A Monopole Resonator Employing a Mono-Static Approach to Detect Strokes in the Brain

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Abstract. This work proposes a compact monopole antenna resonator with a modified ground plane to detect cancer related tumors in the brain. The meander line resonator is modeled on the economical dielectric substrate FR4. The design has dimensions of 9 × 16.8 × 1.6 mm^3 and can radiate at 2.44 GHz with a 170 MHz bandwidth from 2.34 to 2.51 GHz. The proposed structure is compact in size, and it can be easy to assemble in microwave diagnostic systems. The proposed resonator is tested with a human head model in the full-wave simulator. The mono-static radar technique is used to detect unhealthy tissue in the brain. This technique employs RF reflection and detects brain tumors by comparing the variations in signals received from the brain model with and without the tumor. The radiation exposure due to the monopole resonator on the human head model was also analyzed using the full wave simulator.

Keywords: Monopole Resonator · Meander Line · Brain Tumor · Mono-static Radar

1 Introduction

In the world, there are many health issues that cause humans, among which cancer is one that causes significantly high death rates. This has happened due to late identification and also a lack of self confidence [1]. If it is detected in the early stages, such as the first and second stages, there is a good chance of extending the patient's life and even finding a cure. The imaging techniques, such as CT scan (Computed Tomography), Magnetic Resonance Imaging scan (MRI), Electro Encephalography scan (EEG), and Electrical Impedance Tomography Technique (EIT), etc., are used in the detection of tumors. But these methods require pre-medical preparation of the patient and the need for an experienced operator observation. The process is time-consuming, costly and also, the results are not obtained instantly. As a result, the most recent advances in RF engineering are being made to support biomedical applications such as the detection of tumor cells in the human body in less time and at a lower cost.

The antenna is critically vital to the functioning of this system. Microwave frequency can be used by an impressive flexible antenna to detect tumors [2]. This antenna

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is based on the electromagnetic impedance tomography (EIT) technique, which can also be used to detect various glands. Several studies have been done in which the characteristics of substrates like Giigml1032, FR4, and Taconic (TLY-5) have been altered, and satisfactory results have been obtained for breast cancer detection [3, 4]. Patients, however, have reported that the sizes do not feel right when worn over their breasts. In [3], researchers used smart antennas equipped with pre-processing algorithms to distinguish cancer tumors from normal glands. In some studies, the Inverse Fast Fourier Transform (IFFT) was utilized to filter out noise in order to obtain accurate results from spectral analysis. An antenna array that is fabricated on a polyethylene terephthalate substrate is presented in proposal as a method for detecting tumors. In their research on the detection of brain tumors, Alqadami et al. propose a multilayer and large size polyester-based antenna array as well as a head wearable array antenna [4]. An imaging system is responsible for the detection work. In addition, planar UWB antennas based on the specific absorption rate (SAR) are utilized in the detection of tumors [5].

Therefore, in order to make the microwave imaging equipment more accessible, it is preferable to use antennas with a low profile. In this work, a compact monopole resonator with modified ground is proposed. The proposed design is patched on a 1.6 mm thick FR4 substrate. The design is made to radiate at 2.4 GHz and simulations are done using full wave simulator and results are recorded.

The article is organized into four sections. Section I includes an introduction along with literature, the patch antenna design geometry is discussed in Section II, human head modeling using full wave simulator values is covered in Section III, results and discussion are in Section IV, and finally Section V concludes the work.

2 Antenna Design Geometry

The proposed meander line resonator is constructed of three layers: the ground layer, substrate, and patch. Here, the shape of the patch is considered a meander line. The substrate material is FR4 dielectric material, and the properties of this material are noted as a height is 1.6 mm, dielectric constant of 4.3, and 0.02 loss tangent. The micro strip line method is used to provide the excitation. The final dimension of the substrate is $9 \times 16.8 \times 1.6\ \text{mm}^3$, and the length and width of the feed line are 8.1mm, and 3.12mm, respectively.

A rectangular U-shaped slot is introduced in a meander line resonator. In this the ground is removed till the feed line that allows radiation in the desired ISM band frequency. The finalized design shown in Fig. 1 is obtained by number of approximation using the software shown in Fig. 2 and the final design metrics of proposed antenna are listed in Table 1.The resonator that has been proposed was developed using these four steps. As a result of the initial step in the evolution process, which was the construction of a straightforward L-shaped resonator with a partial ground plane, antenna-1 was designed to resonate at 3.75 GHz. The shift in operating frequency from 3.75 GHz to 2.55 GHz that resulted from the addition of the inverted U-shaped strip to the antenna-1 is depicted in Fig. 3. Step three of the evolution process involves modifying the ground plane with a rectangular U slot that has triangular edges.

This is done in order to obtain the appropriate operating frequency and proper impedance matching. In the end, rectangular slots were added to the meander line resonator so that it could be tuned to the desired frequency band.

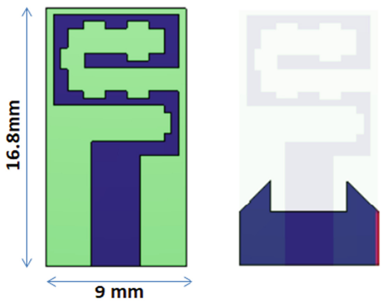

Fig. 1. Proposed monopole resonator **(a)** Front view **(b)** Back view.

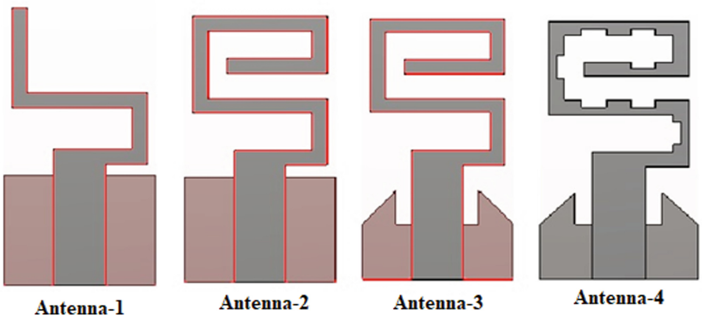

Fig. 2. Evolution study of monopole resonator.

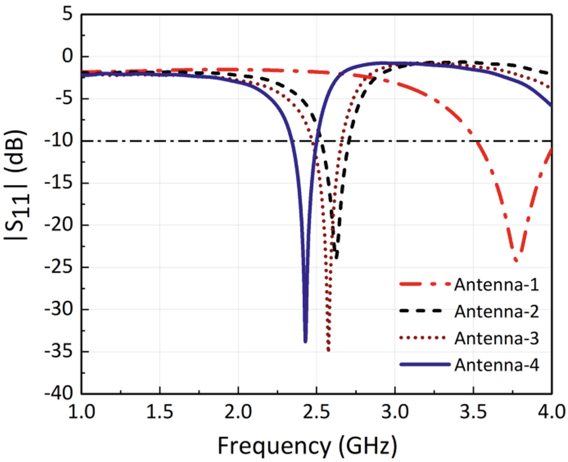

Fig. 3. Evolution analysis of reflection coefficient for proposed meander line resonator

Table 1. Antenna design parameters

Design Variable	**Unit (mm)**
Width of the feed	3.12
Length of feed	8.1
Width of meander	1.6
width of ground plane	9
Slot in ground	1.5 × 1.2

3 Designing of Human Head Model

The proposed antenna is built to identify instances of strokes that occur in human brains. The human head model is made up of seven different layers, all of which were produced in the full wave simulator by utilizing dielectric properties. Figure 4 illustrates the seven layers that characterize the human head model: skin, muscle, fat, skull, dura, cerebrospinal fluid, and brain. These layers are in order from outside to inside the head. The dielectric properties, including dielectric constant and conductivity, are listed in Table 2 [2]. These properties change depending on the size and thickness of the layers. Excitation can be provided to the antenna while it is kept at a distance of 25 mm towards the human skull model without the presence of a tumor. The positioning of the antenna in relation to the human head model can be seen in Fig. 5(a). Following this, the antenna will display characteristics such as its reflection coefficient, electric field, and current density. Following the examination of these values, a tumor measuring 5 millimeters in diameter is simulated on a human head model.

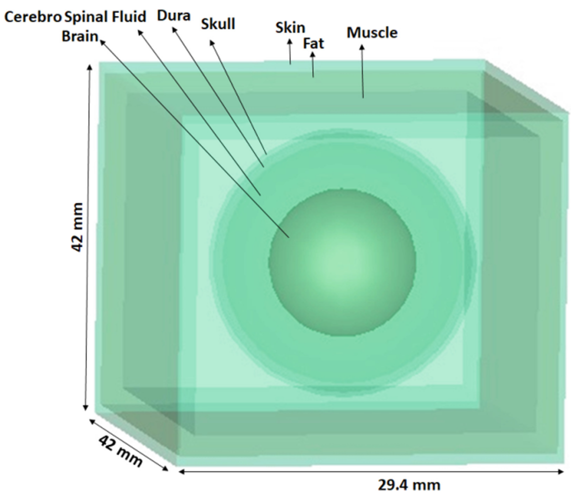

Fig. 4. 7-layer human head model.

The same antenna parameters as before are analyzed, and the results are compared with the results of the previous analysis. In Fig. 5(b), a stroke model (tumor) is used to show the human head model. The human head's skin, fat, and muscle are all created in the same manner as a rectangular shaped cubic model with the dimensions of 42 mm wide by 42 mm high by 29.4 mm deep. Afterwards, using the full wave simulator, the remaining head layers are modeled into a spherical shape.

Then the antenna exhibits parameters like reflection coefficient, electric field, and SAR. These values are analyzed and then a tumor of size 5 mm is positioned on a human head model. The same antenna parameters are analyzed and compared with previous antenna parameters. Figure 5(b) shows the human head mode with a stroke model (tumor). The different sizes of stoke models are introduced in a brain and analyse the maximum SAR at 2.44 GHz.

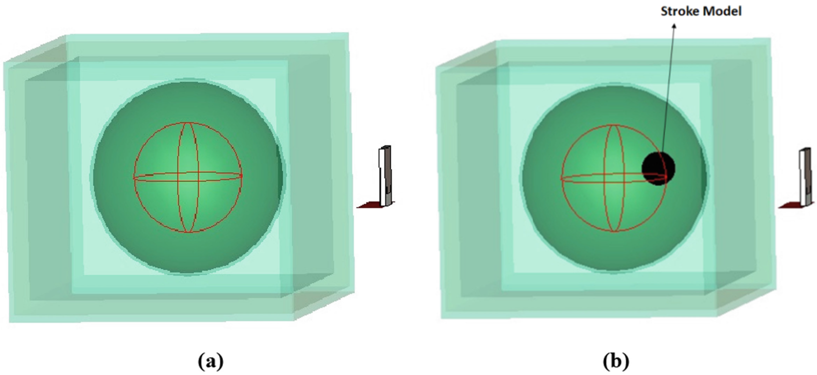

Fig. 5. **(a)** Human head model **(b)** and including stroke model (tumor) with the proposed antenna placed over a far field distance.

Table 2. Die-electrical properties for the human head layers and unhealthy tumor at 2.4 GHz

Tissue	ϵ_r	σ (S/m²)	**Thickness (mm)**
Skin	37.9	1.5	2
Fat	5.3	0.1	2
Muscle	53.5	1.8	4
Skull	15	0.6	10
Dura	42	1.67	1
Cerebra spinal fluid	3.5	3.45	2
Brain	42.5	1.51	10
Brain tumor	58.2	2.54	5

4 Results and Discussion

The fabricated prototype model, simulation and measured results of the proposed micro strip patch antenna are shown in Fig. 6. According to the measured S-parameters graph (return loss Vs frequency), the proposed resonator operates at 2.44 GHz and has a band width of 170 MHz with a return loss of less than -10 dB and a reflection coefficient of -33.82. The VSWR is less than 2, and Fig. 7 shows the measured and simulated far-field results at 2.44 GHz. For H-plane ($\phi = 0°$), the pattern is omni-directional, and for E-plane ($\phi = 90°$), it has an eight-shaped structure. The simulated and measured gains are 1.8 dBi and 1.62 dBi, respectively.

The maximum SAR is a measurement that determines how much electromagnetic (EM) energy the human body absorbs when it is subjected to electromagnetic (EM) radiation. According to the guidelines established by the IEEE Std C95.1TM-2019, the highest peak value that can be achieved for 1g of tissue is 1.6W/Kg [6]. By observing Table 3, the values of SAR differ between healthy and unhealthy tissue. The SAR values for skin healthy brain and with a 5 mm radius brain tumor, are 0.932 and 0.958 (1g) [W/Kg] at 2.44 GHz respectively.

The proposed meander line resonator has an E-Field of 29345 V/m in the absence of tumor and 30091 V/m in the presence of 5mm tumor at 2.44 GHz, respectively.

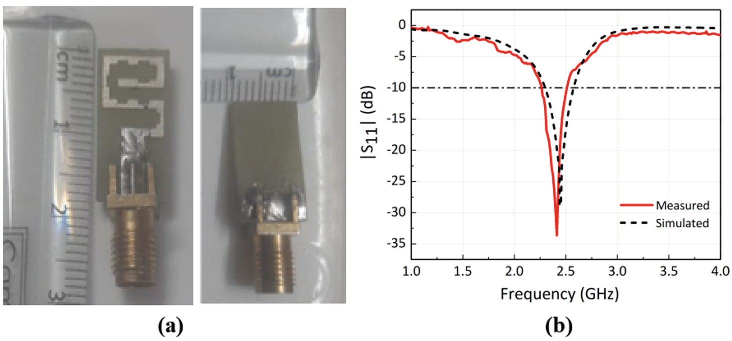

Fig. 6. **(a)** Fabricated prototype, and **(b)** the $|S_{11}|$- plot at free space for both measurement and simulation of proposed resonator.

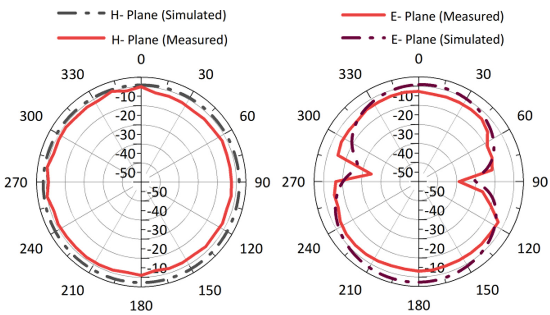

Fig. 7. Far field plot of proposed meander line resonator at 2.44 GHz.

Table 3. SAR analysis for the human head model with and without stroke at 2.44 GHz

SAR (1g) [W/kg]			
without Stroke model	**with Stroke model**		
	3 mm	**4 mm**	**5 mm**
0.932	0.944	0.951	0.958

The reflected time signals plot absence and presence of tumor is shown in Fig. 8. The proposed meander line resonator could also send and receive signals from the human head brain model.

A difference in reflected output between a brain model with and without a tumor aids in the detection of any malignant cells in brain tissue. As a result, the proposed monopole resonator is ideal for detecting brain cancer at an early stage. The comparison proposed meander line resonator with several reported antennas for various diagnostic biomedical applications shown in Table 4.

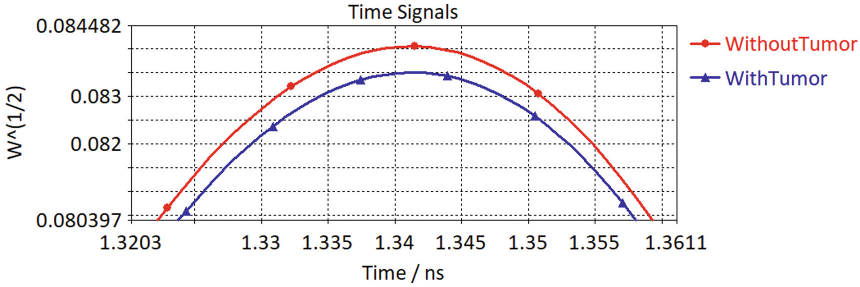

Fig. 8. Reflected time signals of proposed meander resonator.

Table 4. Comparative analysis of the proposed meander line resonators with other reported biomedical application antennas

Ref.	**Antenna Size (W x L x H) (mm^3)**	**Volume (mm^3)**	**Operating Frequency (GHz)**	**Electrically Small Antenna (ESA)**
[7]	38.1 × 38.1 × 2	2903.22	2.5	No
[8]	39 × 39 × 0.503	765.063	2.45	No
[9]	30 × 32 × 1.6	1536	2.45	No
[10]	35 × 35 × 0.508	622.3	2.45	No
This work	**9 x 16.8 x 1.6**	**241.92**	**2.44**	**Yes**

5 Conclusion

In this work, a compact monopole resonator with modified ground is proposed for stroke detection in brain. It has significant radiation band from 2.34 to 2.5 GHz allows and applications along with ISM 2.44 GHz band. Removal of partial ground gives the radiation similar to monopole. The slot provided in the resonator makes the resonator radiate at low frequencies and very lower volume, so one can treat it as electrically small antenna (ESA). The size $9 \times 16.8 \times 1.6$ mm^3 shows compactness and easy to assemble in the microwave imaging system. More accuracy can be obtained by using a group of such pact antennas by forming a bowl shape to suit the skull structure. An array of proposed resonators will be positioned on the head model in the future, and reflected signals will be gathered and analyzed using advanced image processing algorithms to visualize the tumor. This resonator could be the building block for a futuristic diagnostic tool for first responders to detect strokes at the point of care.

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