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Improved 3D Antenna for Human Head Imaging Applications

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Abstract
a 3D antenna is built and simulated using HFSS software. The optimization of the developed antenna is evaluated by analysing the choice of substrate, thickness of substrate, feeding mechanism and position of the feed. It is observed that the designed antenna showed improvements in antenna parameters such as gain, impedance matching, return loss and bandwidth compared to other research works The peak gain value is found to be 7.132 dB operating at a frequency of 2.5 GHz which is the suitable frequency for microwave imaging across an operating band of 1-4GHz for microwave imaging applications. The bandwidth of the antenna is found to be 300MHz (2.37-2.67 GHz) and achieving a front to back ratio of over 22 dB.

***Keywords:** 3D, Antenna, HFSS.*

I. INTRODUCTION

Human head imaging [2] is the process of detecting damaged brain tissue due to blood clot inside the human brain also known as hemorrhagic stroke. Normal human brain tissues have different dielectric properties [3] as compared to damaged brain tissues which helps in tumor detection using microwave imaging as the microwaves will tend to locate the tumor due to the difference in damaged brain tissues and normal brain tissues dielectric properties [5].

Achieving the use of microwaves to a reliable medical imaging applications such as human head imaging, the use of antennas stands out as more convenient method to opt to due to its improved reliability, cost and effectiveness. Antennas work on the principle of using electromagnetic waves to transmit and receive information from one point to another. Thus parameters such as dielectric substance, antenna directivity, gain, resonant frequency and bandwidth will be taken into consideration when using antennas to achieve human head imaging.

Most studies and researchers have proposed various antenna designs to achieve microwave imaging in turn achieving properties such as high gain and better efficiency from the designs which has led to an increased demand of the antenna design for the applications of microwave imaging [6]. Therefore this study also aims at improving the antenna parameters by designing a three dimensional antenna so as to achieve better results in applications such as human head imaging so as to detect brain tumors at early stages. Such improved parameters are better sensing characteristics, better gain and a better antenna efficiency and size

A. Research Problem

Antennas employ a wide range of applications in various fields such as human head imaging applications to detect brain tumors due to their capabilities of using microwaves to achieve microwave imaging [7-9].

There are various imaging methods [11] used to achieve human head imaging such as Magnetic Resonance Imaging (MRI) scans and Computer Tomography (CT) scans. MRI’s use powerful magnets and radio waves to obtain cross sectional images of the head. Thus providing better image resolution but it is an expensive procedure and CT

TEST Engineering & Management
March - April 2020
ISSN: 0193-4120 Page No. 189 - 194

scans use a powerful computer processing to combine various x ray images to produce cross sectional images of the internal human body also providing a better image resolution, but also it is an expensive procedure and involves exposing the body to ionizing radiation which is medically harmful.

There have been many proposed antenna designs for human head imaging application by various researchers [13] before and currently, though the antennas designs mostly have significant success in achieving human head imaging [14], some have gaps to be filled such as some antenna designs achieve in minimizing size but fail to obtain a wideband property [15]. Further, some antennas have failed to achieve uni-directional antenna, since the aim is to detect brain tumors a highly directional antenna is required to fulfill the purpose.

Some researchers have proposed the antennas in array elements but most of these array designs are so large in size that fails to eliminate the portability factor.

B. Justification for the Research

The purpose of this research is to achieve human head imaging applications by the use of an improved 3D antenna, due to various interest in microwave imaging in clinical purposes as an optional means for imaging applications as compared to the convenient methods used today. This study will help in designing a more low cost, high effective and portable sized antenna.

Researchers [12] has enforced on the role of antenna in achieving human head imaging since it provides the junction for human head and the system employed in microwave imaging noting that all these factors are achievable and controllable with antenna characteristics such as compact sizes and radiation properties enhancing the antenna performance.

Researchers [10] also observed that microwave imaging is motivated by building an affordable antenna in terms of cost and employing non-ionizing characteristics well enough to replace the convenient diagnostic tools present as of then.

II. PROPOSED ANTENNA DESIGN

The antenna was constructed from the basic microstrip patch antenna [1] and then applied techniques to achieve the low frequency of operation and 3D structure. The microstrip patch antenna is made up of three layers that is the patch, substrate and ground plane [4]. Since the construction of the proposed antenna was done with the help of HFSS software, the radiating patch was built on top of a substrate material FR4 epoxy with a dielectric constant of 4.4 and a height of 4 mm. The height and choice of substrate were clearly optimized and analyzed from value to value so as to meet the requirements of the proposed antenna objectives. The substrate plane had a length of 100 mm and a width of 110 mm.

The antenna was intended for low microwave frequency of operation, hence a folding technique is introduced so as to achieve operation at lower frequency. This further implies the patch of the antenna that is the radiating element is folded along its overall length. The folding technique is the fundamental in achieving a 3D structure whilst miniaturizing the shape of the antenna. The patch of the antenna was a rectangular shape with bends, and this is accomplished by using 3 rectangular planes each of different length but all sharing same width of the patch, since they are all joined together in the bends enabling the folded structure.

The folded inverted like structure is supported by a shorting wall which is built directly with contact from the substrate material joining it with the edge of the first non-used edge of the first rectangular plane. This supports the folded patch and also connects it directly to the substrate material forming a single structure. The height of the shorting wall is chosen as 4 mm so as to miniaturize the antenna structure (smaller overall height of the antenna)

Coaxial feeding technique is applied to the antenna design as a feeding technique due to the nature of the radiating element and also it reduces spurious radiation. The point of feeding of the antenna is kept at an optimal distance with the bending points of the radiating folded structure so as to minimize the disturbance in how current is generally distributed in the radiating element.

March - April 2020
ISSN: 0193-4120 Page No. 189 - 194

The simulated designed antenna is shown in Figure 1 and the corresponding dimensions are shown in Table 1.

Table 1: Positioning of the folded radiating structure

Name	Plane drawn from	Coordinate position (x, y, z)	Length (mm)	Width (mm)
Rectangle 1	x-y	60, 70, 6	-31.2	-40.8
Rectangle 2	x-z	60, 38.8, 6	4	-40.8
Rectangle 3	x-y	60, 38.8, 10	24	-40.8
Shorting wall	x-z	60, 70, 2	4	-40.8

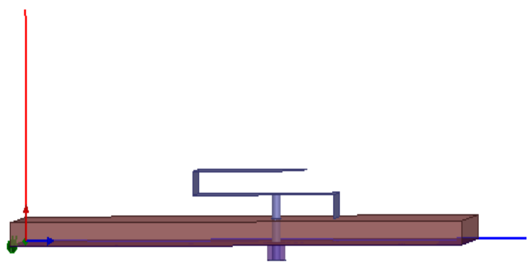

Figure 1: Side view of the proposed antenna design

III. RESULTS AND TESTING

The proposed antenna is designed through HFSS software and is simulated to operate at a lower microwave frequency chosen on the range that is suitable for the human head imaging application, which ranges from 1 GHz to 4 GHz. So the proposed frequency of operation for the antenna is 2.5 GHz which is the mid-frequency of the operating band.

A. Analysis of Substrate Thickness

From Table 2, it is can be seen that the height is varied from 2 to 4 mm. For a substrate height of 2mm, a gain of 5.0912 dB with a return loss of -10.4643 dB with a front back ratio of 18.46 dB is achieved. But as the height is increased to 2.5 mm, a significant increase in all the parameters from gain, return loss and front to back ratio has improved prior to when the height was 2mm. Further, when the height is increased to 4mm, an improved gain of 7.132 dB a return loss of -17.8741dB and a front to back ratio of 22.69 dB is achieved.

Observing the results from 2.5 mm and 4mm height of substrate, the change tends to be very slight. Although the height is increased for more than 1mm, the change in the antenna parameters is very minimal as compared to when the height changed from 2mm to 2.5mm. Thus the thickness of substrate is good at improving gain and return loss but it can only be extended to a certain height. Since at height 4mm, there is a great improvement in gain, front to back ration and return loss, it is considered as the ideal height for the final design.

Table 2: Analysis of substrate height

Substrate height (in mm)	Operating Frequency (GHz)	Return loss (dB)	Gain (dB)	Front to back ratio (dB)
2	2.5	-10.4643	5.0912	18.46
2.5	2.51	-17.4258	6.8358	21.77
4	2.51	-17.8741	7.1328	22.69

B. Analysis of various substrates

This is done to verify the effect of different dielectric constant to the 3D design. From Table 3, it can be seen that for various substrates, as the dielectric constant is varied from 2.2 to 4.4, the return loss and gain has increased along with the front to back ratio. Hence, the higher dielectric constant of FR-4 substrate is selected.

Table 3: Analysis of various substrates

Substrate Name	Dielectric constant	Operating frequency (GHz)	Return loss (dB)	Gain (dB)	Front to back rati

					o (dB)
RT Duroid 5880	2.2	2.51	-5.4189	0.9225	13.94
GIL GML 1032	3.2	2.48	-5.4583	1.5028	16.43
FR-4	4.4	2.5	-10.4643	5.0912	18.46

C. *Analysis of Feeding Mechanisms*

The frequency of operation for the designed 3D antenna is 2.5 GHz, so the 3D design is simulated under this frequency for both feeding mechanism, that is, coaxial feed and microstrip feed line. From Table 4, it can be observed that the microstrip feed line mechanism did not resonate at the intended frequency of operation and exhibited a very low gain. This may be due to poor mismatch of the feed line because the 3D design is achieved through folded structure, meaning for the feed line to have proper impedance matching, the position supply excitation to majority part of the antenna which is not achieved when using microstrip feed line.

Further, from Table 4, the other feeding mechanism that is coaxial probe, operates at frequency 2.51 GHz which is close to the intended frequency and even the gain, return loss and front to back ratio exhibited a major improvement due to proper impedance matching achieved by the coaxial feed mechanism.

Table 4: Analysis of various feeding mechanisms

Feeding technique	Substrate (Dielectric constant)	Operating frequency (GHz)	Return loss (dB)	Gain (dB)	Front to back ratio (dB)
Microstrip feed line	FR-4 (4.4)	1.86	-4.8932	1.531	19.59
Coaxial probe	FR-4 (4.4)	2.51	-17.8741	7.1328	22.69

D. *Analysis of Position of Coaxial Probe Feed*

It is to be noted that one can argue the position of the feed is necessary to improve parameters such as front to back ratio but also impedance matching is achieved when an ideal position is reached that's when the antenna radiates at the intended operating frequency and improve other parameters such as gain due to an antenna cannot radiate equally some parts will have higher gain than other due to current distribution so position of the feed will help ensure this is achieved.

Initially the x-axis coordinate is varied while keeping the y-axis constant and the changes are observed and tabulated for these various positions as shown in Table 5.

Table 5: Various position of coaxial feeding showing changes from varying x-coordinates

Position (x, y)	Operating frequency (GHz)	Return loss (dB)	Gain (dB)	Front-to-back ratio (dB)
51, 57	2.51	-17.8741	7.1328	22.69
45, 57	2.52	-7.0431	5.9854	22.39
40, 57	2.32	-1.5176	5.0513	22.66

First the x-coordinates of the feeding position is varied from the base position. The values of x are decreased. It can be observed from Table 5, that the gain of the antenna is slightly decreasing and the return loss also decreases gradually, though the front to back ratio experienced very minor changes close to unnoticeable.

Now, the y axis from the basis position (51, 57) is varied while the x-coordinate is kept constant and the results are observed and tabulated for further analysis as shown in Table 6.

Table 6: Various position of coaxial feeding showing changes from varying y-coordinates

Position (x, y)	Operating Frequency (GHz)	Return loss (dB)	Gain (dB)	Front to back ratio (dB)
51, 57	2.51	-17.8741	7.1328	22.69
51, 60	2.66	-14.6538	5.727	19.98
51, 50	2.32	-30.2114	4.573	17.74

March - April 2020
ISSN: 0193-4120 Page No. 189 - 194

From Table 6, it can be seen that the y-value is increased to 60, the return loss is decreased and as the value is reduced to 50, the return loss is increased but in turn reducing the front to back ratio in both cases. Also, the gain is decreasing regardless of the y-value incremented or decremented.

Thus, the feeding position of the final design is assumed to be at x=51 and y=57 (51, 57).

E. Simulation Results

The return loss of the simulated antenna is shown in Figure 2 and the maximum return loss is -17.8741 dB at a frequency of 2.51 GHz, and the antenna utilizes a bandwidth taken below -10 dB of 300 MHz ranging from 2.37-2.67 GHz.

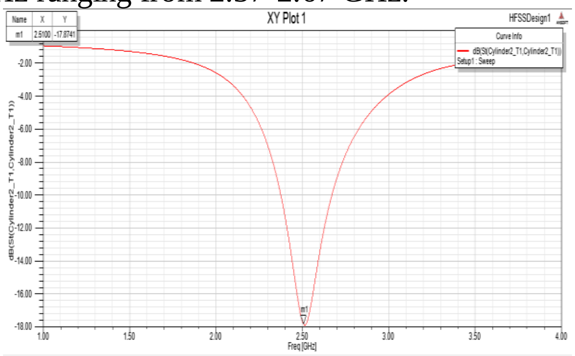

Figure 2: Return loss of the proposed antenna design

Figure 3 indicates the radiation pattern in the x-z direction of the proposed antenna at the operating frequency of 2.5 GHz. It can be observed that a highly directional pattern at the direction of propagation is yielded. Figure 3 indicates the peak gain achieved as seen is 7.1328 dB.

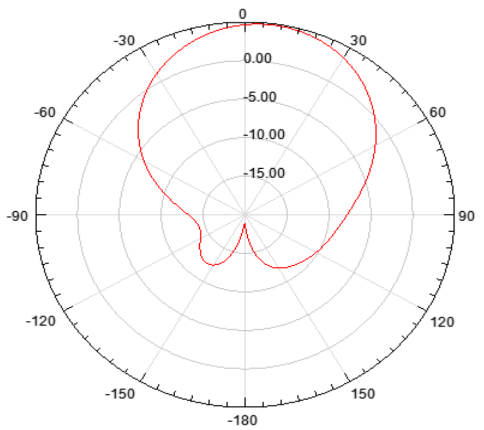

Figure 3: Radiation pattern in X-Z direction at 2.5 GHz of the proposed antenna

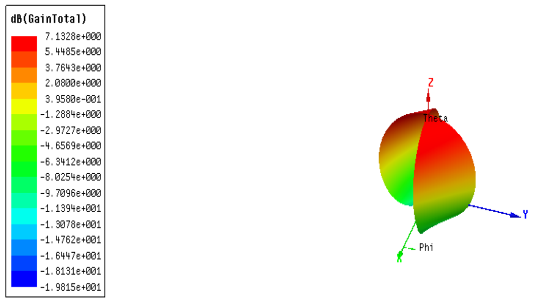

Figure 4: Gain plot of the proposed antenna

The VSWR plot across the operating frequency range is shown in Figure 5. It can be seen that the VSWR of 1.2929 at 2.5 GHz is observed. Also, by observing the plot carefully the bandwidth across 2.37-2.67 GHz, all has a VSWR of less than 2, which indicates proper impedance matching across the bandwidth.

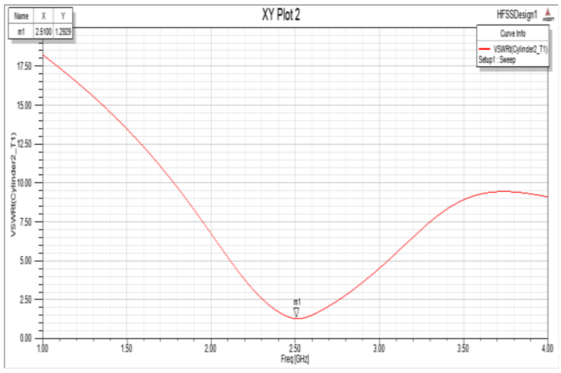

Figure 5: VSWR distribution across frequency of operation

IV. CONCLUSION AND FUTURE RECOMMENDATION

The antenna designed is capable of achieving a 3D miniaturized structure through the introduction of the folding technique and shorting wall that has enabled the 3D structure and also operates at lower microwave frequency of 2.5 GHz.

This improved 3D antenna for microwave human imaging applications operates at a frequency of 2.5 GHz built on a FR4 epoxy substrate material and fed by coaxial feeding technique, attained a bandwidth of 300 MHz, return loss of -17.8741 dB, across a frequency band of 2.37-2.67 GHz, with a maximum gain achieved of 7.1328 dB and a front to back ratio of over 22 dB.

March - April 2020
ISSN: 0193-4120 Page No. 189 - 194

Though the proposed antenna design accomplished in improving various antenna parameters such as gain, front to back ratio, there were some limitations to the work done such as the bandwidth is so narrow and this is mainly due to the use of coaxial feeding technique and even though it was much improved from the research base paper [12] but still it is narrow compared to the operating band that is only utilizing 300 MHz of a 1-4GHz operation band.

Ultra-wideband antennas operating at dual bandwidth can help to solve the limitation on narrow bandwidth encountered due to the use of coaxial feeding technique, that even though reduces spurious radiation compared to other feeding techniques, it depicts a narrow bandwidth of operation. Thus dual band antennas can help in improving the bandwidth of operation by having an antenna or antenna array resonating at different frequencies thus covering a larger bandwidth together due to the dual bands, which will be done as a future work.

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