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A Novel ANN Optimized CPW Fed Truncated Star Shaped Fractal Antenna for Wireless Applications

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ABSTRACT

This paper presents the new structure of truncated star shaped antenna with a Co-Planar Waveguide (CPW) feed as well as a defected ground structure (DGS). This proposed antenna has been developed with the patch dimension of 18mm x 19.5mm. Copper has been preferred as the conducting material for patch and ground. The concept of truncation has been introduced in the proposed antenna. On truncating each peak side length of the star patch with the 3mm a wider bandwidth is achieved in the 2.2 – 6.3GHz range. For optimizing the antenna dimension the Artificial Neural Network (ANN) tool available in MATLAB has been used and the design and simulation have been carried out using high frequency simulation software (HFSS) Software. The proposed antenna covers all applications in lower region of microwave spectrum.

Key words : ANN,CPW Feed, DGS, HFSS, Truncated Star Patch

1. INTRODUCTION

Designing miniature antenna operating in the lower region of microwave spectrum which can be used for all applications such as global system for mobile (GSM), Wi-Fi lower, Industrial scientific medical ISM, local area network (LAN), Wi-Max, Bluetooth, Zigbee, personal area network (PAN)) and Wi-Fi upper is a challenging task.

Compactness in everything is important in the present day wireless communication. The French mathematician B.Mandelbrot [15] introduced the term 'Fractal' and later it is being applied for miniature antenna design by various researchers. The demand for low-profile antennas, wide-band and multi band antennas is increasing a lot in the field of military, communication systems, satellite communication etc. It is a challenging task to obtain multiple resonances in a single patch antenna [22]because of its limitations such as single resonance and narrow bandwidth. The fuzzy fractal feature based sum classifies different types of air-craft targets effectively and has an excellent classification performance in condition of no compensation for airframe echo components [27]. Broad frequency and is possible when multilayered dielectric substrate are used in antenna design [23].

Bandwidth enhancement in snowflake structure has been explained in [2]. However introduction of slot in the antenna also provides bandwidth enhancement [3].Slots, defects and modification made in the ground plane can also support bandwidth enhancement [5]. Fractals concept allows the antenna designer to achieve multiband and broadband antenna geometries [15]. Stacked miniaturized fractal antenna support improving gain [16, 19].

1.1 Feed Systems in Antenna

Antenna feed is the one which combines the source and the antenna with proper impedance matching [29]. For emerging the patch antenna there are five different feed methods generally used such as microstrip feed, co-axial feed, CPW feed, aperture coupling feed and proximity coupled feed.

Each of the above said feed method pertains its own advantages. In the microstrip feed, it provides easier fabrication and well impedance matching is obtained. The flexibility in placing the feed position is achieved in coaxial feed. CPW feed deals with advantages such as low radiation leakage and less dispersion. The easiness in modeling and low spurious radiation is achieved in aperture coupling and the largest bandwidth achievement takes place in proximity coupling. In order to facilitate better matching, the vertical stub is placed at the proper position of the feed [24].

Among the number of feed systems the CPW feed provides the wide bandwidth [1].Though it provides advantage there is a drawback that the CPW feed also get radiated with the antenna. A wide bandwidth is possible when CPW feed is used in slot and hexagonal antenna [4, 28].

1.2 Truncation in the Shape of Fractal

Truncation introduced in the shape of antenna results in two benefits such as reduced return loss [13] and miniaturization. The bandwidth enhancement is also possible with the increase

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in the thickness of the substrate and the type and shape of the slot introduced in the patch [14, 17 and 18]. In this paper an attempt is made to truncate the shape of the antenna for obtaining shift in resonance towards lower side

1.3 Artificial Neural Networks (ANN)

An ANN is an information processing paradigm [30]. It is composed of many artificial neurons that are linked together according to specific network architecture with input, hidden and output layers as shown in Figure 1.

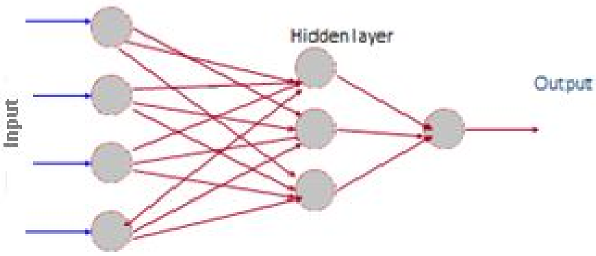

Figure 1: Neural Network

The design procedure and synthesis using forward side and analysis using reverse side of the problem is explained in [7]. The microwave modeling simulation and optimization with the CPW feed and the use of algorithms in ANN is depicted in [8]. The synthesis and analysis process, to verify the error performance is discussed in [9]. The comparison of accuracy of various algorithms in forward side and reverse side is explained in [10]. The relationship between number of epochs and error value is said to be inversely proportional as provided in [11]. The calculation of resonant frequency for different microstrip resonators using neural network is explained in [12].In the nonlinear set of data ANN provides a promising modeling technique [20]. Degree of interconnectivity is high in ANN hence it provides the advantages of superior computational ability [21]. The upper limit of the bandwidth depends on the ANN training parameters and shape of the printed elements[26].

From the literature review it is understood that obtaining multiple resonance at lower region of microwave spectrum is a challenging task and hence this paper is aimed to achieve this same while keeping miniaturization of antenna. This paper uses a slot and truncation in the antenna shape for achieving performance enhancement.

2. DESIGN OF PROPOSED ANTENNA

The ultimate aim of this work is to develop an antenna which will work at lower frequency spectrum of microwave even in smaller dimension. This is because many of the applications fall on the lower frequency spectrum of microwave. In this Koch Snowflake structure has been adopted on by introducing truncation in the star patch. The first iteration of Koch Snowflake structure has been considered for our design. This design starts with the triangle. This design has been developed in to a star structure which is shown in Figure 2(a) and (b).

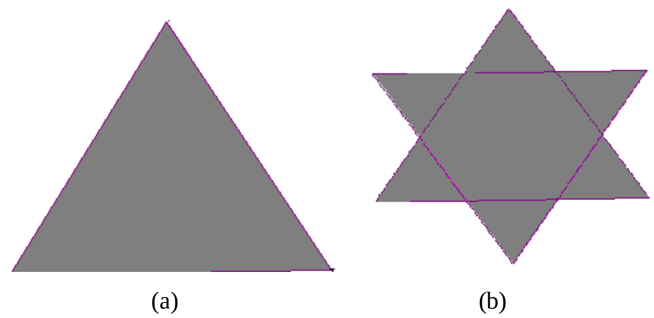

Figure 2: (a) Basic structure of Koch Snowflake (b) First iteration of Koch snow flake

The first stage of Koch Snowflake is used in this design. The design of the DGS truncated star patch antenna involves the following steps. Different results are obtained by simulating the structures with various modifications on star patch.

The antenna with a patch size of 18mm x 19.4mm and with substrate size of 27.5mm x 35mm is preferred in this design. On providing a CPW feed with a length of 13.7mm simulation is done. The material used for the patch and ground is Copper whereas for the substrate it is FR4with thickness of 3.2mm and permittivity of 4.4. The structure and dimensions of the antenna are shown in Figure 3and 4.

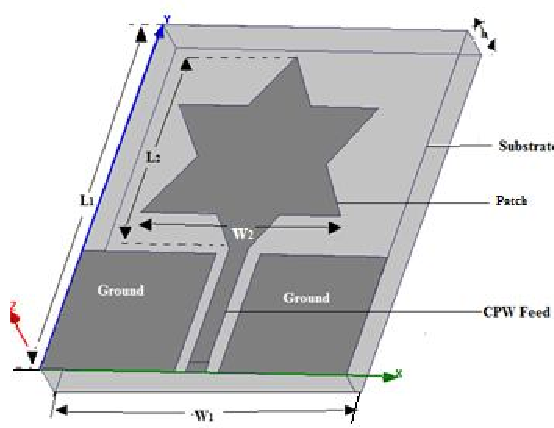

Figure 3: Basic Star Patch Antenna Structure

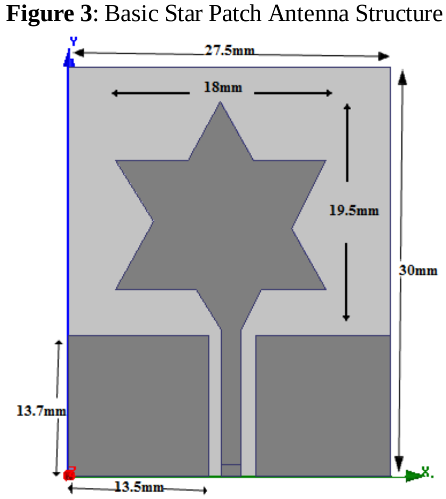

Figure 4: Dimension of proposed star patch antenna

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In order to act upon the low frequency shifting a defected ground structure through L shaped slot has been introduced. For obtaining most of all the wireless applications with new structure the truncation concept has been followed.

The resonance frequency [6] of the equilateral triangular patch can be determined from the empirical formula is given in equation (1)

$$f_r = \frac{2c}{3S_{eff}\sqrt{\varepsilon_{eff}}} \qquad (1)$$

where, $S_{eff} = S_1 + \frac{h}{\sqrt{\varepsilon_r}}$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{4}\left(1 + \frac{12h}{S_1}\right)^{-1/2}$$

Table 2: Abbreviations and expansions

Abbreviation	Expansion
f_r	Resonant frequency (GHz)
S_{eff}	Effective side length of the equilateral triangle (mm)
ε_r	Substrate relative permeability
H	Height of substrate (mm)
ε_{eff}	Effective relative permeability
s_1	Side Length of the equilateral triangle (mm)

3. OPTIMIZATION USING ANN

The term optimization is followed for the purpose of selecting the best value within the list of values that has been computed from MATLAB. In this proposed work three types of input are given to the artificial neural network in the form of resonant frequency (f_r), height of the substrate (h) and the di-electric constant (ε_r). The target value is taken as Side-length of the equilateral triangle (s_1) is given to the neural network which is shown in Figure 5.

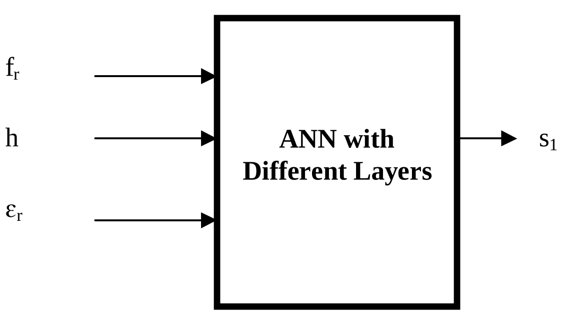

Figure.5: Schematic Representation of ANN

The input value given as well as the target value taken should be in the form, as represented in (1) and (2).

Input set = {fr, h, ε_r} (1)
Target set= {s_1} (2)

There are different algorithms present in the neural network which are, Levenberg Marquardt (LM), Conjugate gradient (CG), Quasi Newton (QN), and Adaptive Gradient descent (AGD), used for analyzing of highly non-linear antenna. In the Microstrip Antenna modeling, the Levenberg Marquardet Algorithm provides a least error value explained in [9]. Figure 3 gives the diagrammatic representation for the trained network.

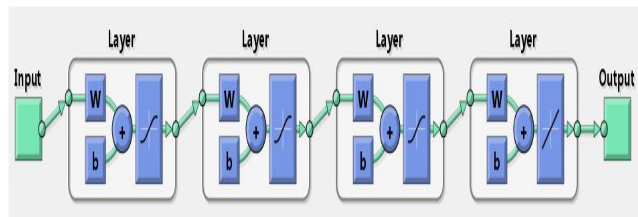

Figure 6: Diagrammatic representation of ANN

The network consists of three layers such as input, hidden and output. Among these the input layer is selected to be a linear function whereas the output layer is a sigma function. There can be any number of hidden layers which normally depend on the number and complications of relationship between input parameter. In this paper the training of network takes place with four hidden layers as shown in Figure 6.

3.1 ANN Results

The performance graph for the case of Levenberg Marquardt algorithm is given in Figure 7. This represents the graph of mean square value as a function of number of epochs. This graph shows results of test, validation, test and best. At a particular value the results for validation and test seems to give a better performance with a least error value of 0.3077 at epoch 3.

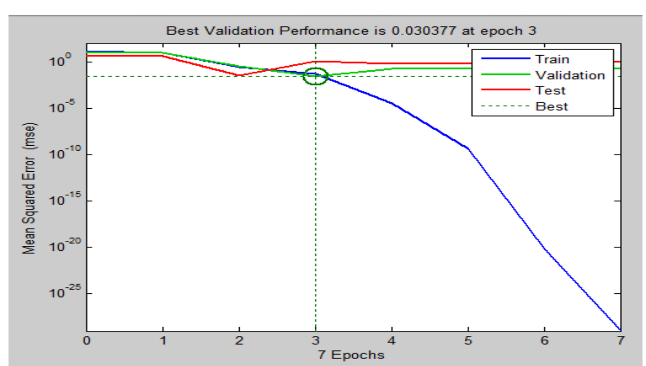

Figure 7: Performance graph of Levenberg Marquardt Algorithm

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From the results of ANN and comparison of three algorithms, the suitable algorithm is chosen in the way that they provide the least average error value and with better performance. From the list of obtained values the particular dimension is preferred that gives the least error value and operate in lower frequency. The dimension that satisfies the above mentioned requirement is 18mm.

Table 1: Comparison of Three Different Algorithms

Input			Target	Algorithm Error values		
f_r	H	ε_r	s_1	LM	CG	AGD
6.16	3.2	4.4	15	0	-0.0240	-0.0.165
6.41	3.2	4.4	16	1.776e-015	0.0321	0.1627
6.06	3.2	4.4	17	0	-0.6043	-0.3951
5.74	**3.2**	**4.4**	**18**	**0**	**-0.0459**	**0.43739**
5.45	3.2	4.4	19	-3.552e-015	0.0460	-0.1399
5.19	3.2	4.4	20	0	-0.0095	-0.1033
4.95	3.2	4.4	21	0	-0.1340	-0.8982
4.74	3.2	4.4	22	0	0.0111	0.5107
4.54	3.2	4.4	23	-7.105e-015	0.1889	0.5956
4.36	3.2	4.4	24	-7.105e-015	-0.1398	-0.5238
4.19	3.2	4.4	25	-7.107e-015	0.02588	0.46629
Average Error				-3.11e-16	-0.0748	-4.789e-3

Error value is zero at lower frequency range of 5.7 GHz. The chosen dimension has been highlighted in the Table 1. Hence this dimension is preferred for antenna design and the preferred material is copper and the substrate height is 3.2mm.

4. OPTIMIZED ANTENNA STRUCTURE

The structure of antenna after optimization through ANN is utilized for the simulation. Firstly the original star shaped antenna is designed as shown in Figure 4.

Secondly a defect in the ground plane is introduced by a L-shaped slot as shown in Figure 8. The defected ground is obtained by etching L shaped slot of 0.2mm on the CPW ground. In this design the dimensions of the patch as well as the substrate remains same.

Thirdly as an attempt to improve the bandwidth performance of the antenna a truncation in the shape is performed by etching the peak sides of the star shape as shown in Figure 9. In this case the original dimension of the antenna, CPW and DGS remain unaltered. The truncation is performed only at a length of 1.5mm from the peak point considering a equilateral triangle. Finally the antenna is truncated by etching the peak side length of 3mm from the peak point as shown in Figure 10.

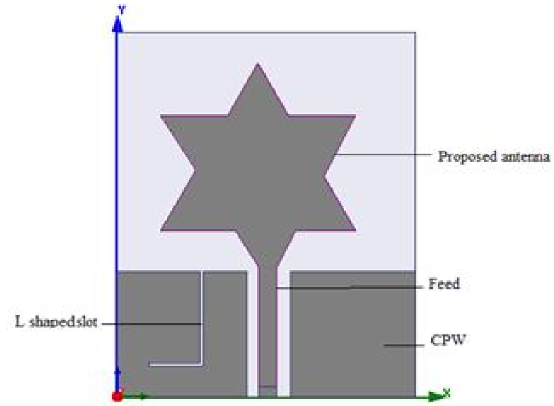

Figure 8: Design of Defected Ground Plane Structure (DGS)

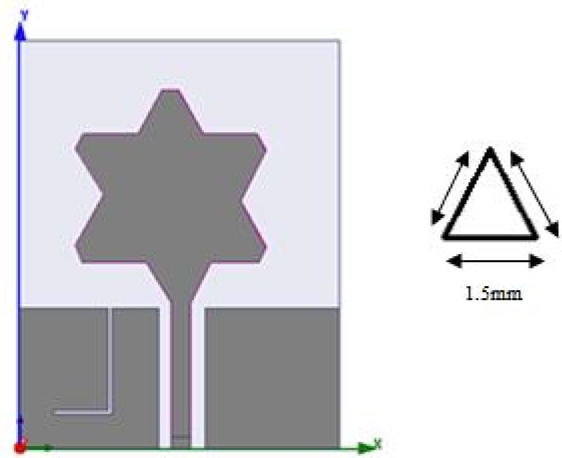

Figure 9: Design of DGS 1.5mm Truncated Star patch Antenna

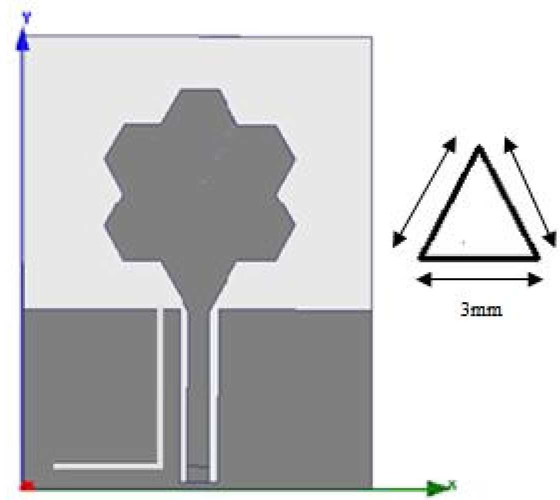

Figure 10: Design of DGS 3mm Truncated Star patch Antenna

5. SIMULATION

The HFSS EM simulation software is used for the antenna design and simulation. A sweep frequency range of 1-7 GHz has been utilized for the simulation. The original defected and truncated antenna have been designed and simulated separately.

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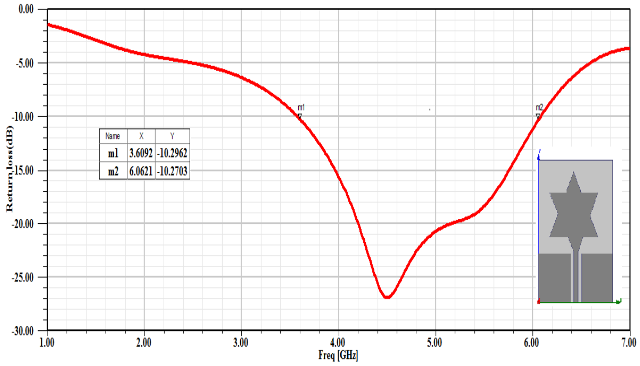
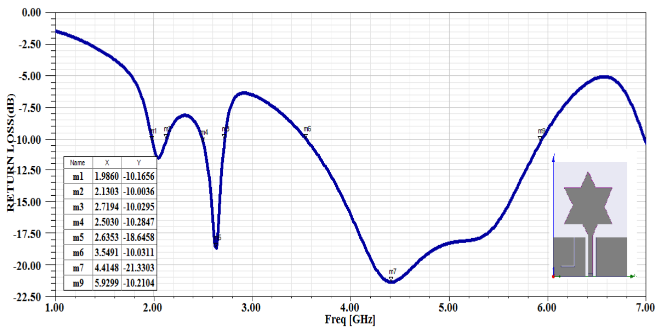
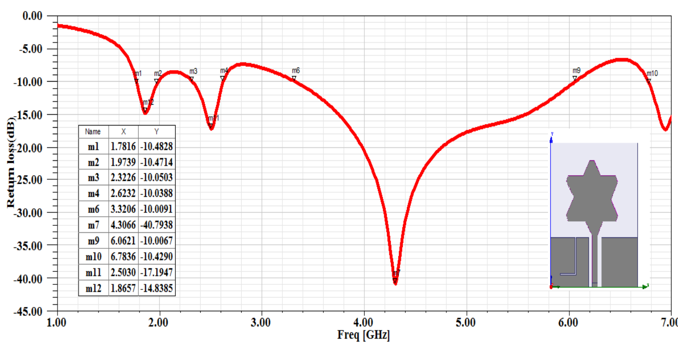
6. RESULTS AND DISCUSSIONS



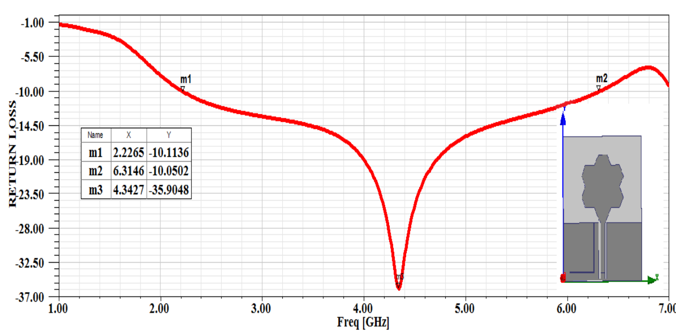
(a)



(b)



(c)



(d)

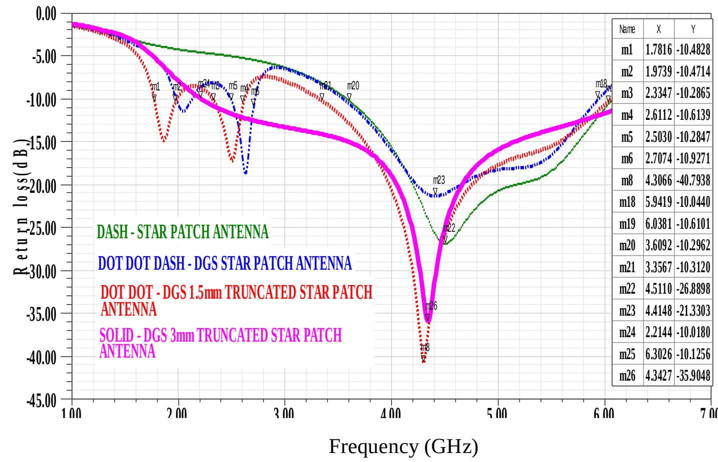
Figure 11: Simulation Results on Return loss (a)Basic Star patch antenna (b)Design of Defected Ground Plane Structure (DGS) (c)Design of DGS 1.5mm Truncated Star Patch Antenna (d)Design of DGS 3mm Truncated Star Patch Antenna

The return loss characteristic of the proposed Star patch antenna is shown in Figure 11 (a). The inset indicates the shape of the antenna. This antenna resonates at 4.5 GHz corresponding to return loss of -27 dB. The bandwidth produced by the antenna is 25.5 which are broad.

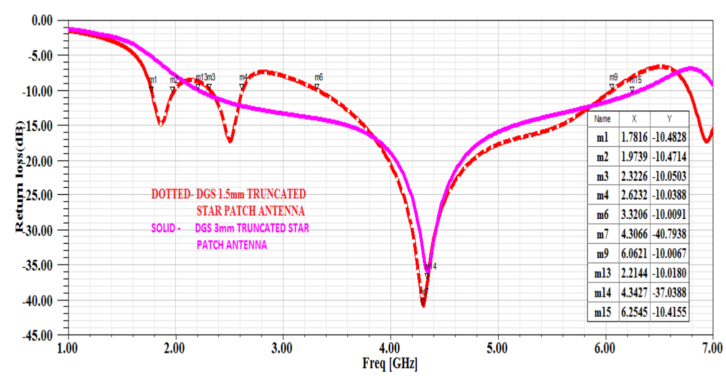
The Figure 11 (b) shows the return loss characteristics of Defected Ground Plane Structure. The inset represents the shape of the antenna. The resonating frequencies of the antenna are 2.05 GHz, 2.6 GHz and 4.41GHz with the return loss of -11 dB, -19dB and -21 dB respectively.

The return loss characteristics of DGS 1.5mm truncated star patch antenna is depicted in Figure 11 (c). The resonant frequencies of this proposed antenna are 1.86 GHz, 2.5 GHz and 4.3 GHz with the corresponding return loss of -14.8dB, -17.19 dB and -40.79 dB.

The Figure 11 (d) represents the return loss characteristics of DGS 3mm truncated star patch antenna. The shape of the antenna indicated the inset. The resonating frequency of this antenna is 4.39 GHz with the corresponding return loss of -36 dB.



(a)



(b)

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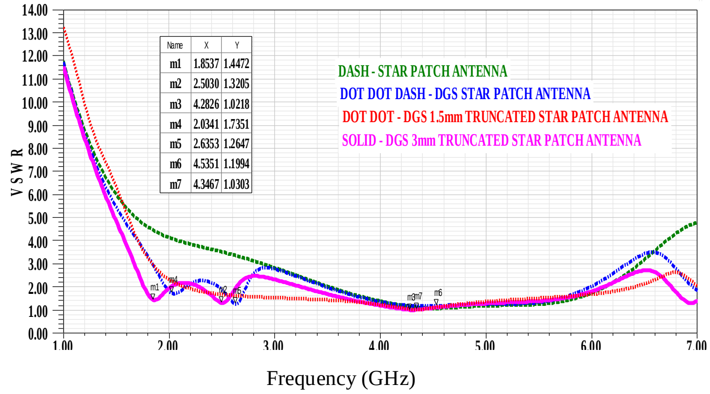


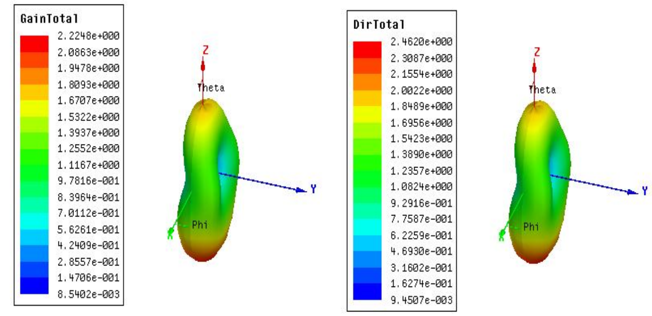
(c)

Figure 12: Comparison graph (a).Return loss characteristics of Star patch, DGS star patch, DGS 1.5mm truncated Star Patch, DGS 3mm truncated Star patch. (b). comparison of effect of truncation made at 1.5mm and 3mm length (c).VSWR characteristics of Star patch, DGS star patch, DGS 1.5mm truncated Star Patch, DGS 3mm truncated Star patch

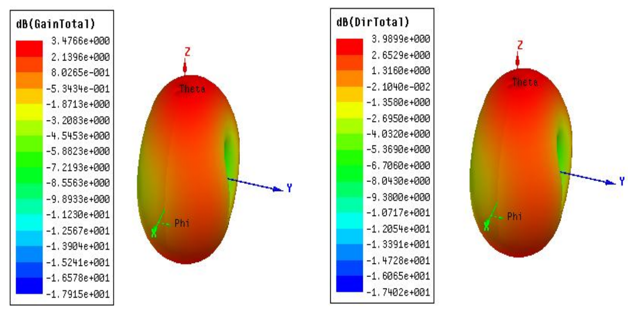
The comparison of performance of antenna with four designs is depicted in Figure 12. In Figure 12 (a) the green dashed shows the bandwidth (BW)for the star patch antenna, in the range of 3.6 – 6.06 GHz, whereas the blue dot dash shows the bandwidth for the DGS star patch antenna are in the range of 1.9 – 2.13 GHz, 2.5 – 2.71 GHz and 3.5 – 5.92 GHz . The 1.5mm truncated DGS star patch antenna represented by red dotted has the bandwidth of 1.7 – 1.97 GHz, 2.32 – 2.62 GHz and 3.32 – 6.06 GHz, whereas for the DGS 3mm truncated star patch antenna, represented in rose solid line has the wide bandwidth in the range of 2.2 – 6.3 GHz. On comparing all the results, DGS 3mm truncated Star patch provides the wide bandwidth and covers all the major applications of lower frequency of microwave spectrum.

The Figure 12 (b) represents the comparison graph of 1.5mm and 3mm truncated star patch antenna. The DGS 1.5mm truncated star patch antenna, represented by red dotted has the bandwidth of 1.7 – 1.97 GHz, 2.32 – 2.62 GHz and 3.32 – 6.06 GHz with the return loss of 40 dB. Compared to 1mm truncated star patch antenna 3mm truncated star patch antenna gives a wide bandwidth in the range of 2.2 – 6.3 GHz with the return loss of 36 dB at 4.3 GHz.

Green dashed in Figure 12 (c) shows the VSWR value 1.1994 for star patch antenna at 4.5 GHz, whereas blue dot dash represents the VSWR values of 1.7351, 1.2677 and 1.1994 with the corresponding resonant frequencies of 2.05 GHz, 2.6 GHz and 4.41 GHz for the DGS star patch. The VSWR values of 1.4472, 1.3205 and 1.0218is in the operating frequencies of 1.86 GHz, 2.5 GHz and 4.3 GHz respectively in depicted by red dotted is for DGS 1.5mm truncated star patch antenna. For DGS 3mm truncated star patch, the VSWR value is 1.03 at 4.3066 GHz is shown by rose solid line.



(a)



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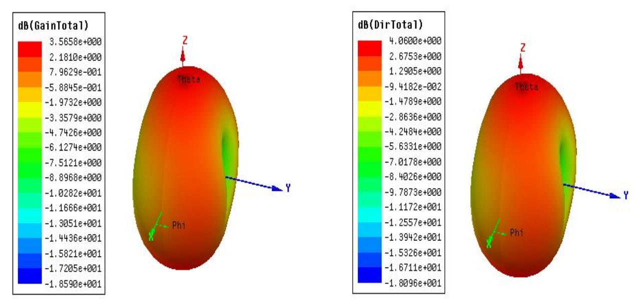

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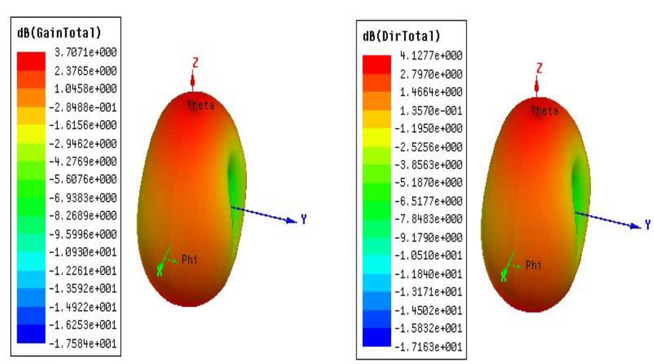

(d)

Figure 13: Simulation Results on Gain and Directivity (a). Basic Star patch antenna (b).Design of Defected Ground Plane Structure (DGS) (c). Design of DGS 1.5mm Truncated Star Patch Antenna (d). Design of DGS 3mm Truncated Star Patch Antenna

The gain (G) and directivity (D) of basic star patch antenna are 2.24 dB and 2.462 dB respectively. The radiated area by

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this antenna is very small as shown in Figure 13(a). The Figure 13 (b) represents the gain and directivity of defected ground (L slot) plane. The L slot introduced in the ground leads to the better current flow with improved gain of 3.4dB and directivity of 3.9dB. The truncation done with the height of 1.5 mm from each peak side length of the star. It provides the gain and directivity of 3.5 dB and 4dB respectively as depicted in Figure 13 (c). By increasing the truncation height to 3mm from each peak side length the gain and directivity is improved from 3.5dB to 3.7dB and 4dB to 4.1dB as shown in Figure 13 (d).The comparison between the various parameters of the four structure of the antenna is shown in Table 3.

Table 3: Comparison of antenna performances

Antenna	f_r (GHz)	R_L (dB)	VSWR	BW (GHz)		%BW	G dB	D dB
				f_L	f_H			
Basic Star patch	4.5	-27	1.1994	3.6	6.06	25.4	2.2	2.4
Defected ground plane structure	2.05	-11	1.7351	1.9	2.13	5	3.4	3.9
	2.6	-19	1.2677	2.5	2.71	4		
	4.41	-21	1.1994	3.5	5.92	25.6		
DGS 1.5mm truncated star patch	1.86	-14.8	1.4472	1.7	1.97	7	3.5	4
	2.5	-17.19	1.3205	2.3	2.62	6		
	4.3	-40.79	1.0218	3.3	6.06	29		
DGS 3mm truncated star patch	4.342	-35.96	1.030	2.2	6.31	48.11	3.7	4.1

6. CONCLUSION

The proposed CPW fed DGS Truncated star shaped antenna have many advantages, whenever the truncation is made at the peak side length of 3mm length when compared to the 1.5mm truncated antenna. It provides wide bandwidth of 2.2– 6.3 GHz. Hence it covers all of the low frequency application such as Wi-Fi lower (2.45 GHz), ISM (2.4 - 2.483 GHz), LAN (2.5 GHz), Wi-Max (2.3 – 4 GHz), Bluetooth (2.4 - 2.485 GHz), Zigbee, PAN (2.45 GHz) and Wi-Fi Upper (5.5 GHz) and improved return loss of -36 dB at single resonance of 4.3 GHz. This proposed antenna provides an appreciable gain and directivity of 3.7 dB and 4.1 dB respectively. This has been achieved with miniature size antenna. The gain and directivity of proposed antenna are improved to the extent of 3.56 dB and 4.06 dB respectively. The future scope of this work would be the fabrication and measurements of antenna parameters using network analyzer and anechoic chamber to validate the simulated results.

6. ACKNOWLEDGEMENT

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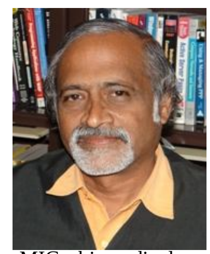

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