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MICROSTRIP PATCH ANTENNA WITH SKEW-F SHAPED DGS FOR DUAL BAND OPERATION

A. K. Arya, A. Patnaik, and M. V. Kartikeyan*

Millimeter Wave Laboratory, Department of Electronics and Computer Engineering, Indian Institute of Technology, Roorkee 247667, India

Abstract—The goal of this paper is to use defected ground structure (DGS) in microstrip antennas for dual band operation at microwave frequencies. The soft nature of the DGS facilitates improvement in the performance of microstrip antennas. A design study on microstrip patch antenna with specific DGS slot has been presented in the proposed work. In this paper, a stacked microstrip patch antenna (SMPA) has been designed for broadband behavior, and then skew-F shaped DGS has been integrated with a detailed study of possible DGS slots in a small area for dual band operation. The design and optimization of both the SMPA and DGS structures along with the parametric study were carried out using CST Microwave Studio V.9. Further, the dual band antenna, i.e., the SMPA with skew-F shaped DGS, has been fabricated, and the experimental results have shown a good agreement with the simulation ones.

1. INTRODUCTION

Microstrip antennas are quite an obvious choice for the wireless devices because of their properties as low-profile, light weight, low cost and easy fabrication. As far as the size is concerned, the patch length should be around half a wavelength for the structure to work as a good radiator [1]. Defected ground structure is realized by etching off a simple shape (defect) from the ground plane. Depending on the shape and dimensions of the defect, the shielded current distribution in the ground plane is disturbed, resulting in a controlled excitation and propagation of the electromagnetic waves through the substrate layer. The shape of the defect may be changed from a simple shape to a complicated one for a better performance [2].

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* Corresponding author: M. V. Kartikeyan (kartik@iitr.ernet.in).

Several methods have been considered in the literature for dual band operation of the antennas [3–13]. A new approach using the defect in the ground plane of microstrip antenna has been presented in this work. Here, a stacked microstrip patch antenna has been designed in such a way that one patch is placed above another with air-gap between them. The lower patch is fed by microstrip line along with a quarter wave transformer. This arrangement provides a fairly good broadband operation (≈ 20% Bandwidth). In the second stage, a variety of DGSs were realized with a mictrostrip transmission line and antenna as well to see their effect on the transmission and resonant properties, respectively. Later, a specific skew-F shaped DGS has been etched in the ground plane of the lower patch of the fabricated modified SMPA to produce a dual band operation.

2. DEFECTED GROUND STRUCTURE (DGS)

Recently, there has been an increasing interest in the use of DGSs for performance enhancement of microstrip antennas and arrays. They are realized by etching off a simple shape defect from the ground plane of the microstrip antenna. The shape may vary from a simple geometry to a complicated one. Due to its resonant behavior, the DGS may be compared to the LC parallel resonator, i.e., the equivalent circuit of the DGS consists of an inductance and a capacitance in parallel to itself [14, 15].

Figure 1(a) shows the simple and mostly used dumbbell shaped DGS which is etched in the ground plane below the microstrip line, in which both the areas ($a \times b$) and slot gap (g) play very important roles

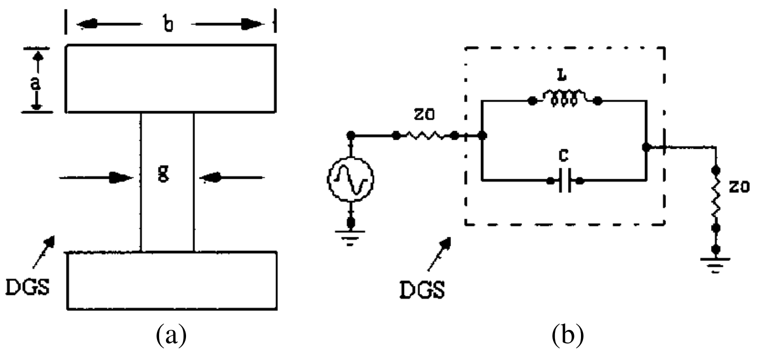


Figure 1. DGS unit cell: (a) Dumbbell DGS unit cell, (b) L-C equivalent of DGS.

for finding the resonance behavior of the DGS. Figure 1(b) shows the equivalent circuit of the DGS as a parallel combination of Inductance (L) and Capacitance (C). The head areas ($a \times b$) are very useful for the variation in the inductance (L), and slot (g) produces the capacitance (C). The L and C may be calculated from the formulae given below [15].

$$L = \frac{1}{4\pi^2 f_0^2 C}; \quad C = \frac{f_c}{2Z_0} \cdot \frac{1}{2\pi(f_0^2 - f_c^2)};$$

where f_0, f_c and Z_0 denote the resonant frequency, cutoff frequency and characteristics impedance of microstrip line above the DGS, respectively.

When this DGS is applied to the antenna, the equivalent inductive part, due to the DGS, increases and produces equivalently a high effective dielectric constant [16], thereby, decreasing the resonant frequency. Figure 2(a) shows the DGS size variation and its effect on the resonance frequency of the DGS and the effective dielectric constant of the medium due to the DGS when a defect is created under the microstrip line of 50 Ohm impedance. The EM simulator [17] and a small MATLAB code were used to analyze the resonance frequency behaviors of a particular DGS, and the effective dielectric constant behavior was analyzed with the help of transmission line model [1].

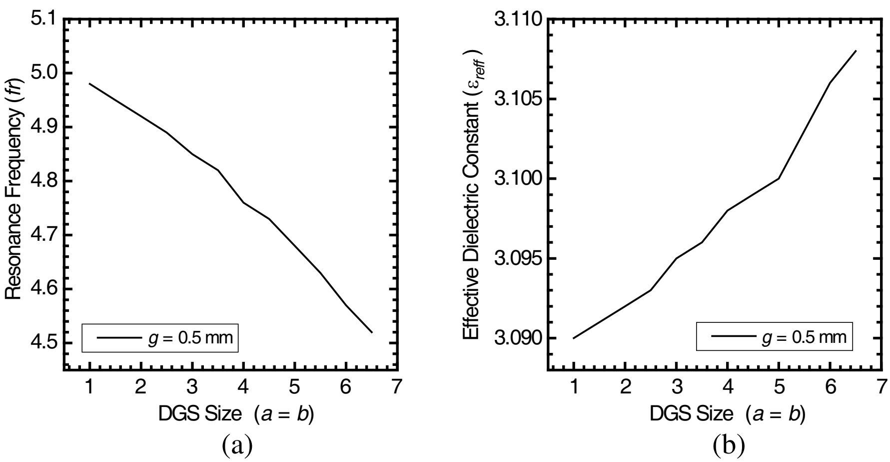


Figure 2. DGS size response with respect to the resonance frequency and effective dielectric constant.

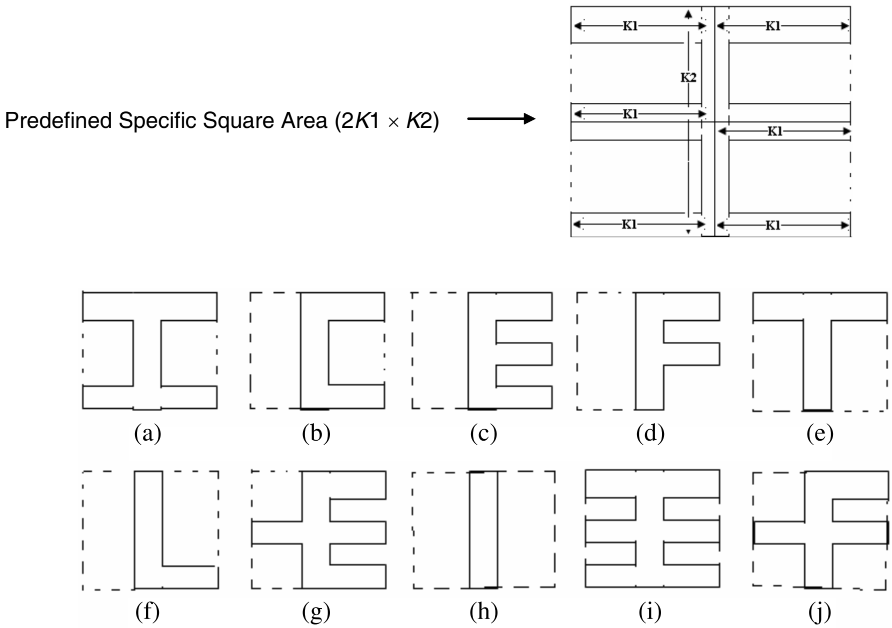
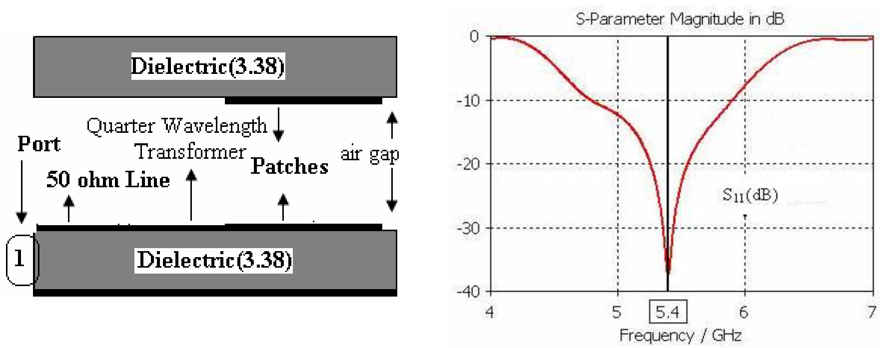


Figure 3. Schematic diagrams for different DGS slots in a specified area.

3. DGS STRUCTURES AND STACKED MICROSTRIP PATCH ANTENNA GEOMETRY

Some specific DGS structures have been used for the study of the stacked patch antenna with the DGS as shown in Figures 3(a)–(j). It is very interesting to note that within a particular size of the ground plane, different DGSs produce different resonances, cutoff frequencies, and 3-dB bandwidths depending upon their geometry and size. For this to validate, some possible slots were created in the ground plane of a 50 Ohm microstrip line in the first step and simulated and analyzed using the standard EM simulator [17]. From these results as tabulated in Table 1, one can see that for a skew-F shape DGS (shown in Figure 3(j)) the microstrip line shows a dual-band regime of operation.

Using these DGSs in the stacked patch antennas, to check the performance of the SMPA in terms of resonance frequency, radiation pattern and other performance figures, becomes a novel and interesting topic to the antenna designers, and not much work on the antennas with DGS has been reported by the researchers in this view. For the integration of the specific DGS that has been found from the previously created structures (Figure 3) and their characteristics (Table 1), a stacked patch antenna has been designed and simulated by the CST microwave studio V.9. The patch dimensions are calculated from the transmission line model [1]. Figure 4(a) shows the schematic diagram of the stacked antenna that has been fabricated using Neltec NH 9338 substrate with a dielectric constant of 3.38, thickness of 1.524 mm and loss tangent of 0.0025. An air gap is given between the patches, and again the same dielectric sheet is used over the upper patch which works as a superstate. This geometrical configuration of the antenna may be useful as the radome, i.e., to protect the patch antenna from



(a) (b)

Figure 4. Stacked patch antenna: (a) Microstrip fed stacked patch antenna, (b) S_{11} (dB).

Table 1. Different slots response under microstrip line.

	DGS SHAPE	f_r (GHz)	f_c (GHz)	BW (GHz)
1	(a)	4.04	3.12	1.38
2	(b)	5.019	3.6	3.09
3	(c)	5.05	3.611	3.09
4	(d)	6.04	5.76	1.0057
5	(e)	6.18	5.72	1.5086
6	(f)	6.78	5.97	1.5269
7	(g)	5.07	3.6571	3.05
8	(h)	7.37	6.54	1.37
9	(i)	4.05	3.16	1.384
10	(j)	5.85 7.53	5.58 7.0263	1.1246 0.89

the natural phenomena.
where, f_r, f_c and BW denote resonance frequency, cutoff frequency and the 3-dB bandwidth of the DGS structure, respectively, when the DGS is created in the ground plane of 50 Ohm microstrip line.

The modified broadband stacked patch antenna was designed for frequency 5.4 GHz with bandwidth 1.009 GHz. The lower patch is fed by the microstrip line with the help of the quarter wavelength transformer. Figure 4(b) shows the response of the stacked patch antenna working with a center frequency of 5.4 GHz and having around 1 GHz bandwidth with an S_{11} of -37.3926 dB. Table 2 shows the design parameters of the stacked microstrip patch antenna for broadband application.

Table 3 shows the DGS behavior when it is created in the ground plane of designed antenna. It is seen that the same 10th slot, i.e., (j)

Table 2. Stacked patch antenna design parameters.

Dielectric Constant	3.38 ($\tan\delta = 0.0025$), thickness (h) = 1.524 mm
Air Gap between two layers	10 mm
Patch Dimensions	Lower $(12.2 \times 12.2)\,\text{mm}^2$ Upper $(14.4 \times 14.4)\,\text{mm}^2$
Ground Plane Size	$(47.2 \times 24.4)\,\text{mm}^2$
Feeding Technique	Microstrip Feed with Quarter Wave Length Transformer

Table 3. Slots response in modified broad band SMPA.

	DGS SHAPES	f_r (GHz)	BW (GHz)	SIZE REDUCTION (%)
1	(a)	2.425	0.0511	55.09
2	(b)	2.8379	0.0597	47.44
3	(c)	2.8513	0.064	47.22
4	(d)	3.362	0.083	29.74
5	(e)	3.268	0.078	39.48
6	(f)	3.4089	0.085	36.87
7	(g)	2.8617	0.063	47.00
8	(h)	3.92	0.132	27.40
9	(i)	2.44	0.050	54.81
10	(j)	3.31, 5.63	0.0837, 0.152	38.70, −4.25

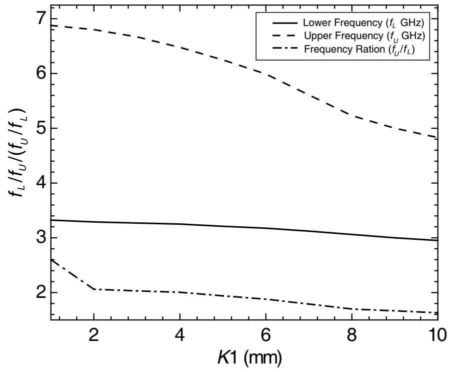


Figure 5. Integration of antenna with skew-F shaped DGS.

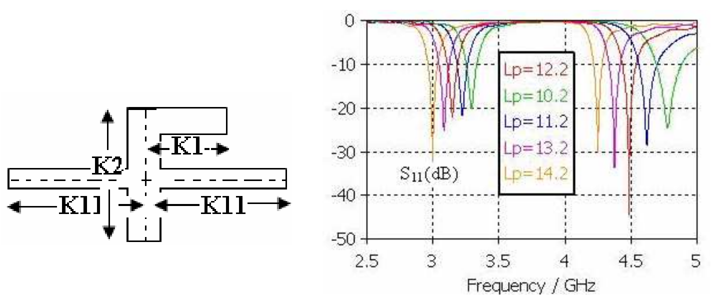


Figure 6. (a) Skew-F shaped DGS. (b) Lower patch length (Lp) variation study (keeping other parameters constant and $K1 = 13\,\text{mm}$).

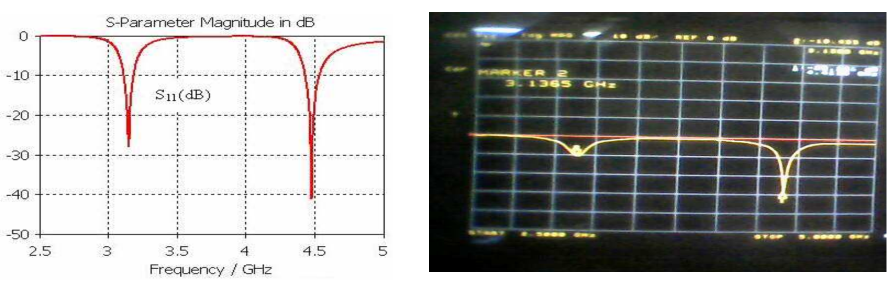
slot or exactly the skew-F shaped slot, gives the dual band response in the antenna. The maximum size reduction is found to be 55.09% due to the slot (a) in terms of frequency. The higher bandwidth is found as 132 MHz at 3.94 GHz frequency when the slot (h) was used in the ground plane of the antenna. Figure 5 shows the modified SMPA response with the skew-F shaped DGS.

From this figure, it is seen that increasing the $K1$ (modified as $K11$ in Figure 6(a) for making skew shaped), there is a little effect (decrease) in the lower frequency (f_L) and faster effect (decrease) in the upper frequency (f_u) because of the inductance incorporation by the DGS. The frequency ratio depends on the middle arm of the F-shape DGS. As it is clear from the Figure 5, while increasing the length of that arm, the frequency ratio is decreasing. For the validation of this skew-F shaped DGS, it has been optimized and analyzed with the full wave simulator and fabricated along with the measurement. The f_U/f_L has been taken 1.42 in this paper. Figures 6(a)–(b) show the skew-F shaped DGS and variation of the lower patch length (L_p) after integrating the DGS in the ground plane of the antenna, respectively.

This study gives the idea of the F-shaped DGS for the dual band performance. The upper and lower frequencies can be changed in the further modification in the skew-F shaped DGS. For this purpose, to work in the lower ranges with respect to the original frequency, the middle arm of the F-shaped DGS plays a very important role. The modified F-shaped DGS is shown in Figure 6(a), and it is also shown that when the patch length is increasing, while keeping the DGS parameters constant, the resonance frequencies (f_u and f_L) shift towards the lower value, which is in fact a good agreement with the antenna theory that as the length (Lp) is increasing, the frequency is decreasing (Figure 6(b)), where Lp is the lower square patch dimension. Finally, the skew-F shaped DGS is created in the ground plane of the stacked patch antenna to work at the frequencies lower than the original frequency (< 5.4 GHz). Design parameters of the modified DGS, i.e., skew-F shaped DGS, are tabulated in Table 4.

Table 4. Skew-F shaped DGS design parameters.

DGS Shape	Skew-F
DGS Dimensions	$K1 = 7.2$ mm, $K2 = 14.4$ mm, $K11 = 12.33$ mm
Slot width	1.2 mm (uniform)



(a) (b)

Figure 7. S_{11} (dB) of the dual band antenna. (a) Simulated. (b) Measured.

4. RESULTS AND DISCUSSION

The design configuration (Figure 4(a)) with skew-F shaped DGS was fabricated and measured results in terms of S_{11} (dB), and radiation patterns were in good agreement with the simulated results. The simulated and measured S_{11} (dB) plots have been shown in Figures 7(a) and 7(b), respectively.

As in the measurement, the lower resonance is found at 3.135 GHz, having a S_{11} (dB) of -10.49. There is a change in the S_{11} (dB) of the lower resonance; it may be due to the fabrication error of the antenna or else at the connector's end. The main task was to validate the design of the stacked patch antenna with the skew-F shaped DGS for the dual band operation. The measurement results show this validation. The S_{11} (dB) was measured by network analyzer HP8720B (130 MHz–18 GHz). The radiation pattern was measured in anechoic chamber. The standard horn antenna (900 MHz–8 GHz) was used as a transmitter, and the fabricated antenna was kept in the receiver position. The distance between the transmitter and receiver was kept 1.5 meter, and the transmitted power level was kept at 15 dBm. Both the E and H-plane patterns for both frequencies (3.15 GHz and 4.47 GHz) were measured and shown in Figures 8(a)–(b), respectively.

Figure 9(a) shows the fabricated antenna. Both the dielectrics used as the substrate and superstate are the same. The F-shaped slot is shown in the ground plane of the antenna (Figure 9(b)). The

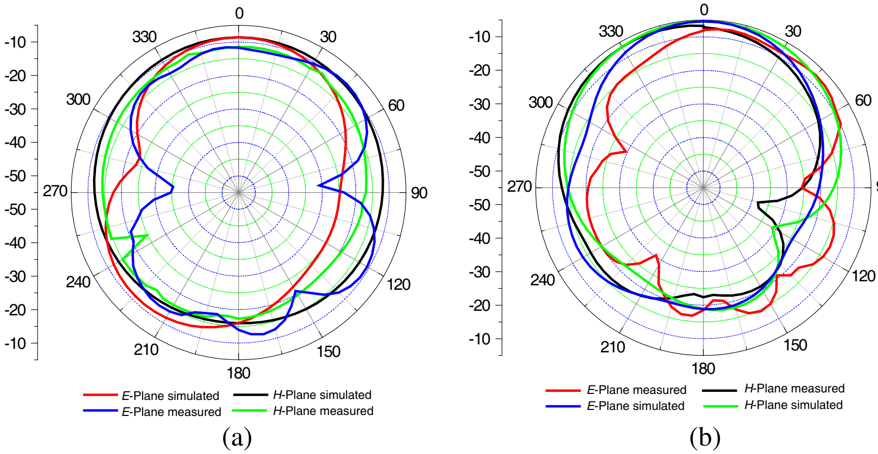
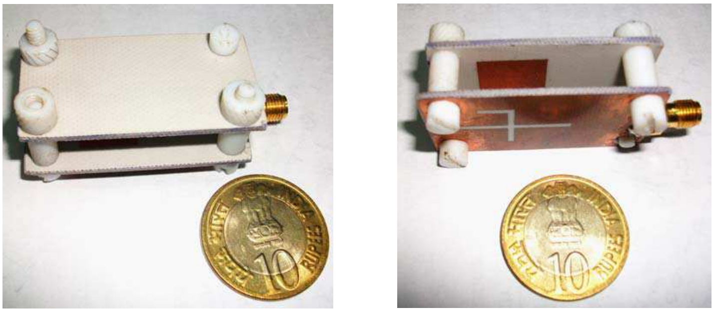
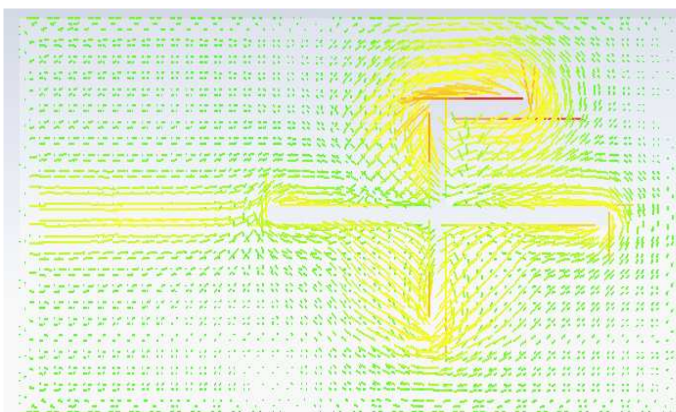


Figure 8. Dual band antenna radiation pattern. (a) 3.15 GHz frequency. (b) 4.47 GHz frequencies.

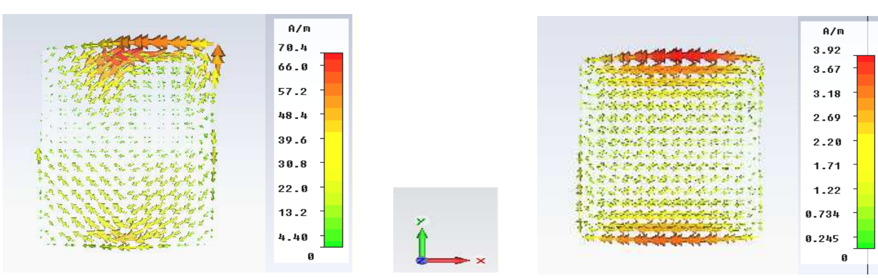


(a) (b)

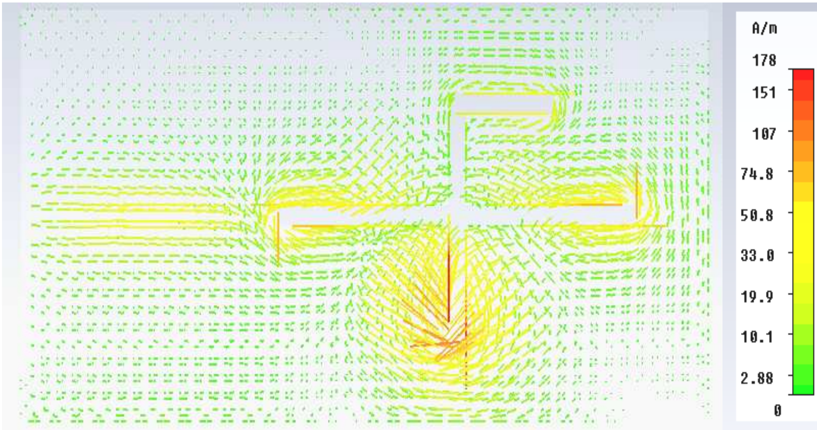
Figure 9. Fabricated antenna using Neltec NH9338 as substrate. (a) Side view. (b) F-slot in ground plane.



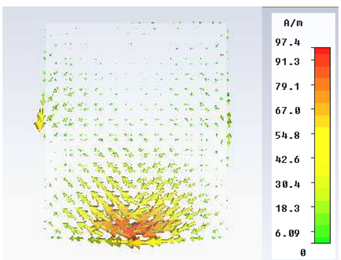
(a)

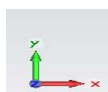


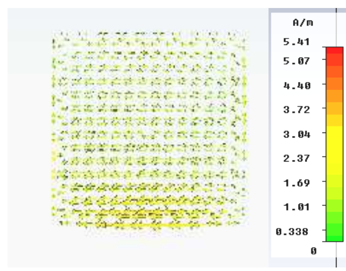
(b) (c)



(d)







(e) (f)

Figure 10. Current distribution at 3.15 band and 4.47 GHz. (a) Ground plane at 3.15 GHz, (b) lower patch at 3.15 GHz, (c) upper patch at 3.15 GHz, (d) ground Plane at 4.47 GHz, (e) lower patch at 4.47 GHz, (f) upper patch at 4.47 GHz.

measured radiation pattern was found in good agreement with the simulated ones. The current distribution for both the frequencies in each part (ground plane, lower patch and upper patch) has been shown in Figures 10(a)–(f). As seen from Figures 10(a) and (d) the current paths are different for the two frequencies, which is useful for finding the lower and upper resonances. As for the lower frequency (3.15 GHz), the current path is larger than the upper one (4.47 GHz) in the ground plane.

Due to the skew-F shaped DGS, the higher current density is on the upper part of the F which makes a long electrical path ($K2/2 + K1 + K1 + K2/2$), and similarly for the higher frequency the current path is smaller ($K2/2 + K2/2$) as compared to the lower

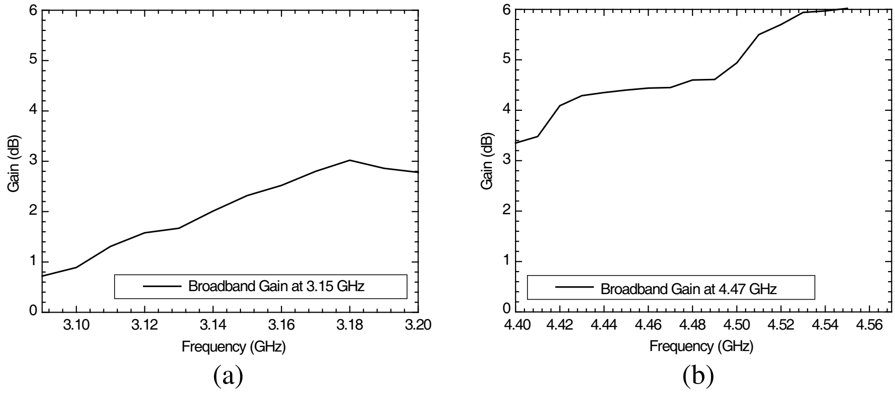


Figure 11. Measured gain (a) 3.15 GHz, and (b) 4.47 GHz.

frequency (Figure 10(d)). The current distribution on the lower patch for both the frequencies is shown in Figures 10(a)–(f). It is also seen that there is no more effect on the upper patches for both the frequencies only in term of the current path, but in terms of the current density, the lower frequency has more effect than the upper frequency.

The antenna gain has also been measured in the anechoic chamber with the reference antenna (900 MHz–8 GHz), having the gain specification as 18 dB and 20.2 dB for the frequencies 3.15 GHz and 4.47 GHz, respectively. Figure 11 shows the broadband measured gain at different frequencies around 3.15 and 4.47 GHz. The simulated gain at 3.15 GHz was found 2.35 dB which is close to the measured gain at the same frequency, and for the 4.47 GHz band, the simulated and measured gains were calculated as 4.45 and 4.35 dB, respectively (Figures 11(a)–(b)), which shows the good approximation between the theoretical and measured results.

5. CONCLUSION AND OUTLOOK

A novel study on the modified broadband stacked patch antenna with different DGS structures has been carried out in detail. The simulated results in terms of the S_{11} (dB) and the radiation patterns have been compared with the measurement results. Specific modified stacked patch antenna with broadband application has been partitioned in dual band frequencies due to the single skew-F shaped defect which was created in the ground plane of the antenna, along with the size reduction. This property of the F-shaped DGS can be used in the future antennas for getting multiband operation as well as for antenna miniaturization.

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