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Novel Structure Design of Micro Strip Patch Antenna Loaded with Slot and DGS Technique for Wideband Applications

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Abstract: - This paper focused on dual band Micro strip Patch Antenna Using Slots and Defective Ground Structure (DGS) to achieve moderate gain and wide bandwidth. The multiple octagonal patches are integrated using slots in a top layer. The proposed antenna dimensions are 35mm width, 45 mm length and 1.6mm height. Analyzed various iterations, observed that the best results are achieved using slot and DGS technique for this proposed novel design structure. The antenna resonates at 11.40GHz and 13.16GHz with return loss of -20.7dB and -25.83dB respectively. Voltage standing wave ratio (VSWR) 1.20 and 1.10, peak gain (G) is achieved 4.13dB at 11.40GHz and 5.15dB at 13.16GHz. Maximum directivity notify 4.13 at 11.40GHz and 4.22 at 13.16GHz. The proposed antenna is very good applicant for wideband applications.

Keywords: Defective Ground Structure (DGS), Micro strip Patch, Slots, return loss and wide band.

I. INTRODUCTION

In present scenario, wireless communication technology focuses on the construction of an antenna of compact size, light weight and large coverage areas in various telecommunications sectors [1]. The Federal Communications Commission's (FCC) 2002 approval of the UWB frequency range of 3.1GHz to 10.6GHz generated a lot of interest in the antenna sector [2]. Due of UWB technology's ability to transmit data at fast speeds, researchers are now investigating antenna for a range of uses, including imaging, wireless communication, and location tracking [3].The frequency range for the antenna is 3 GHz to 7.5 GHz. The circuit of a rectangular shaped patch antenna with lumped element topology was modeled by Ghorbani et al. [4], who did not attempt to reach higher resonances but instead provided a good fit for the first resonance at about 1 GHz.

In the past, several types of antennas are designed such as Yagi-Uda antenna, helical antenna, horn antenna, planar array antenna etc., Antenna is an important element in wireless communication systems. The performance characteristics of micro strip antenna [5-7] can be improved by using different techniques. The compactness and range of frequencies of the micro strip antenna can be enhanced by introducing slots and defective ground structure in its design.

Micro strip Antennas with Slot and DGS are good applicants for the applications where circular polarization, small size and wide range of frequencies are required. Micro strip antenna's negative aspects: it has low capacity, low performance, narrow bandwidth and low coverage area. These limitations can be overcome by designed antenna reported in [8]. The micro strip antenna comprising of multiple octagonal shaped integrated patches as a copper material with the help of slots [9] i.e., front, back, left side and right side because energy distributed over all octagon patches from the feed.

The RF power is fed directly to the multiple octagons patches which are integrated with slot technique. Integrating slots are used to distribute the power to all octagonal patches. Accordingly total top area of the patch and more energy will be concentrating on edges of the patches. The DGS [10] technique is also implemented for the antenna design to enhance gain and bandwidth [11]. The antenna construction is easy to design, simulate, and fabricate thanks to its basic structure and compact planar design. With slots added to the ground plane and micro strip patch, there is a greater chance of achieving a low Q-factor for the effective bandwidth augmentation [12].

Investigating research on a range of antenna configurations, including T-, E-, S-, L-, F- and inverted F-shaped antennas as well as polygon shapes like the octagonal-structure compact sized micro strip patch antenna,for a range of S to X band applications including WLAN, GPS, GSM, mobile radio and wireless applications [13]. Studies have shown that the micro strip patch antenna's attractive profile, optimally acceptable performance and ease of manufacture allow it to function effectively in the Wi MAX (3.5 and 5.8GHz) and X-band (8-12GHz) frequencies [14].The Proposed antenna structure is more significant because of multiple octagons are integrated with slots which gives good return loss in dB, gain in dB and provide wider bandwidth using DGS technique.

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II. METHODOLOGY

In order to implement the novel design of micro strip patch antenna, various designs are implemented for better parametric analysis. Various design iterations are shown in below fig. (i) to (vi).

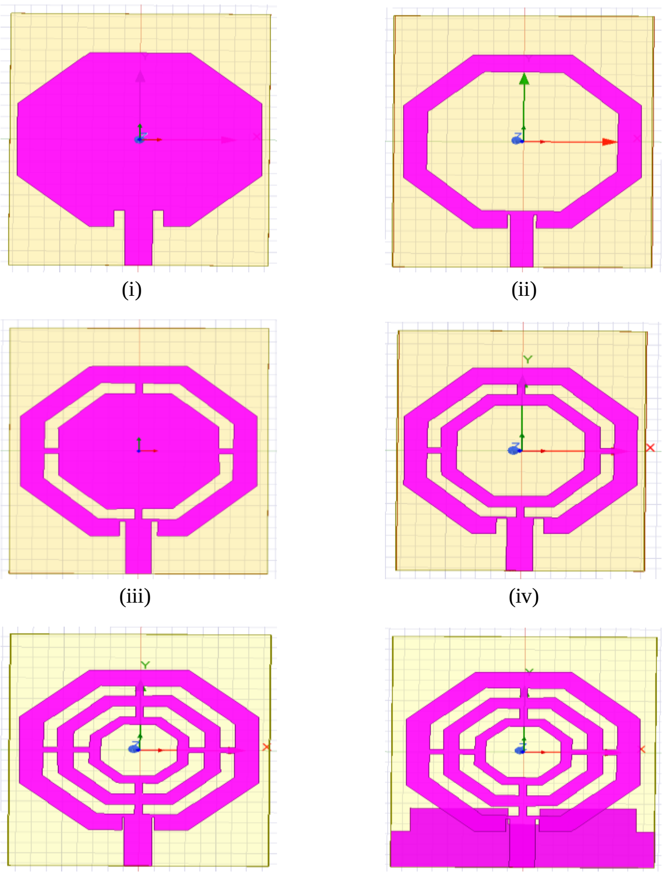

(i) (ii)
(iii) (iv)
(v) (vi)

Fig.1. (i) to (vi) various design iterations of Micro strip patch antenna

The algorithm and mathematical analysis explored to design proposed micro strip patch antenna.

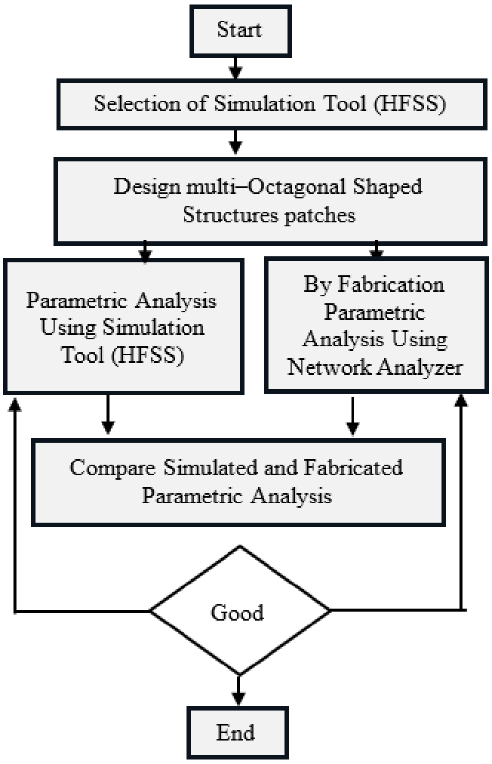


Fig.2. Step by step design procedure for proposed antenna

Step I. Effective dielectric constant

(ε_{eff}): $\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}}, \frac{h}{w} > 1$

Where
ε_{reff} = Effective dielectric constant
ε_r = Dielectric constant of substrate
h = Height of dielectric substrate
W = Width of the patch
The length of the antenna increases electrically because of fringing, so the increase in length is:

Step II. Effective length (L_{eff}): $L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}}$

Step III. Extension length (ΔL):

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

Step IV. Actual length of the micro strip patches (L): $L = L_{eff} - 2\Delta L$

The length 'L' is considered to determine the radiating frequency of the projected patch antenna. Owing to the fringing field the actual length is bit large and L is considered less than half the dielectric wavelength. The antenna performance characteristics are analyzed with the proposed design and fringing effect.

Step V. The formula to calculate the radiating frequency of the initial or basic octagonal shaped patch antenna is

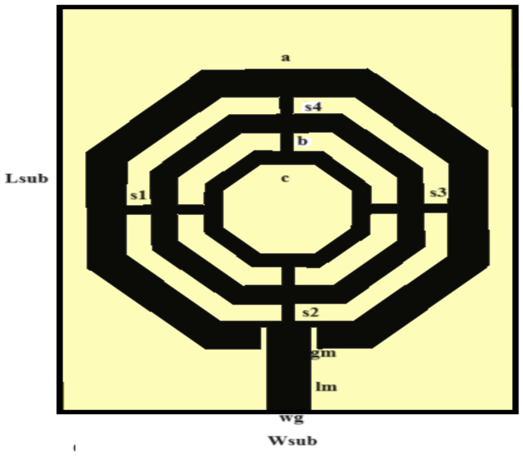
$$f_r = \frac{c}{2a\sqrt{3}}\frac{1}{\sqrt{\varepsilon_{eff}}}$$

Where
a = Side length of the octagonal Patch
c = Light velocity
ε_{eff} = Effective dielectric constant

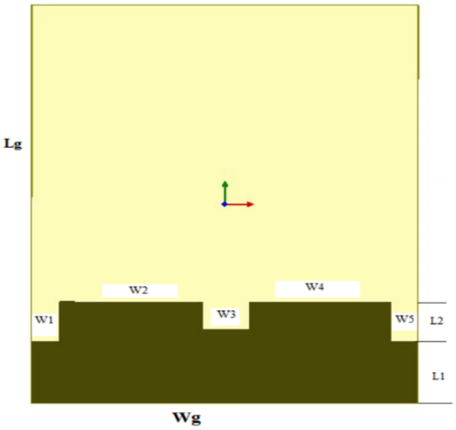
The aforementioned procedure is essential to design micro strip patch antenna, accordingly each design iterations of patch antenna is simulated using HFSS antenna design tool and analyzes parameters or characteristics of the antenna. It is observed that the design iteration (vi) has harvested best parametric results when compared with other design iterations.

III. ANTENNA CONFIGURATION

The proposed antenna comprising of multiple octagonal patches are integrated with slots and DGS technique. This is designed to resonate at dual band i.e., 11.40GHz and 13.16GHz respectively. The Fig.3 (a) & (b) projects the simulated antenna top and bottom views Fig.4. (c) & (d) shows the fabricated antenna top and bottom views of the projected antenna with perfect impedance matching between the multiple octagonal patches with the micro strip line and bottom Plane.



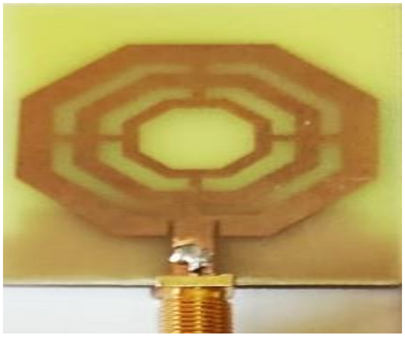
(i) Top View



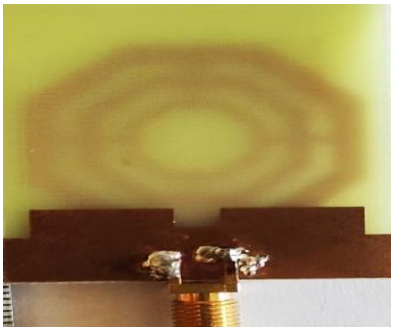
(ii) Bottom View

Fig.3. Geometry of Simulated antenna

In the proposed design slots are play key role to integrate multiple octagonal patches to improve the gain of the antenna. DGS permits voids, patches and other ground plane omissions. The shape and dimensions of the flaws were deliberately chosen to reduce some resonances. The effective permittivity of the substrate inside the antenna element can be significantly altered using DGS.



(i) Top View



(ii) Bottom View

Fig.4. Fabricated antenna

Table1 1: Parametric dimensions (in mm) of the antenna

Parameter	Dimensions(mm)
W_{sub}	35
L_{sub}	45
W_g	35
L_g	45
$S_1=S_2=S_3=S_4$	1
a	12.86
b	7.03
c	2.32
W_1	13

Parameter	Dimensions(mm)
W_2	12.8
W_3	4.2
W_4	2.5
W_5	2.5
L_1	4.5
L_2	4.5
w_f	3.4
gm	0.5
h	1.6
lm	9.6

The dielectric constant influences the electromagnetic waves phase velocity. DGS affects the phase velocity of waves moving through the substrate by altering the dielectric characteristics. Impedance mismatches are reduced, and bandwidth is increased, as a result. The DGS primarily modifies the electrical length of the antenna by acting as a distributed capacitive or inductive loading.

By using DGS techniques such as impedance matching networks and antenna geometry design, this antenna design reduces the reflection coefficient and controls the reflection coefficient's phase within the desired frequency range. With strong impedance matching, this leads to wideband functioning. In the designated frequency range, this guarantees that the antenna is well-matched and effective. Often, a low VSWR for a wideband antenna is required to minimize reflections and good performance over a broad frequency range. This requires innovative design structures and impedance matching techniques.

The various directions in three-dimensional space where a wideband antenna transmits electro magnetic energy are described by its radiation pattern. It provides significant information about the antenna's gain, directivity, and other directional characteristics throughout a range of frequencies within its bandwidth. It indicates that they radiate energy uniformly and perpendicular to the axis of the antenna in all horizontal directions. Applications that require coverage in all directions frequently employ these antennas.

To ensure that the wideband octagonal patch antenna would perform as planned in real applications, simulation and measurement data are compared with DGS. Any discrepancies should be properly studied and corrected in order to enhance the antenna's design and performance. Since there is frequently a trade-off between gain and bandwidth in wideband antenna design, it can be challenging to strike the right balance between bandwidth enhancement and gain.

A wide range of frequencies can be used in wideband antennas. As a result, the proposed octagonal patch antenna is employed for wideband operations, particularly in the X band and Ku band.

IV. RESULTS AND DISCUSSION

Designed various design iterations of micro strip patch antenna analyze the parameters.

A. Return Loss

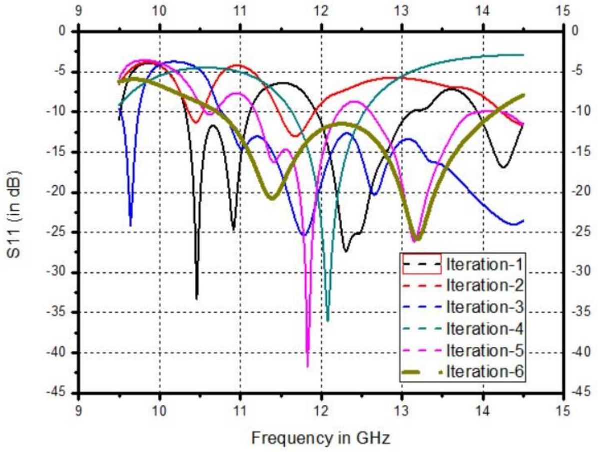


Fig.5. Return loss Plot

The above diagram shows the return loss of design iterations of the micro strip patch antenna. Comparatively all the iterations, iteration 5 having very good return loss approximately -43dB but bandwidth is very low, where as iteration 6 having wideband.

B. VSWR

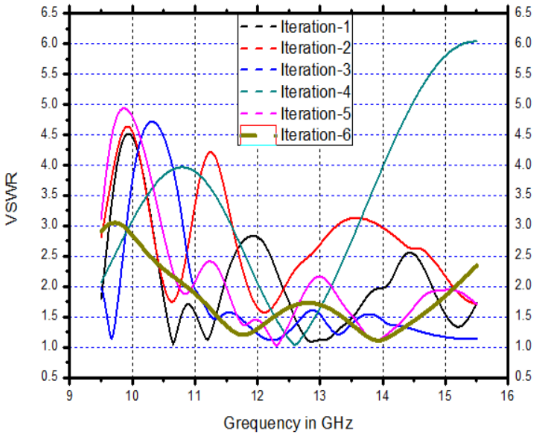


Fig.6. VSWR Plot

From the above VSWR analysis plot iteration 1, 2, 4 and 6 having very less VSWR value as compared with iteration 3 and 5.

C. Gain

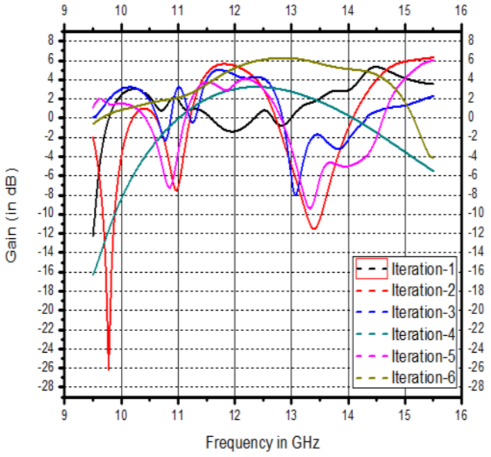


Fig.7. Gain Plot

Gain is an important parameter; it indicates the radiation ability of the antenna. Fig.7 shows the projected gain of various design iterations of the micro strip patch antenna. It shows that design iteration 6 harvesting Peak gain compared with other iterations.

D. Directivity

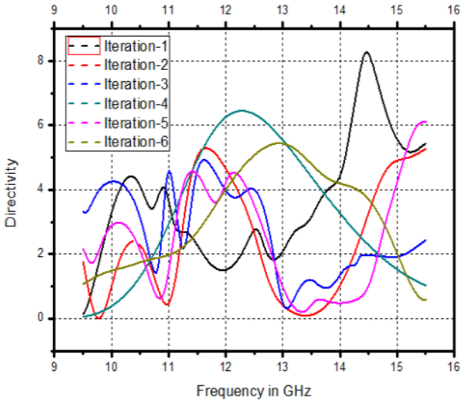


Fig.8. Directivity Plot

Directivity is defined as maximum gain of the antenna; it indicates the directional radiation ability of the antenna. Fig.8 shows the projected directivity of various design iterations of the micro strip patch antenna. It shows that design iterations 1 and 3 are having high directivity but low bandwidth whereas design iteration 6 which is proposed antenna provides wide bandwidth with good directivity.

E. Bandwidth

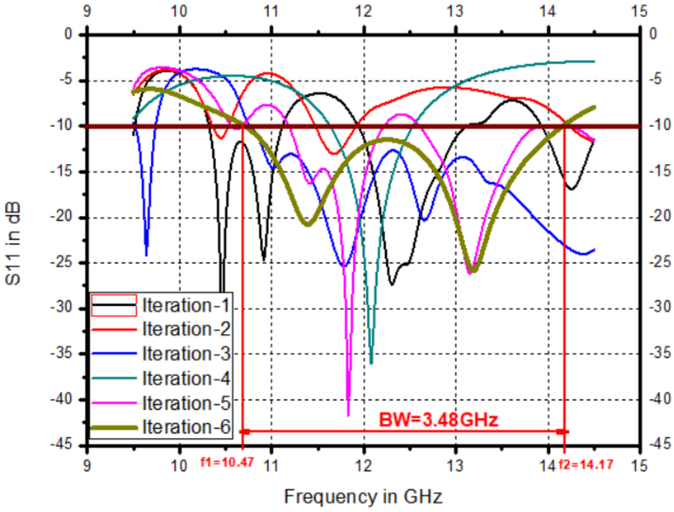
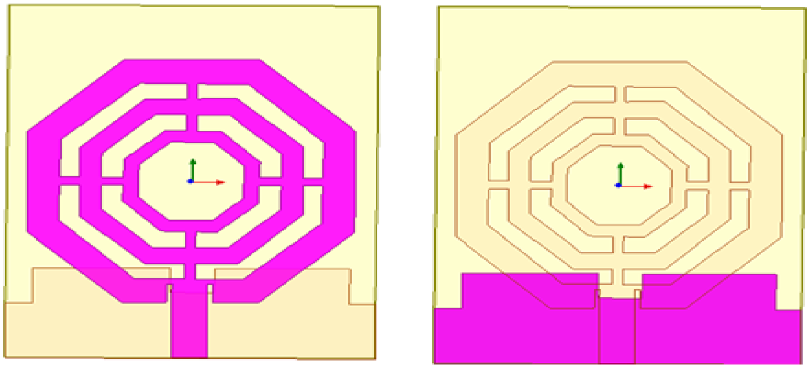


Fig.9. Directivity Plot

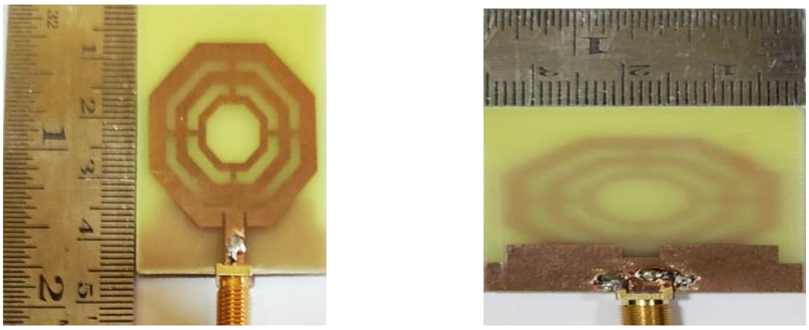
Bandwidth is calculated based on upper cut-off and lower cut-off frequencies to the below -10dB line from the return loss graph. Fig.10 shows that bandwidth plot clearly indicates that design iteration 6 harvested maximum bandwidth compared with other design iterations.



(i) Top View (ii) Bottom View

Fig.10. Simulated antenna top and bottom view

The simulated and fabricated proposed antenna’s top and bottom views are shown below Fig.10 and 11 with dimensions 45mm×35mm.



(i) Top View (ii) Bottom view

Fig.11. Fabricated Antenna (45mm×35mm)

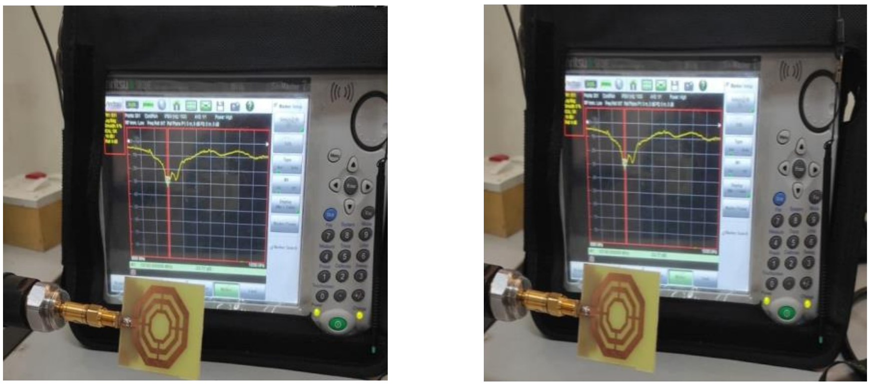
The proposed antenna with slots and DGS designed in 5th iteration provides better results compared to the antennas designed in iteration 1, iteration 2, iteration 3 and iteration 4.

Table 2: Comparative analysis with various design Iterations

Design Iteration	Radiating Frequency (GHz)	Return loss (dB)	VSWR	Peak Gain (dB)	Band width (GHz)
1	10.7,11.2, 12.9& 15.2	-20.8 -24.6 -26.8 & -16.9	1.2 1.12 1.12 & 1.3	0.7 0.8 -0.5 & 3.8	0.97 & 1.40
2	10.14 & 11.62	-11.28 & -13.0	1.75 & 1.57	-0.4 & 5.5	0.21 & 0.54
3	9.15 & 11.72	-22 & -25.3	1.17 1.14	1.3 & 4.17	0.30 & 1.87
4	11.86 & 13.16	-33.4 & -30.2	1.04 & 1.06	3.4 & -4.9	0.96 & 1.12
5	11.82 &13.15	-41.7 & -26.2	1.01 & 1.10	3.95 & -4.9	1.03 & 1.25
6	11.40 & 13.16	-20.7 -25.8	1.20 & 1.10	4.5 & 5.15	3.48

From the table 2 it is clearly noticed that iteration 6 harvesting best results as compared with the remaining iterations. The proposed antenna resonates at two bands [15], [16] at 11.40 GHz and 13.16 GHz. It is providing return loss less than -10 dB over a broad range from 10.7 GHz to 14.17GHz, as it provides wider bandwidth [17].

Fig.12. represents the measurement setup of S11 parameter of the projected antenna.



(i) Top View (ii) Bottom View

Fig.12. S11 measurement setup of proposed antenna

The projected antenna radiating at two bands at 11.40GHz and 13.16GHz. It is providing return loss less than -10 dB over a broad range from 10.7GHz to14.1GHz. As it provides wider bandwidth, it can be used for wideband applications.

The simulated and measured results are aligned with each other.

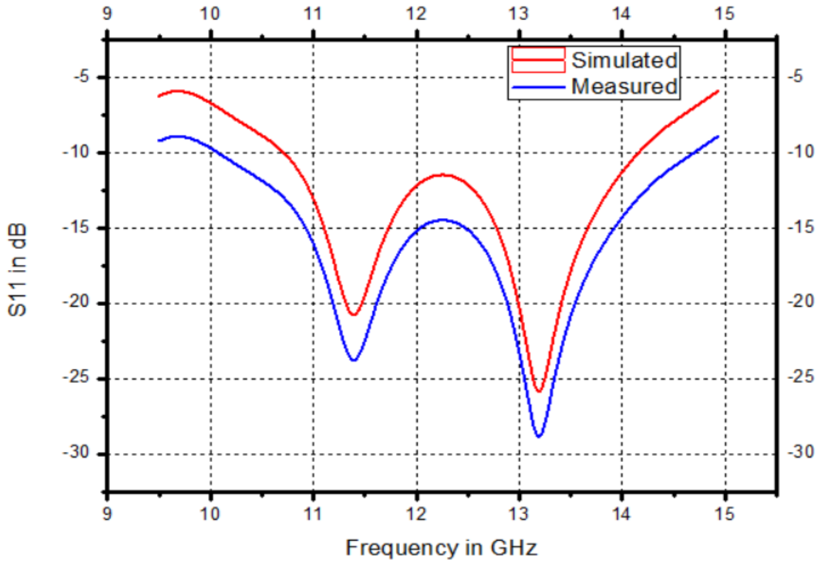


Fig.13. Return loss (S11) Plot for simulated and fabricated proposed antenna

The observed and estimated return loss of the antenna is shown in Figure 13. With the measured result showing its resonance frequencies moved slightly to the left, both results exhibit good resemblance. Following the first resonant frequency at 11.40 GHz with a return loss of -24.2 dB, the second resonant frequency at 13.16 GHz has a very satisfactory return loss of -28.6 dB.

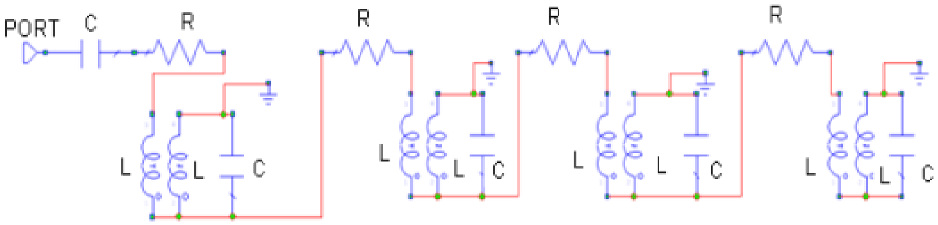


Fig.14. Equivalent circuit model for the projected antenna

To match the outcome of the simulated plot using Ansys HFSS in Fig. 13, the analogous circuit model in Fig. 14 is created using the circuit simulator software.

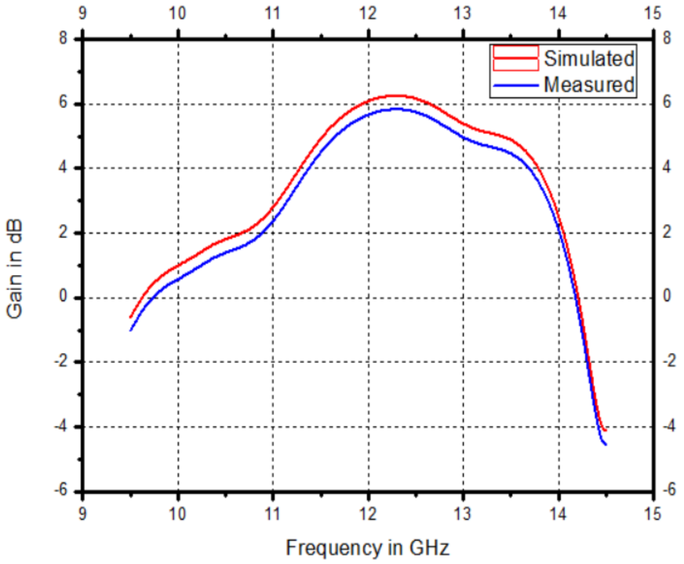


Fig.15. Gain Plot for simulated and fabricated projected antenna

The measured and simulated antenna gain is shown in Figure 15. The measured results, which indicate peak gains of 4.5 dB and 5.15 dB at the corresponding resonant frequencies, are in good agreement with both results.

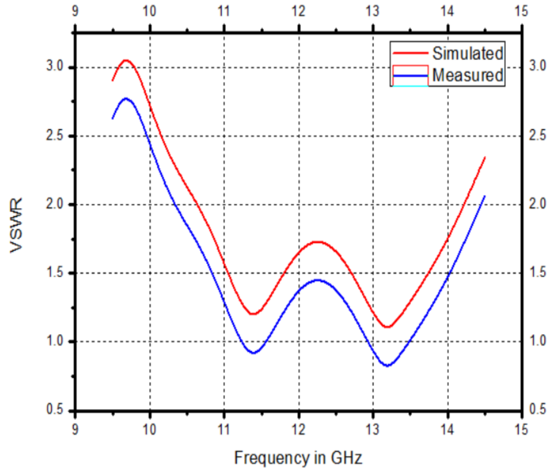


Fig.16. VSWR Plot for simulated and fabricated proposed antenna

The antenna's simulated and measured voltage standing wave ratio (VSWR) is shown in Figure 16. While the observed result displays a similar pattern from 10.4 GHz to 14.15 GHz, the simulated result indicates the range of VSWR between 1 and 2 over the frequency range from 10.5 GHz to 14.2 GHz. The VSWR range of 1 to 2 indicates the minimum return loss required for UWB characteristics, which is less than -10 dB across all operational frequencies. As can be shown in Fig. 13, the VSWR results so validate well with the return loss data.

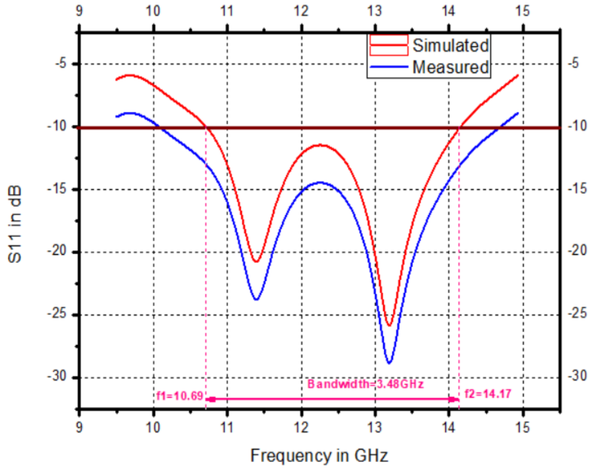


Fig.17. Bandwidth Plot for simulated and fabricated proposed antenna

The measured and simulated bandwidth of the antenna is shown in Figure 17. The computed result illustrates the frequency range from 10.5 GHz to 14.2 GHz, while the observed result displays a similar pattern from 10.4 GHz to 14.15 GHz. Consequently, the resultant bandwidth of 3.48GHz is verified for use in UWB applications.

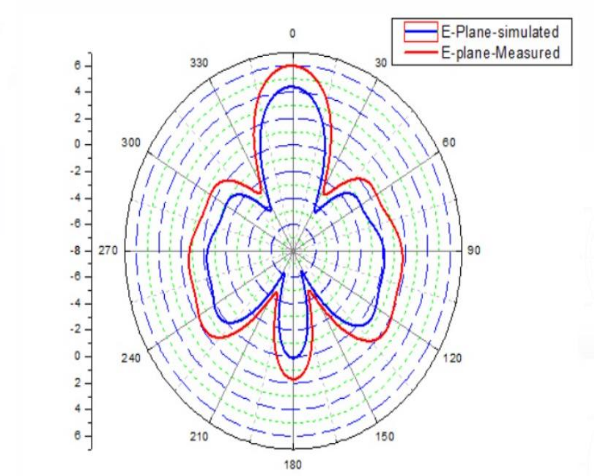


Fig.18. *E*-Plane pattern at 11.4GHz

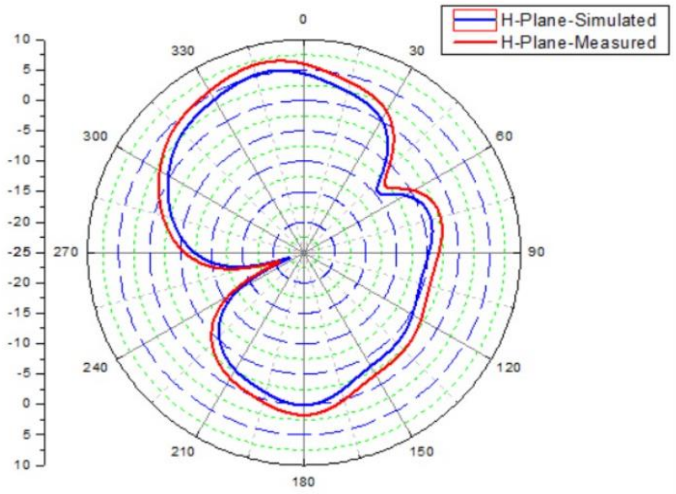


Fig.19. *H*-Plane pattern at 11.4GHz

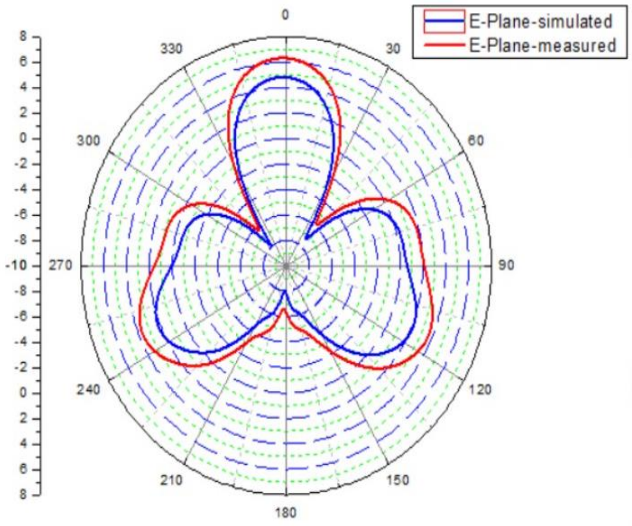


Fig.20. *E*-Plane pattern at 13.16GHz

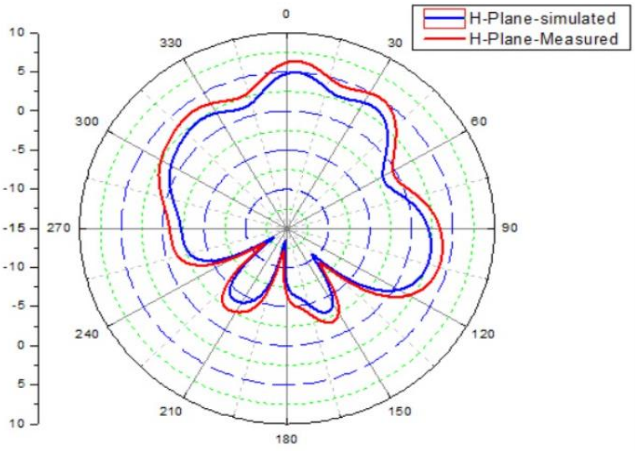
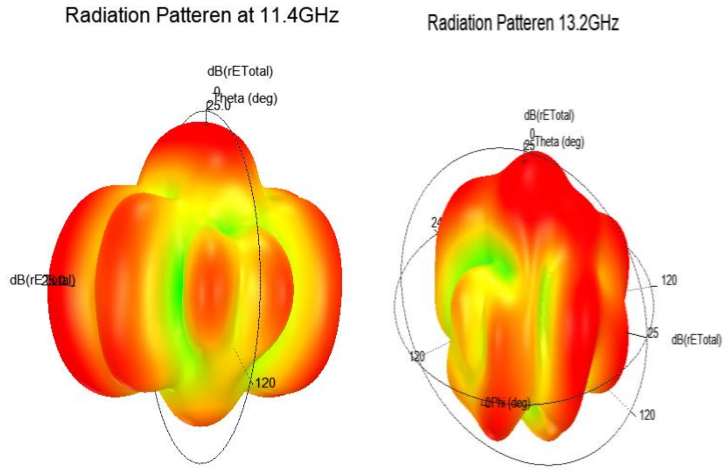


Fig.21. *H*-Plane pattern at 13.16GHz

The radiation patterns of the antenna are depicted in figures 18, 19, 20, and 21, respectively, in terms of the E- and H-planes. It is evident from figures 17 and 19 that the antenna exhibits a directional pattern, with the focus being on the patch antenna's sides. The patterns show omni directional patterns across the frequency as of the H-plane.


Radiation Patteren at 11.4GHz

Radiation Patteren 13.2GHz

Fig. 22. Radiation Pattern 3D Plot

Figure 22 illustrates the three dimensional radiation patterns of projected antenna at respective resonating frequencies.

Table 3: Comparing Existing Antennas with Proposed Antenna

Ref.	Dimension of Antenna(L×W) mm^2	Resonant Frequency (GHz)	VSWR	Band width (GHz)
[18]	21.5x32	4.82 6.67	<2	1.85
[19]	30x30	2.41 2.47	NM	0.1
[20]	14.2x14.2	3.4 3.9	<2	0.5
[21]	48x48	3.30 3.97	NM	0.71
[22]	28.03x23.45	5.8	<2	0.86
[23]	110x110	5.18	<2	0.72
[24]	24.8x30	5.7	<2	0.32
[25]	24x24	3.7	NM	0.21
[26]	40x28	3.65	NM	0.7
[27]	27x27	12.94 19.04	<2	2.38 1.56
[28]	35x35	12.2	<2	0.95
[29]	25x35	16.43	NM	2.18
[30]	32x28	16.45	1.14	2.15
Proposed work	**45x35**	**11.4** **13.16**	**1.20** **1.10**	**3.48**

*NM-Not Mentioned

The projected antenna and existing antennas are compared in Table 3. Along with the slots, this Defective Ground Structure approach is used. The suggested antenna produced a maximum gain of 5.15dB and an impedance bandwidth of 3.48GHz. The antenna's resonant frequencies are 13.16 GHz and 11.40 GHz.

V. CONCLUSION

This design of micro strip line feed antenna with multiple octagonal-shaped patches integrated with slots and defective ground structure is successfully simulated and fabricated. The dual band characteristics are also achieved by introducing slots and DGS technique in the proposed antenna. The dual resonant bands: one is at 11.40 GHz and second one at 13.16 GHz observed with return loss of -20.7dB and -25.83dB respectively. The results show that 3.48GHz wider bandwidth the bands. Italso provides great levels of impedance matching and characteristics of radiation. Hence the designed antenna can be a good applicant for widerband, Radar and Satellite applications.

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