

Optimizing Patch Antenna Performance Through Defected Ground Structure

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Abstract: The main objective of this work is to develop a microstrip patch antenna featuring a Defected Ground Structure (DGS) working at 2.45 GHz of ISM (Industrial, Scientific and Medical) band. It necessitates the use of a suitable substrate with a low dielectric constant to achieve minimal return loss. The antenna has been simulated using CST (Computer Simulation Technology) software, a 3D simulator, and was subsequently fabricated and tested. The measured results indicate a similar match with between the simulated and experimental values for Return Loss (-20dB) and Voltage Standing Wave Ratio (VSWR) of 1.21. Nevertheless, the experimental results confirmed that DGS structure has successfully improved the total effectiveness of the antenna.

Key words: Defected Ground Structure; Computer Simulation Technology; Gain; Microstrip patch antenna; Return Loss

1 Introduction:

Traditional microstrip patch antennas [1] have drawbacks like a single operational frequency, restricted bandwidth, poor gain, huge dimensions, and orientation difficulties. To address these restrictions [2], other techniques have been studied, such as Frequency Selective Surfaces (FSS), stacking, various feeding methods, Electromagnetic Band Gap (EBG) structures, Photonic Band Gap (PBG) structures, and metamaterials. Defected Ground Structure (DGS) is a popular technology due to its easy design. DGS [3] creates cut slots or faults on the ground layer of microstrip circuits. These issues, whether single or several, serve to attain specific qualities [4]. DGS was initially used in filters behind microstrip lines and is now widely used in numerous fields. However, its applications have grown dramatically.

This paper focuses the progress of DGS, covering its underlying concepts, and associated models for diverse shapes. In the realm of microstrip antennas, DGS [2] has been used to improve bandwidth and gain, eliminate higher mode harmonics and mutual coupling between surrounding components, and deal with cross-orientation issues, hence enhancing microstrip antenna features.

Goyal et al. [5] introduced a patch antenna design featuring a DGS structure resonating at frequencies of 1.9 GHz and 2.89 GHz, achieving less than -10dB of S_{11} with an FR4 substrate. The antenna's dimensions are 4.6 cm x 3.8 cm x 0.17 cm, yielding a gain of 3.16dB.

Amirudin Ibrahim et al. [6] devised a rectangular patch antenna for WIMAX applications, operating at resonance frequencies of 2.40 GHz, 3.50 GHz, and 5.80 GHz. The antenna employs an FR-4 substrate with a dielectric constant of 4.3, measuring 34×30×1.6 mm³. Simulation results indicate gains of 2.01 dBi, 2.9 dBi, and -3.3 dBi for the respective resonant frequencies.

Prashanth et al. [7] crafted a patch antenna with a DGS structure on an FR-4 substrate measuring 35×24×1.6 mm³, resonating at multiple frequencies for RADAR applications.

Arun Dev Dhar Dwivedi et al. [8] developed a patch antenna with DGS structure exhibiting dual band frequencies from 2.13GHz to 3.25 GHz and from 5.725GHz to 6.3084 GHz for WiMAX and WLAN applications respectively. The substrate utilized is FR4.

The aforementioned studies demonstrate the versatility of integrating Defected Ground Structures (DGS) into antenna designs, offering a flexible method to customize the electromagnetic environment surrounding the radiating element. Through targeted modifications to the ground plane, DGS effectively improves antenna performance by mitigating surface waves, minimizing mutual coupling, broadening bandwidth, and enhancing radiation characteristics. These functionalities make the significant value of DGS as a pivotal tool for optimizing antenna configurations across diverse applications.

The remaining sections are structures in the following manner : Section 2 and 3 delve into the antenna design and simulation. Section 4 focuses on the fabrication of the antenna and its subsequent measurement. Section 5 is focuses on the results obtained and facilitating discussions. Finally, Section 6 shows the conclusion drawn from the findings and outlines potential avenues for future research.

2. Antenna design

The substrate material used to design the patch antenna is felt. The felt material characteristics dielectric constant ϵ_r (1.45) and loss tangent $\tan\sigma$ (0.02).

The main advantage of selecting the felt material as a substrate is its flexibility. Furthermore, it is readily available in the market.

The flexible microstrip patch antenna is designed using a flexible substrate material known as "Felt." Felt [9] possesses a low dielectric constant, leading to reduced return loss. Copper is employed for both the ground plane and the patch, as well as the strip line. The antenna configuration involves fixing the felt sheet onto the copper ground plane, with a slot incorporated into the antenna structure to decrease its size and enhance gain. The patch and strip line, both composed of copper, are affixed to the felt substrate.

Utilizing standard equations for patch antennas, the parameters of the antenna structure are computed. The dimensions of the patch, which is square-shaped, are determined to be 39mm in length, 46mm in width, and 0.1mm in thickness. These calculated parameters are detailed in the table 1. Figure 1 illustrates the front and back views of the designed antenna design.

Table 1 Designed antenna dimension

Parameters	Dimension (mm)
Length of the patch	39
Substrate	60 × 60
Thickness of the Patch, ground plane and Strip line	0.1
Thickness of the Substrate	1

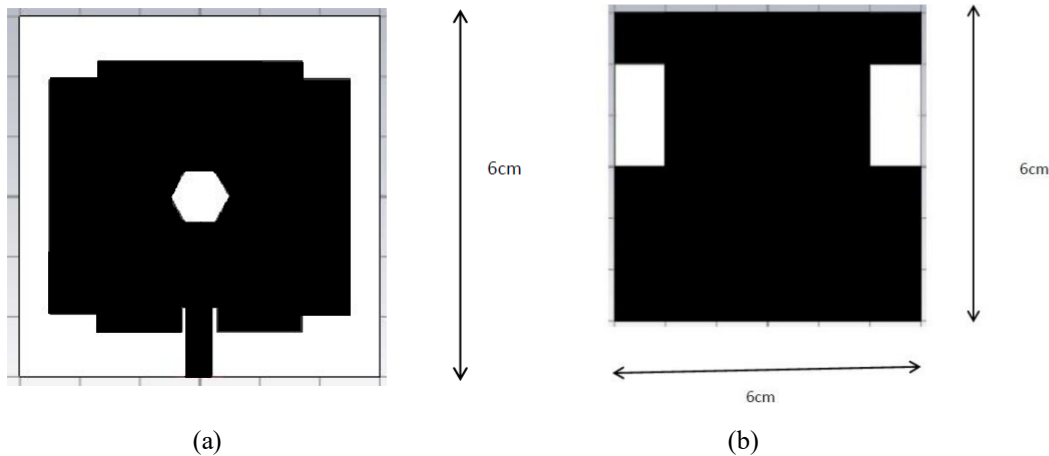


Fig.1. Antenna design - structure (a) Front view (b) Back view

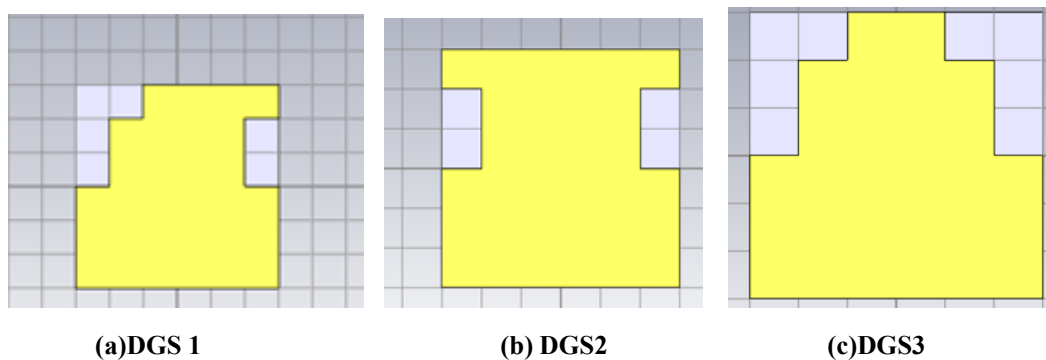


Fig.2. DGS designs in ground plane

3. Antenna Simulation

Firstly, the rectangular patch antenna was designed and carried out using CST software. [10].

With the rectangular patch, all the 3 structures of DGS were designed in ground plane and simulated as shown in figure 2. The results show that the rectangular patch with DGS 2 have better performance. Then the patch antenna design is modified for further improvement with DGS 2 structure in ground plane as depicted in Figure 3.

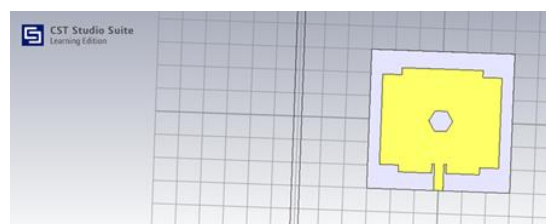


Fig.3. Proposed patch design

The modified patch antenna design with DGS 2 structure is simulated and the parameters are noted,

- **S-Parameters:**

S-Parameters, also referred to as Return Loss, delineate the input-output correlation between ports or terminals within an electrical system. Among these parameters, S11 holds particular significance in antenna

analysis. S11 quantifies the extent of power reflected from the antenna, earning it the designation of reflection coefficient or return loss. This parameter is typically expressed in decibels (dB).

The simulated value of S-Parameter is obtained as -27.3 dB in its operating frequency 2.617 GHz as projected in Figure 4.

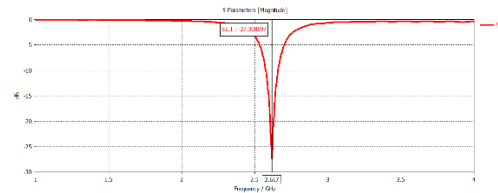


Fig.4. S-parameter measurement

• VSWR

VSWR, stands for Voltage Standing Wave Ratio, is a parameter dependent on the reflection coefficient, which characterizes the power reflected from an antenna. It is invariably a positive real number, with the lowest possible value being 1.0. Ideally, VSWR should remain below 2.0. The determination of VSWR entails measuring voltage along a transmission line connected to the antenna. It represents the ratio between the peak amplitude and the minimum amplitude of a standing wave.

The simulated value of VSWR is obtained is 1.09 in its operating frequency 2.617 GHz as shown in figure 5.

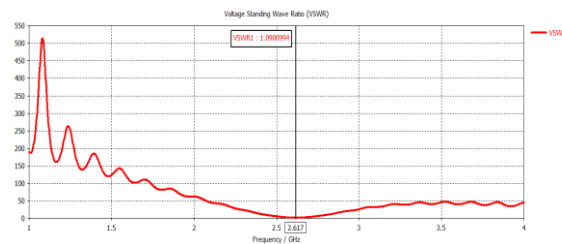


Fig.5. VSWR measurement

• Gain and Radiation pattern

The Gain and radiation properties of the designed patch was shown in figures 6 and 7 respectively. The obtained Gain is 6.2 dBi for the proposed antenna.

$$\text{Antenna Gain} = \text{Directivity} \times \text{Antenna Efficiency}$$

Gain is calculated as the multiplication of directivity and efficiency. Efficiency encompasses various losses in the antenna system, including manufacturing imperfections, surface coating losses, dielectric and resistance losses, VSWR, and other contributing factors. The directivity obtained is 6.59 dBi. Thus the efficiency (Gain/Directivity) computed is 94.08%.

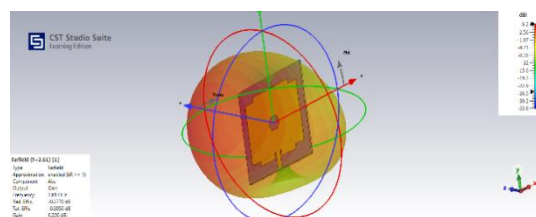


Fig.6. Gain measurement

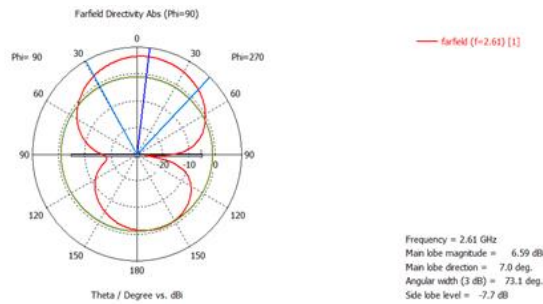


Fig.7. Radiation Pattern measurement

4 Fabrication and Measurement of Antenna

The antenna is fabricated using the calculated parameter and the material described. The proposed antenna is fabricated by using Photolithography method [11] as shown in figure 8.

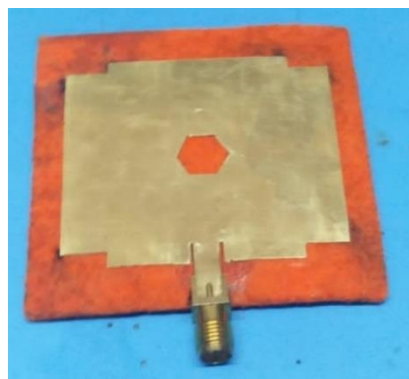


Fig.8a. Fabricated Antenna –Front View

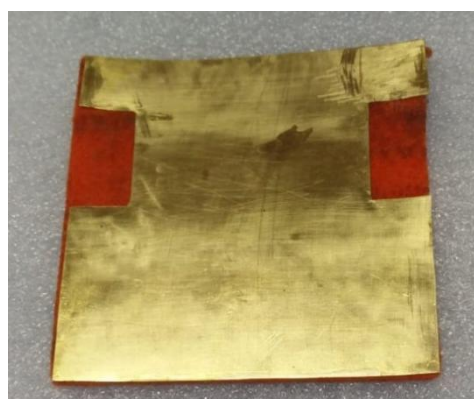


Fig.8b. Fabricated Antenna –Back View

The fabricated antenna is tested using VNA (Vector Network Analyzer) [12] as shown in figure 9 and the S_{11} and VSWR results were shown in figures 10 and 11 respectively.

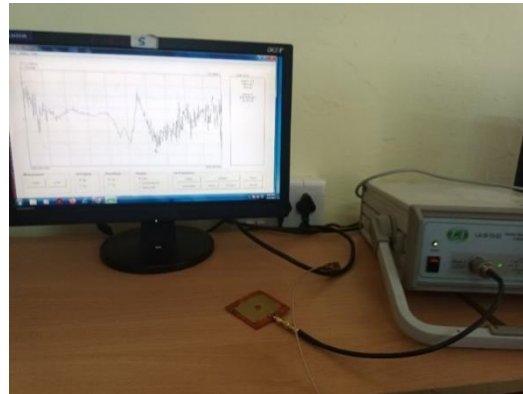


Fig.9. Antenna measurement using VNA

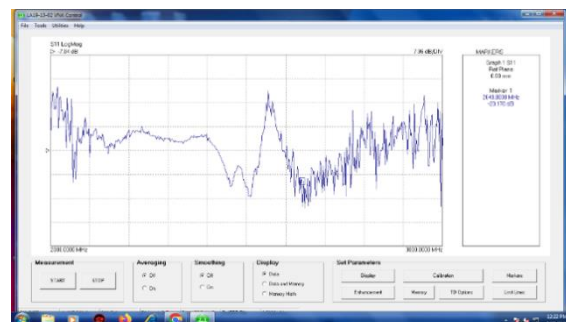


Fig.10.Return Loss measurement-Screenshot

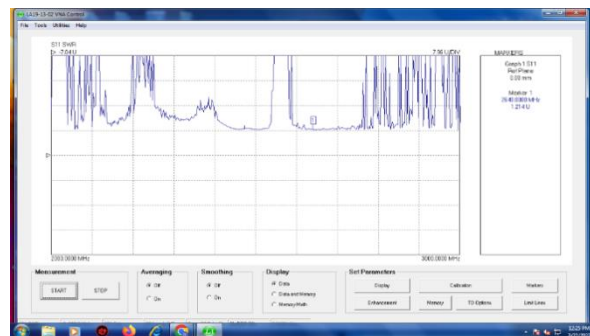


Fig.11. VSWR measurement-Screenshot

5 Results and Discussion

Table 2 Comparison of simulated and measured results of proposed antenna

Parameters	Proposed work		Work by Goyal et al. [5]
	Simulated value	Measured Value	Simulated value
Frequency (GHz)	2.61	2.61	2.89

Return loss S_{11} (dB)	-27	-20.1	-18
VSWR	1.09	1.21	3.41
Gain	6.2 dBi	-	3.16 dB

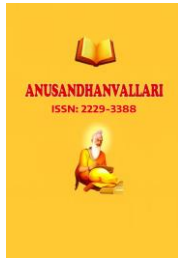
A comparison was made between the simulated and measured results of the proposed antenna with the work done by Goyal et al. [5] and tabulated in Table 2. From the comparison, the results shown that the antenna parameters are very well matched in both simulated and measured and the gain value (6.2dBi) in proposed work is very well higher value compared to that (3.16dB) of work by [5]. Thus the usage of felt substrate and the DGS structure means a lot for the patch antenna to act as a primary candidate to be applicable in wearable and modern communication system.

6 Conclusion and future work

The proposed antenna represents a pioneering approach of felt material as a flexible substrate integrated with a DGS structure for ISM band applications. The results show that the efficacy of this new material as a viable substrate option for flexible applications. Noteworthy attributes such as lightweight construction, extended durability, cost-effectiveness, and minimal environmental impact position it as a potential substitute for rigid substrate materials. The obtained results, including a S_{11} of -27 dB, VSWR of 1.09, and Gain of 6.2 dBi, validate its suitability for WLAN, wearable technology, and modern communication systems. Moreover, achieving an efficiency of 94.32% further reinforces its performance credentials. The readily available and affordable nature of the antenna substrate and patch material, coupled with their reliable operation, underscores their practicality. Experimental validation confirms the close alignment of measured results with simulated values, while affirming the beneficial impact of the DGS structure on overall antenna performance. Additionally, there exists potential for antenna miniaturization, bandwidth enhancement, and application in 5G networks.

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