A Compact Array with Low Mutual Coupling using Defected Ground Structures

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Abstract: **A modified ground plane structure that can enhance the performance of the closely packed radiating elements is proposed and studied in this paper. The structure consists of a two element square patch array having defected ground structure (DGS). Two different classes of DGSs were used (i) to reduce the size of the whole array and (ii) to reduce the mutual coupling between the radiating elements. Size reduction of approximately 26% and at the same time mutual coupling reduction of about 12dB was achieved with 0.5 λ_0 spacing between the radiating elements at the center frequency of 5.25 GHz. A bandwidth of 235MHz was obtained, making it suitable for WLAN applications. Although developed for a 2-element array, the developed principle can easily be extended for larger arrays.**

I. Introduction

Design and development of compact arrays is one of the major areas of research among antenna engineers now-a-days. With the increase in compactness, the fear of mutual coupling affecting other parameters of the array also increases. Therefore there is a growing challenge to reduce this mutual coupling in compact arrays. Recently DGSs of different shapes were reported in the literature for the same purpose. DGS is an etched lattice shape in the ground plane of planar circuits such as microstrip lines or microstrip antennas that has been used mostly for size reduction of microwave amplifiers [1], cross polarization reduction in microstrip antennas [2], and suppression of the higher order harmonics in antennas [3] and mutual coupling reduction in antenna arrays [4-9].

During the design of planar array, the effect of mutual coupling should be handled carefully, because it affects the other parameters of the array to a large extent. A dumbbell shaped DGS on the ground plane of the E-coupled antenna array has been used to achieve a reduction of mutual coupling of 18.28 dB [4], also the reduction in the higher order harmonics is obtained. A DGS based on narrow closely packed rectangular slots has been proposed to reduce the mutual coupling around 10-12 dB [5], in this case the elements were spaced at $0.7\lambda_0$ distance. An array of two element planer inverted F- antenna (PIFA) has been proposed and parallel slots have been used for the mutual coupling reduction between the elements [6]. A multiband antenna array with Dumbbell shaped DGS has been proposed for the mutual coupling reduction of 5 dB [7-8]. Cylindrical dielectric resonator antenna array has been designed with the ring shaped DGS for the mutual coupling reduction of around 3-5 dB [9].

In the present work multiple DGSs have been used in a two element antenna array. The role of one set of DGS is to reduce the size whereas the other one is used basically to reduce the mutual coupling between the array elements. The overall effect is a compact array with the low mutual coupling. Theoretical investigations are made to show these characteristics.

II. Defected Ground Structure

The basic dumbbell shaped DGS consists of the two square/rectangular areas and one connecting slot in the ground plane of the microstrip circuits. Other geometries can also be used such as rectangular head, circular head and triangular heads etc for the different defects in the ground plane of the microstrip circuits [11]. The DGS is considered as an equivalent circuit consisting of capacitance and inductance as given in the Fig. (1). The equivalent inductive part increases due to the defect and produces equivalently the high effective dielectric constant, that is, slow wave property.

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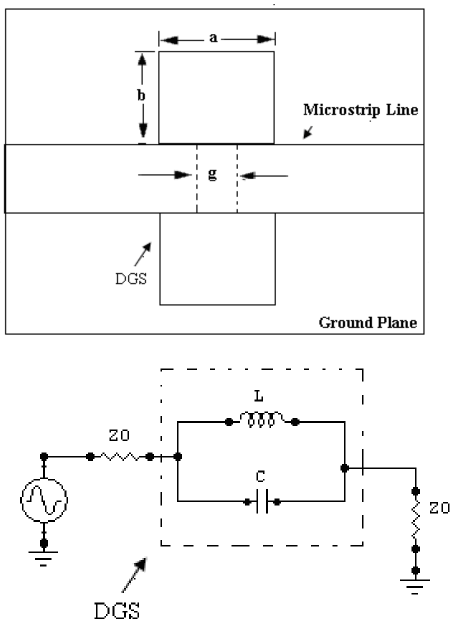


Fig. 1. DGS unit: (a) Dumbbell DGS unit, (b) L-C equivalent of DGS.

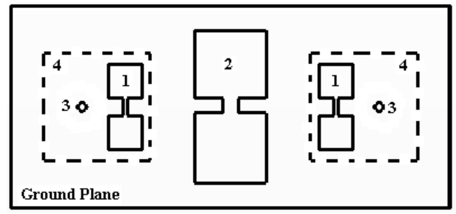
Fig.1 (a) shows the simple and widely used dumbbell shaped DGS which is etched in the ground plane below the microstrip line, in that the both the areas ($a \times b$) and the slot gap (g) play a very important role to find the resonance behavior of the DGS. Fig.1(b) shows the equivalent circuit of the DGS as a parallel combination of Inductance(L) and Capacitance(C). The head areas ($a \times b$) is very useful for the variation in the inductance(L) and the slot (g) produces the capacitance(C). The L and C may be calculated from the formulae given below [12].

$$L = \frac{1}{4\pi^2 f_0^2 C} ; C = \frac{f_c}{2Z_0} \cdot \frac{1}{2\pi(f_0^2 - f_c^2)}$$

where, f_0, f_c and Z_0 denote the resonant frequency, cutoff frequency and characteristics impedance, respectively, of microstrip line above the DGS.

III. Antenna Array Design

A two element E-coupled coaxial feed microstrip patch antenna array is shown in Fig. 2. The material properties of this array are shown in Table 1. Initially the square patch dimensions were calculated from the simple cavity model to operate at 6 GHz. The coax feeds (3) are located 1.666 mm. distance from the centre, in opposite direction to each other. The proposed antenna geometry is shown in the Fig. 2.



1. Square-head dumbbell DGS, **2**. Rectangular-head dumbbell DGS, **3**. Coaxial feed positions, **4**. Radiating patches

Fig.2. Back view of two coax-fed patch antenna array with DGS slots in the ground plane

In this geometry, square-head dumbbell shaped DGS (1) is used under the patch antennas for the size reduction to operate at 5.2 GHz. The elements spacing was fixed initially and taken as $0.5\lambda_0$ corresponding to 5.2GHz frequency. Further the rectangular-head dumbbell shaped DGS (2) has been incorporated in between the patches for the improvement in the mutual coupling reduction. The rectangular-head dumbbell shaped DGS suppresses the surface wave of the antenna elements when the frequency of the antenna elements matches with the resonance frequency given by the rectangular head dumbbell shaped DGS. The design parameters for the antenna arrays are shown in Table-1.

Table-1: Antenna array design parameters

Performance Parameter	With DGS Slots
a. Frequency Band	5.2 GHz
b. Dielectric Material	3.38 (tan δ = 0.0025, thickness = 1.524 mm.)
c. Ground Plane Size	(50×23) mm^2
d. Radiating Element Size	(12.2×12.2) mm^2
e. Resonance Frequency	5.24 GHz
f. Square head dumbbell shaped DGS	$(3.87\times3.87) mm^2$
g. Rectangular head dumbbell shaped DGS	$(8.16\times7.66) mm^2$

IV. RESULTS AND DISCUSSION

The theoretical results of the prototype was obtained using CST microwave studio®[10]. Fig. 3 shows the antenna performance when the antenna was designed at the 5.2 GHz with square patches and without DGS, when all the other parameters were kept constant such as separation distance, ground plane size, dielectric material etc. The $|S_{(1,1)}|$ and $|S_{(21)}|$ were found to be of 15.1 dB and 32.7 dB , respectively, with a bandwidth of 150 MHz (5.12-5.27 GHz).

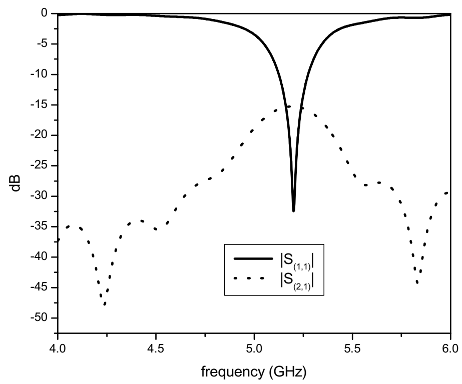
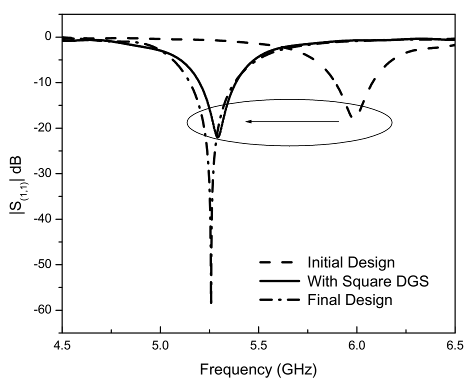
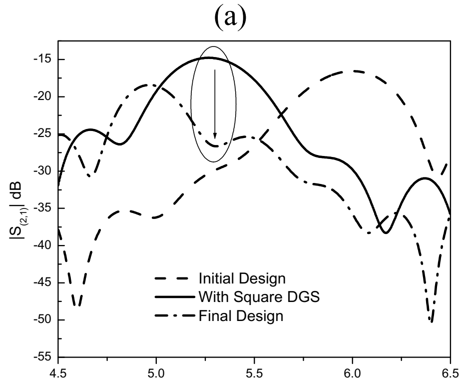


Fig. 3. Antenna performance without DGS at 5.2 GHz



(a)



(b)

Fig.4. Antenna array performance (a).$|S_{(1,1)}|$ dB, and (b).$|S_{(2,1)}|$ dB

Fig. 4. shows the antenna array performance in terms of the S-parameters when the right patch is activated. As it may be seen that, in case of the antenna array with the square DGS (1) under the microstrip antenna elements, the operating frequency moves downward up to 5.2GHz with the same bandwidth which was obtained at 6GHz. When the rectangular-head dumbbell DGS was used, the mutual coupling $S_{(2,1)}$ was found at -27.5dB with $S_{(1,1)}$ of -57.91dB. Thus the DGSs has played important role in terms of the sized reduction or the antenna miniaturization as well as the mutual coupling reduction in a small ground plane of (50×23) mm^2. Table-2 gives the comparison of the final antenna with and without DGSs.

Table 2: Comparison between the antenna arrays with and without DGS

Performance Parameter	Without DGS	With DGS
Patch Size (Calculated)	(14.2 × 14.2) mm^2	(12.2 × 12.2) mm^2
Resonance Frequency	5.204 GHz	5.24 GHz
BW	147.3 MHz	235.1 MHz
S1,1 and S2,1	-32.57 dB and -15.348 dB	-57.91 dB and -27.5 dB
Gain	5.836 dB	6.181 dB

The radiation pattern of the antenna with DGS at the 5.2GHz and the current distribution is shown in Fig.5 and Fig.6, respectively. As marked, the current is highly distributed on the antenna array with the DGS resulting in increased inductance and capacitance. The gain of the antenna is shown in the Fig. 7.

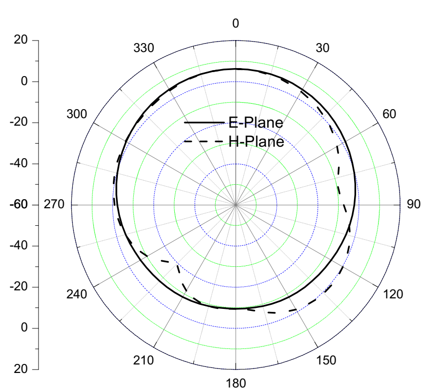


Fig.5. Antenna radiation pattern (E and H-plane)

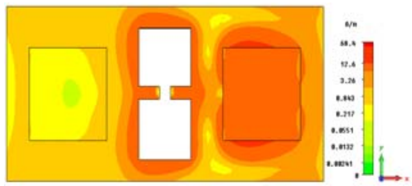


Fig.6. Current distribution on the ground plane of the DGS antenna at the resonance frequency 5.25 GHz, when right patch is activated by the coaxial probe

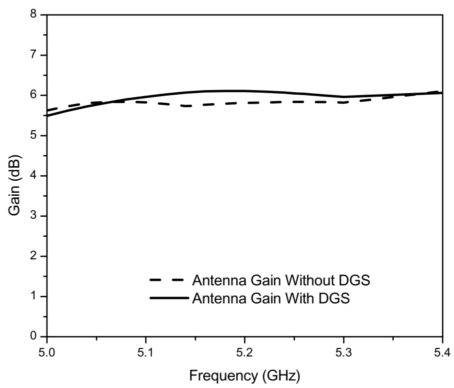


Fig.7. Antenna Gain

V. Conclusion

Performance enhancement of antenna arrays such as size miniaturization of about 26%, improved bandwidth (approximately 235 MHz) and also gain enhanced with the mutual coupling of -27.5 dB which is the reduction of around 10-12 dB for this configuration using a ground plane of a very small size of $(50\times 23)\text{mm}^2$ has been demonstrated in this work with the proper use of DGSs. This antenna array may be used for WLAN application for which the required frequency band is 5.2 GHz (5.15-5.35 GHz). This technique may be extended in various compact antenna array designs with a needful further investigation.

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