



Performance Enhancement of a Novel ANN Optimized Mushroom Shaped Microstrip Antenna for Wireless Applications

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ABSTRACT

This work proposes the design of mushroom shaped patch antenna for lower spectrum of microwave frequencies. The patch has radius of 10mm placed on the FR4 substrate. Slots have been introduced in order to improve the performance of the antenna. To ease the calculation of dimensions MATLAB coding is used. In order to get the optimized radius Artificial Neural Networks (ANN) is used. The proposed antenna resonates at 2.4 GHz, 3.1 GHz, 3.6 GHz, 5.6 GHz and 6 GHz. Hence its applications fall on Industrial Scientific and Medical (ISM, 2.4 - 2.483 GHz) band, fixed mobile Wi-MAX (2 - 6 GHz) applications. Since the antenna is designed with miniaturized size it can also be preferred for bio-telemetry applications. To design and simulate the antenna High Frequency Structure Simulator (HFSS) software tool has been used.

Key words: ANN, HFSS, Mushroom shape, Slotted, Wireless Applications

1. INTRODUCTION

In the current world, the innovation in medical field has become a basic requirement. This has been possible by implementing microwave antenna in medicine. This also overcomes the need for remote monitoring. Many authors have investigated about performance of various implantable antenna structures. The modified helical shaped 3D spiral antenna covering Medical, Industrial, Commercial and Scientific (MICS) band has been discussed in [1]. Implantable antenna specially designed to detect the heart failure detection and monitoring of internal pressure measurements of the pulmonary artery has reported in [2].

Implantable planar inverted-F antenna (PIFA) for an artificial cardiac pacemaker is proposed in [3]. It has a simple structure with a low profile and is placed on the top side of the pacemaker. The antenna identifying maximum frequency shifts caused by variations in the electrical properties of body tissues and different anatomical distribution has been discussed in [4]. The design of circular patch antenna loaded with metamaterial for C band applications is described in [5]. The efficiency of the antenna can be improved using some

methodologies like inclusion of metamaterial [6]. The design of wideband microstrip antenna using ANN is described in [8]. The circular patch Microstrip array antenna using for Ku-band is explained in [9]. Design of microstrip antennas using ANN is described in [10]. Design of the circular patch antenna loaded with metamaterial [11]. The Spiral Artificial Magnetic Conductor (SAMC) has a wide frequency range for practical applications in wireless communications bands such as GSM 900 MHz [12]. The Rectangular Microstrip Antenna using Double Negative (DNG) left-handed metamaterial method is applicable for miniaturization is explained in [13]. Electrically small rectangular Microstrip antenna is loaded with Multiple Split Ring Resonator (MSRR) metamaterial which is working at the Ka- band frequency range is discussed in [14]. The design of compact and efficient tunable antenna is applicable for 540-890 MHz [15]. The use of wide slots to enhance the Bandwidth of the antenna is explained in [16]. The antenna which exhibits very broad bandwidth by using different stubs such as 40% impedance bandwidth with F-stub and 44% impedance bandwidth with V-shaped stub as found in [17]. The antenna is applicable for impedance bandwidth is achieved over the Ultra Wide Band (UWB) frequency range (3.1-10.6 GHz) is explained in [18]. The printed slot antenna using the printed structure in order to improve its dual-band and compact size performances is explained in [19]. The patch antenna design using ANN is expressed in [20]. Variety of feeding technique applicable to Microstrip patch antenna is discussed in [21]. The Small compact UWB Antenna design with good impulse response with minimal distortion [22]. A Reactive impedance Substrate (RIS) can be tuned anywhere between perfectly electric (PEC) and magnetic conducting (PMC) surface suffering a property to achieve the optimal bandwidth and miniaturization factor is described in [23]. Technique for reducing the dimensions of the cavity-backed antenna with slots is discussed in [24]. The design and characterization of Antennas for bio-implantable communication devices is explained in [25]. ANN has been developed for the calculation of bandwidth of resonant microstrip antenna as in [26]. A new method of calculation of resonating frequency of a Rectangular Microstrip patch Antenna using ANN is discussed in [27]. The technology of Feed-Forward Back propagation-ANN (FFBP-ANN) with one hidden layer which is trained using Levenberg-Marquardt

Algorithm is found in [28]. In bio-medical applications and wireless communication systems, the Microstrip Antennas are extensively used because of their low-profile features and ease of fabrication is discussed in [29]. The methods for the design of patch antenna for Modern Applications as found in [30].

In this paper a miniaturized modified semi-circular antenna with multiple slots is proposed. ANN is also utilized for optimizing the design.

2. ANTENNA DESIGN

2.1 Basic Antenna Structure

The proposed antenna has been developed from the basic circular shaped patch antenna. Since miniaturization is the main need in many of the applications, certain structural modifications have been implemented in the circular patch. Hence a semicircular shape is preferred for patch. The resonant frequency of antenna can be determined from the empirical formula [7] as given in Equation (1).

$$f_r = \frac{1.8412c}{4\pi a_e \sqrt{\epsilon_r}} \quad (1)$$

$$\text{where } a_e = a \left(\sqrt{1 + \frac{2h}{\pi a \epsilon_r} \left[\ln \left(\frac{\pi a}{2h} + 1.7726 \right) \right]} \right)$$

where, f_r – Resonant Frequency in GHz

c – Speed of light in m/s

a – Radius of the patch in mm

a_e – Effective Radius in mm

h – Thickness of the substrate

ϵ_r – Relative permittivity

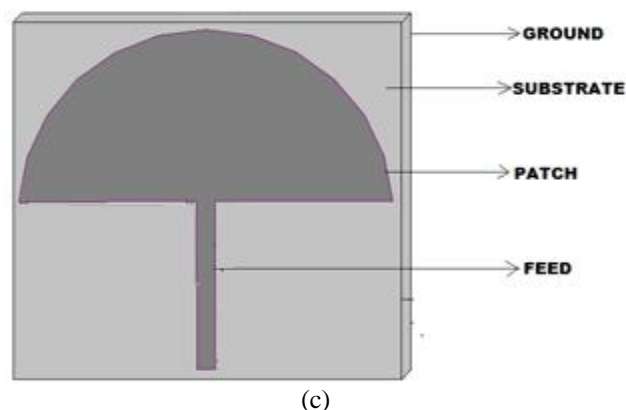
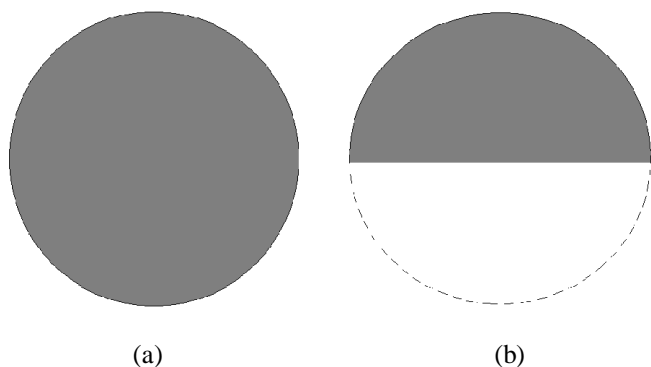


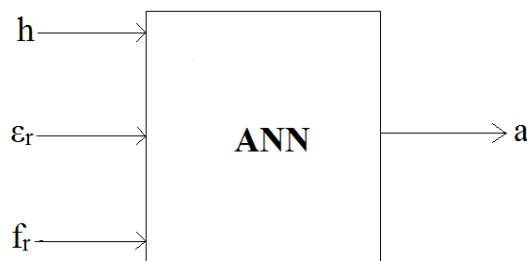
Figure 1: (a) Conventional Circular Patch (b) Semicircular Patch (c) Geometry of Semicircular Microstrip Feed Antenna

For calculating the dimensions of the Antenna MATLAB coding has been developed. For optimizing the dimensions the ANN has been used.

2.2 TRAINING AND OPTIMIZATION USING NETWORK MODEL

2.2.1 Basic Concepts

Artificial Neural Network is an interconnected assembly of simple processing elements, units or nodes, whose functionality is loosely based on the animal neuron. In this work the patch geometry of the Microstrip Antenna is obtained as the function of input variables such as thickness of the substrate (h), dielectric constant of the substrate (ϵ_r), resonant frequency (f_r) using the synthesis ANN techniques and the radius of the patch (a) is the output parameter .



The resonant frequencies for the various shapes of antennas such as triangular, circular, rectangular etc., can be accurately evaluated with the help of ANN. Training and test data sets used for the ANN model is obtained from MATLAB coding.

2.2.2 Layers in ANN

The processing ability of the network is stored in the inter-unit connection strengths, or weights, obtained by a process of adaptation to, or learning from a set of training pattern. There are three major layers in ANN namely input layer, hidden layer and output layer. There is also another layer known a hidden layer which is used when input and output relation is not quite simple or clear so as to re-modify input and given desired output. Supervised learning and Self Organization are the two types of ANN.

In supervised learning the input data as well as the desired output data is given to the network. In self-organization model, only the input data set is given and the network produces output according to the relation between the inputs. The input layers use Tran sigmoid signal whereas the output layer uses the pure linear signal. The ANN architecture used in this paper is utilizing the feed forward back propagation algorithm. The performance of the network depends on the number of neurons assigned to the layers, nature of the algorithm used and the number of epochs. For each training, the weights are randomly assigned to the network. The errors can be calculated by comparing the ANN outputs with the target values. The network is trained until the error values are as low as possible

2.2.3 Network Model

ANN Model chosen for the optimization of the proposed antenna design uses 3 hidden layers in addition to input and output layers. This is shown in Figure 2. For obtaining the optimized radius of the semicircular patch three different algorithms such as Levenberg Marquardt (LM), Conjugate Gradient (CG), and Adaptive Gradient Decent (AGD) have been preferred.

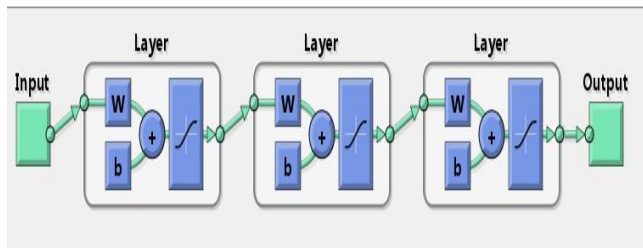


Figure 2: Model of Neural Network

The input data given to the network are thickness of the substrate (h) which is kept constant as 0.5mm, the relative permittivity which is also kept as a constant value (4.4) and the resonant frequency of range 2.35 – 2.50 GHz. As supervised learning is used for the optimization purpose, the target data is also given to the network. Here the target data is the radius of the patch (a) and with variation in the range of 10 – 11 mm. Different frequency value have been calculated for different radii by keeping the substrate thickness (h), relative permittivity (ϵ_r) as constant. The average error value has been calculated for the above said three algorithms and compared in Table 1. It is found that LM algorithm provides minimum error of 0.112928 as noted from the Table 1. Hence the dimension (radius) corresponding to the LM algorithm providing minimum error has been considered as the optimized value. The best validation performance is obtained at epoch 6 as shown in the Figure 3.

Table 1: Comparison of three algorithms using ANN

Input			Target	ANN output using different Algorithms for the target value (radius)		
f_r	ϵ_r	h	A	ANN (LM)	ANN (CG)	ANN (AGD)
2.15	4.4	0.5	9.5	0.2083	0.64187	0.51194
2.2	4.4	0.5	9.6	0.18466	1.0057	1.638*10 ⁻⁹
2.25	4.4	0.5	9.7	0.17537	1.1183	5.1406*10 ⁻⁹
2.3	4.4	0.5	9.8	0.03125	1.4632	4.5275*10 ⁻⁹
2.35	4.4	0.5	9.9	0.018863	1.4567	0.073545
2.45	4.4	0.5	10	-0.03359	1.4583	3.105*10 ⁻⁹
2.55	4.4	0.5	10.1	0.021155	1.4423	6.172*10 ⁻⁹
2.65	4.4	0.5	10.2	-0.02535	0.58796	5.6973*10 ⁻⁹
2.75	4.4	0.5	10.3	-0.11959	0.76482	0.61249
2.8	4.4	0.5	10.4	-0.02946	0.93315	0.98515
Average Error				0.112928	1.08723	0.2183

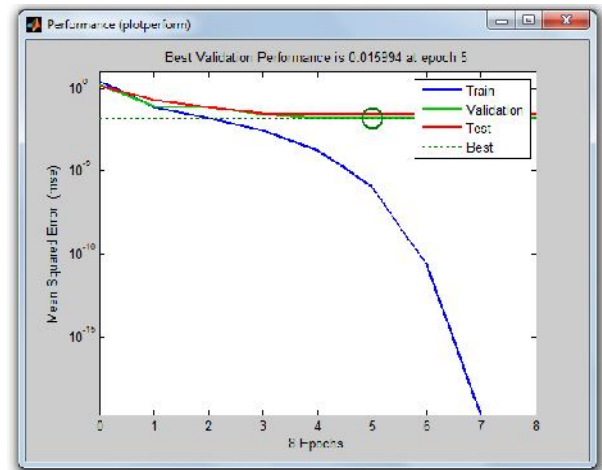


Figure3: Performance graph

2.3 MUSHROOM SHAPED ANTENNA DESIGN

The Semicircular Patch Antenna has been designed with radius (a) 10mm, Substrate thickness (h) 0.5mm and Relative permittivity as 4.4 for the resonant frequency (f_r) of 2.45 GHz.

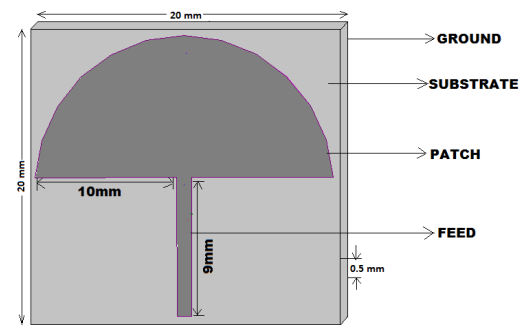


Figure 4: Semicircular Microstrip Feed Antenna

In order to improve the performance of the Antenna slots are introduced in the Semicircular shaped patch. The slots are introduced in the order of 1:3:6. The Figure 4, depicts the proposed antenna with single, triple and six slots with the gap of 0.2mm in all the cases.

2.3.1 Single Slot

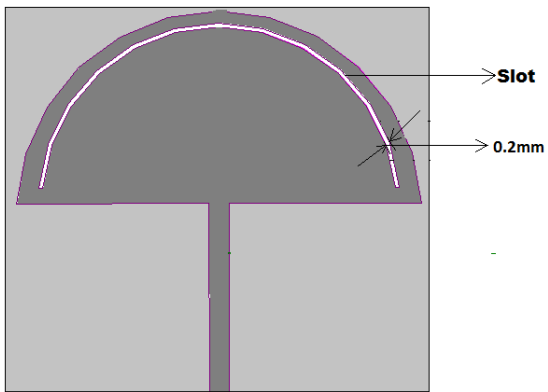
A semicircular antenna is designed with the patch radius of 10mm. The substrate material is FR4 ($\epsilon_r=4.4$), with the dimension of 21mm x 21mm x 0.5mm. For patch and ground copper material is assigned.

2.3.2 Triple Slots

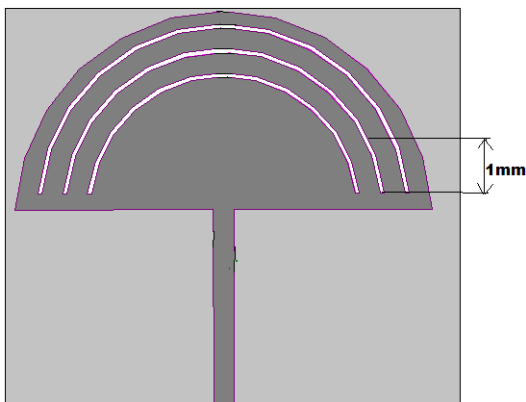
At this stage threeslots are introducedwith the same gap of 0.2mm.The distance between three slots is kept constant as 1mm.Thus three slots are introduced in the patch. The Antenna with triple slots is shown in Figure 5(b).

2.3.3 Six Slots

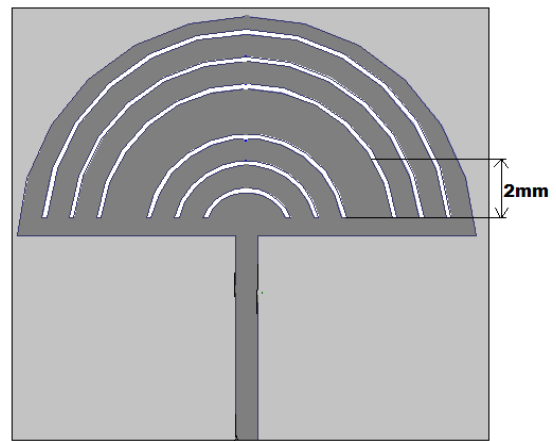
At third stage six slots of 0.2mm gap are introduced such that the distance between the first set of slots and the second set is maintained as 2mm. Figure 5(c) shows the antenna with six slots.



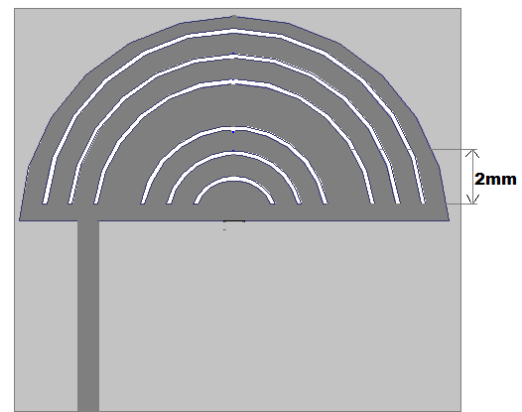
(a)



(b)



(c)



(d)

Figure 5: Antenna Shapes (a) Geometry of Mushroom Shaped Antenna with Single Slot (b)Mushroom Shaped Antenna with Triple Slot (c)Mushroom Shaped Antenna with Six Slots (d)Mushroom Shaped Antenna with Six Slots shift in the feed position

2.4 PERFORMANCE ENHANCEMENT WITH FEED POSITION

In the fourth case, by retaining six slots the feed position is shifted to half of the center position. The antenna input impedance is matched with the microstrip feeding the antenna at this point. The Figure 5(d) depicts the corresponding shift in the feed position.

3. SIMULATION AND RESULT DISCUSSION

3.1 Simulation Software

The proposed antennas have been modeled and simulated using HFSS software. The analyses have been carried out in the sweep frequency range of 1-7 GHz.

3.2 Results and Discussions

The results of simulation are depicted in Figure 4 and the comparison graphs are shown in Figure 5. In Figure 6(a), the proposed antenna with single slot resonates at 2.7 GHz with a return loss of -12 dB. This also provides VSWR value of 1.0573 is maintained which is good enough for impedance

matching. As an improvement reduced return loss with dual bands is noticed by the addition of three slots as shown in Figure 6(b). The resonance occurs at 3.45 GHz and 4.1 GHz with return loss of -34 dB and -43 dB respectively.

Further increment in the slot up to six with the gap of 0.2mm separated by 1mm between adjacent slots has been performed. The antenna resonates at 2.5 GHz, 3 GHz and 6.18 GHz with return loss of -11 dB, -10 dB and -16 dB respectively which is shown in the Figure 6(c). A shift towards lower frequency region occurs and the proposed antenna resonates at 2.4 GHz, 3.2 GHz, 3.6 GHz, and 5.6 GHz along with the return losses values of -20 dB, -13 dB, -16 dB and -17 dB respectively as in the Figure 6(d). The resonant frequencies which provide prominent return loss are only considered while others are neglected.

The comparison among the antenna with the introduction of various numbers of slots is given in the graph as shown in the Figure 7(a). Figure 7(b) describes the comparison between the performances of the antennas with two different feed positions. Hence it is observed that a compromise is noticed in the return loss levels while the number of resonances is increasing.

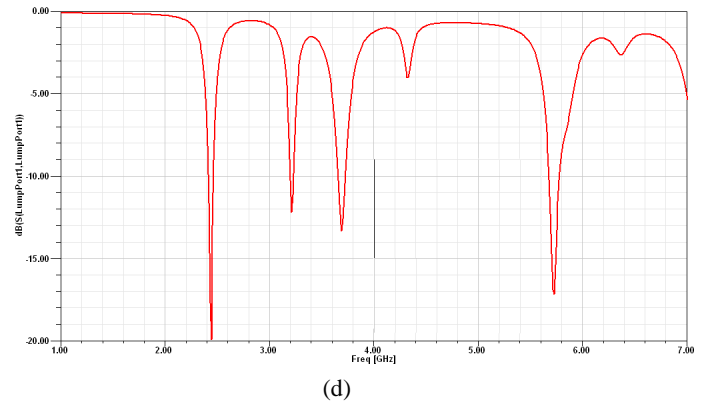
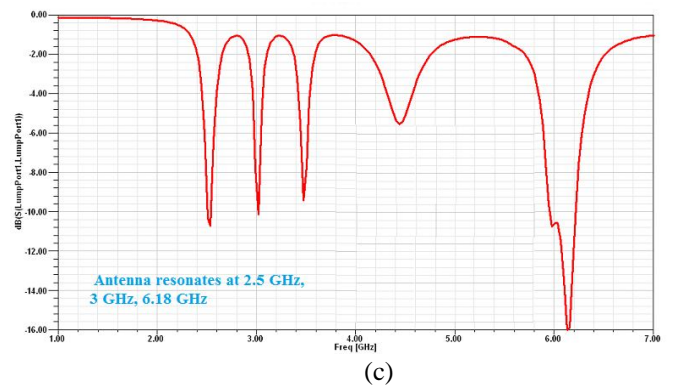


Figure 6: (a) Performance of Antenna with single slot (b) Performance of Antenna with triple slot (c) Performance of Antenna with six slots (d) Performance graph of Antenna with feed at half of the radius of the patch.

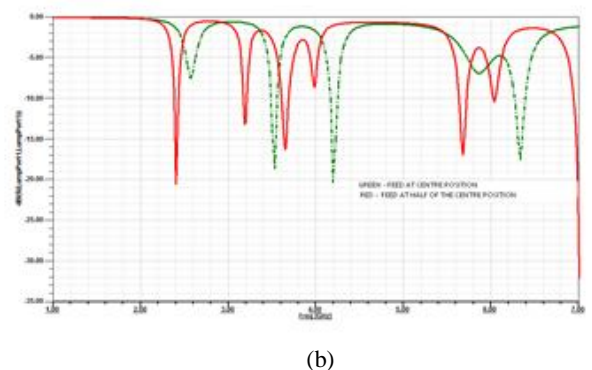
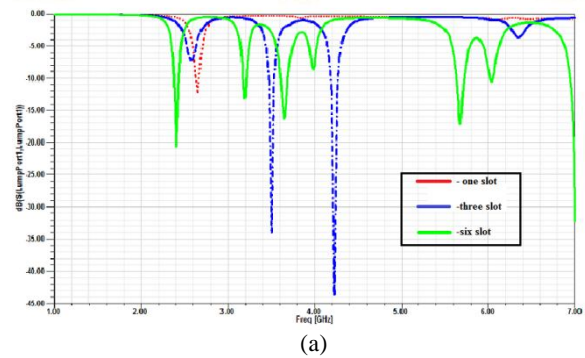
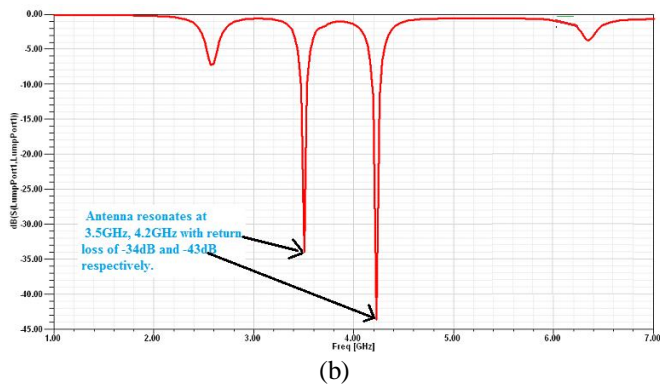
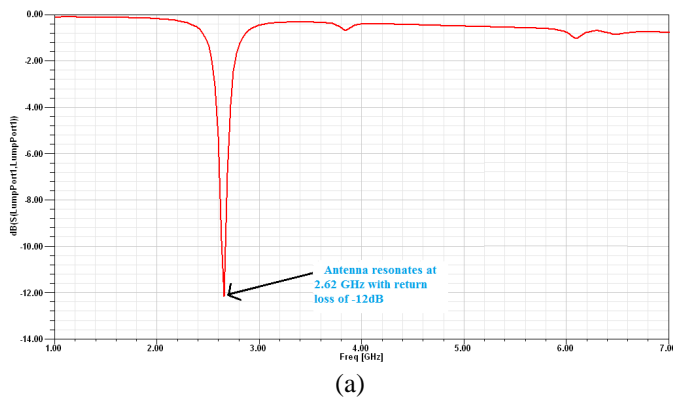


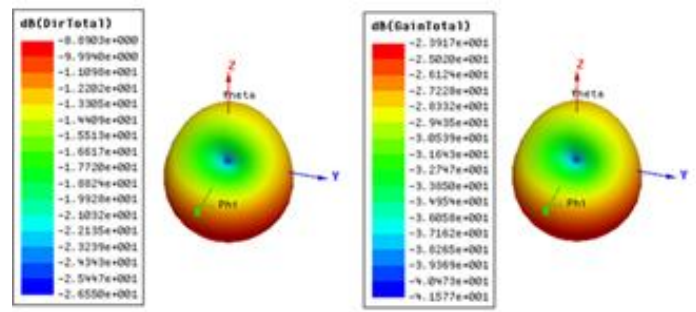
Figure 7: Comparison of Performance of Antenna (a) Various Slots (b) Comparison of Performance of Antenna with Two Different Feed Positions

(b) Various Feed Positions

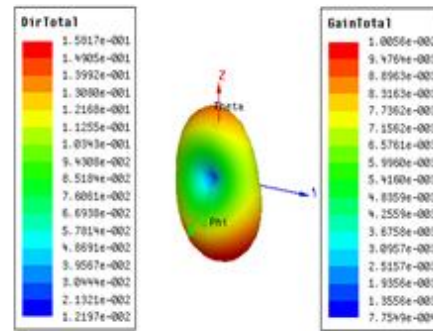
When the feed position of the antenna is changed from center position to half of the center position the frequency is shifted to lower side compared to center fed antenna. The Table 2 presents the various antenna properties resulting from simulation. The Figure 8 depicts the gain and directivity of various antennas.

Table 2: Comparison of performance of mushroom antenna

Mushroom Antenna	Resonant Frequency(GHz)	Return Loss (dB)	VSWR
Single slot	2.7	-12	1.0573
	3.45	-34	1.0409
Triple slots	4.1	-43	1.0134
	2.5	-11	1.25
Six slots	3	-10	1.28
	6.18	-16	1.32
Six slots with shifted feed position	2.4	-20	1.2
	3.1	-13	1.5
	3.65	-16	1.3
	5.6	-17	1.3
	7	-32	1.3

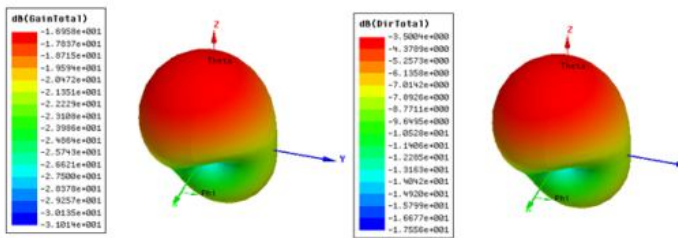


(c)

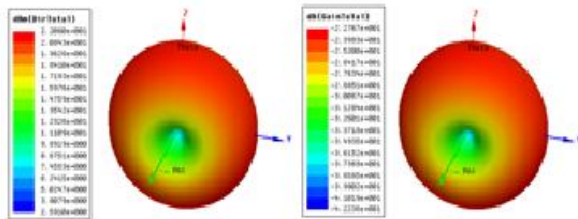


(d)

Figure 8: Directivity and Gain of (a) Antenna with single slot (b) Antenna with triple slot (c) Antenna with six slots (d) Antenna with shifted feed position



(a)



(b)

5. CONCLUSION

The proposed antenna meets the suitability of application in the lower part of microwave spectrum. The antenna resonates at multiple frequencies and give reduced return loss. It provides narrow bandwidth, however this can be improved by various methods proposed by different investigators as found in the literature. In addition to multi-band resonance, miniaturization is also achieved. The antenna resonates at 2.4GHz, 3.1 GHz, 3.65 GHz, 5.6 GHz and 7 GHz. Hence this type of antenna can be recommended for applications in the ISM (2.4 - 2.483 GHz) band, fixed mobile Wi-Max (2.4 GHz, 3.2 GHz, 3.65 GHz and 5.61 GHz) regions. It can also be made suitable for bio-telemetry and implantable applications by properly simulating and experimenting in the lossybody environments appropriately. The performance of the antenna can further be improved using metamaterials.

ACKNOWLEDGMENT

The author¹ acknowledges the authors^{2,3} for their moral and technical supports.

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