particularly promising because they are quick, cost-effective, and compact. Traditional techniques like CT scans and MRIs are also commonly used for diagnosing brain tumors. However, there's a lot of ongoing research into using microwave technology for tumor detection[24]. This is because the dielectric properties of healthy and tumor-affected tissues differ, causing changes that can be detected by microwaves. Antennas are widely used in medical applications for their ability to detect these changes.[2]

Advancements in antenna technology have enabled the detection of tumors in the human body by converting radio signals into electromagnetic waves. These waves have special properties, like absorption and reflection, which are extremely useful for medical applications.[4]

The microstrip patch antenna is particularly advantageous in the medical field. It is low-cost, easy to make, and simple to use, making it more favourable than other types of antennas. To create antennas that operate at multiple frequencies, modifications are made to both the patch and the ground plane. This paper focuses on a rectangular shaped patch antenna, examining its design and performance.[1]

Antennas, including various types like microstrip patch antennas, are crucial for sending and receiving signals. Microstrip patch antennas are especially popular in mobile applications due to their cost-effectiveness and compact size. These antennas typically consist of three main parts: a ground plane at the bottom, a dielectric layer in the middle, and a patch on top.[3]

Additionally, they have feed lines connected to the edge of the patch. These lines link the antenna to the transmitter and receiver, enhancing compatibility between devices. Modifying the ground plane helps achieve a broader range of frequencies and allows customization of the antenna's characteristics as needed. [22].

The patch in a microstrip patch antenna can be designed in any shape needed by the designer. Both the patch and the ground plane are made from conductive materials like copper The patch sits on a dielectric substrate, and when a voltage is applied between the patch and the ground plane, the antenna becomes active and radiates signals in the broadside direction (directly outward), with no radiation occurring at the level of the substrate.[12]

Microstrip technology involves a type of electrical transmission line that can be manufactured and used in various devices. These lines carry microwave frequency signals. Microstrip patch antennas are widely used because they are lightweight, low-cost, and can be easily fabricated with computer-aided design (CAD) tools.[11]

This paper explains how the antenna's design was created and simulated using HFSS software. The initial antenna shape was adjusted to achieve the desired radiation pattern and performance. The paper then compares and analyses the original shape with the modified versions, detailing the improvements and changes made.

ANTENNA CONFIGURATION

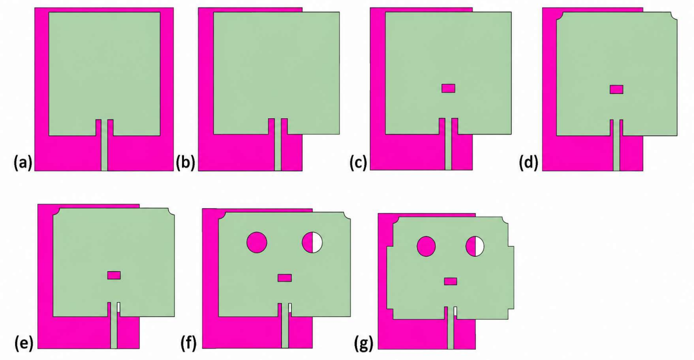


Fig. 1. The evolution of the proposed CPPMA during the design process: (a) Antenna 1, (b) Antenna 2, (c) Antenna 3, (d) Antenna 4, (e) Antenna 5 (f) Antenna 6 and (g) Proposed Antenna.

Figure 1 illustrates how the antenna design has changed step by step throughout its development. In Figure 2, shows how these design changes have affected the reflection coefficient. The addition of a rectangular slots on the ground plane of the antenna is what creates the return loss. This means that bandwidth covers frequencies from 2.4386 GHz to 2.4633 GHz.

Figure 3 shows the front and back view of the proposed antenna and figure 4 shows the reflection coefficient of that antenna. Which can be clearly seen the that is in ISM band.

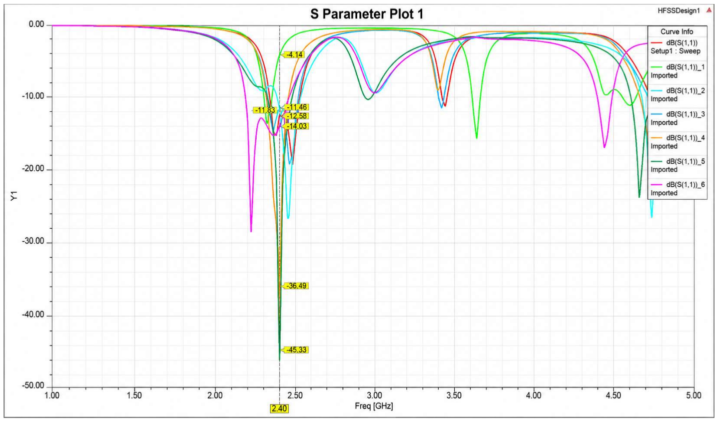


Fig 2. (a) Reflection coefficient of Antenna a, b, c, d, e, f and g

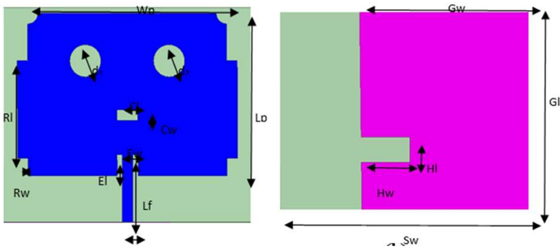


Fig 3. Geometry of the designed antenna (a) front view (b) back view

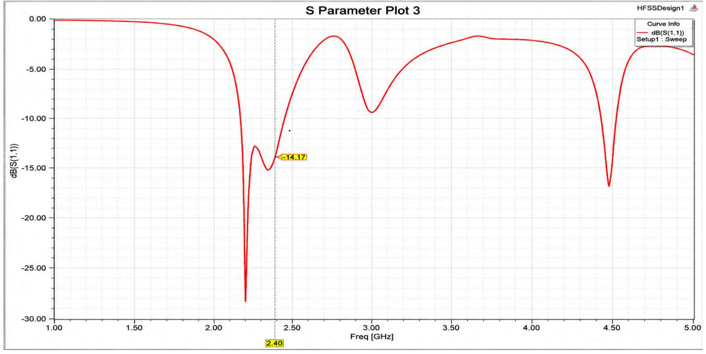
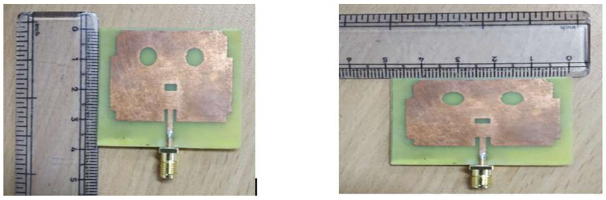


Fig. 4. (a) Reflection coefficient of proposed antenna

Table1: Parameters of the proposed antenna

Parameters	Value (mm)	Parameters	Value	Parameter	Value (mm)
Sw	47	Gl	39	d 1	4
Lp	30	Wp	38	d 2	4
Lf	19	Wf	3	Hl	5
Gl	39	Gw	32	Hw	10
Cl	4	Rl	18	El	4
Cw	2	Rw	2	Ew	4



(a) (b)

Fig 5. Fabricated prototype of the proposed Antenna :(a) front view and (b) back view

Figure 5 displays the physical prototype of the designed antenna. This prototype is printed on a material called FR4-Epoxy and measures 39 × 47× 1.6 mm. The antenna was created using the PCB prototyping machine.

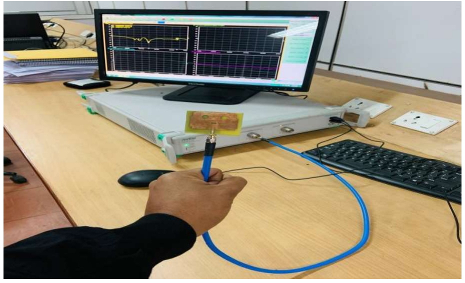


Fig 6. VNA testing of the antenna in free space

Figure shows how the reflection coefficient of the antenna is measured using a Vector Network Analyzer (VNA).

Fig 7. Comparison between Simulated and Measured Return loss S11 (dB) of antenna in free space

Fig 7 compares the simulated and measured reflection coefficients of the antenna and shows they match well.

Human head Phantom model

In this paper, a cylindrical -shaped model of a human head is used. Figure 8 shows that this model is made up of 7 layers: dry skin, fat, muscle, skull, dura, cerebrospinal fluid, and brain. Table 2 provides detailed properties for both this human head model and the tumor model, which includes a tumor.

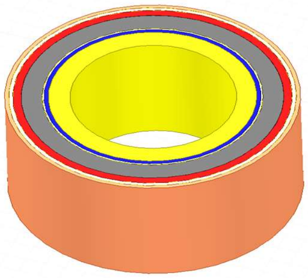


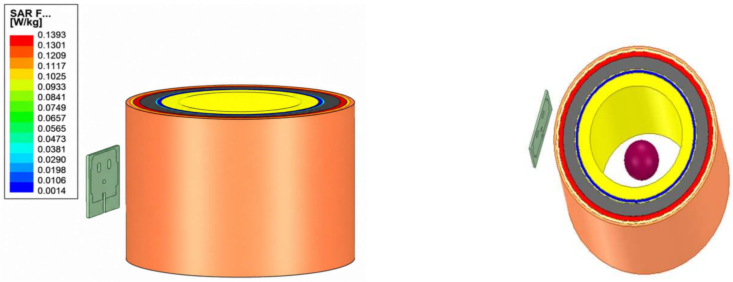
Fig 8. Human head Phantom model

Table 2 lists the characteristics of the 7-layer human head model and the brain tumor model (including a tumor) specifically at a frequency of 2.45 GHz.

Frequency (MHz)	Head Layers	Thickness (mm)	Permittivity (ε)	Conductivity (S/m2)
2450	Dry Skin	2	38.006660	1.464073
2450	Fat	2	5.280096	0.104517
2450	Muscle	4	53.573540	1.810395
2450	Skull	10	14.965101	0.599694
2450	Dura	1	42.035004	1.668706
2450	Cerebra Spinal Fluid	2	66.243279	3.457850
2450	Brain	10	42.538925	1.511336
2450	Tumor Model	Radius= 10	58.263756	2.544997

Brain tumor detection

This section examines how radiation from the antenna affects the human head model. Initially, the antenna was placed 10 mm away from a healthy human head model, as shown in Figure 9 (a). and figure 9 (b) shows the antenna with the human head phantom model with tumor.



(a) (b)

Fig.9 Antenna positioned at a distance of 5 mm from the human head phantom model: (a) without brain tumor, and (b) with brain tumor.

In Figure 10. there is a comparison graph between the simulated result of the antenna in free spaces and when connected to a phantom without a tumor model applied to the head phantom.

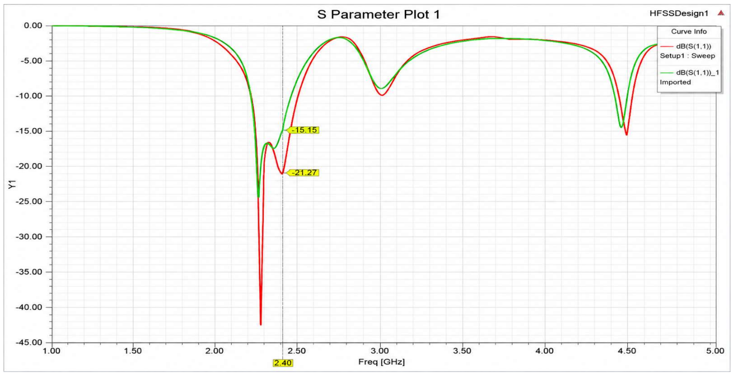


Figure 10: Comparison of return loss S11(dB) for antenna in free space and antenna with head phantom.

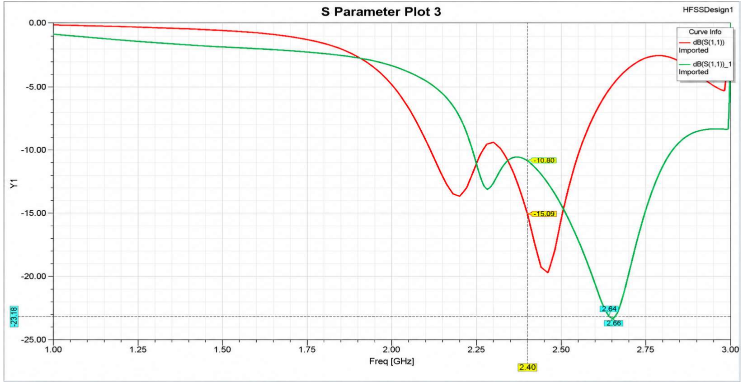


Figure 11. Comparison between return loss S11(dB) of antenna with head phantom and the antenna with tumor model at 2mm distance.

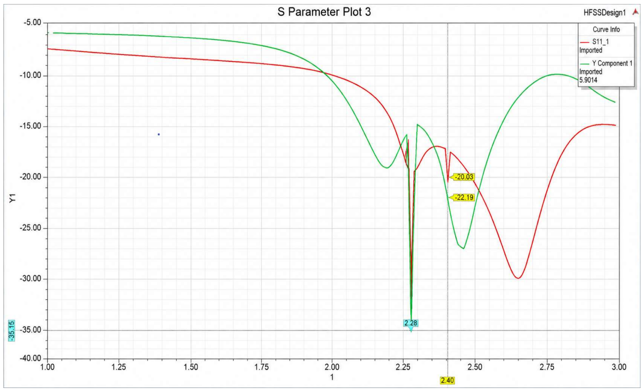


Figure 12. Comparison between return loss S11(dB) of antenna with head phantom and the antenna with tumor model at 15 mm distance.

Table 4.3: Comparison of the proposed Antenna with other work

Ref.	Dimension (mm)	Return Loss (S11)	Gain (dB)	Bandwidth (MHz)	SAR (W/kg) (simulated)
Rana *et al.* (2023)	100*100*1.6	-20	2.5	0.746	1.46
Guetaf *et al.* (2023)	34*28*1.5	-25	2.6	195	1.9
Joe at al. (2023)	44*34*1.6	-20	2.1	150	1.5
Devi *et al.* (2022)	40*40*1.6	-16	0.2	-	-
Talukdar *et al.* (2020)	70*60*1.6	-25	2.5	230	0.9
Pracha *et al.* (2019)	71*49*1.6	-23	1.44	300	-
Akbar *et al.* (2019)	56*56*1.6	-40	1.5	110	0.5
Proposed Antenna	47*39*1.6	-15	2.6	280	1.01

CONCLUSIONS

This paper introduces a rectangular antenna designed for brain tumor detection. The antenna prototype, measuring 39 × 47 × 1.6 mm³, was fabricated on a cost-effective FR-4 substrate. Testing showed that the antenna works within a narrow frequency range of 250 MHz (from 2.30 to 2.55 GHz) and supports circular polarization. The antenna's effectiveness in detecting brain tumor was demonstrated using various model simulations. Additionally, tests confirmed that the antenna is suitable for health-monitoring devices. Overall, the results highlight the antenna potential for biomedical application.

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