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A Dual- Band Microstrip Array Antenna with Defected Ground Structure

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Abstract :

This paper objective is to construct and analyse a dual-band inset-fed microstrip array antenna for 4.77 GHz and 5.09 GHz dual band frequency with a defective ground structure (DGS) plane. An inset-fed microstrip patch antenna array's ground plane could have H shaped slots etched out of it to permit operation in the second frequency band (4.77 GHz), which is a design concept. To achieve this goal,a wide parametric analysis is applied to select the placements of etched slots that have the desired impedance bandwidth, high gain in the desired bands, and mismatching in the undesirable bands. The proposed dual-band antenna that acts as a monopole-like antenna and it can be used for wireless communications.

Keywords: Inset fed microstrip patch antenna, Array antenna, Enhance Bandwidth, Defected Ground Structure

I. Introduction

Microstrip antennas have attracted a considerable attention in the reserach area of wireless technology due to their compact size, ease of fabrication, and versatility [1] in various frequency bands. These antennas are widely used in wireless communication systems including mobile devices, satellite communications, radar systems and many others. Dual-band models have emerged as a promising solution to meet the growing demand for multifunctional antennas operating in multiple frequency bands[2].

This study presents a dual-band microstrip chip array antennathat uses an insert feed mechanism and an innovative defect ground structure to improve its performance. Dual-band antennas are particularly advantageous in today's communications systems because they allow simultaneous operation in different frequency bands, which improves network throughput, spectrum efficiency and overall system flexibility [3]. The proposed antenna structure exploits both the power technology and the faulty ground structure [3], [4]. The input method optimizes input switching and impedance matching, ensuring efficient power transfer to the radio patch elements. In addition, the integration of the defective ground structure strategically prevents the propagation of surface waves and reduces their effect on the radiation characteristics of the antenna. This improves the gain, directivity and overall efficiency of the antenna [4].

This research work presents the design, analysis and simulation of a dual-band inset fed microstrip patch antenna array. The steps sections discuss the design aspects of the antenna, the basics of the input mechanism and the faulty ground structure, simulation methods, and comprehensive results that demonstrate the effectiveness of the antenna in achieving dual-frequency functionality. In addition, this paper discusses the possible applications and importance of this antenna in modern wireless communication systems, highlighting its contribution to the development of technology and meeting evolving communication needs.

1.1 Introduction to defected ground structure (DGS)

Defective ground structure (DGS) is a key element in the field of electromagnetic wave engineering, mainly used to manipulate the electromagnetic properties of microwave or printed circuit antennas and other microwave devices. This is an innovative way to adapt the ground electrical characteristics of microwave circuits [4], [5].

The basic concept of DGS involves adding carefully designed patterns or holes to the substrate of microstrip or other planar transmission line circuits. These patterns are strategically etched or loaded onto the substrate, creating a structured pattern with a specific geometry and size. The purpose of this structure is to influence the propagation of electromagnetic waves and the performance of an antenna or

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circuit[6]. DGS designs often include periodic arrays or non-periodic structures etched into the substrate to damp or amplify certain frequency components. By changing the electromagnetic environment in the vicinity of the antenna or circuit, DGS achieves several goals, such as improved bandwidth, reduced resonance frequency, better radiation characteristics and reduction of unwanted radiation or surface waves [7], [8].

Scientists and engineers use the versatility of DGS in various applications such as antennas, filters, connectors and other microwave components. Various geometric configurations such as slots, slits and additional shapes can be used to achieve the desired electromagnetic responses [9]. Through careful design and analysis, DGS is proving to be an invaluable technique for achieving optimal efficiency and effectiveness in modern microwave and RF circuits [10].

This research article structure is as follows. In Sec II, the proposed antenna design methodology for dual-band operation is presented together with a thorough parametric analysis. The simulation results are shown in Sec III and this section wraps up the paper.

II. Proposed antenna design

The equations for a one-band patch antenna are pre-owned to construct the dual-band inset fed microstrip patch antenna array, which is then based on modifying the geometry of the one-band antennas to obtain an necessary resonated frequency.

A. Antenna with a single-band microstrip technology.

The inset fed microstrip array antenna's shape for a single band operation is displayed. An substrate for the microstrip patch antenna is made of FR4 epoxy, measuring 116.624 by 98.607 milli meters in size, with a height of 1.6 milli meters, a dielectric constant of 4.4, and a loss tangent of 0.0009. For the center resonance frequency (fr) of 5 GHz, an antenna dimension and parameters of an inset-fed micropstrip single patch antenna can be determined as shown below equation (1). A rectangular patch antenna's width (W) is computed using.

$$W = \frac{v_0}{2f_r} \frac{2}{\varepsilon_r + 1} \qquad \text{-----------} \qquad (1)$$

where v0 is the velocity of light in free space. L is the length of the patch antenna.

$$L = L_{eff} - 2 \times L \qquad \text{------------} \qquad (2)$$

where L = extended length due to fringing fields, and Leff = effective length of patch antenna due to fringing field

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1+12h/w}}\right) \qquad (3)$$

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(\frac{8h}{w} + \frac{w}{4h}\right) & \text{for } \frac{w}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_{eff}}\,[w/h + 1.393 + 0.667\ln(w/h) + 1.444]} & \text{for } \frac{w}{h} \geq 1 \end{cases} \qquad (4)$$

$$v_p = \frac{V_0}{\sqrt{\varepsilon_{eff}}} \qquad (5)$$

For a given characteristic impedance Z0 and substrate relative permittivity (, the w/h ratio can be found as:

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$$\frac{w}{h}=\begin{cases}\dfrac{8e^{A}}{e^{2A}-2} & \text{for } w/h<2\\ \dfrac{2}{\pi}\left[B-1-\ln(2B-1)+\dfrac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1)+0.39-\dfrac{0.61}{\varepsilon_r}\right\}\right] & \text{for } w/h>2\end{cases} \quad (6)$$

Where,

$$A=\frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}}+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23+\frac{0.11}{\varepsilon_r}\right) \quad (7)$$

$$B=\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (8)$$

B. Microstrip Antenna Array

As shown in single element antenna calculation as same as array factor can be expressed with equation (9)

AF = e jξ0 + e jξ1 + e jξ2 + · · · + e jξN−1 (9)

where "ξm" refers to the phase of an inbound plane wave at an element location ("m" = 0, "1"), and "" refers to some point ("1" = 0). Therefore, the wave phase that arrives at element m is the phase that arrives at the origin of the wave.

Let's say that the path length of the wave to element m+1 is d cos m longer than the path length of element m+1 to element m. We can see that the phase "m + 1" precedes this phase "m" by Kd cos. Let's say we randomly set a reference point to "0" ("0" = 0) and write array factor1:

$$\begin{aligned} AF &= 1+e^{jkd\cos\theta}+e^{jk2d\cos\theta}+\cdots e^{jk(N-1)d\cos\theta}\\ &= \sum_{m=0}^{N-1} e^{jkmd\cos\theta} = \sum_{m=0}^{N-1} e^{jkm\frac{d}{N-1}\cos\theta} \end{aligned} \quad (10)$$

Then the final the expression for array factor becomes

$$AF=\sum_{m=0}^{N-1} e^{jm\psi} = 1+e^{j\psi}+e^{j2\psi}+\cdots+e^{j(N-1)\psi} \quad (11)$$

III. Measurements and Simulation Results

A. Single-Band Antenna

Figure 1(a) displays the single-band two patch antenna's return loss (measured in dB). The antenna and feed line are well-matched because the return loss at 4.99 GHz is -30.2 dB. At 5 GHz, the center frequency. Figure 5 displays the 3-D radiation pattern in a

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rectangle plot for the H-Plane (z = 90) and the E-Plane (z = 0) are the two planes of radiation pattern. The peak directive gain of only one -band microstrip antenna is 5 dB.

TABLE-I

Design specifications for a 5 GHz insert fed microstrip single patch antenna

Parameters	L_p	W_p	W_f	Lin	FEED GAP
Values(mm)	35.968	39.712	16.79	13.4	2.399
Parameters	Z0(L9)	L1/ W1	L2/ W2	L3/W3	HH
Values(mm)	50.2	10.3/ 4.93	18/ 2.866	16.2/ 1.404	10
Parameters	HW	HL	H1W	SL	SW
Values(mm)	2	5	1	12.5	12.5

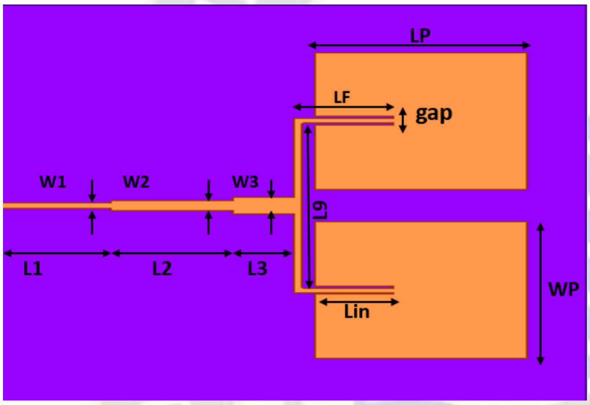

Fig.1(a)

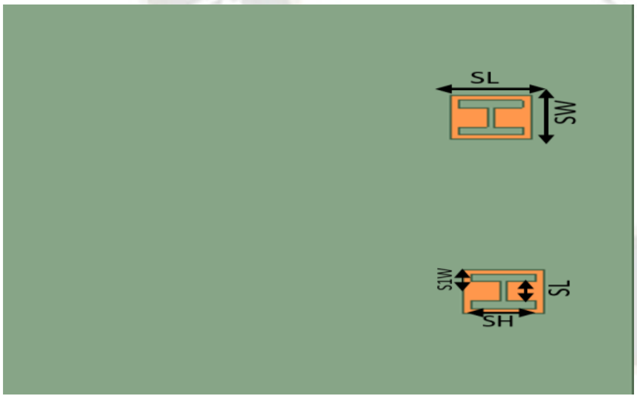

Fig.1(b)

Fig.1(a) (b) The stated rectangular microstrip radiator for 5GHz has the above geometry.

(a) A frontal view. (b) The back view.

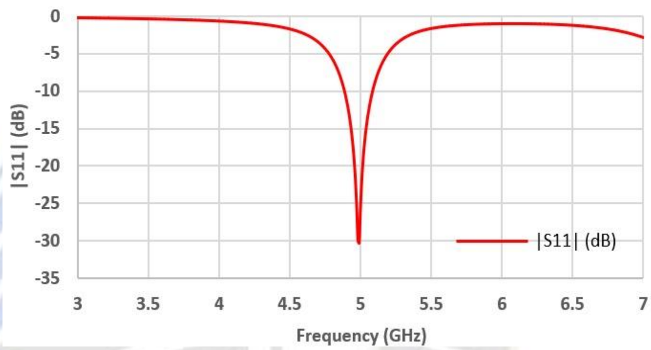

Fig. 3.2 Simulate result for return loss at 4.99 GHz is -30.2 dB.

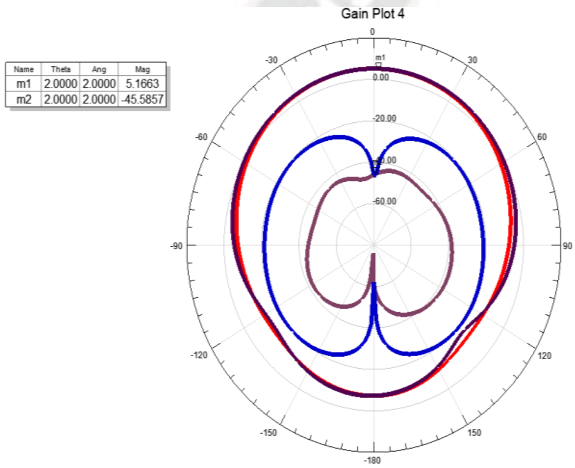

Fig.3 Simulated and experimental measured gain plot of 2 element array antenna

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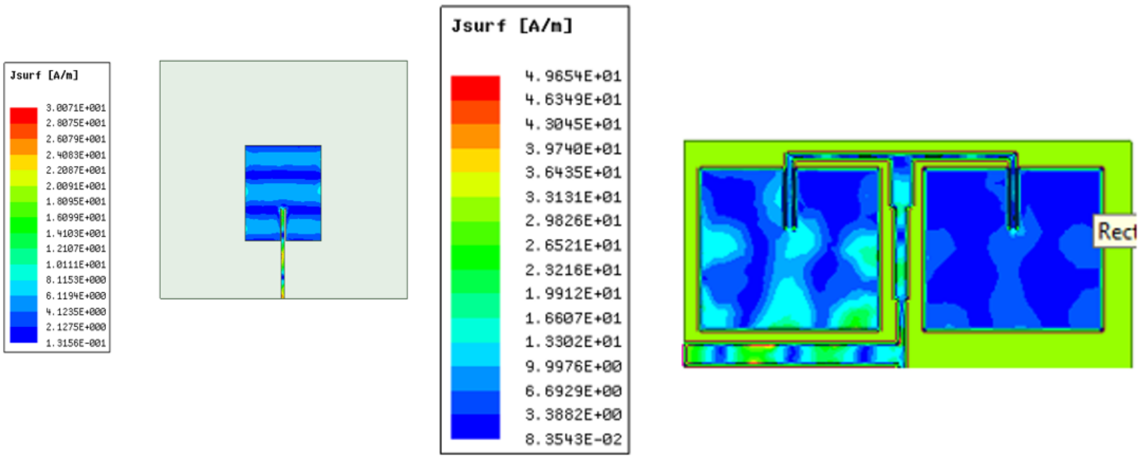


(a) (b)

Fig 4. Surface current of single and two element inset fed microstrip patch antenna

Then let us consider about total gain (in dB) for two element insert fed microstrip patch antenna, the maximum gain is 5dB with two different fields in radiation pattern. 3D gain plot shown as:

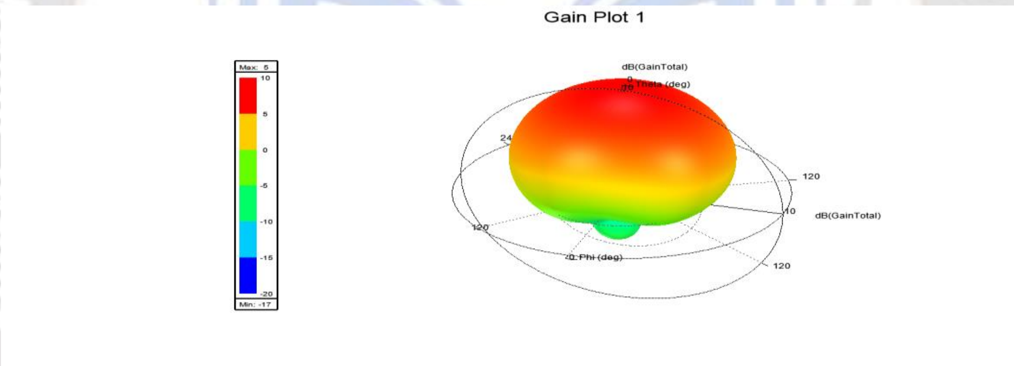


Fig. 5 3D gain pattern of two element inset fed microstrip patch antenna with minimum -17dB and maximum 5dB at center frequency 5GHz

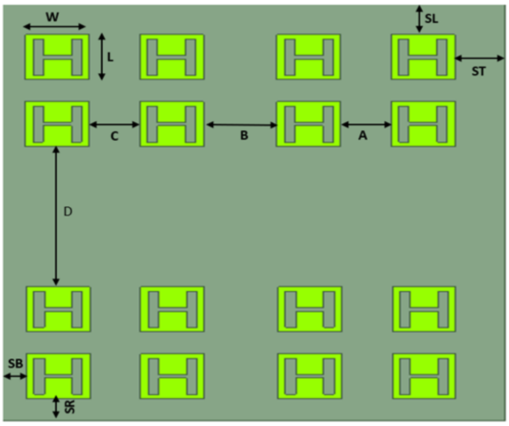
I. Dual -Band Array antenna

The proposed dual-band array antenna's return loss is (in dB) -30dB represented in Fig. 7.

TABLE-II

The stated dual-band microstrip array antenna design specifications

Parameters	L4	L5	L6	L7	L8	FW	W4	W5	S/S1
Values(mm)	9.729	48.64	20.674	10.662	18.911	4.93	4.93	2.866	9.6/29.86
Parameters	GP	GP1	W	L	A/C	B	D	SL/ST	SB/SR
Values(m)	1.2	1	12.5	12.5	9.2/9.2	14.4	36.26	5.5/4.8	4.8/4.8



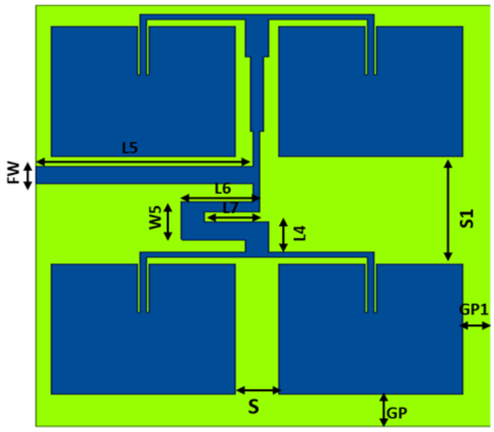


Fig. 6(a) Top view **Fig. 6(b)** Bottom view

Fig. 6 (a) (b) Geometry of the proposed microstrip array antenna for 5GHz

As it is seen, the stated antenna achieves large bandwidths in desired frequency bands while mismatching in the undesired frequency range of 4.5-5.2 GHz.

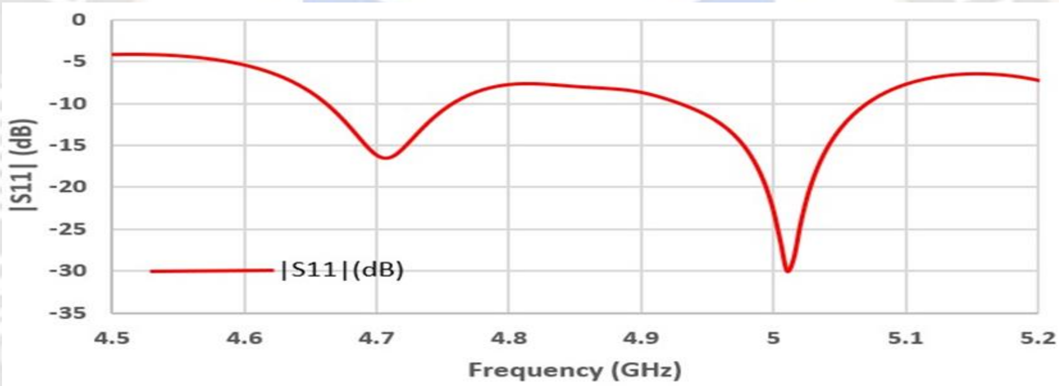
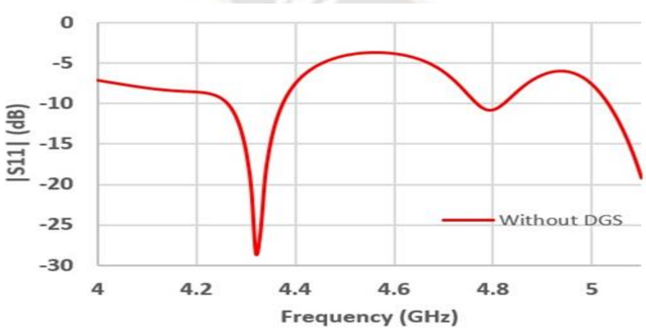


Fig.7 simulated return loss at 4.77 GHz is -17.2 dB and at 5.09 GHz is -30.01 dB

From fig 8(a) shows that radiator without DGS structure bandwidth is from 4.25 to 4.35 for operating frequency at 4.5GHz and fig 8(b) shows with DGS structure bandwidth is from 4.65 to 4.77 and 4.92 to 5.09 at operating frequency 5GHz.



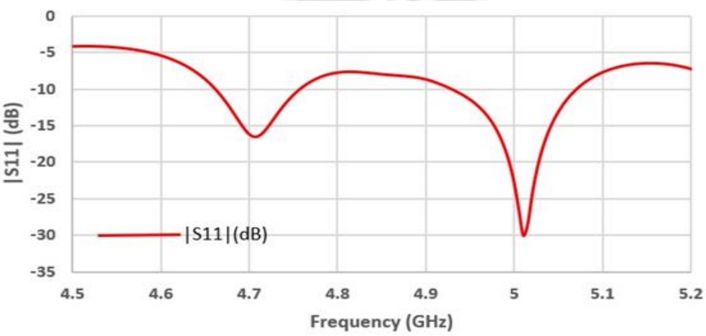


Fig. 8(a) **Fig. 8(b)**

Fig. 8(a, b) plot for S_{11} parameter (a) without DGS and (b) with DGS at resonating frequencies

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As a result, the receiver will pick up all of the frequencies in the useful bands while excluding unwanted signals from these undesirable frequency ranges.

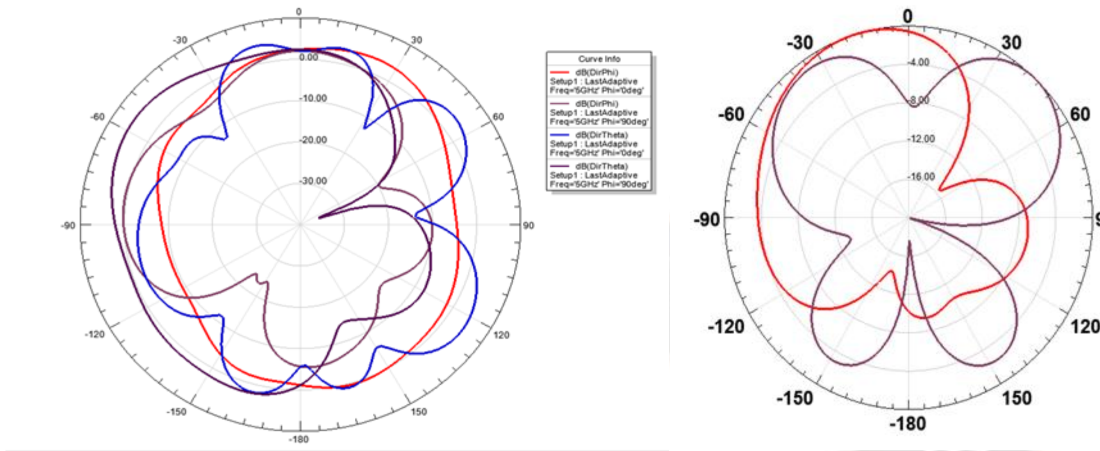

Fig. 9 3D gain pattern of inset fed microstrip patch array antenna with minimum -21dB and maximum 8dB at center frequency 5GHz

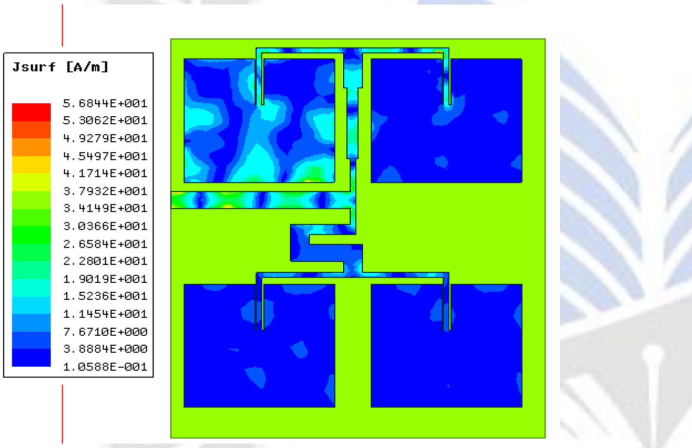

Fig.10 Surface current of 2x2 inset fed microstrip patch array antenna

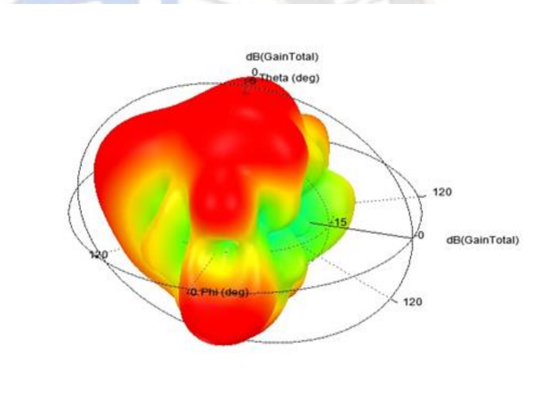

Fig. 11 Simulated and measured 3D Radiation plots of array antenna with-DGS

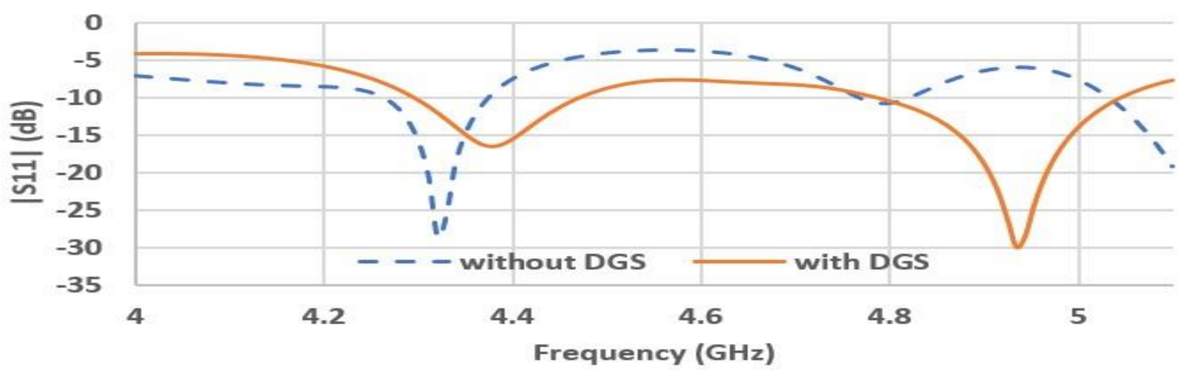

Fig. 12 Comparison of inset fed microstrip array antenna without DGS and with DGS in terms of impedance matching.

Comparing both with and without DGS ground slotted array antenna are operating at different frequencies with maximum return loss of -35dB. An inset fed microstrip array antenna without DGS ground slotted Bandwidth occurs 4.25 to 4.35 GHz at operating frequency of 5 GHz, by using DGS ground slotted Bandwidth occurs 4.65 and 4.77 to 4.92 and 5.09GHz at same operating frequency of 5GHz. Therefore the bandwidth has been enhanced by using DGS in the ground plane

Fig.13(a) **Fig. 13(b)**

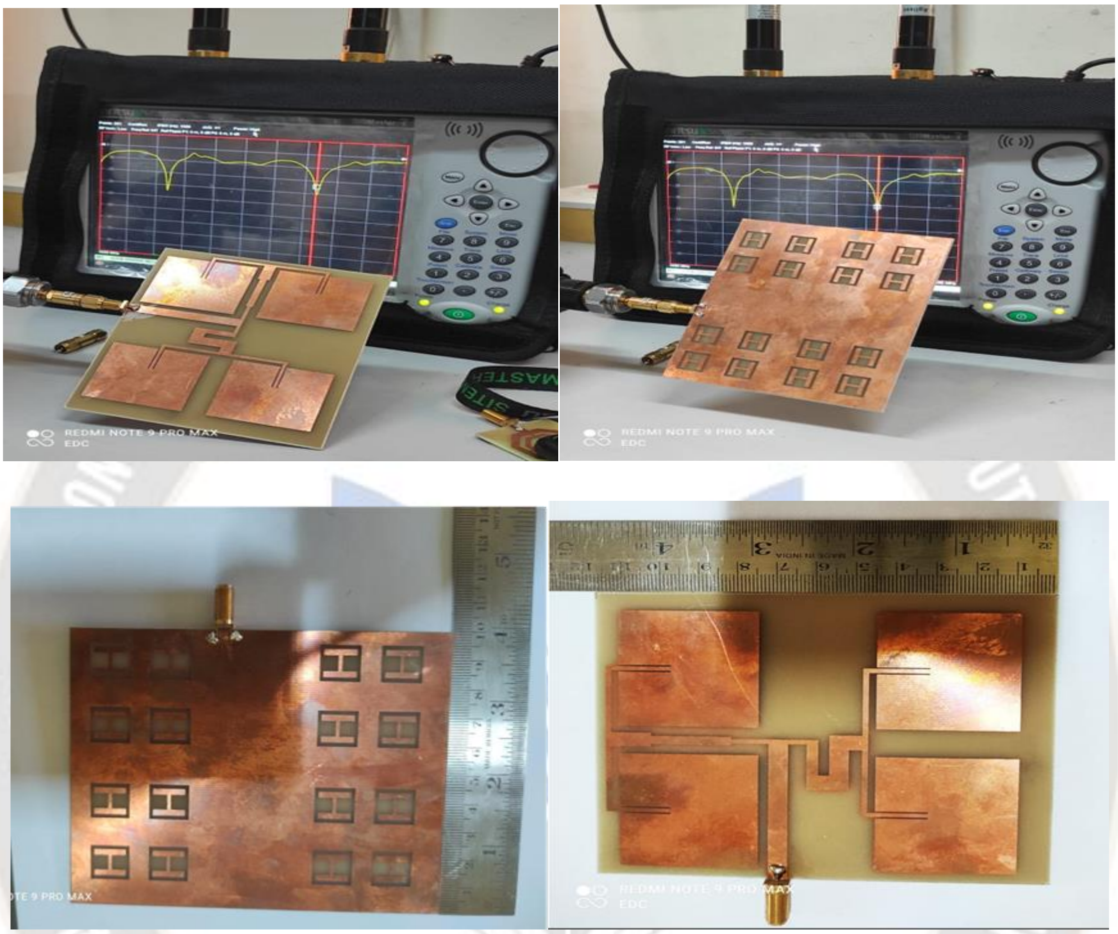

Fig.13(c) **Fig. 13(d)**

Fig. 13(a, b, c, d) Snapshot of fabricated antenna and tested with network analyzer

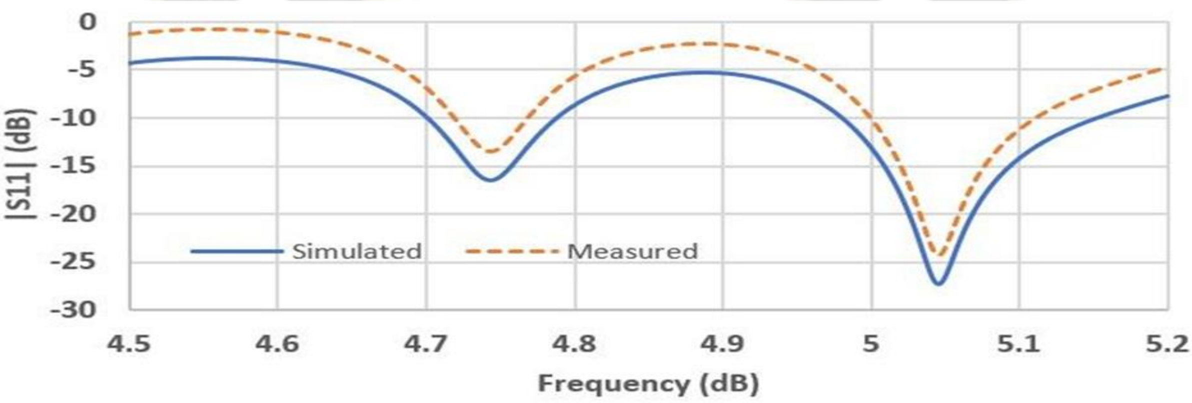

Fig. 14 Comparison of simulated and measured results of an Inset-fed microstrip array antenna with DGS

IV. Conclusion

For various wireless applications at 4.77GHz and 5.09GHz, a dual-band microstrip array antenna was designed and tested. The ground plane slots are etched to produce the dual-band resonance. To choose the appropriate slot sizes and placements, thorough parametric evaluations are conducted. The proposed antenna has a greater gain than previously reported antennas that employed the deficient ground plane approach.

To sum up, successfully designed and deployed a two band inset fed microstrip array antenna with a defect in ground structure. This new antenna configuration has many benefits, such as dual band operation and improved performance due to the integration of the DGS. The inset fed mechanism allows the antenna to work at two different frequency bands, making it flexible and adaptable to meet the needs of modern wireless communications systems. The careful design of DGS contributes significantly to the antenna's performance by reducing unwanted surface waves, improving impedance matching and radiation patterns, as well as improving overall antenna efficiency. The dual band operation and improvements in antenna characteristics enable this array antenna to be used in a variety of wireless applications such as RADAR, satellite communications and other communication & contributes significantly to the antenna's performance sensing devices.

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