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Full Length Article

Miniaturized microstrip antenna array using defected ground structure with enhanced performance

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A B S T R A C T

The aim of this work is to obtain a miniaturized microstrip patch antenna array using defected ground structure (DGS) for S band at 2.2 GHz. Initially the patch antenna array designed at C band resonates at 5.2 GHz. The proposed DGS is integrated in the ground plane of the patch antenna array for size reduction. However, this miniaturization is at the cost of gain of the antenna. In order to improve the gain of this miniaturized radiator, the patch radiator is further modified to retain its radiation properties. Finally, the resonance frequency of an initial microstrip antenna array shifts from 5.2 GHz to 2.2 GHz and with better performance miniaturization up to 83% with respect to conventional microstrip antenna is successfully accomplished. A prototype of the antenna was fabricated with the RT-Duroid substrate. This technique is validated experimentally and measured results were in good agreement with simulated results.

1. Introduction

Microstrip antennas are quite an obvious choice for wireless devices because of their properties, and several advantages as compared to other bulky type of antennas. Some of the main advantages of microstrip antenna are that it has low fabrication cost, light weight, low volume, and low profile configuration that can be made conformal, it can be easily mounted on rockets, missiles and any conformal shaped satellites without major modifications and arrays of these antennas can simply be produced [1]. However, the microstrip patch antennas suffer from a number of disadvantages as patch length is around half a wavelength.

In recent years, the miniaturization of antennas has become more and more important due to the increasing demand for small antennas as the rapid development in wireless communications. Many efforts have also been made in order to achieve the size reduction like using planar inverted F antenna structure (PIFA) [2] or using a dielectric substrate of high permittivity [3], defected microstrip structure (DMS) [4], defected ground structure (DGS) [5], or a combination of them.

Mainly DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar wave guide) which disturbs the shield current distribution in the ground plane because of the defect in the ground .The defect geometry is easy to implement and does not need a large area. These features enable such structures to acquire a great relevance in microwave circuit design [6]. In particular, DGS is employed to design microstrip antennas for different applications, for instance, cross polarization, mutual coupling reduction in antenna arrays and harmonic suppression. Moreover, DGS has been widely used in the development of miniaturized antennas [7].

In this paper DGS is used to design a miniaturized microstrip patch antenna array as compared with a conventional one. Initially the proposed typical rectangular microstrip patch array antenna designed at C band, resonates at 5.2 GHz. However it is further miniaturized by introducing the new DGS to shift the resonance frequency from C band to S band keeping the physical volume of the antenna constant and hence the size reduction about 79% compared with the conventional one is carried out. This size reduction significantly reduces the gain and degrades the antenna performance due to the increase in ohmic losses. Further in order to enhance the antenna performance with size reduction, it has been proposed to modify the patch radiator of the typical rectangular antenna with the same DGS structure. Finally, the modified

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E-shape patch antenna with same DGS gives the size reduction of about 83% with the minimum reduction in gain and better impedance matching compared with the conventional one.

2. Microstrip patch antenna array resonating at 5.2 GHz

The proposed 2 by 1 element array microstrip patch antenna is shown in Fig. 1. In this design the substrate RT Duroid was used due to its advantages. The substrate height was 0.762 mm with dielectric constant of 2.2 and the loss tangent was 0.0004. The dimensions of the antenna were optimized by using CST Microwave Studio tool. On the top of the substrate, a metal patch with dimension Lp = 18.6 mm and Wp = 22.80 was connected to 50 ohm feed line with an inset, the dimensions of inset feed were Li = 11 mm and Wi = 2.3 mm. The microstrip line 1:2 power divider is used to feed the two antennas and hence the line widths are adjusted according to the power division. The simulation result of reference antenna is shown in Fig. 2. The polar radiation plots simulated at $\phi = 90^\circ$ and $\phi = 0^\circ$ are shown in Figs. 3 and 4 respectively.

The design and simulation of the proposed antenna have been carried out. Fig. 2 shows S_{11} of the antenna without any DGS in ground plane resonates at frequency 5.2 GHz (C band) with the gain 9.9 dBi. The objective of this work is to miniaturize antenna using DGS without degradation of antenna performance.

3. Defected ground structure (DGS)

The defected ground structure (DGS) and the Electromagnetic band gap structures (PBG) are the two different types of the generic structures mostly used for the design of compact and high performance microwave components [8]. These structures are employed to reject unwanted frequency and circuit size reduction. DGS is an etched lattice of certain shape located on the ground plane. The performance of microstrip antennas and their array can be enhanced by introducing the defects in the ground plane [9]. The shape of the defect may be changed from the simple shape to the complicated shape for better performance. The DGS equivalent circuit consists of a parallel tuned circuit in series with the transmission line to which it is coupled as shown in Fig. 5.

The different shapes of DGS structure have the same role and same characteristics of slow wave effect and high impedance, band rejection, miniaturization of size with the same equivalent circuit [10]. However to improve the circuit performance of antenna the shape of DGS can be further change or modified. In this work we have employed DGS in metallic ground plane for antenna miniaturization. When DGS is introduced in a microstrip antenna, the defect geometry etched in the ground plane disturbs its current distribution. This disturbance affects the transmission line characteristics, such as the line capacitance and inductance. In other

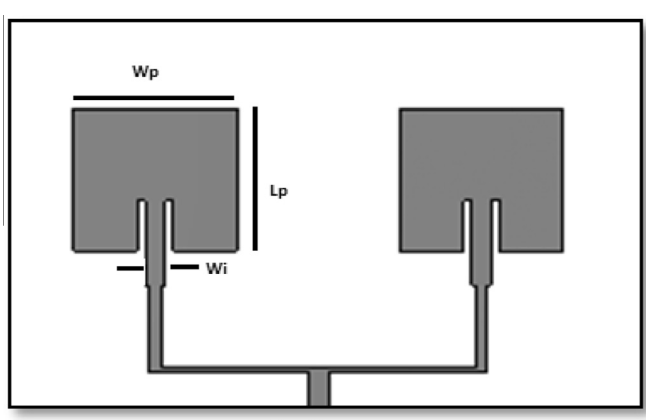


Fig. 1. Reference 2 by 1 element array antenna without DGS.

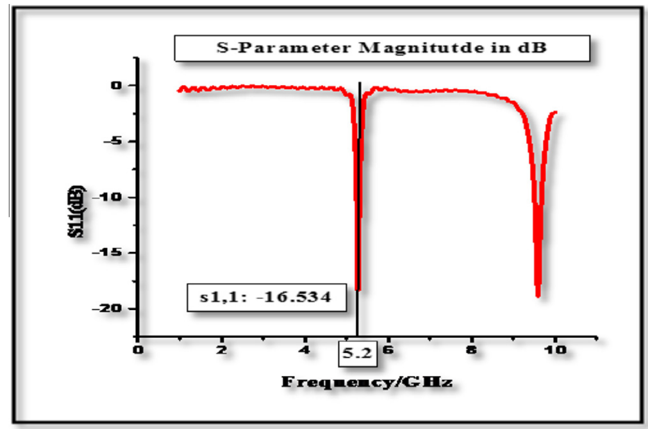


Fig. 2. Simulated S11 of the patch antenna array resonating at 5.2 GHz.

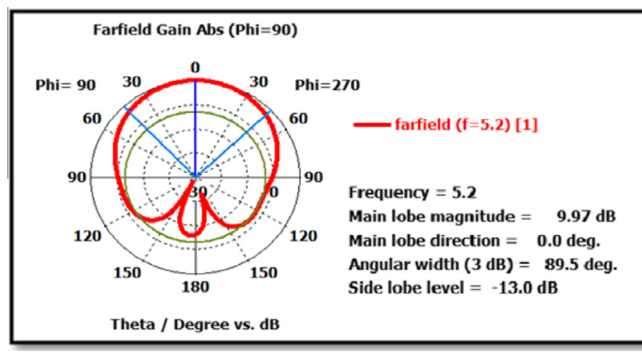


Fig. 3. Reference antenna radiation pattern at Phi = 90.

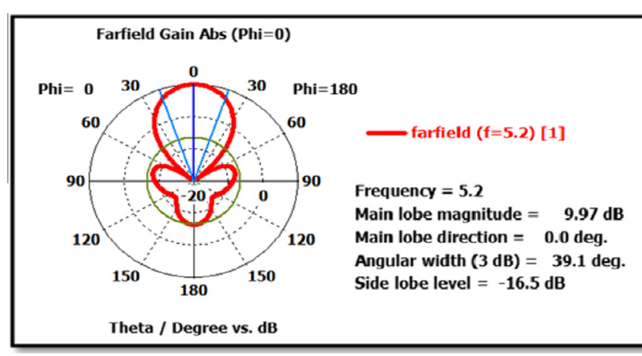


Fig. 4. Reference antenna radiation pattern at Phi = 0.

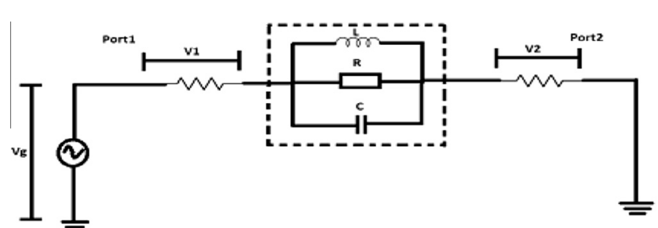


Fig. 5. Equivalent circuit of DGS.

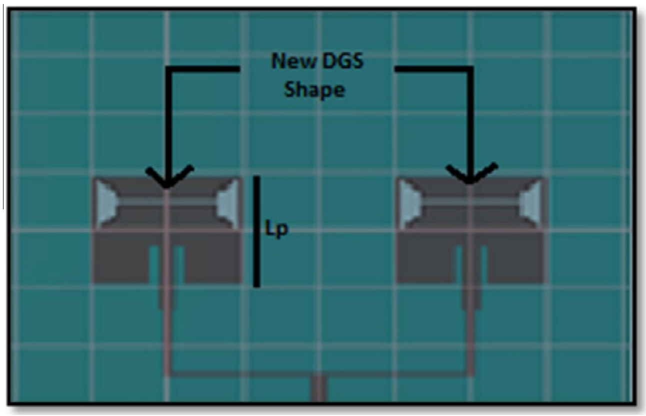


Fig. 6. Microstrip 2 by 1 element array antenna with DGS.

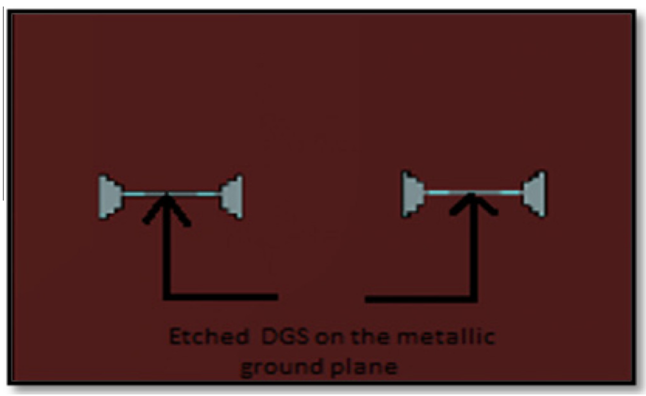


Fig. 7. Back-view of microstrip 2 by 1 element array antenna with DGS.

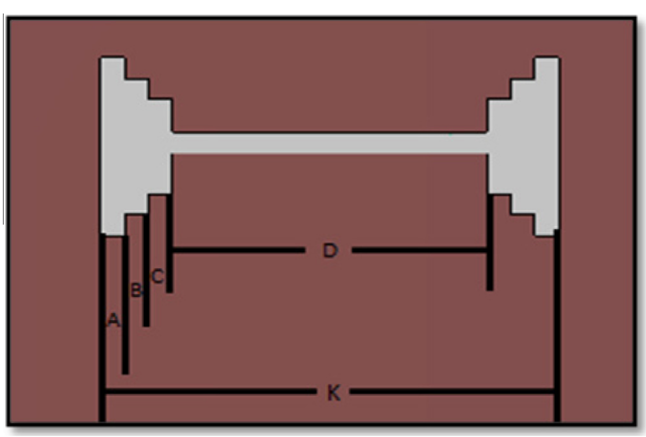


Fig. 8. DGS geometry ($K = 20$ mm, $D = 14$ mm $A = B = C = 1$ mm).

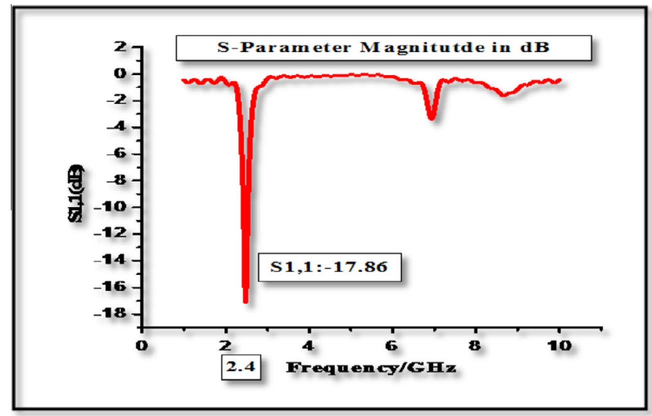


Fig. 9. Simulated S11 of the patch antenna with DGS resonating at 2.4 GHz.

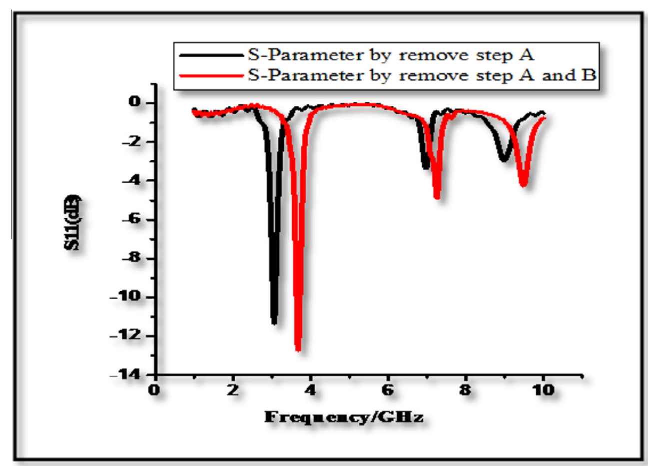


Fig. 10. Simulated S11 without step A and B.

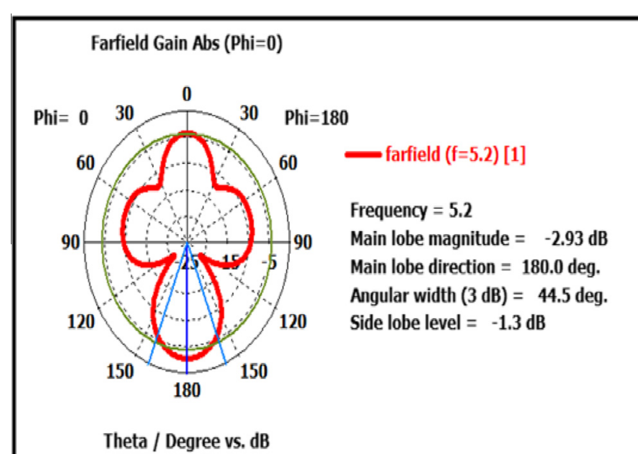


Fig. 11. Radiation pattern for the DGS antenna at Phi = 90.

words, introducing DGS in a microstrip antenna can result in an increase of the effective capacitance and inductance which influences the input impedance and current flow of the antenna [11] thus reducing its size with respect to a given resonance frequency.

4. Microstrip patch antenna array with DGS

In order to shift the resonance frequency of the conventional microstrip antenna array (Fig. 2) from C band to S band, initially a new DGS shape is etched on the metallic ground plane of the antenna shown in Figs. 6 and 7.

Fig. 8 shows the detail geometry of DGS with the specified dimensions. Fig. 9 shows the antenna performance with DGS. It is observed that the resonance frequency has been significantly influenced by the DGS and it has been shifted from 5.2 GHz to 2.4 GHz without changing physical dimension or distance between the antennas.

Table 1
Size comparison of antenna resonating at 2.4 GHz.

Frequency	Conventional patch size without DGS	Conventional patch size with DGS	Size reduction
2.4 GHz	2065.33 mm^2	424 mm^2	79%

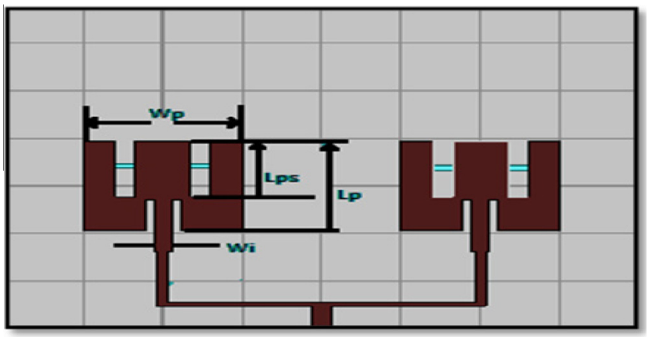


Fig. 12. Top view of the patch antenna (Wp = 22.80 mm, Lp = 18.6, Wi = 2.3 mm, Lps = 12 mm).

Table 2
Comparison of E-shaped patch antenna with regular rectangular antenna without DGS.

Patch shape	Regular rectangular shaped antenna	Modified E-shaped patch antenna
Resonant Freq.	5.2 GHz	5.2 GHz
S11	−18.32	−31.07
Bandwidth	100 MHz	120 MHz
Gain	9.8	10.89

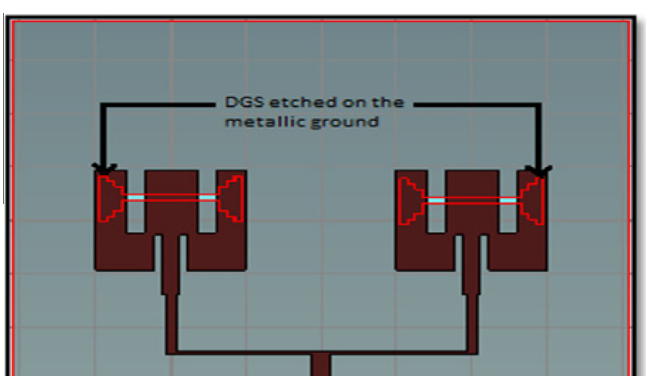


Fig. 13. Modified patch shaped antenna with DGS.

Table 3
Comparison of E-shaped patch antenna with regular rectangular antenna with DGS.

Patch shape	Rectangular shaped antenna with DGS	E-shaped patch antenna with DGS
Reduced Freq.	2.4 GHz	2.2 GHz
S11	−17.06	−32.36
Bandwidth	100 MHz	120 MHz
Gain	1.93	4.8
% size reduction	79%	83%

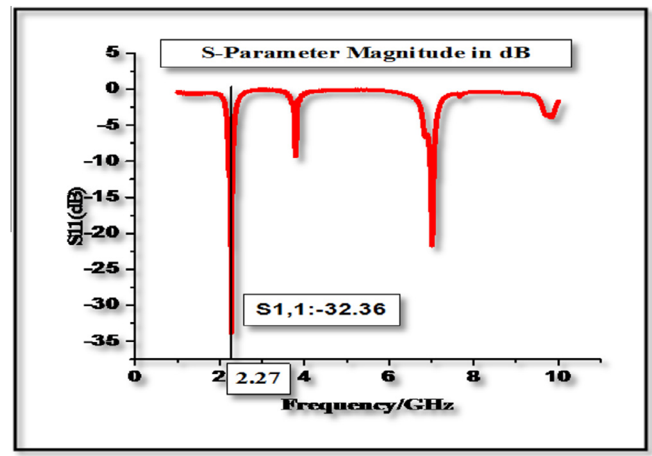


Fig. 14. Simulated S11 of the modified patch antenna with DGS resonating at 2.2 GHz.

Table 4
Size comparison of antenna resonating at 2.2 GHz.

Frequency	Conventional patch size without DGS (in mm^2)	Modified E-shape patch size with DGS (in mm^2)	% size reduction
2.4 GHz	2459.99	424	83%

The effect of adding or removing the step A, B and C from the final new DGS structure (Fig. 8) is also illustrated in order to clarify the consequence of DGS shape on antenna for size reduction. Fig. 10 shows the antenna performance by removal of steps A and B from the specified final DGS geometry. It has been observed that the resonance frequency has been shifted to 3 GHz by removal of step A with the gain 4.42 dBi and by removal of step A as well as B the resonance frequency has been shifted to 3.6 GHz with the gain of 5.5 dBi. With the presence of all steps the antenna resonates at 2.4 GHz with the gain 1.9 dBi as shown in Fig. 11. Also the effects of the DGS position on the antenna characteristics have been studied by changing the DGS at different positions. From the simulation result it has been observed that as the DGS position shifted below with respect to current position, resonating frequency shifts at the higher side i.e. 3.2–3.8 GHz. Finally from the simulation result (Fig. 9) it can be revealed that the specified DGS structure with the presence of all steps (A, B and C) along with the current position gives maximum best possible size reduction, however by removal of the steps or by changing the DGS position the antenna resonates at higher frequencies i.e. 3 GHz, 3.2 GHz, 3.6 GHz or 3.8 GHz which reduces the percentage of overall size reduction.

Table 1 shows the actual size required to design a microstrip patch antenna which resonates at a frequency of 2.4 GHz and also the amount of size reduction using DGS. This gives the overall size reduction of 79%. Although the physical size of the antenna array is same, it now works at a lower frequency hence in terms of wavelength at new frequency the antenna size is reduced. It is also revealed from the result that with miniaturization the gain of the antenna is reduced to 1.94 dBi as shown in Fig. 11 this is mainly because with DGS in the ground plane, the antenna will radiate on both sides of the ground plane due to the aperture efficiency resulting in high back radiation level which explains the maximum gain reduction. In fact one of the major problems in microstrip antenna applications is to reduce the size with good performance. However, this miniaturization is at the cost of gain of the antenna. In order to improve the gain of this miniaturized antenna, we further modified the patch radiator keeping the physical volume of the antenna constant with the same DGS structure to retain its radiation properties.

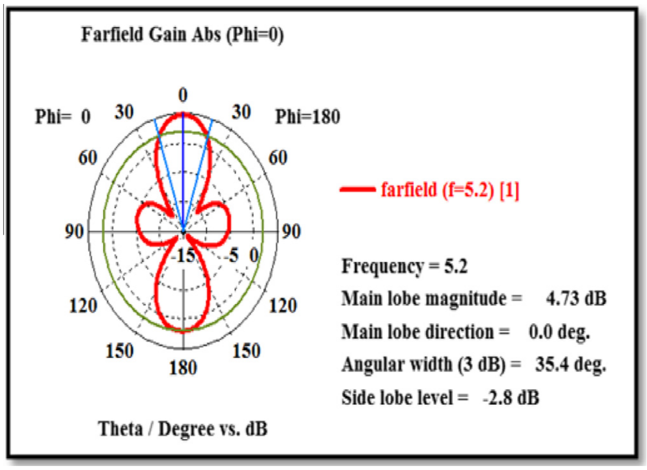


Fig. 15. Radiation pattern for the modified DGS antenna.

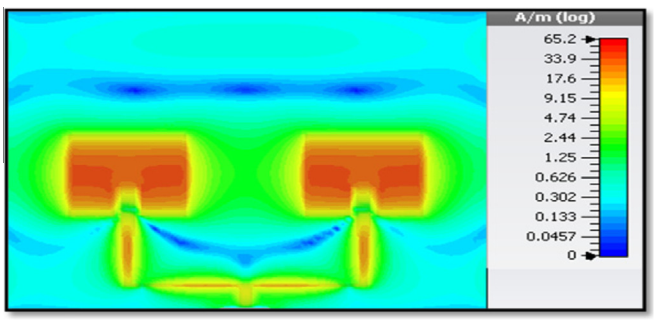


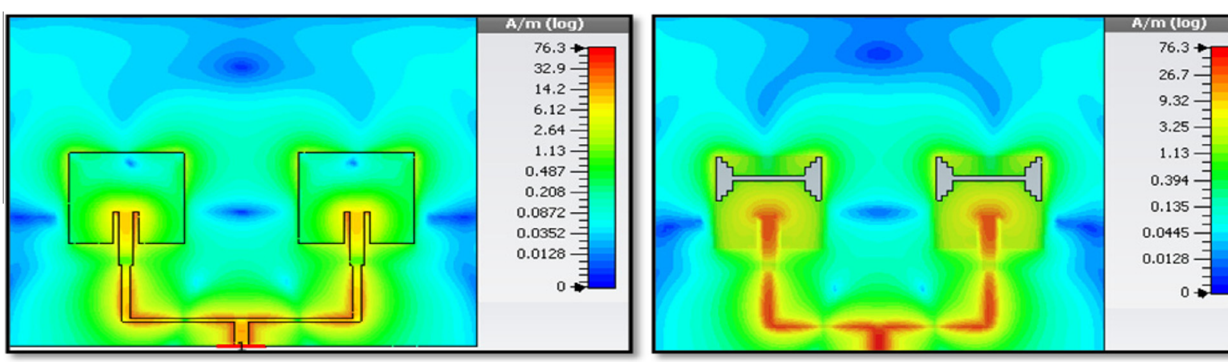
Fig. 16. Current distribution of conventional antenna without DGS.

5. Modified patch shape to enhanced antenna performance

The proposed antenna is shown in Fig. 12. In order to enhance the performance of the antenna, two slots are introduced on the patch radiator keeping the physical volume of the antenna constant. Initially, the performance of the antenna with the slots on patch without DGS structured was observed. The modified E-shape patch antenna gives better results compared to regular rectangular patch shaped antenna as shown in Table 2. Further the same DGS structure is etched on the ground plane of the modified patch shaped antenna as shown in Fig. 13.

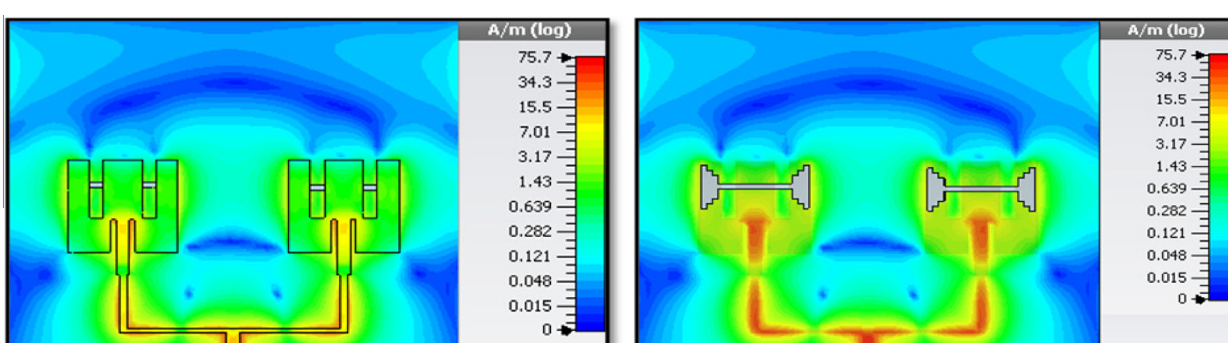
The modified shape of the typical rectangular patch antenna with the same DGS structure has improved the gain of the antenna with the better impedance matching as observed from Table 3. In the original regular rectangular antenna designed to resonate at 5.2 GHz with the specified area of 424 mm^2 and without changing the physical dimension or distance between the antennas the operation frequency shifts from the C band to the S band with the use of DGS. Fig. 14 shows S_{11} of the E-shaped antenna with DGS in the ground plane resonating at a frequency of 2.2 GHz. Table 4 shows the actual size required to design a microstrip patch antenna which resonates at a frequency of 2.2 GHz and also the amount of size reduction using DGS. This gives the overall size reduction of 83% without much degradation of the antenna performance.

The radiation pattern as shown in Fig. 15 is obtained. By comparing the radiation pattern of the regular rectangular patch shaped antenna with DGS (Fig. 11) with the radiation pattern of the modified patch shaped antenna with the same DGS structure as shown in Fig. 15, it is observed that there is a high back radiation in the regular rectangular antenna by employing the DGS, whereas the modified E-shaped patch antenna with the same DGS reduces the back radiation and hence increases the gain from 1.94 dBi to



(a) (b)

Fig. 17. Current distribution of patch antenna with DGS, (a) front view, (b) back view.



(a) (b)

Fig. 18. Current distribution of modified patch antenna with the same DGS (a) front view, (b) back view.

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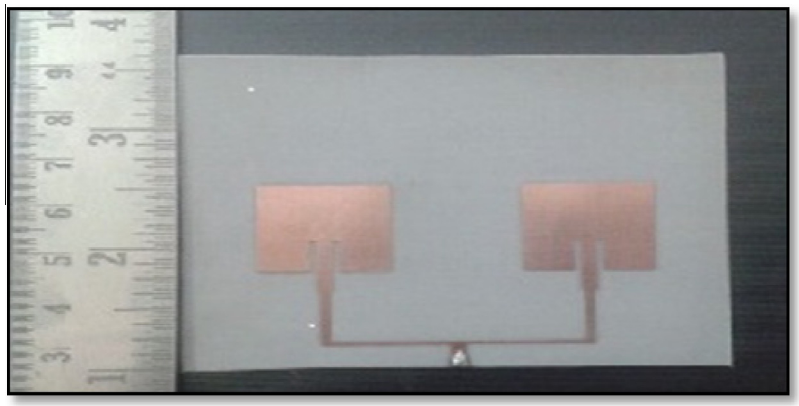
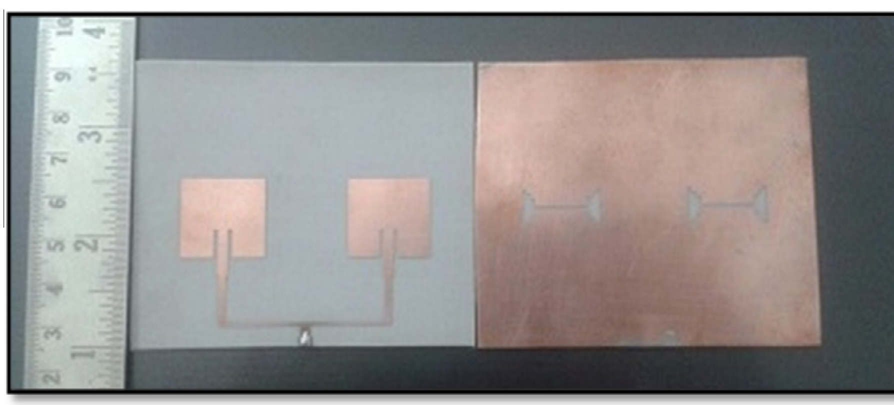
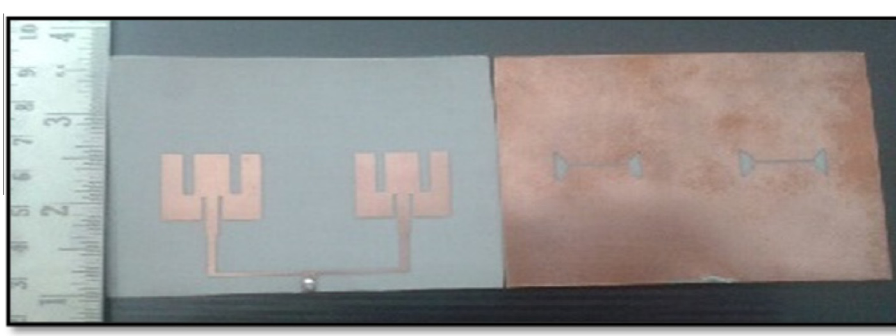


Fig. 19. Prototype of the fabricated 2 by 1 element regular rectangular microstrip patch antenna array without DGS.



(a) (b)

Fig. 20. Prototype of the fabricated (a) 2 by 1 element regular rectangular microstrip patch antenna array with DGS (b) Back view with etched DGS.



(a) (b)

Fig. 21. Prototype of the fabricated (a) 2 by 1 element modified rectangular microstrip patch antenna array with DGS (b) Back view with etched DGS.

4.8 dBi compared to the conventional antenna with DGS. Thus we obtained less reduction in gain and good impedance matching with miniaturization of about 83% from the modified shape of the antenna with DGS.

To observe the excitation mechanism, average surface current distributions obtained from CST simulation on both patch and ground plane for optimized antenna were studied. Fig. 16 shows the current distribution of patch antenna without DGS. Figs. 17 and 18 show the current distribution of the patch antenna with DGS and modified patch shaped antenna with the same DGS structure respectively. In conventional antenna, a large surface current was observed over the patch and along the microstrip line (Fig. 16). On the contrary, the current was more concentrated along the DGS on the ground plane of the patch antenna as well as along the transmission line as observed from Figs. 17 and 18. The defects on the metallic ground structure disturb the current distribution, resulting in a controlled excitation and propagation of the electromagnetic waves via the substrate layer and change in the resonance peak.

6. Fabrication and measurement

A prototype of designed microstrip patch antenna array without DGS and with DGS was fabricated as reference antenna and the

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proposed antenna respectively. We have used RT-Duroid substrate with relative dielectric constant of 2.2 and the thickness of 0.762 mm. Fig. 19 shows the size of regular rectangular microstrip patch antenna array without DGS. Fig. 20(a) and (b) shows size of the top and back view respectively of regular rectangular microstrip patch antenna array with DGS. Fig. 21(a) and (b) shows the size of the top and back view respectively of the modified microstrip patch antenna array with the same DGS.

In order to measure the various parameters of the antenna we have been employing MS2028C vector network analyzer, with frequency range limited to 20 GHz. Thus S11 parameter was measured and compared to the simulated result. Figs. 22–24 shows the comparison between measured and simulated results of the regular rectangular microstrip patch antenna array without DGS, with DGS resonating at 2.4 GHz and the modified microstrip patch antenna array with same DGS resonating at 2.2 GHz respectively.

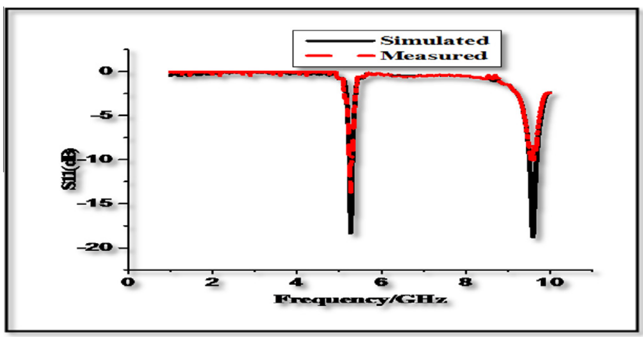

Fig. 22. Measurement and simulation result of regular rectangular microstrip patch antenna array without DGS (resonating at 5.2 GHz).

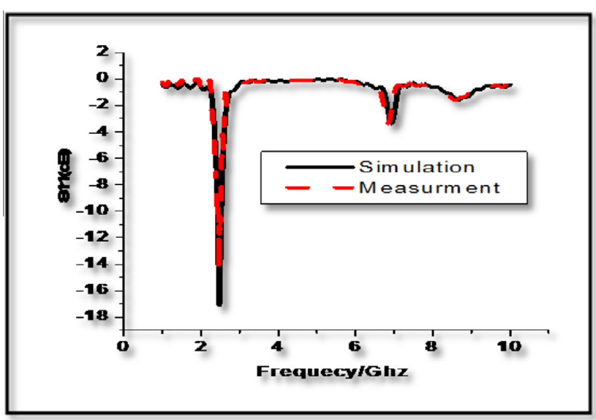

Fig. 23. Measurement and simulation result of regular rectangular microstrip patch antenna array with DGS (resonating at 2.4 GHz).

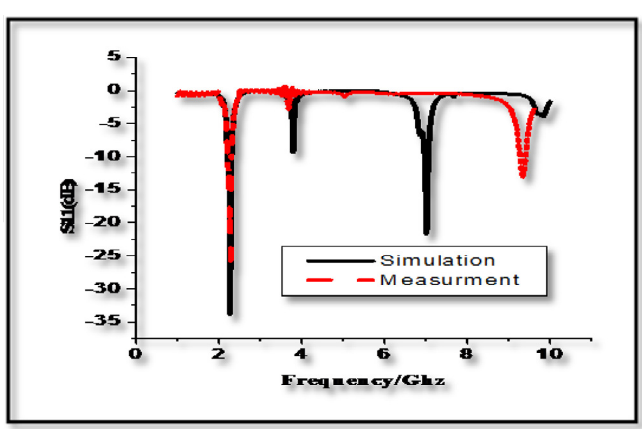

Fig. 24. Measurement and simulation result of modified microstrip patch antenna array with same DGS (resonating at 2.2 GHz).

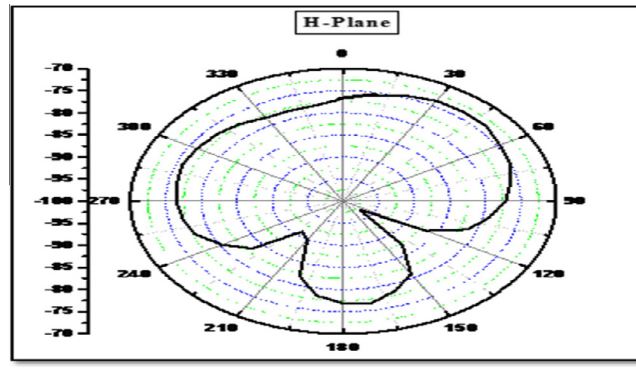

Fig. 25. Measured pattern of modified microstrip patch antenna array with the same DGS (resonating at 2.2 GHz).

Also the measured radiation patterns of the final modified patch radiator at the resonant frequency 2.2 GHz are shown in Fig. 25. From Fig. 25 it can be found that the antenna has same polarization planes and similar radiation pattern. The measured gain in the operation band is typically 4.14 dBi. The high back lobe is caused due to DGS in the ground plane. Experiment shows an excellent agreement of the measured result with simulated result in both the cases.

7. Conclusion

The miniaturization procedure initiated with a typical rectangular patch shaped array antenna with DGS gives a size reduction up to 79% as the resonance frequency of the initial antenna without DGS has been shifted from 5.2 GHz to 2.4 GHz resonating at −17.86 dB with the gain of 1.94 dBi and 100 MHz bandwidth. To achieve miniaturization without much degradation of antenna performance, further the patch radiator is modified keeping the physical volume of the antenna constant with the same DGS structure to retain its radiation properties which gives a size reduction up to 83% as the resonance frequency of the initial antenna without DGS has been shifted from 5.2 GHz to 2.2 GHz resonating at −32.26 dB with the measured gain of 4.14 dBi and 120 MHz bandwidth. In this way we have been able to reduce the maximum antenna size up to 83% as compared to conventional antenna without much degradation of the performance of the antenna.

Acknowledgments

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