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Improved Radiation and Bandwidth of Triangular and Star Patch Antenna

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Abstract: This study presents a hexagonal shape Defected Ground Structure (DGS) implemented on two element triangular patch microstrip antenna array. The radiation performance of the antenna is characterized by varying the geometry and dimension of the DGS and also by locating the DGS at specific position which were simulated. Simulation and measurement results have verified that the antenna with DGS had improved the antenna without DGS. Measurement results of the hexagonal DGS have axial ratio bandwidth enhancement of 10 MHz, return loss improvement of 35%, mutual coupling reduction of 3 dB and gain enhancement of 1 dB. A new wideband and small size star shaped patch antenna fed capacitively by a small diamond shape patch is proposed. To enhance the impedance bandwidth, posts are incorporated under the patch antenna. HFSS high frequency simulator is employed to analyze the proposed antenna and simulated results on the return loss, the E- and H-plane radiation patterns and Gain of the proposed antenna are presented at various frequencies. The antenna is able to achieve in the range of 4-8.8 GHz an impedance bandwidth of 81% for return loss of less than-10 dB.

Key words: Bandwidth enhancement, radiation properties, star patch, triangular antenna

INTRODUCTION

Microstrip antennas are widely used in various applications because of low profile, low cost, lightweight and conveniently to be integrated with RF devices. However, microstrip antennas have also disadvantages. One disadvantage is the excitation of surface waves that occurs in the substrate layer. Surface ired because when a patch antenna radiates, a portion of total available radiated power becomes trapped along the surface of the substrate. It can extract total available power for radiation to space wave. Therefore, surface wave can reduce the antenna efficiency, gain and bandwidth. For arrays, surface waves have a significant impact on the mutual coupling between array elements (Garg *et al*., 2001). One solution to reduce surface waves is using Electromagnetic Bandgap (EBG) or Photonic Bandgap Structure (PBG). Recently introduction of EBG and DGS made a significant break-through in the improvement of microstrip antennas characteristics. EBG are a new type of engineered materials with periodic structures that can control the propagation of electromagnetic waves to an extent that was previously not possible. However, in implementing EBG, a large area is needed to implement the periodic patterns and it is also dicult to define the unit element of EBG. Whereas DGS has similar microwave circuit properties as EBG, it can also modify guided wave properties to provide a bandpass or bandstop like filter and can easily define the unit element. DGS is realized by etching the ground plane of microstrip antenna, this disturbs the shield current distribution in the ground plane which influences the input impedance and current flow of the antenna.

The geometry of DGS can be one or few etched structure which is simpler and does not need a large area to implement it.

Many shapes of DGS slot have been studied for single element microstrip antenna such as circle (Guha *et al*., 2005), dumbbells (Liu *et al*., 2005) and spiral (Chung *et al*., 2004), however not many have realized it in antenna arrays. In (Yu and Zhang, 2003), they proposed using a dumbbell EBG structure and in (Waterhouse, 1999) using a fork-like EBG structure. Both references implemented EBG between two element arrays, these antenna designs are complex structure. The author found papers by (Salehi *et al*., 2006; Ge *et al*., 2004) and by (Zainud-Deen *et al*., 2008; Wong and Lin, 1998) which used dumbbell shape DGS for antenna array,

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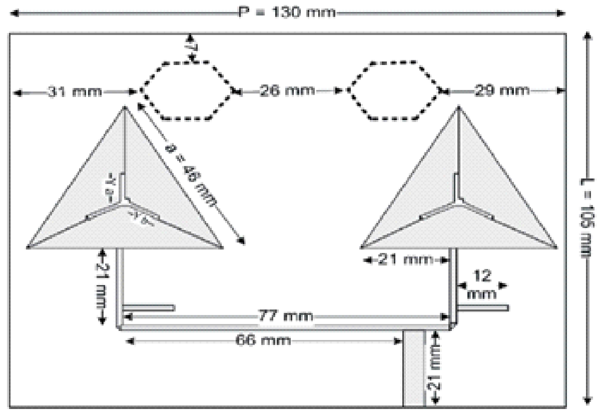


Fig. 1: Configuration of double hexagonal DGS antenna design

however the results were simulation one and not realized through experimental results.

In an antenna array, the mutual coupling effect will deteriorate the radiation properties of the array. Therefore in this study, the reduction of the mutual coupling effect was investigated by proposing a new hexagonal shape DGS to be implemented between the two elements triangular patch microstrip antenna array. Simulation and measurement results have been done and showed that the antenna with DGS can improve the antenna performance of the antenna without DGS. This study discusses the influence of hexagonal shape DGS towards the improvement of the radiation properties. By adding the DGS, therefore, will suppress surface wave propagation in the dielectric layer.

Conventional microstrip antennas in general have a conducting patch printed on a grounded microwave substrate and have the attractive features of low profile, light weight, easy fabrication and conformability to mounting hosts. However, microstrip antennas inherently have a narrow bandwidth and bandwidth enhancement is usually demanded for practical applications. In addition, applications in present-day mobile communication systems usually require smaller antenna size in order to meet the miniaturization requirements of mobile units.Thus, bandwidth enhancement and size reduction are becoming major design considerations for practical applications of microstrip antennas (Mirzapour and Hassani, 2006). Many techniques such as meandered ground plane (Yang *et al*., 2004), slot-loading (Salehi *et al*., 2006), stacked shorted patch (Zainud-Deen *et al*., 2008), feed modification (Rahardio *et al*., 2007), chip loading (Wong, 2002) and teardrop dipole in an open sleeve structure (Kuo and Wong, 2001) have been reported to achieve wideband and to reduce the size of microstrip antennas.In addition, the bandwidth of the patch antenna can be increased by using air substrates, (Eldek *et al*., 2004). Another method of increasing the impedance bandwidth of a patch antenna is to use shorting posts between the patch and the ground plane. The performance of such structures depend on parameters such as the number of the posts used, the radius of each post and the height of the posts (the thickness of the substrate) (Ang and Chung, 2007). A star shaped microstrip patch with corners shaped and fed by a rectangular patch showed a bandwidth of around 63%.

In this study, a wideband microstrip antenna in the shape of a novel star shaped patch loaded with shorting posts and capacitive fed by a small diamond shaped patch is presented. The dimension of the patch and the parameters of the shorting posts are optimized to obtain an efficient design leading to the highest possible impedance bandwidth in the range of 4 to 8.8 GHz, i.e., 81% of the centre frequency.

Antenna design-triangular: A configuration of double hexagonal DGS implemented to the antenna is shown in Fig. 1. The antenna without DGS, as in (Chen *et al*., 2007), is designed on a single layer dielectric substrate with $\epsilon_r = 2.2$, thickness of 1.57 mm and tangential loss of 0.0009. The antenna is designed to have circular polarized bandwidth of minimum 50 MHz and resonant frequency at 2.61 GHz. Two element triangular microstrip antenna arrays with a distance between each element of 77 mm are fed asymmetrically to achieve tilted angle radiation pattern towards 30º. The stub is given for matching in the antenna without DGS and the Y slot in the triangular patch is inserted to excite circular polarization.

The DGS is then inserted into the ground plane of the antenna with position between the two element triangular patch. In Fig. 1, the DGS is drawn with dash lines to indicate that the DGS is located on the bottom of the substrate. The patch and the feeding system with stub from the antenna are not changed; only hexagonal shape slot is inserted to the ground plane of the antenna.

The proposed hexagonal DGS design in this study was simulated by varying the dimension and locating the position of the DGS on the antenna without DGS. The first simulation used one hexagonal DGS implemented to the antenna and showed no significant result. However,

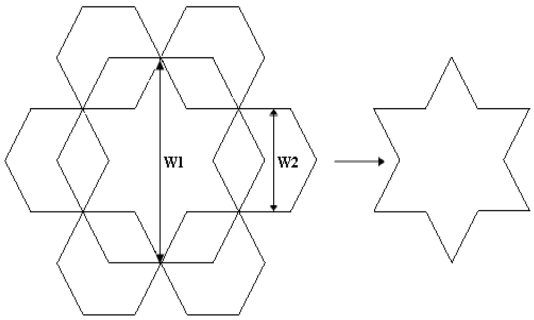


Fig. 2: Process of building the star shaped patch antenna

the best result shown for a single hexagonal is when the area of the hexagonal equals to 259 mm^2 with the side length of 14 mm. Therefore, based on the previous simulation, the next one is expanded to two hexagonal DGS with the total area of the DGS maintained at 259 mm^2. The separation of one hexagonal to two hexagonal was carried out because it is assumed that the surface wave which has a zigzag path can be trapped by the two hexagonal instead of one. Therefore the hexagonal design was separated into two hexagonal. Finally, the double hexagonal shape DGS is designed between the two elements, in which the distance between the two elements as well as the location is varied. A good result was achieved for hexagonal with the side length of 10 mm and with the displacement between the two hexagonal of 26 mm.

Antenna geometry-star: Figure 2 shows the process of building the new star shaped patch antenna. The proposed antenna shape is based on a hexagonal patch in which 6 smaller hexagonal are cut from the edges. To increase the bandwidth of the antenna four shorting posts are added under the patch. The antenna is capacitive fed by a diamond shape patch that is connected to a coaxial feed. Figure 3 shows the geometry of the complete antenna.

Table 1: Specification of the proposed antenna in mm

W1	W2	P	H	X	X1	X2	Y1	Y2	R
23.5	11.5	5	8	5.7	4.5	2	4	8	1.5

The star-shaped patch is separated from the ground plane with an air-filled substrate. The specification of the proposed antenna is present in Table 1.

RESULTS AND DISCUSSION

Simulations: The simulation was carried out by using method of moment. Figure 4 exhibits the simulation result of the return loss of the antenna with and without DGS. The antenna with and without DGS has return loss of -43.22 and -33.3 dB at the resonant frequency of 2.61 GHz, respectively. The simulation result of DGS shows return loss improvement of 29.8% compared to the antenna without DGS.

The triangular patch microstrip antenna array was designed to have circular polarization. The simulation result of the antenna with and without DGS for circular polarization shows a 3 dB axial ratio bandwidth of 2.6 and 1.9% respectively. This result shows that the antenna with DGS could increase the circular polarization bandwidth of the antenna without DGS to 10 MHz.

Another antenna parameter was also simulated, namely the mutual coupling. The simulation showed that the antenna without DGS has a mutual coupling of -39.68 dB and with DGS shows a reduction of mutual coupling to -41.84 dB which is 2.16 dB lower than the antenna without DGS. The simulation results showed that the antenna parameters of the antenna without DGS were improved by the DGS.

Measurements: The antenna with hexagonal DGS was fabricated and measured. The DGS antenna showed characteristic improvement compared to the antenna without DGS. The measurement results demonstrated that the hexagonal DGS antenna improved the impedance

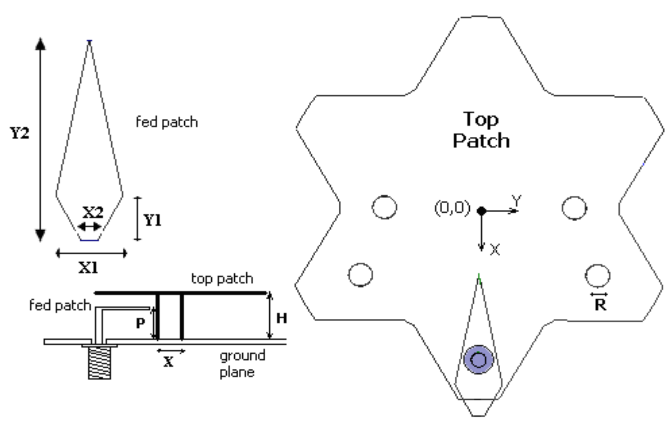


Fig. 3: Geometry of proposed antenna with the diamond shaped feed patch

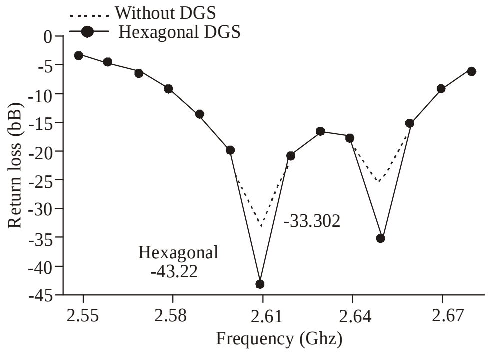


Fig. 4: Comparison of simulated return loss between antenna with and without dgs antenna

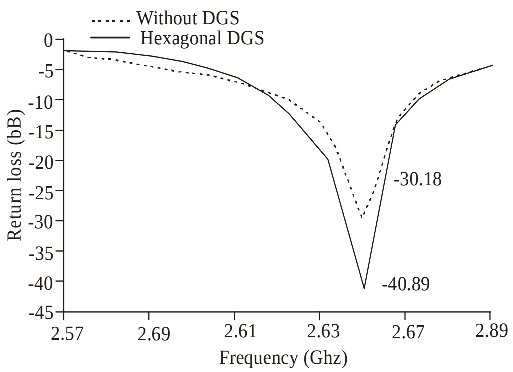


Fig. 5: Measurement result of return loss

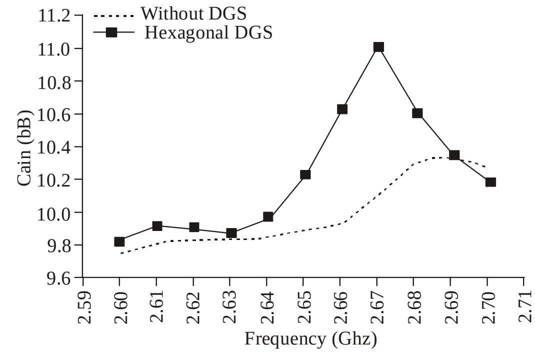


Fig. 6: Comparison of measured gain between antenna with and without DGS

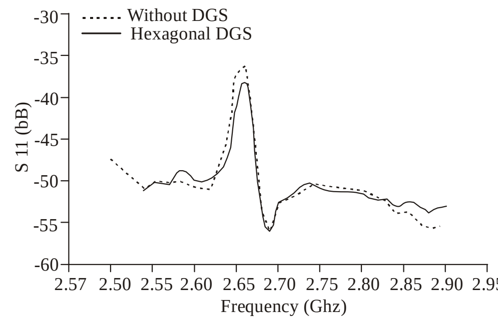


Fig. 7: Comparison of measured mutual coupling between antenna with and with DGS

matching of the antenna without DGS from minimum return loss -30.18 to -40.89 dB. This means there is an improvement to 35% of the minimum return loss which can increase the efficiency of the antenna. This improvement is displayed in Fig. 5. Figure 5 shows the measured resonant frequency of the antenna with and without DGS is at 2.66 GHz.

There is a slight shift of resonant frequency from simulation compared to measurement results. However the measured result of the antenna with and without DGS shows the same resonant frequency, therefore this measured result can be compared.

For the circular polarization of the antenna, axial ratio bandwidth was measured. The result showed an increase of 3 dB axial ratio bandwidth of 10 MHz for the DGS antenna. The antenna without DGS has axial ratio bandwidth from 2.63 to 2.67 GHz and the antenna with DGS from 2.63 to 2.68 GHz.

Furthermore, the antenna gain was measured from 2.6 to 2.7 GHz and the results are shown in Fig. 6. It is shown that there is gain improvement of about 1 dB from the DGS antenna. This gain enhancement justifies the impedance matching result of the return loss, which proves that the efficiency of the antenna is also improved.

Figure 7 shows the comparison of measured mutual coupling between the antenna without and with DGS. The measured mutual coupling results showed that the antenna with DGS has a mutual coupling of -38 dB at the resonant Researchfrequency of 2.66 GHz, while the antenna without DGS has a mutual coupling of -35 dB. It is obvious from the result that there is a substantial mutual coupling reduction.

Moreover, the measured radiation patterns of the antenna in the *E*- and *H*-plane for both with and without DGS are shown in Fig. 8 and 9, respectively. The antenna radiation patterns were measured at frequency 2.66 GHz. It is shown from Fig. 6 that both antennas have similarity in the *E*-plane pattern with maximum beam tilted towards 10-30º. This result agrees well with the intended design. While in Fig. 7, the antenna with DGS has a slightly higher backlobe level in the *H*-plane due to the presence of the hexagonal defected structure acting as a slot antenna which causes leakage field distributions.

Star patch: The antenna performance has been investigated through simulation via a Finite Element program, HFSS. The simulated result for the return loss is shown in Fig. 10. Based on a -10 dB return loss, 81% impedance bandwidth (in the frequency range of 4 to 8.8 GHz) is obtained.

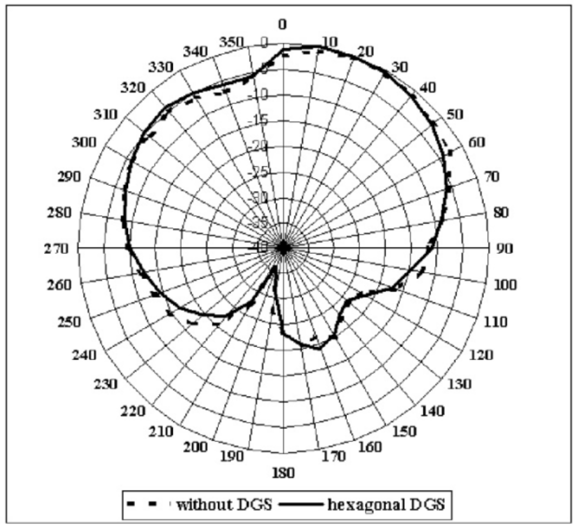


Fig. 8: Measured Eplane radiation pattern of antenna with and without DGS

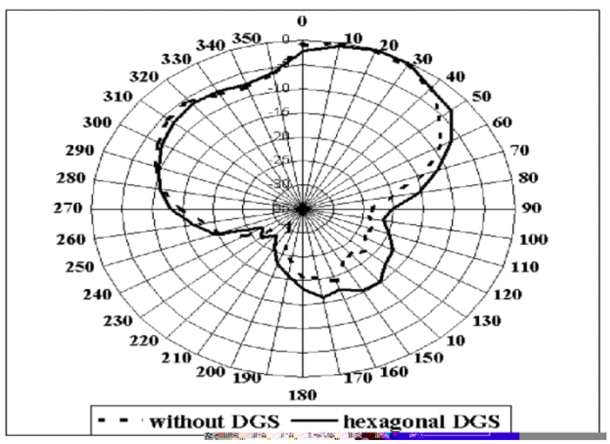


Fig. 9: Measured H-plane radiation pattern of antenna with and without DGS

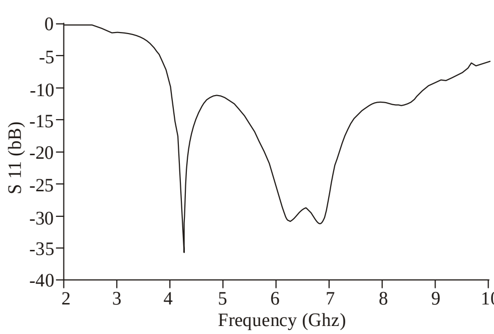


Fig. 10: Return loss of the proposed antenna W 1: 22 mm; W 2: 11.5 mm; P: 5 mm; H: 8 mm; X: 5.7 mm; X: 4.5 mm; X 2: 2 mm; Y 1: 4 mm; Y 2: 8 mm; R: 1.5 mm

It has to be mentioned that various shapes of the feed patch were used (circular, rectangular ...) but through simulation it was found that the present diamond shape patch gives the best impedance bandwidth result.

Through simulation it has been noticed that two of the most important parameters that affects the bandwidth performance of the antenna are W 1, the star shaped patch diameter and *R*, the diameter of the posts. Small variations on the rest of the parameters of the antenna do not significantly affect the antenna performance. Variation of return loss against slight changes on W 1 from 22 to 23 mm is shown in Fig. 11. It is noticed that the highest bandwidth is achievable when W 1 is equal to 22 mm leading to 81% impedance bandwidth.

Figure 12 shows the return loss with and without the posts. From this figure it is obvious that without posts, we have 23% of bandwidth. When the posts are added to the structure, the percentage of bandwidth increases. For diameter of the posts, *R*, equal to 1.5 mm.

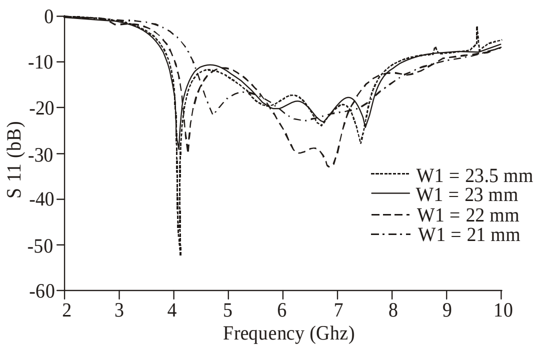


Fig. 11: The return loss of the antenna for various values of patch diameter, 1. W2: 11.5 mm; P: 5 mm; H: 8 mm; X: 5.7 mm; X 1: 4.5 mm; X 2: 2 mm; Y 1: 4 mm; Y 2: 8 mm; R: 1.5 mm

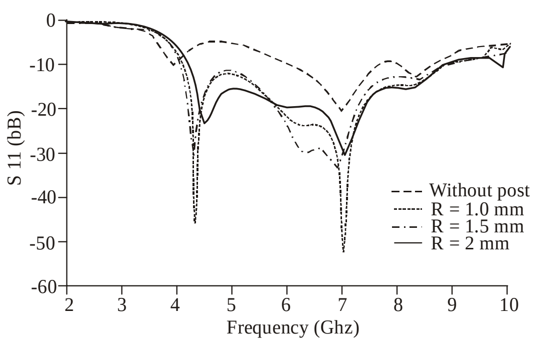


Fig. 12: Return loss of the antenna for various diameters of the posts W 1: 22 mm; W 2: 11.5 mm; P: 5 mm; H: 8 mm; X: 5.7 mm; X 1 : 4.5 mm; X 2: 2 mm; Y 1: 4 mm; Y 2: 8 mm

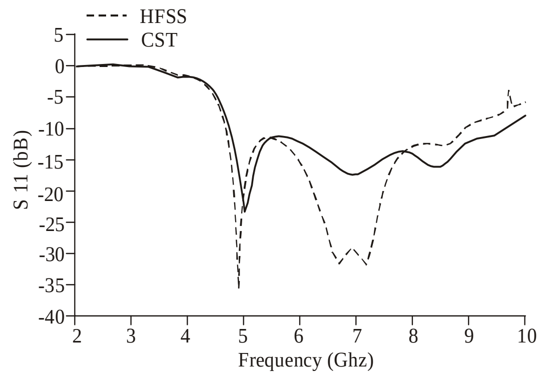


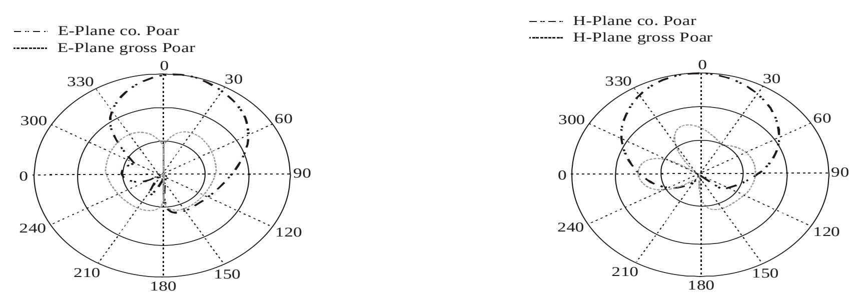
Fig. 13: Comparison of the S11 obtained through HFSS and CST W 1: 22 mm; W 2: 11.5 mm; P: 5 mm; H : 8 mm; X: 5.7 mm; X 1: 4.5 mm; X 2: 2 mm; Y 1: 4 mm; Y 2: 8 mm; R: 1.5 mm

The bandwidth is 81%, while for diameter of 1 mm the bandwidth reduces to 73%.

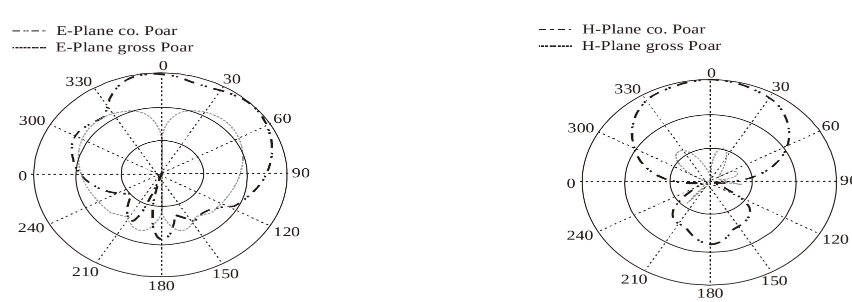
To confirm the simulation results of Fig. 11 which where obtained through HFSS method, a second powerful computer package of CST has also been used. Figure 13 shows the comparison of S11 of this antenna with HFSS and CST.

For the structure shown in Fig. 2, the simulation of the radiation pattern over the frequency range of 4 to 8.8 GHz has also been done. Figure 14 Shows the simulated E- and H-plane patterns at 4, 6 and 8 GHz including both Co- and Cross-polarizations.

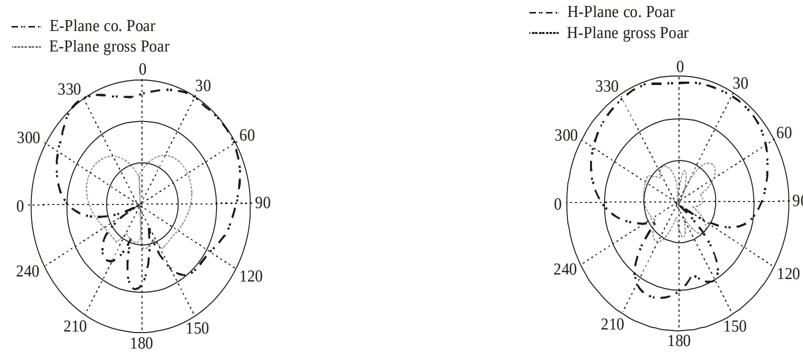
Figure 15 shows the antenna gain over the entire frequency range from 4 to 10 GHz.



(a)



(b)



(c)

Fig. 14: E and H-plane radiation pattern (a) at 4 GHz, (b) at 6 GHz, (c) at 8 Ghz

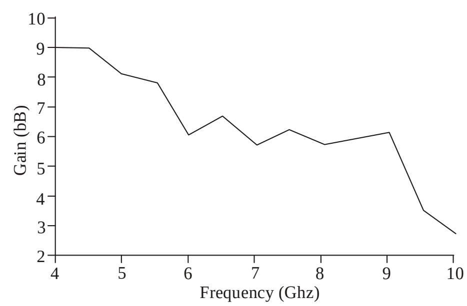


Fig. 15: Gain of the proposed antenna at various frequencies

CONCLUSION

A new DGS geometry, the double hexagonal shape have been used for two element triangular microstrip antenna array. The results demonstrated that the radiation properties of the antenna with DGS have better performance than the antenna without DGS. It is also shown that the geometry of the DGS has an influence towards the performance of the antenna characteristics.

A novel wideband and small size star-shaped microstrip antenna including simple feed structure is presented. The proposed antenna has a 81% bandwidth over the frequencies 4-8.8 GHz. It has good cross polarization level and uniform H-plane pattern over the wireless communication band. It has more bandwidth and has a smaller surface area than similar designs reported in the literature.

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