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Design and Measurement of Novel Shaped Microstrip Antenna with DGS for Radar Applications

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Abstract

In this paper, a novel shaped patch antenna for triple band frequency of operation in X-band (radar) is defined. The antenna resonates under three frequency bands at 10 GHz, 10.93 GHz and 11.68 GHz respectively which are included in the X-band frequency range. The substrate material used as the dielectric between the patch and the ground is of Flame Retardant Version 4 (FR4) Epoxy. The DGS (Defected Ground Structure), usually included in the back conductor of the Microstrip patch antenna is used to tune the frequency and also to boost the characteristics of the antenna. The same is included in this depicted antenna with circular ring shaped slot to vary the performance. FEM (Finite Element Method) based Ansoft High Frequency Structural Simulator (HFSS) V.12 is used for designing and verifying the features of the proposed antenna. The size of the depicted model on the whole is of $31.34 \times 28.33 \times 1.6$ mm^3. For the first, second and third resonant frequency, a bandwidth of 480 MHz, 600 MHz and 420 MHz correspondingly is obtained with a return loss value of -18.47 dB, -42.22 dB and -19.74 dB. The other parameters of the antenna are also conferred in this paper.

Index Terms: Defected Ground Structure; FR4 Epoxy; bandwidth; return loss.

1. Introduction

Nowadays, wireless communication has been employed in most of the applications. For those devices, antenna plays an important role at its end terminal. The main role of the antenna is to transfer the Radio Frequency signal into electromagnetic wave in free space and vice versa due to its reciprocity. Microstrip patch

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antenna is such a type of antenna and is used in most of the wireless applications because of its smaller size, low profile characteristics, etc,. They are of mechanically stiff plane, less weight, have the capability of low expenditure and easy manufacturing characteristics with printed circuit technology [1]. Few applications of Microstrip antenna are of radar, satellite, MMIC, mobile handset etc [6]. The performance of an antenna can be improved by providing stacked structure [16]. In turn, the size of the antenna is generally of larger value when designed for low frequency applications. But miniaturization is important for portable wireless applications. This can be achieved by providing slots on the patch [8] [14] or by using the fractal shaped structures as the patch itself [15]. The antenna is usually designed to resonate under single frequency band. But with the inclusion of slot in the patch and ground plane, there will be a better improvement in performance with multi-band frequency of operation. There are various methods used to introduce slots on the patch such as H-slot [4], C-slot [3], U-slot, and with all these in a combination with parasitic strips adjacent to the radiating patch.

DGS, abbreviated as Defected Ground Structure is an intentional non-periodic or periodic fractal shape or defect added in the conducting ground plane for a purpose of either tuning the frequency or to enable miniaturization of the antenna size [7]. Defected Ground Structure also provides band notch characteristics in an antenna [2]. The LPF (Low Pass filter) [10] and other filters [9] can be manipulated and adjusted using DGS provided in the ground plane. Various shapes are available for DGS to be provided in the ground plane such as arrow headed DGS, polygonal, concentric ring slot, open loop square, etc [5].

The second section gives a brief detail about designing the depicted antenna model with its parameter value calculation for each and every dimension included. The results obtained for the designed model is given under the third section with gain, VSWR (Voltage Standing Wave Ratio), directivity and current distribution for all of the three resonant frequencies. Also the simulated and measured comparison of return loss value is given under the same section.

2. Design Configuration

In this section, the design consideration and the parameters of the depicted design model is conferred. A grouping of conventional shapes like rectangular and circular, with slots included in it forms the radiating patch above the substrate. The FR4 substrate that has a loss tangent value of 0.02 and relative permittivity (ε_r) of 4.4 has a conducting ground plane below which includes a circular ring slot in order to provide additional tuning frequency. The entire size of the antenna is of $31.34 \times 28.33 \times 1.6$ mm^3 as width, length and height respectively. The FR4 dielectric substrate has a height or thickness (h) of 1.6 mm.

The conventional formulas given under (1-7) are used to calculate each of the magnitude of the depicted model and is given below:

$$W = \frac{C_o}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}}; \frac{W}{h} > 1 \tag{2}$$

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

$$L = \frac{C_o}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

$$L_g = 6h + L \tag{5}$$

$$W_g = 6h + W \tag{6}$$

$$a_e = \frac{1.8412 c}{2\pi f_r \sqrt{\varepsilon_r}} \tag{7}$$

The formula (1-4) is used for Width (W) and Length (L) calculation of rectangular patch and for the slots used in the design. Equation (5-6) is used to define the breadth (W_g) and Length (L_g) of the conducting ground plane. The final equation is used to calculate the radius (a_e) of the circle for a given resonant frequency (f_r). ε_{reff} denotes the effective dielectric constant of the material.

2.1. Design parameters

As mentioned earlier, the designed top and bottom view of the depicted antenna model simulated using Ansoft HFSS (High Frequency Structural Simulator) V.12 is given below in Fig. 1. The excitation provided is by means of Microstrip line Feeding Technique [11].
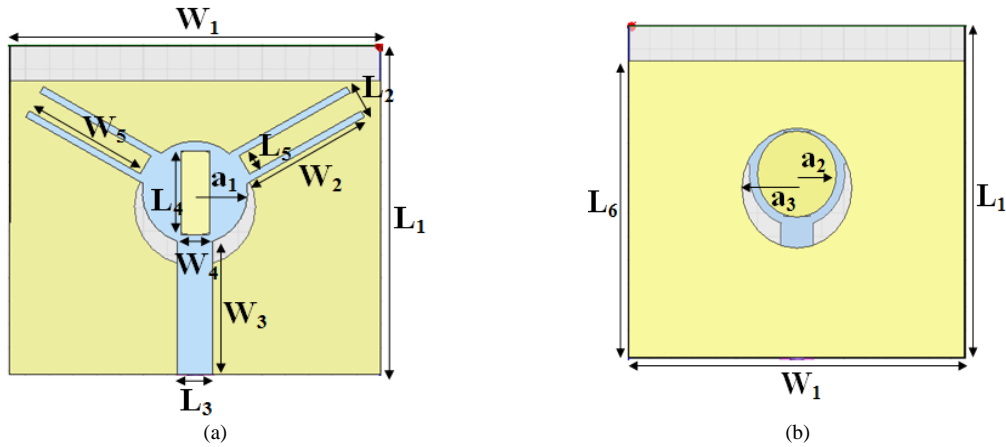

Fig.1. Proposed design model (a) view at front (b) view from bottom

Table 1 illustrates the value of each of the parameters included in the design model that have been calculated using the conventional formula (1-7) as referred from the literature survey [13][12].

Table 1. Design Parameters of the depicted antenna model

Parameters	L_1	W_1	L_2, L_3	W_2, W_3	L_4	W_4	L_5	W_5	L_6	a_1	a_2	a_3
Values in mm	28.3	31.3	3.01	11.5	7.23	2.41	1.8	10.9	25.3	4.46	3.68	5.12

For a resonant frequency of 9.1 GHz, the dimension of circular and rectangular shapes provided in the radiating patch is calculated. Similarly, the dimension of the shapes or defect provided in the conducting ground plane is formulated for the resonant frequency of 11 GHz. Particularly, the length L_1, L_2, L_3, L_4 and L_5 are calculated based on 9.1 GHz with variation in dimension as a multiples of L_1 to obtain an optimized result. The same is done for the widths used in the patch. The DGS a_2 and a_3 provided in the ground plane are calculated for a centre frequency of 11 GHz.

(a) Top view	(b) Back view

Fig.2. Prototype of the proposed antenna

3. Results and Discussion

The computer-generated and measured characteristics of the depicted antenna structure are conferred. The measurement was done using ZVL Network Analyzer and simulation was performed using Ansoft HFSS V.12 as said earlier. The measured parameters such as return loss and VSWR are given in Fig. 3 and are shown below.

(a) Return loss (dB)	(b) VSWR

Fig.3. Measurement setup of the fabricated antenna

3.1. Return Loss

The comparison of the computer-generated and measured result of the reflection coefficient vs frequency obtained using HFSS v.12 and ZVL Network Analyzer respectively are shown in the Fig. 4. It is clearly inferred from the graph that the antenna resonates under three frequency band with a return loss value of   -18.47 dB, -42.22 dB and -19.74 dB with a bandwidth of 480 MHz, 600 MHz and 420 MHz for the first, second and third resonant frequency under simulation.
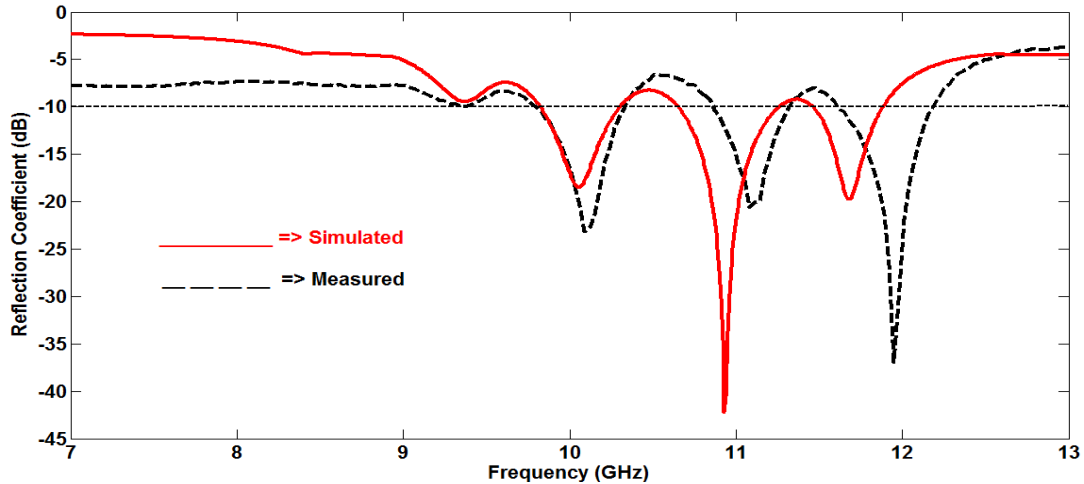
Fig.4. Simulated and Measured result of return loss plot

3.2. VSWR

Voltage Standing Wave Ratio (VSWR) is created due to the impedance mismatch at the input terminals. The plot of VSWR vs frequency is given as follows in Fig. 5. The value of VSWR obtained is of 1.15, 1.12 and 1.37 for the first, second and third resonant frequency.
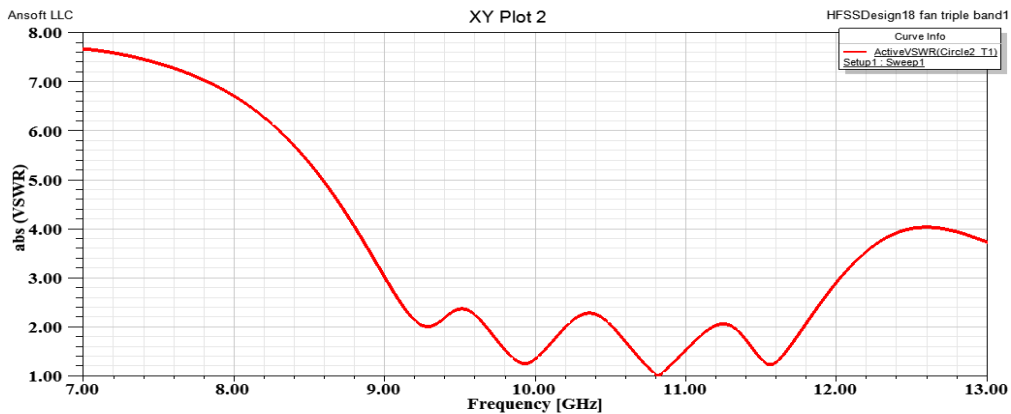
Fig.5. VSWR vs Frequency (GHz) graph of the proposed model

3.3. Other Parameters

Gain and directivity is another important parameter of an antenna. The 3D polar plot of total gain and directivity obtained in terms of dB is shown in Fig. 6 for three of the resonant frequencies. An overall gain of 3.33 dBi, 2.91 dBi and 1.17 dBi with a directivity of 5.56 dB, 4.94 dB and 4.75 dB is obtained for the first, second and third resonant frequency respectively.
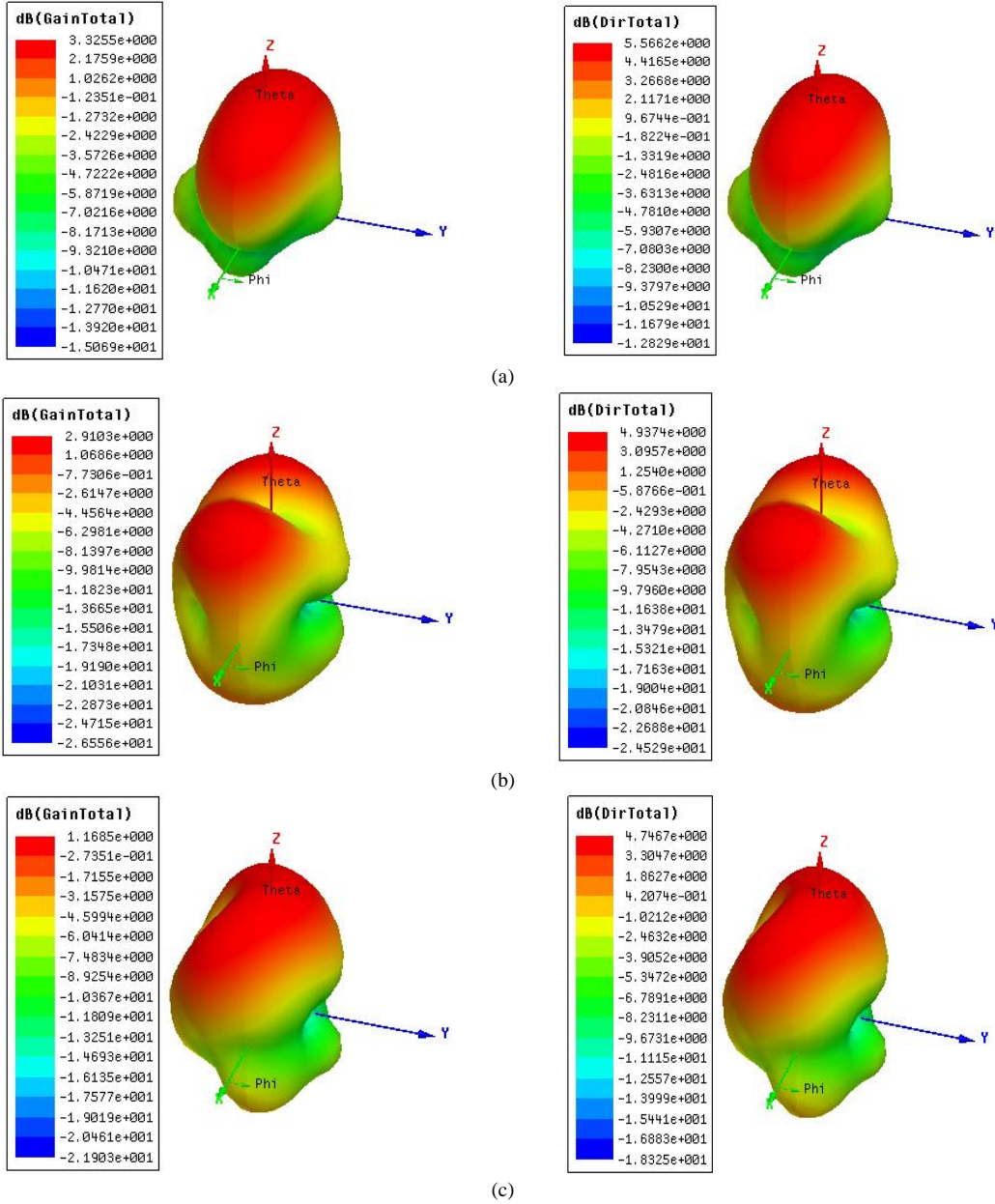
(a)

(b)

(c)

Fig.6. 3D gain and directivity plot at (a) 10 GHz, (b) 10.93 GHz, (c) 11.68 GHz

The radiation characteristics of an antenna for a particular resonant frequency can be easily identified from its surface current distribution. The fringing field produced is along the edges than at the centre of the radiating patch for all of the resonant frequencies.
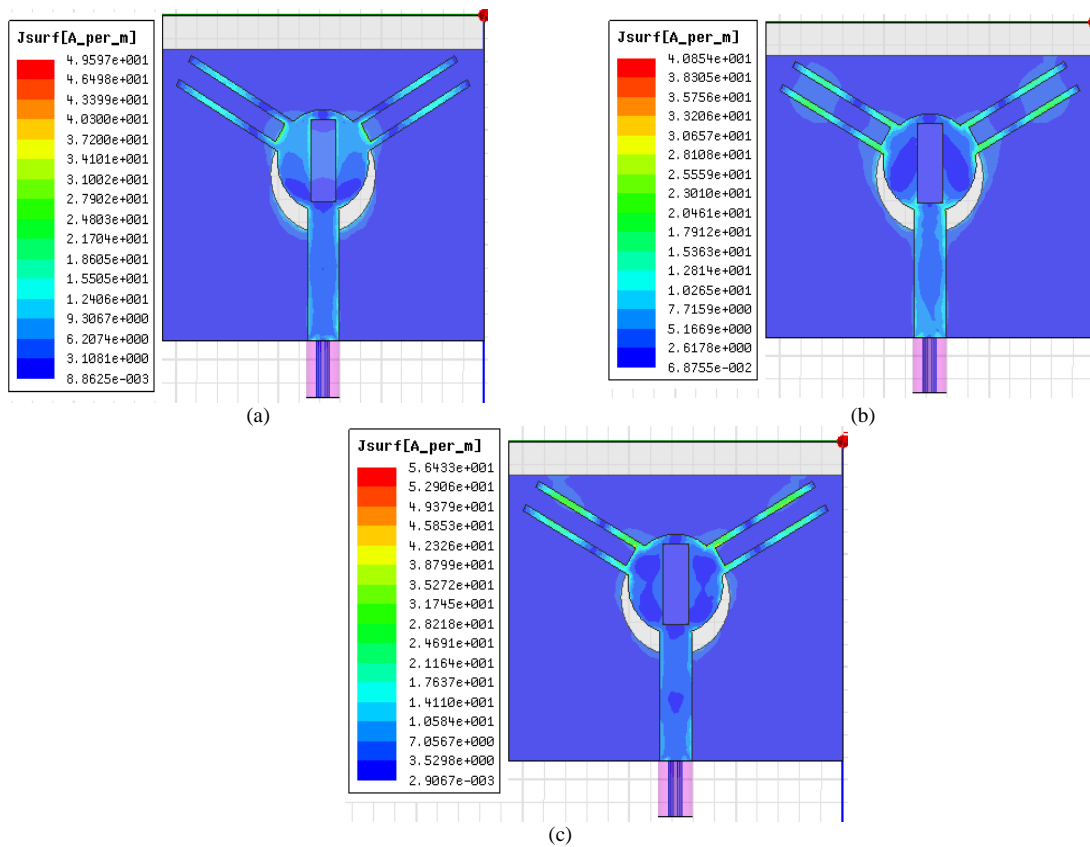

(a)

(b)

(c)

Fig.7. Current Distribution at (a) 10 GHz, (b) 10.93 GHz, (c) 11.68 GHz

4. Conclusions

As described above, the depicted model works well by satisfying all the parameters of an antenna particularly under radar frequency application. The bandwidth obtained is of considerable value and also it is greater than UWB (> 500 MHz) for the second resonant frequency of 10.93 GHz. The measured and simulated reflection coefficient vs frequency matches in a considerable manner with each other. Other characteristics such as Voltage Standing Wave Ratio, gain and directivity are at an optimal level with compact nature of the proposed model.

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Authors' Profiles

R. Kiruthika received B.Tech. Degree in Electronics & Communication Engg from Alpha College of Engg & Technology (affiliated to Pondicherry University) in 2015 and M.Tech. Degree in Electronics and Communication Engineering in the Dept. of Electronics Engg, School of Engg and Technology, Pondicherry Central University, Puducherry in 2017. Research area interest is of Antennas, Microwave/Millimeter-Wave Engineering.

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