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Compact Microstrip Patch Antenna with Dual Frequency Tuning Characteristics using E-Shaped Defected Ground Plane Structure

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Abstract

Study of the effect of ''E''- shaped defected ground structure (DGS) on frequency tuning and size reductions of a square microstrip antenna in comparison with the conventional and slit added compact patches are presented. It has been shown, how the variation of the arms of the E-shaped slot embedded in the ground plane results in frequency shifting. By changing the length of the slot, the lower resonant frequency (f1) of the proposed antenna can be tuned from 3.94 GHz to 2.13GHz and higher resonant frequency can be tuned from 5.14GHz to 3.99 GHz. A significant size reduction of about 86% has been achieved compared to the conventional rectangular microstrip reference antenna.

***Keywords*:** Defected Ground Structure (DGS), Dual Frequency Tuning, Microstrip Patch Antenna, Compactness.

1. INTRODUCTION

Microstrip antennas are now extensively used in various communication systems due to their compactness, economical efficiency, light weight, low profile and conformability to any structure. Frequency agile systems must be able to receive signals over a large frequency range and therefore, requires either wide-band or tunable antennas. However, conventional microstrip patch antennas have disadvantage of narrow bandwidth. Hence, tunable narrow-band antennas can be advantageous, if small efficient antennas are required to cover a large frequency range. In addition, tunable narrow-band antennas provide frequency selectivity which relaxes the requirement of the receiver filters. Some of the recent works on tunable antenna found that an optimization between size reduction and nearly constant fractional bandwidth was maintained.

An electrically tuneable rectangular microstrip antenna is proposed by Kang and Song [1]. It was shown that the resonant frequency can be lowered by controlling the air gap thickness of the substrate layer due to an application of external DC bias. As a result, 10 GHz resonant frequency shifts 361MHz. However, the work presents very small shifts of the resonant frequency. It suffers from Single Frequency Tuning. A maximum antenna size reduction of 41% with multi frequency operation was achieved in [2] by varying the positions and dimensions of the rectangular slots on the patch. It was also reported by Singh [3] that by using cross slot on the rectangular and trapezoidal patch, the size of the antenna can be reduced by 34% and 41% respectively. In Ref. [4], a maximum size reduction of 46.2% was achieved by introducing a triangular slot at the upper edge of the patch. A maximum size reduction of less than 40% was reported in [5] for slotted edge fed microstrip antenna. A maximum size reduction of 47.4% has been achieved in Ref. [6] by embedding three unequal rectangular slots at the edge of the patch. Kaya designed and studied rectangular microstrip antenna with a pair of parallel slots loaded close to the radiating edge of the patch and three meandering narrow slots embedded in the antenna surface resulted in a size reduction of 34% and 45% [7]. Antenna size reduction of 41.8% with dual frequency operation was also reported by Chatterjee [8]. A compact equilateral triangular patch antenna with maximum size reduction of 43.47% was reported by Dasgupta [9]. In another work, a frequency reconfigurable ‘‘U’’-slot antenna was proposed by Yang et al[10]. The method they have used to lower the resonant frequency was variation of the impedance matching frequency using a trimmer circuit. It was reported that the tunable range was 2.6 GHz–3.35 GHz and f2/f1 was 1.28. However, the article limits the frequency ratio which is below 2. Some of the works for tuning the resonant frequency have been made by reactive loading of the microstrip patch using [11-14]varactor diode , switching diode[15-17] and changing the external DC bias voltage. Although these electrical reconfiguration techniques have been widely used, they have some undesired performance characteristics when they are not designed carefully. Their impedance mismatch with the antenna structure creates a challenge for antenna designers. In another works, a single frequency tunable capabilities was proposed by Ujjal Chakraborty. This method used a "T" shaped defected ground structure (DGS) and a triangular slit [18]on the patch. It was reported that the tunable range was 1.800–3.188 GHz and f_2/f_1 was 1.77.It achieved a size reduction of only 80%.

In this article, a single layer coaxial probe fed size reduced square microstrip antenna with frequency tuning capability and constructed with FR4 substrate is proposed. Authors have tried to investigate the effect of a simple defected ground structure (DGS) on

(i) Resonant frequency tuning

(ii) Reflection Coefficient (S_{11})

(iii) Size reduction

Due to the small size, low cost, and low weight, the proposed antenna is suitable for the applications in the frequency range of from 3.94 GHz to 2.13GHz and 5.14GHz to 3.99 GHz.. The proposed configuration was first optimized using the IE3D software. The advantages of the proposed antenna in comparison to the reported antennas [1-21] are as follows:

(i) The structure of the proposed antenna is less complex.

(ii) The proposed antenna provides better size reduction.

(iii) The proposed antenna provides dual frequency tuning with better frequency tuning capability.

(iv) The proposed antenna provides better tuned frequency ratio.

2. ANTENNA CONFIGURATION

Antenna 1 (Conventional Antenna):

The width (W) and length (L) of Antenna 1 is calculated from Conventional equations [19].

$$W=\frac{C}{2fr}\sqrt{\frac{2}{1+\varepsilon r}} \tag{1}$$

$$L=L_{eff}-2\Delta L \tag{2}$$

$$\frac{\Delta L}{h}=0.412 \times \frac{(\varepsilon reff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon reff-0.288)(\frac{W}{h}+0.8)} \tag{3}$$

$$\varepsilon_{reff}=\frac{\varepsilon r+1}{2}+\frac{\varepsilon r-1}{2}[1+12\frac{h}{W}]^{-1/2} \tag{4}$$

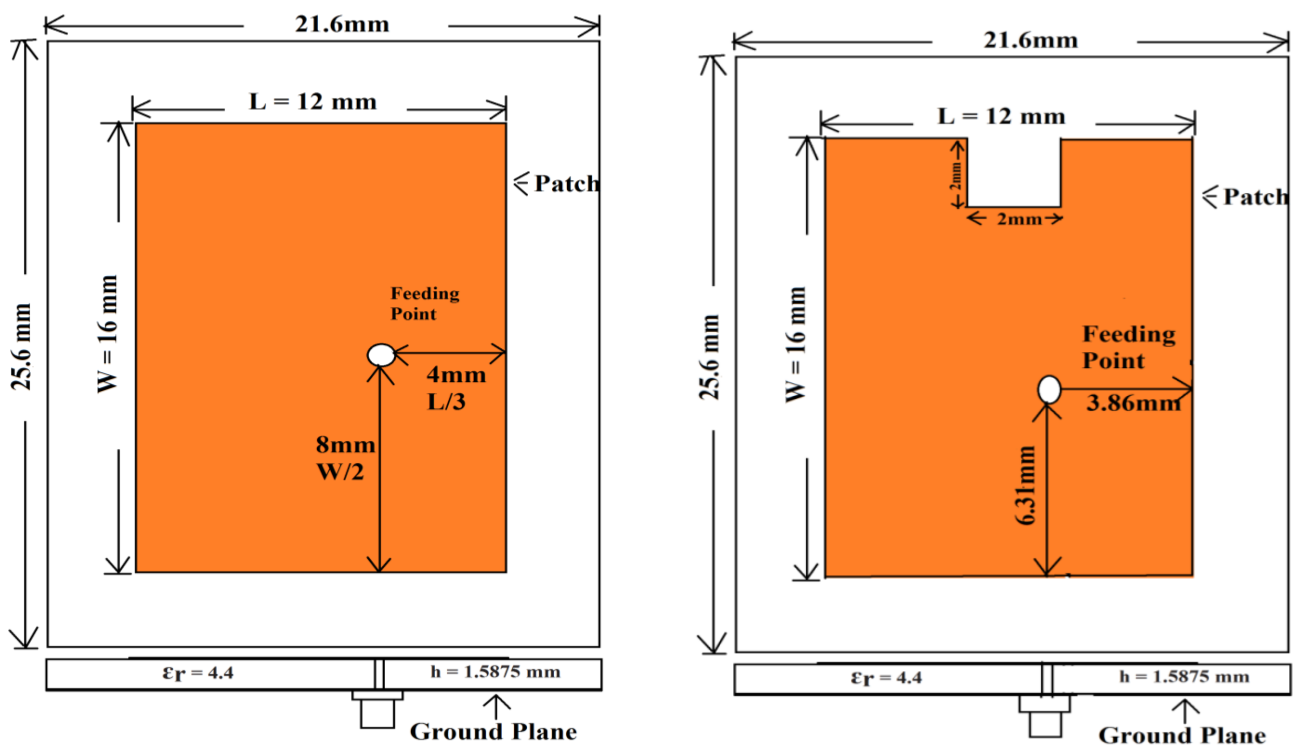
$$L_{reff}=\frac{C}{2fr\sqrt{\epsilon reff}} \tag{5}$$

Where, fr= Resonant frequency, W= Width of the antenna, L_{eff} = Effective length of the patch, $\frac{\Delta L}{h}$ = Normalized extension of the patch, ε_{reff}= Effective dielectric constant. The length and width of Antenna 1 (conventional antenna) operating at frequency 5.5 GHz are 12 and 16 mm, respectively, with substrate thickness h = 1.5875 mm and dielectric constant ε_r = 4.4 (FR-4). The width and length of the conventional patch antenna in terms of wavelength are $0.293\lambda_r$ and $0.22\lambda_r$, respectively, where, λ_r is the wavelength of the resonant frequency (i.e., 5.5 GHz). Figure 1 shows the structure of the conventional rectangular microstrip patch antenna with length (L) = 12 mm and width (W) = 16 mm. Coaxial probe-feed (radius = 0.5 mm) is located at a position W/2 (8 mm) and L/3 (4 mm) from right side edge of the patch for best impedance matching.

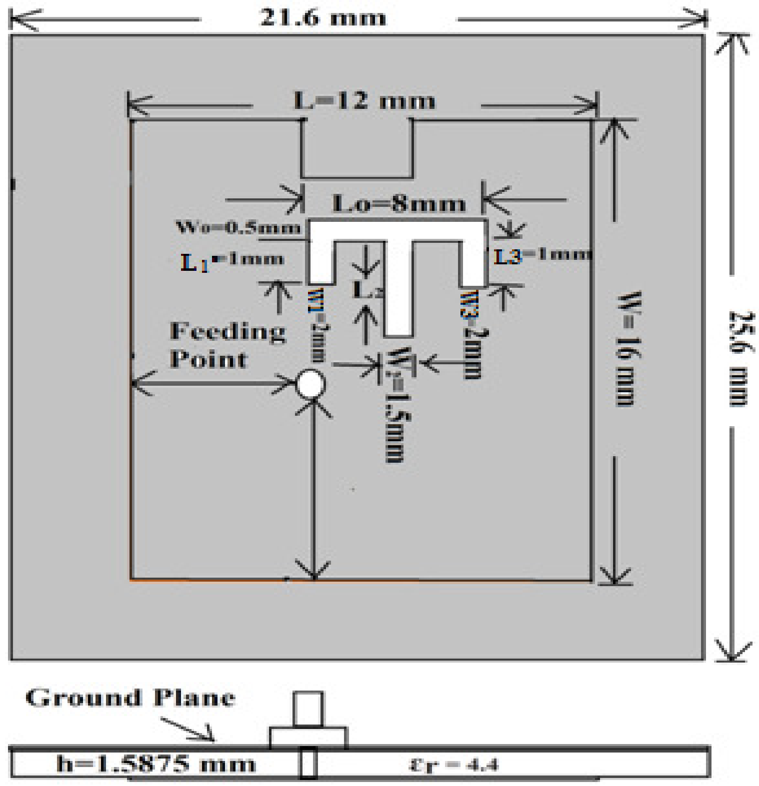
The geometry of the proposed antenna is formed from the three stages of modifications. Initially a rectangular microstrip antenna with sides 16 mm X 12mm is designed to work as a reference antenna (antenna 1) as shown in Figure 1(a). The antenna substrate has dimensions of (1.5875 x 16 x 12) mm3 and is an FR4 epoxy with relative permittivity ε_r = 4.4. The antenna is excited by a coaxial probe (radius = 0.5 mm), and the feed point is located at the distance of (2.14 mm, -1.69 mm) away from the centre of the rectangular patch [Figure 3.1(a)]. Another reference prototype (antenna 2) is constructed by inserting a square slit of sides 2mm on the radiating patch of the antenna 1 to design a compact microstrip antenna in the second stage as shown in Figure 3.1(b). The final design of the proposed antenna (antenna 3) is achieved by embedding a ‘‘E’’-shaped DGS on the ground plane of the antenna 2 as shown in Figure 3.1(c). A parameter ‘L_2’ is considered to vary which is the length of the ‘‘E’’-shaped DGS Figure 3.1 (d) where all other dimensions are optimized to obtain the best miniaturization value for the proposed design. The parameter “L2” is considered to vary which is the length of the vertical slot where all other dimensions are optimized to obtain best miniaturization value with frequency tuning for the proposed design. The method of moment based electromagnetic simulator IE3D [21] is applied for numerical investigation in the proposed antenna design. The dimensions of the proposed antenna parameters are optimized by parametric study to meet the design goal.

3. SIMULATED RESULTS AND ANALYSIS

This section presents the modification results of the proposed antenna and the parametric analysis of the modified proposed antenna. Parameter ‘‘L_2’’ is varied over the range 0 to 17.13mm to study the effect of the DGS.



(a) (b)



(C)

Figure 1 Geometry of the proposed antenna:
(a) Conventional Rectangular microstrip patch (antenna 1)
(b) Rectangular microstrip patch with Square slit (antenna 2)
(c) Rectangular microstrip patch with Square slit and DGS (back view, antenna 3)

In antenna 1,i.e Conventional Rectangular Microstrip Patch Antenna having Length =12mm and Width =16mm has a return loss of -25.78dB at 5.472 GHz and its corresponding bandwidth is 31.25 MHz respectively.With the insertion of the square slit, area size of the antenna 2 is reduced by 42% and 13% compared to a conventional microstrip patch i.e. antenna 1.The return loss is found to be -24.05dB at 4.34GHz and -20.5dB at 5.196 GHz also its peak gain is 4.11dBi at 5.19GHz. Simulated results of antenna 1 and 2 are shown in Table 1. Resonant frequency of the antenna 3 shifts toward a lower value with the higher value of the parameter ''L_2''. Values of ''L_2'' is varied from 0 mm to 17.13 mm and corresponding resonant frequency, return loss, peak gain and amount of size area reduction is given in Table 2.
For ''L_2'' = 17.13 mm, resonant frequency is obtained at 2.13 GHz and 3.99GHz and at this frequency, observed return loss is -23.83 dB and -12.5dB,peak gain is 1.96 dBi at frequency 3.99GHz and the area size reduction is 86.46% and 53.62% at frequency 2.13 GHz and 3.99GHz compared to a conventional microstrip patch.

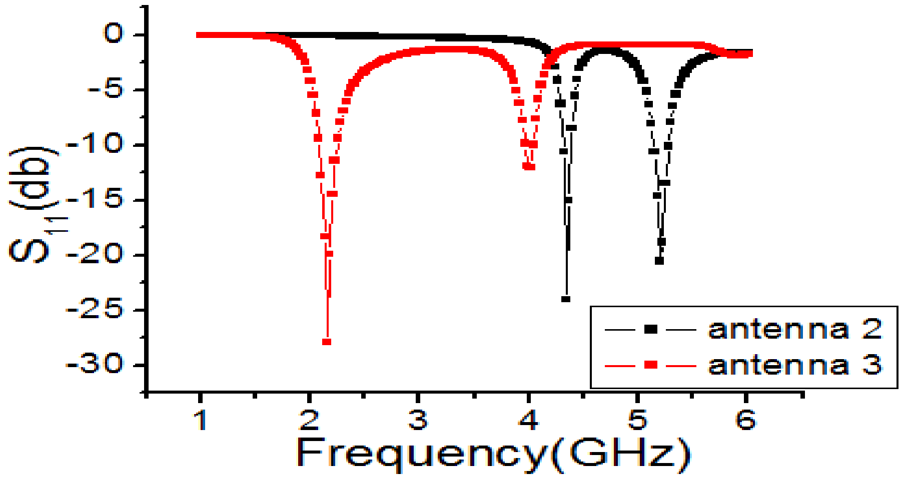


Figure 2 Plot of S_{11}(dB) versus Frequency of the two antennas as illustrated in figure 1.

TABLE 1 Simulated Result of Antenna 1 and Antenna 2

PARAMETERS	Antenna 1 Without slit and DGS	Antenna 2 With Slit But Without DGS
Frequency	5.472 GHz	4.34GHz 5.196GHz
Return Loss	-25.78dB	-24.05dB -20.5dB
Peak Gain		4.11dBi
Size Reduction		42% 13%

4. PARAMETRIC STUDY

The structure of Antenna 3 (proposed antenna), designed with defected ground structure (DGS) is shown in Figure 1.The FR-4 substrate chosen for realizing the antenna has dielectric constant, $\varepsilon_r = 4.4$ and thickness (h) of 1.5875 mm.

(i) Defected Patch

Initially the proposed antenna is incorporated with a square slit of side 2mm on the patch. This square slot on the patch made the contribution for better S_{11}(dB) parameter and a size reduction of 42.4% and 13.1% with respect to conventional antenna. The square slit is introduced to generate dual frequency. The plot of S11(dB) with frequency of the antenna 2 (i.e. square slit on the patch) with respect to the conventional antenna is show in figure 3.

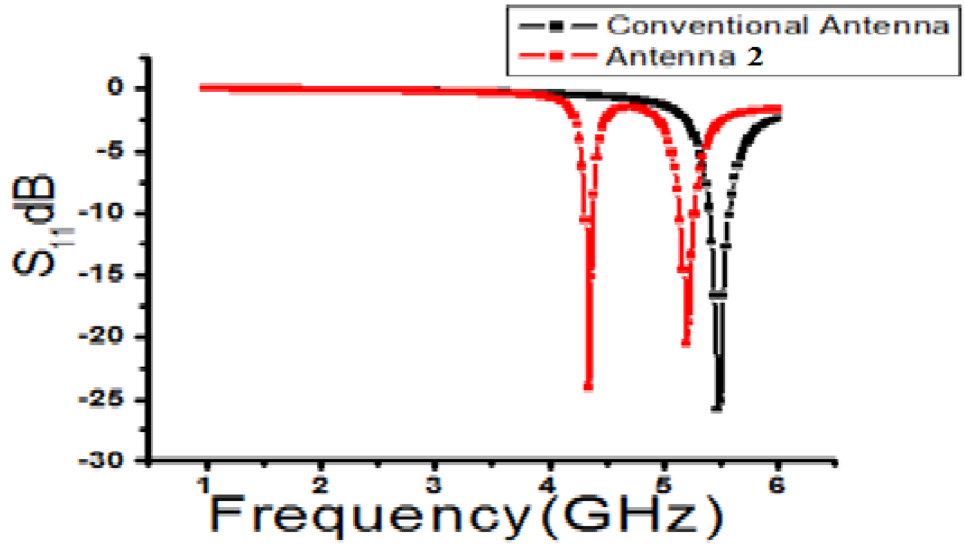


Figure 3: Plot of conventional antenna versus antenna 2 (i.e. square slit on the patch).

(ii)Defected Ground Structure

Effect of Width (W_2) on Ground Plane:

On the ground plane an "E" shaped slot(Figure 1.c) has been introduced so as to get dual tuning capabilities with better compactness. The effects of varying the dimensions of the slots on the resonant characteristics of the proposed antenna are investigated by parametric study. The effective parameters are investigated by simulating the antenna with one geometry parameter slightly changed from the reference design while all the other parameters are fixed.

The width W_2 has been made to vary , considering L2= 17.13mm. From the simulated result given in figure 4, it has been observed that when width W_2 is 1.5mm and length L_2 is 17.13mm (Proposed) then better size reduction is achieved with S_{11}(dB) < -10dB. The value of S_{11} should be at least –10 dB, which is the main criterion for an antenna to radiate in the far field region. The impact of design parameter W2 is shown in Figure 4. The changes in slot width (W2) yields a constant value of frequency at f1 and f2. It is seen from Figure 7 that when the parameter W2 is varied from 0.5 mm to 2 mm, there is negligible effect on frequency change. the resonant frequency f1 attains a constant frequency i.e. 2.13 GHz and f2 attains a constant frequency of 3.99GHz. Best S_{11}(dB) has been achieved with the rest value of the W_2 .So,W2=1.5mm is selected as the proposed antenna.

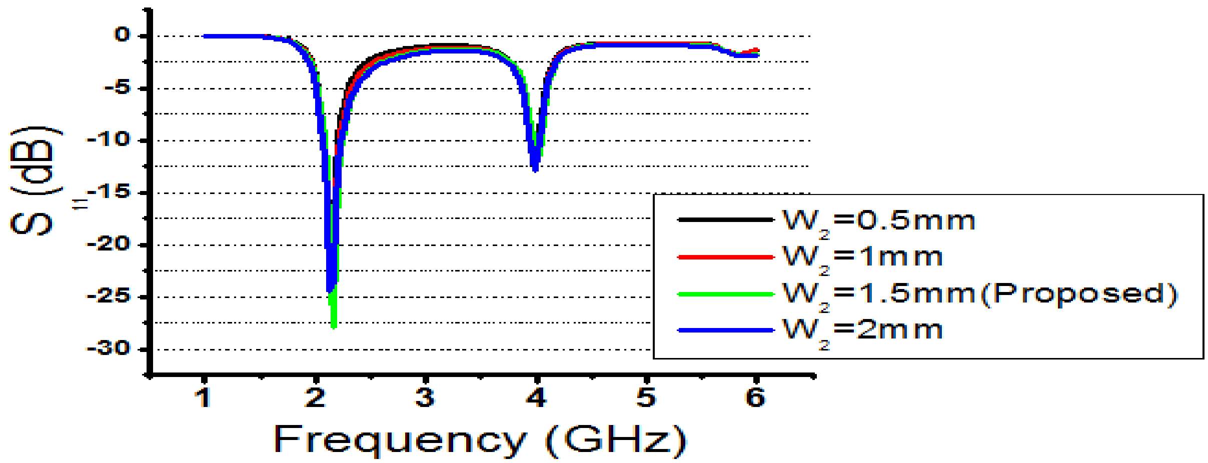


Figure 4 Variation of different values of W2

Effect of Antenna parameter L1 and W1

The *S*11 variations of the proposed antenna for different values (L1 and W1) of small rectangular notch are shown in Figures 5 and 6. It is observed from the figures that further frequency shifting or tuning is not possible by changing the dimension of the parameters. Though W1=0.5mm has best value of S11(dB) for frequency f1,but it lacks S11(dB) for frequency f2.So Width W1=1mm and Length L1=2mm is selected for the proposed antenna.

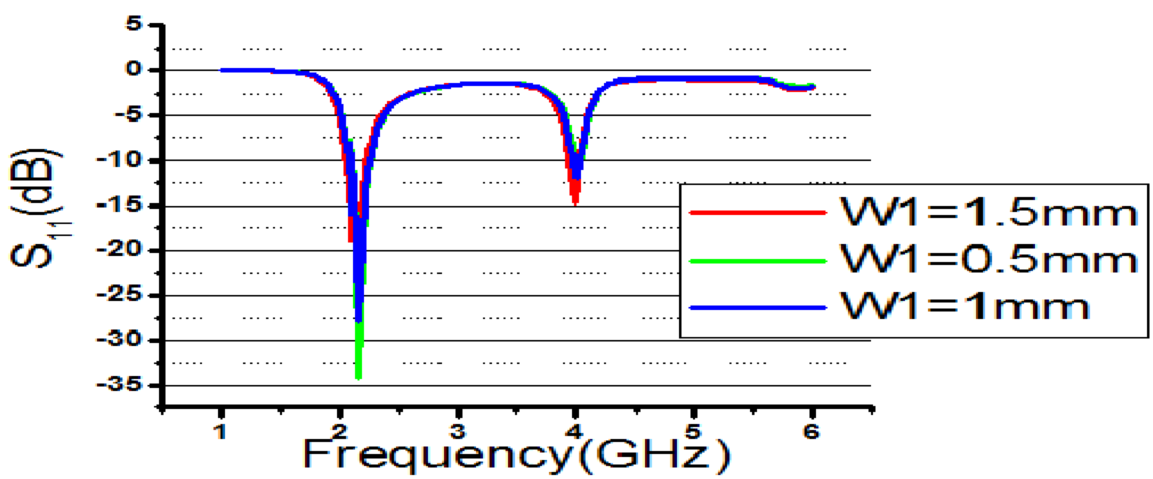


Figure 5: Variation of different values of W1

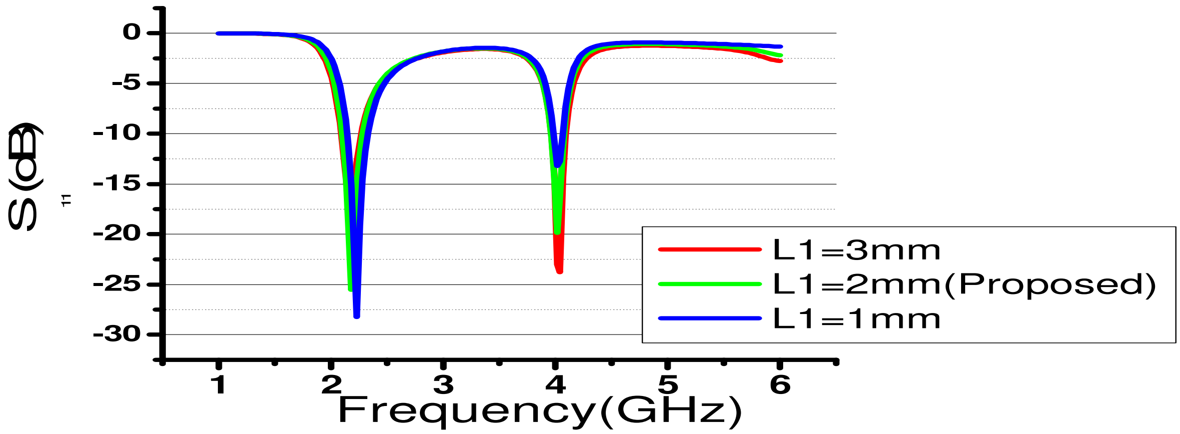


Figure 6: S11 Variation of different values of L1

The variations of reflection coefficient and resonant frequency of the proposed antenna as a function of design parameter L2 is shown in Figure 7. The parameter L2 has great impact on resonant frequency of the first and second mode. The resonant frequency of the first mode can be tuned from 3.98975 GHz down to 2.131 GHz with S11 ≤– 10 dB, when length is increased from 8mm to 17.13mm. The second resonant mode remains unchanged with this variation of L2.The second resonant mode can be tuned by adjusting the value of L2.When the Length L2 is increased from 0mm to 8mm then the second resonant mode is tuned from 5.14566 GHz down to 3.99057 GHz. The parameter L2 cannot be further increased beyond the antenna dimension due to 16 X 12 mm patch . So, it is clear from Figure 6 that L2= 17.13 mm is the optimum value for the proposed antenna to achieve dual frequency tuning with best size reduction. The variation of two resonant frequencies as a function of slot length L2 is shown in Figure 7. It is observed that the shifting of resonant frequencies depend inversely on dimension of L2 parameter of the proposed antenna.

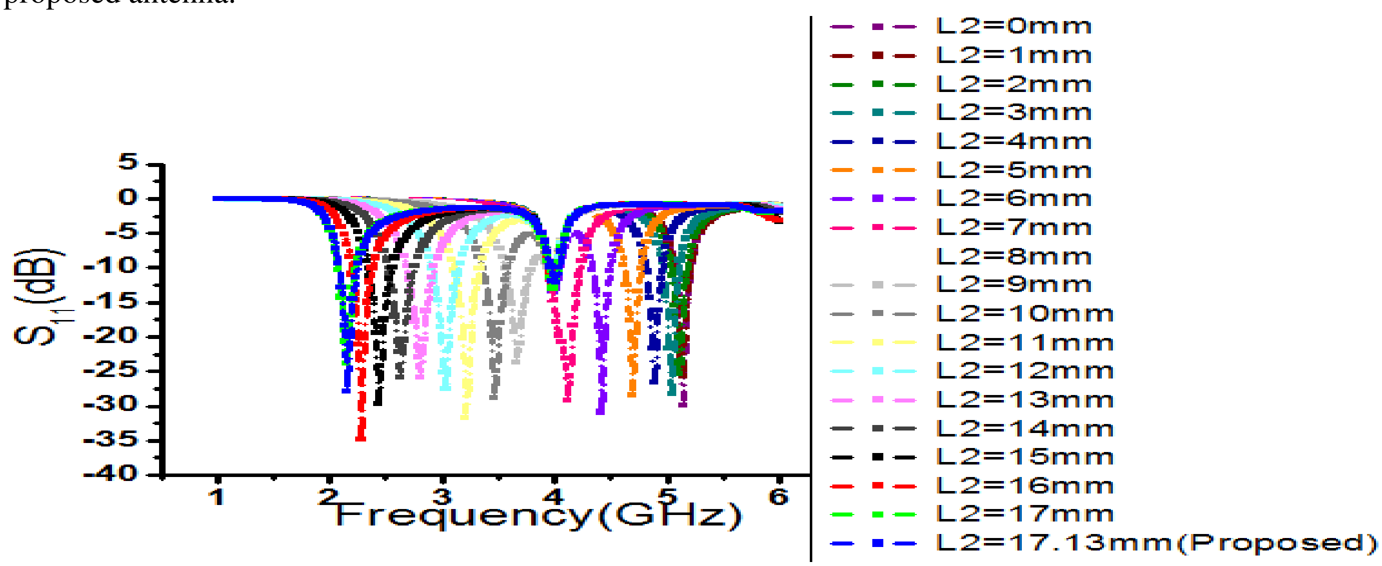
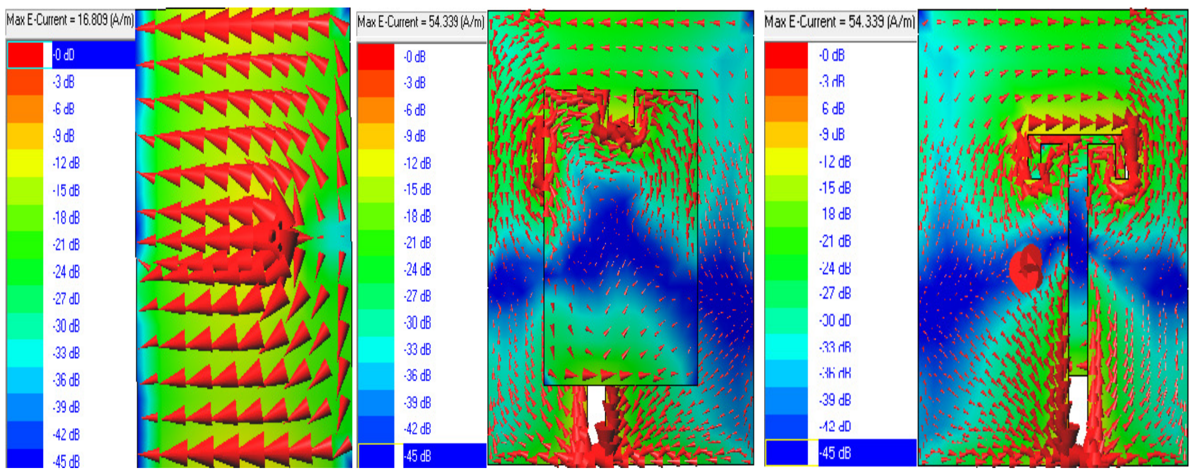


Figure 7: S11 variations for different values of L_2 parameter

For better understanding the excitation behaviour of the proposed antenna, the simulated surface current distributions at different resonant frequencies are displayed in Figure 8. It is clearly observed from Figure 8 (a) that the surface current density of the conventional patch antenna is much less 16.809 A/m. So, the current density of the patch at that radiating edge can be increased by introducing additional slots[21]. In comparison to surface current density of conventional antenna, the surface current density slightly increases to 54.33 A/m for the proposed antenna at 2.13 GHz operation .



(a) **(b)** **(c)**

Figure 8 : (a)Surface current distribution of conventional antenna at frequency 5.47GHz, (b) and (c) Surface current distribution of antenna 3 (Proposed at 2.13GHz frequency)

TABLE 2 Simulated Result of Antenna 3 for Different Values of DGS Parameter 't'

L0=8 , W0=0.5 , W1=1 , L1=2, W2=1.5 mm , L2 varies ; W3=1, L3=2

Sol no	**Length L2**	**FREQUENCY 1 GHz**	**FREQUENCY 2 GHz**	**S11(1) dB**	**S11 (2) dB**	**Peak Gain in dBi**	**Area reduction F1**	**F2**
0	0	3.98975	5.14566	-12.13	-34.27	4.71	**51.81**	**18.44**
1	1	3.98970	5.1454	-12.0303	-25.8485	4.58	51.8	18.44
2	2	3.98966	5.09535	-12.444	-24.5	4.31	51.8	13.12
3	3	3.99098	5.04525	-12	-25.48	4.53	51.6	22.00
4	4	3.9893	4.89446	-12.697	-33.5455	4.19	51.1	35.6
5	5	3.98949	4.69337	-13	-25	3.56	52.0	32.6
6	6	3.98991	4.4419	-13	-26.51	2.25	52.0	39.57
7	7		4.11655		-30	1.91		48.58
8	8	3.94056		-14		1.04	52.8	
9	9	3.71389	3.96581	-26.0303	-12.9394	1.55	58.4	51.6

10	10	3.48755	3.99057	-29.333	-12.1333	1.82	63.5 51.6
11	11	3.23628	3.99055	-38	-11	1.52	73.5 51.6
12	12	3.06032	3.9902	-26.0909	-11.9091	4.67	71.8 51.6
13	13	2.80987	3.99005	-24.2222	-11.99444	1.13	76.5 51.6
14	14	2.60812	3.9909	-24.6667	-12.1111	1.58	79.8 51.6
15	15	2.48259	3.99051	-25.667	-12.2727	1.04	81.6 51.6
16	16	2.28157	3.99098	-29.6	-12.4667	1.94	84.5 51.6
17	17	2.15616	3.99021	-27.4	-12.6667	1.8	86.4 51.6
18	17.13	2.13148	3.99143	-23.8333	-12.5	1.96	86.4 51.6

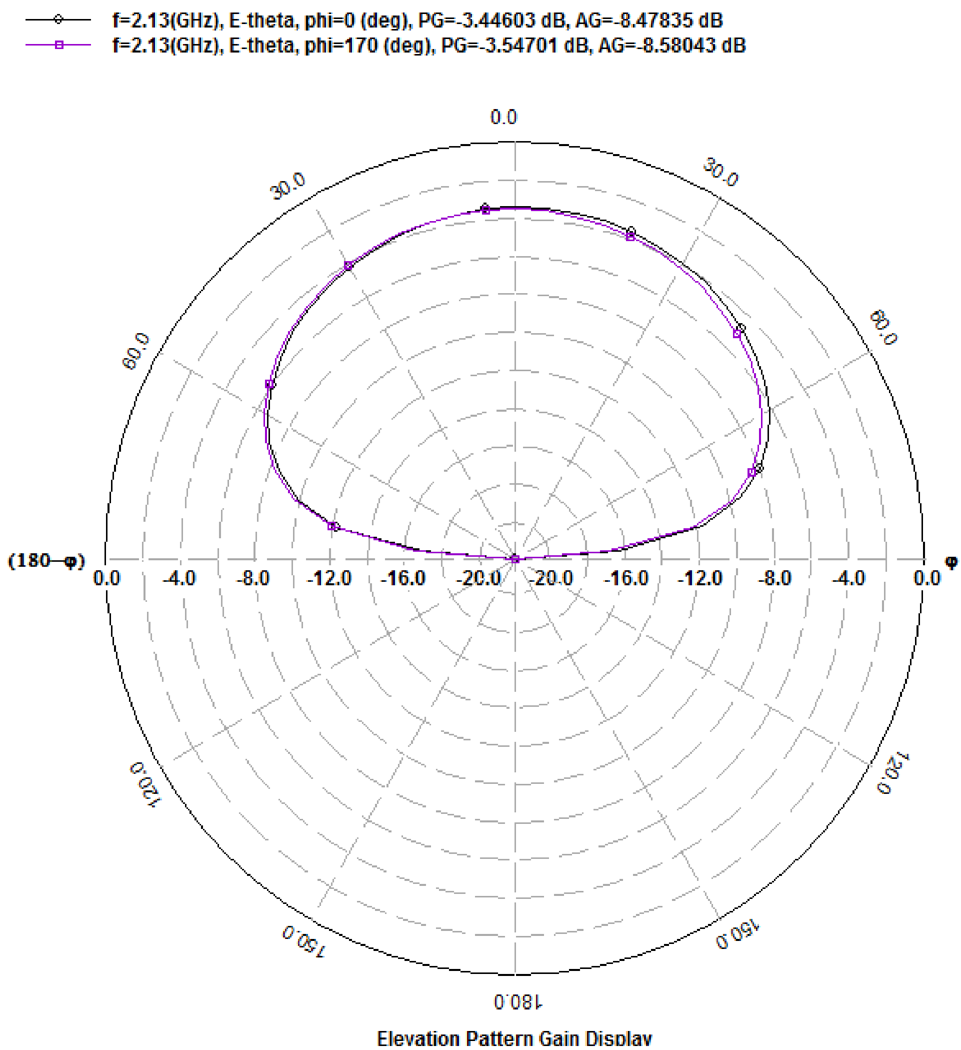


Fig. 3.9(a) Proposed antenna E- Plane pattern

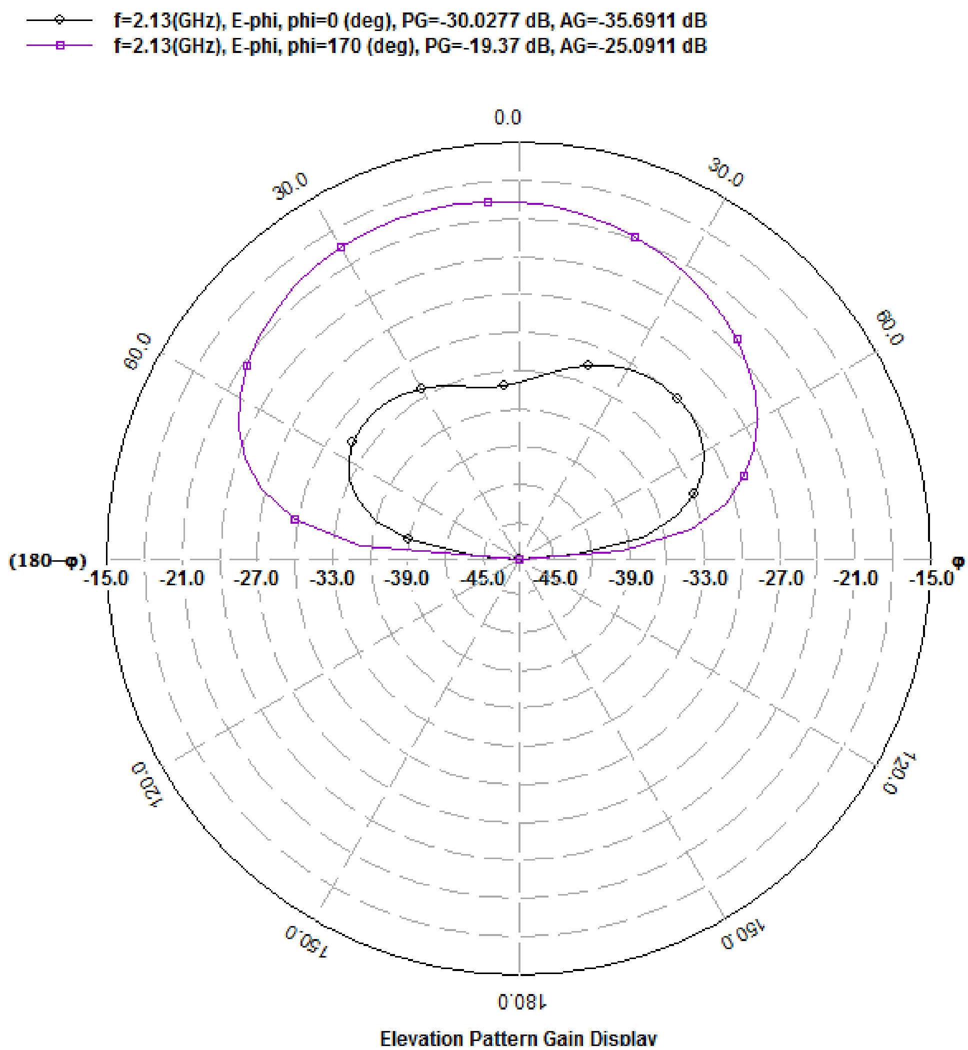


Fig. 3.9(b) Proposed antenna H- Plane pattern

5. CONCLUSION

A double layer single feed slot loaded microstrip patch antenna is proposed in this paper. It is shown that the proposed antenna can operate in two frequency bands. For antenna 3 (proposed antenna), the effect of slot has reduced the lower resonant frequency from 3.98 GHz to 2.13 GHz which shows an area reduction of about 86.4%. Similarly, the higher resonant frequency can be tuned to any value between 5.14 GHz and 3.99 GHz. The proposed antenna could be promising and suitable for 3.3GHz-3.5GHz band for amateur radio,2.4GHZ - 2.5GHz band for Radio Frequency Identification(RFID),5.091GHz-5.25GHz band for Non Geostationary Satellite and mobile receiver.

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