

Performance enhancement of hexagonal-patch dual-band array antenna with omega-shaped DGS for dual Band RADAR Applications

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This article presents an antenna array with novel-shaped defected ground structure (DGS) incorporated into the ground plane to enhance the bandwidth. It is observed that cross-polarization of the antenna is reduced by inserting omega-shaped DGS into the design. A 4×4 planar antenna with corporate feed has been designed with and without omega-shaped DGS into the ground plane. Four Omega-shaped DGSs have been placed vertically between the patch elements. These have been placed exactly at the back portion of the microstrip feed line in the ground plane. This antenna array is designed for dual-band applications. It has been observed that the bandwidth of the antenna get enhanced drastically. At 2.4 GHz, the bandwidth is 1860 MHz and at 5.8 GHz it is 2500 MHz with DGS. This type of antenna array can be used for WLAN and weather radar systems. The antenna has been designed using CST software.

Keywords: Antenna array, cross-polarization, defected ground structure, performance enhancement, radar.

MICROSTRIP antennas are currently one of the fastest emerging segments in the telecommunication industry and are become a promising medium in the field of communication. These are high-bandwidth, high-gain antennas in the radar systems. The requirements of radar systems are higher bandwidth with lower side lobe level. High-gain antennas are also needed for specific applications. Research has been conducted in the recent past to enhance the performance and efficiency of these patch antennas¹. Due to their superiority, microstrip antennas are commonly preferred for radar applications. Various techniques are incorporated in the antenna array for enhancement of antenna parameters like gain, bandwidth, and surface wave cancellation. Complimentary Split Ring Resonator (CSRR) has been incorporated into the design. It is the dual counterpart of split ring resonator which manifests band-stop characteristics at resonant frequency if electromagnetic fields are arranged appropriately². Bandwidth improvement achieve by embedding capacitive slits into the design with a truncated ground plane and exciting the antenna through a meandered strip line

feed³. A novel bandwidth enhanced UWB tapered slot antenna with Y-shaped corrugated edges was proposed earlier⁴. High-efficiency antenna array for automotive radar system has been reported⁵. A combination of series-fed patch antenna arrays and slots has been introduced leading to an antenna array with wide band, low side lobe level and high front-to-back ratio⁶. Feeding techniques play an important role in the antenna array community. Various feeds like corporate feed, centre feed, series feeds are preferred depending on the antenna application. Centre-fed series array antenna for K/Ka band has been designed and fabricated⁷. A 23-elements series-fed linear array designed at Ka band gives a gain of 19 dBi and SLL better than -15 dB. Seven-element series-fed antenna array has also been designed and fabricated for high gain⁸. An array of 32 identical square microstrip patches has been designed at 9.35 GHz and 100 MHz bandwidth for marine radar applications⁹. A differential feeding technique for a broadband planar antenna array has been presented¹⁰. The two antenna beams are realized by exciting the opposite feeds of a dual-fed array antenna¹¹.

In the present study, a 4×4 antenna array is designed at 2.4 GHz and 5.8 GHz. Rectangular patch antenna is common, but in this design we have chosen hexagonal-shaped patch. In this shape a slot is cut out to introduce an additional resonant frequency of 5.8 GHz. By inserting the square open slot into the hexagonal patch, an additional band is introduced. A corporate feeding technique is preferred for this array. Power is equally distributed in the corporate feeding technique. This design gives a good amount of bandwidth for both the frequency bands. At 2.4 GHz the bandwidth is 1100 MHz, while at 5.8 GHz it is 2400 MHz. Figure 1 shows 16-element array antenna design without defected ground structure (DGS).

Design methodology

It is observed that when an omega-shaped DGS is incorporated into the ground plane, the bandwidth improves drastically. It is 1860 GHz for 2.4 GHz and 2500 GHz for 5.8 GHz centre frequency. The antenna parameters also improve to a great extent after the inclusion of DGS into the ground plane. Here the basic aim of the DGS is to improve the bandwidth and decrease cross-polarization between the patch elements. A novel omega-shaped DGS

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is inserted into the ground plane. In this design four omega-shaped DGSs are designed in a vertical fashion into the ground plane. Each DGS is inserted between two patch elements. Due to the effect of the DGS, the current path is also increased, so there will be an increase in bandwidth for both the frequencies. Also, it reduces mutual coupling between the elements. Once mutual coupling is reduced, the antenna parameters will improve. So mutual coupling is the most critical part in array design. A novel structure has been proposed to reduce the mutual coupling between two coplanar microstrip antennas by inserting H-shaped DGS¹². Without affecting the radiation behaviour, this antenna reduces mutual coupling between two antennas. DGS is also used to suppress higher-order harmonics¹³. A multiband, dollar-shaped patch antenna array has been designed¹⁴. Bandwidth of the antenna is also affected by varying the height of the dielectric substrate and width of the patch¹⁵. The omega-shaped DGS is rotated clockwise by 90°. Results are observed with and without DGS and compared. Bandwidth improves by 760 MHz at 2.4 GHz and 100 MHz at 5.8 GHz. Good impedance matching is also observed. Beam width is 30 dB and side lobe level is -20.11 dB. Cross-polarization is also reduced and is observed to be -16.5 dB. The electromagnetic simulation tool CST was used to simulate the

proposed antenna. Figure 2 shows the return loss. Figure 3 a and b shows the two dimensional and three dimensional radiation pattern of the antenna array without CSRR. It can be seen that the proposed antenna exhibits good performance in terms of return loss, bandwidth and cross-polarization for dual-band frequency application. Figure 4 shows the omega-shaped DGS which has been incorporated into the ground plane. Figure 5 shows two-dimensional radiation pattern of 16-element planar array with DGS incorporated into the ground plane. Figures 6–8 show the performance plot of the array. Antenna miniaturization has become the most important topic of research in phased array antenna. DGS has been widely used for antenna miniaturization purpose. Work has also been done on gain improvement. In this study, we focus on bandwidth improvement. Some radar systems require higher bandwidth along with dual band, e.g. weather radar system. Further gain can also be improved by using frequency selective surface as mentioned¹⁶. Initially hexagonal patch antenna is designed at 2.4 GHz (S-band). It is further miniaturized by inserting square broken slots into the design. Hence the second centre frequency is at 5.8 GHz. Again, size reduction takes place by the inclusion of an omega-shaped DGS into the design. The vertical length of the DGS is 28 mm and width is 2 mm. Four omega-shaped DGSs are inserted into the ground plane, each DGS between two patch elements and exactly on the backside of microstrip feed line. The dimensions of the antenna have been optimized using CST software.

The DGS and electromagnetic band gap structure (photonic band gap) are the generic structures mostly used for the design of compact and high-performance microwave components¹⁷. They are incorporated to reject unwanted frequency and to reduce the size of the antenna. DGS is an etched structure of any shape in the ground plane. Performance of the antenna can be improved by inserting defects into the ground plane¹⁸. The shape of the DGS can be changed from simple to complicated for improvement of antenna performance. The equivalent circuit of the DGS consists of a series combination of resistance, inductance and capacitance in parallel combination. After insertion of the DGS at the ground plane, it disturbs the current distribution. This affects the transmission characteristics such as line capacitance and inductance¹⁹. A novel configuration for linearly polarized, dual-frequency microstrip antenna at S- and X-bands has been presented²⁰. Reference 21 elaborates different configurations of microstrip antenna array for phased array radar and beam forming algorithms. CSRR technique is used in ref. 22 for the enhancement of gain and bandwidth. CSRR technique is also used for the antenna miniaturization as explained in ref. 23. Various antenna parameter improvement techniques are discussed in ref. 24.

Results and discussion

This study presents good results regarding bandwidth compared to the impedance bandwidth of an earlier

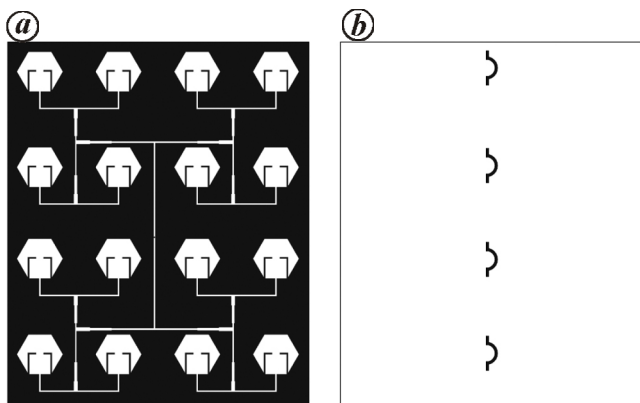


Figure 1. a, 4 × 4 antenna array; b, Four omega shaped DGS on ground plane.

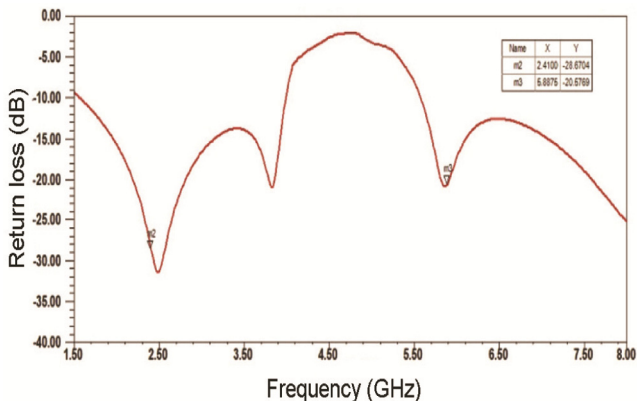


Figure 2. Return loss of antenna array without defected ground structure (DGS).

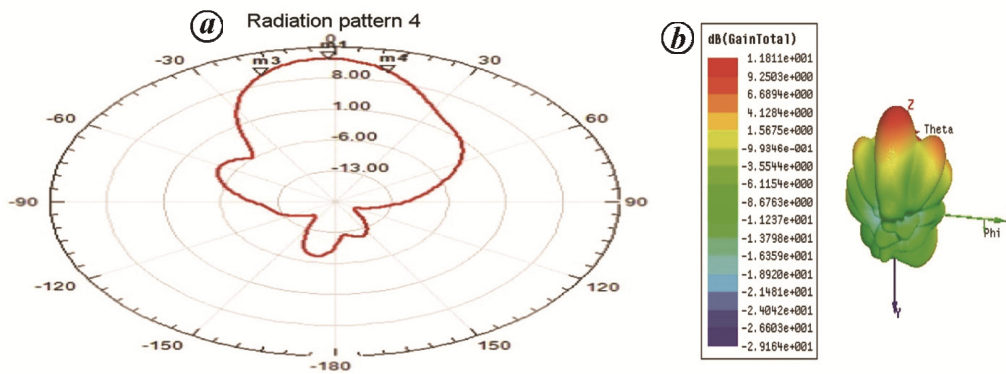


Figure 3. a, Two-dimensional radiation pattern. b, Three-dimensional radiation pattern.

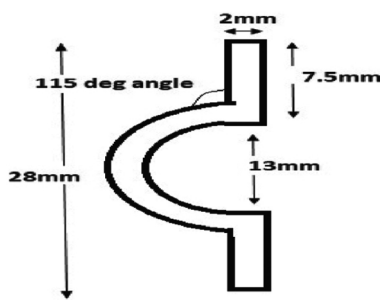


Figure 4. Omega-shaped DGS.

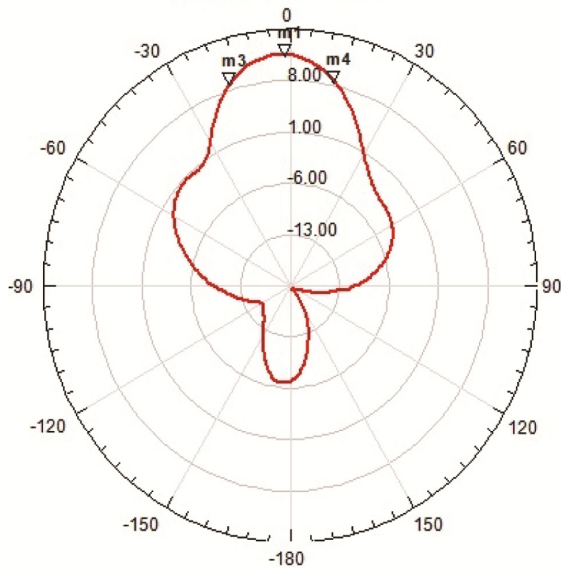


Figure 5. 2D radiation pattern.

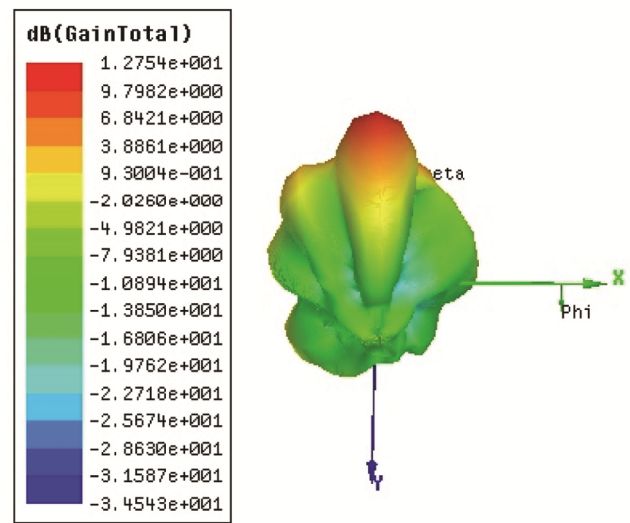


Figure 6. 3D gain radiation pattern.

study²⁵. A 4×4 antenna array with distinct element size has been analysed at 3.5 and 5 GHz. The results of earlier studies^{20,25-27} are compared with those of the present study. It is observed that results of this study are good in the context of bandwidth, cross-polarization and gain. They²⁵ got a bandwidth of 20.4% for the S-band. We obtained a bandwidth of 77.12% for the S-band and 46.56%

for the C-band. Side lobe level was up to -20.11 dB. They²⁵ have utilized the ground plane for S-band. In this article, the vertical length of DGS is 28 mm and width is 2 mm. A 13 mm semicircle opening is chosen. The angle between the semicircle and vertical length is 115° . The amount of current diversion depends on the depth of angle. More the angle, more will be the bandwidth. The 13 mm opening is selected here. If we increase the opening dimension, it will change the shape, i.e. it will become more circular. Figure 6 shows the 2D radiation gain pattern. Beamwidth gets reduced with DGS. It is observed that after DGS, the beamwidth reduces by 10° . It is 30° . Side lobe level is also reduced up to 20.11 dB with DGS. Figure 7 shows the co-cross polarized plot. It is reduced up to -16.5 dB. Polarization is mainly classified into two types, viz. co-polarization and cross-polarization. The latter quantifies how much power is radiated in unwanted directions. So it should be as low as possible. X pol is a loss of signal at the receiver end. It is a noise signal as far as detection is concerned. Co pol is the radiation in the desired direction. The cross polar is

Table 1. Comparison of antenna array with and without DGS

Results	Frequency (GHz)	Return loss (dB)	VSWR	BW (MHz)	Directivity (dB)	Gain (dB)	Beam width (deg)	SLL (dB)	Cross polar (dB)
Without DGS	2.42	-21.16	1.21	1100	12.42	11.8	40.2	-17.5	3.7
	5.87	-16.60	1.34	2400					
With DGS	2.45	-20.09	1.22	1860	13.3	12.7	30.0	-20.11	-16.5
	5.87	-14.94	1.43	2500					

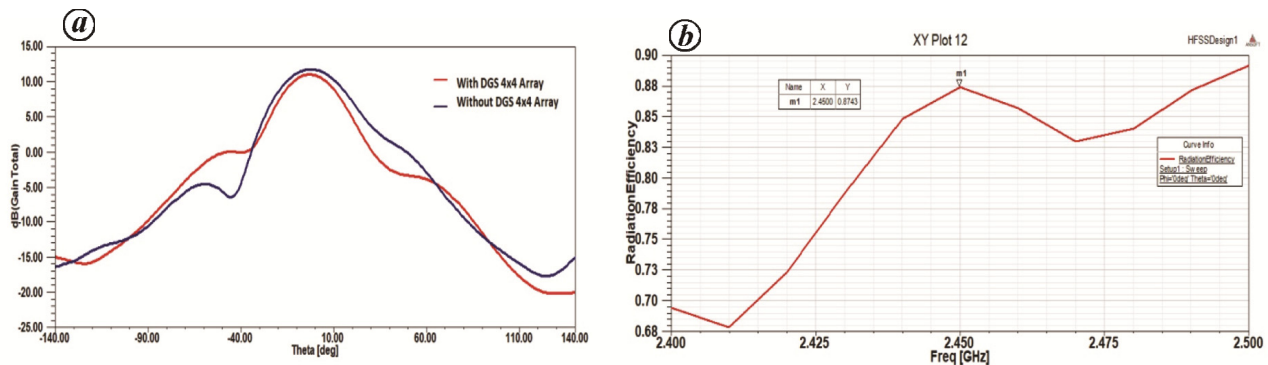


Figure 7. a, Side lobe level plot. b, Frequency versus efficiency plot.

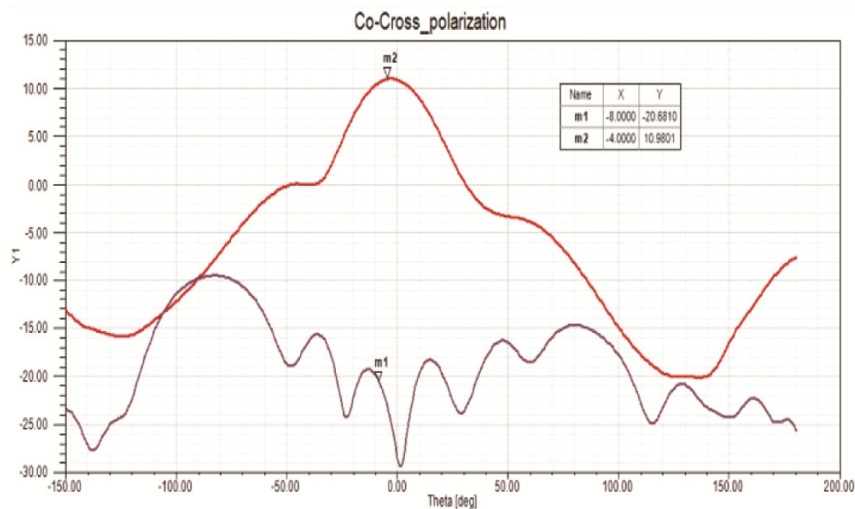


Figure 8. Co-cross polarization.

basically considered as a dissipation in antenna radiation. Co-polarization is defined as the polarization in the desired direction that the antenna was supposed to radiate, while cross pol is defined as its orthogonal pair. A purely polarized antenna will have low cross-polarized radiation. Figure 7 b shows frequency versus efficiency plot, it is up to 88%. Figure 9 shows the E-plane radiation pattern. It is observed that cross-polarization (blue colour) level is below -22 dB and co-polarization level (red colour) is around 12 dB. It is observed that in planar array, cross-polarization has more impact. It is required that the cross-polarization level must be low. In this design, the level is

tolerable. Table 1 shows a comparison between the antenna array with and without DGS. From Table 2, it is observed that bandwidth improved by inserting DGS into the ground plane. Gain and directivity are also enhanced. Cross-polarization is reduced by a great extent.

Conclusion

A novel configuration for a dual-band hexagonal array antenna having wideband performance is proposed in this study. A 4 × 4 hexagonal antenna array with DGS at WLAN 2.4 GHz and C-band 5.8 GHz is used to achieve

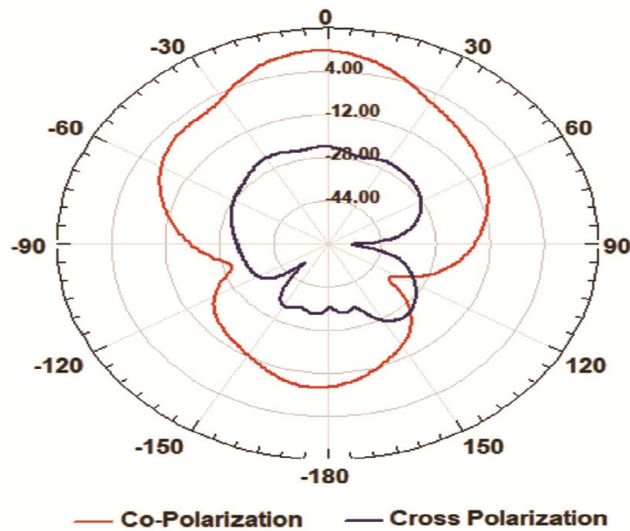


Figure 9. E-plane radiation pattern at 2.4 GHz.

Table 2. Comparison of reference paper results^{19,20,25,26} and proposed antenna array results

Reference	Frequency (GHz)	Bandwidth (MHz)	Gain (dB)	Material	Overall size (mm)
Yin Yue and Jianyi Zhou	2.4	48.96 MHz	7.84	$\epsilon_r = 2.55$, substrate ht = 1 mm	–
Zaakri Safa and Zenkouar Lahbib	12 and 18	Narrowband around 200 MHz	6.49 low	ArlonDiClad 880 of $\epsilon_r = 2.2$	–
Pratigya Mathur and Girish Kumar	2.5 and 8	13%, 6.2%	7.5 dBi, 10.5 dBi	RT 5880	–
R. Rajeswari ¹ , P. Sudharshini ² and S. V. Vidhya Harini ³	3.1 and 4.5	Narrowband around 150 MHz	9.95 high	FR4 ($\epsilon_r = 4.6$)	300 × 340 mm ²
Proposed hexagonal dual band	2.4 and 5.8	Wideband 1860 MHz, 2500 MHz	12.70 high	FR4 ($\epsilon_r = 4.6$)	240 × 290 mm ²

high gain. This configuration uses omega-shaped DGS to reduced size and enhanced bandwidth of the array antenna. It achieves bandwidth of 1860 MHz at WLAN band and 2500 MHz at C-band without any interference between the two bands. We have demonstrated 12 dB improvement in the isolation between co-pol and cross-pol radiations using omega-shaped DGS structure. It is found that the efficiency of this design is 88%. The hexagonal array with corporate feed microstrip antenna characteristics with and without DGS has been studied using CST software. This antenna array is applicable for WLAN and radar systems.

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