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A novel compact defected ground structure and its application in mutual coupling reduction of a microstrip antenna

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Abstract: In this paper, a novel compact T-shape defected ground structure (DGS) is proposed in order to reduce the mutual coupling between elements in a microstrip antenna array structure. The proposed DGS has considerable advantages compared to an H-shaped DGS. As is known, DGS insertion is a common problem in microstrip antenna array structures. However, the proposed T-shaped structure is more compact so it could be suitable for a compact microstrip array antenna. The T-shaped DGS is about 24% more compact than the H-shaped one. However, the most important novelty of our work is reducing mutual coupling both in the E-plane and the H-plane, which previously was discussed just in the E-plane. Finally, we have considered the disturbing effect of mutual coupling on the side lobe level (SLL) of unequally spaced arrays; using these results, a T-shaped DGS has been implemented in an 8-element unequally spaced array antenna in order to reduce its SLL.

Key words: Defected ground structures, mutual coupling, surface waves, side lobe level, unequally spaced array antenna

1. Introduction

Surface waves and mutual coupling are two unwanted parameters in planar-printed circuits (such as microstrip array antennas) that reduce the efficiency and disturb the radiation pattern of the antenna [1]. An efficient method to reduce these effects is implementing defected ground structures (DGSs), which are etched defects in the ground plane of planar transmission lines. DGSs have found various applications in different microstrip circuits like filters, dividers, and amplifiers. They are also widely used in suppressing the mutual coupling and surface waves between the elements of an array antenna [2–4]. These structures change the equivalent capacitance and inductance of the transmission line and perturb the current distribution in the ground plane. Therefore, DGSs can increase characteristic impedance, decrease the effective wavelength, and cause size reduction. DGSs are low-profile and cost less to fabricate than EBG structures, as they can be created just by etching designed defects in the ground plane in a periodic [5–7] or single structure [8]. DGSs provide desired frequency response characteristics, such as a stop band in some frequency range and pass bands in other frequency ranges, which make them appropriate for harmonic suppression [8,9].

Some other applications of DGSs are phase noise reduction [6], improving of amplifier performance [7], and reduction of cross-polarization in microstrip antennas [10]. There are various DGS configurations such as rectangular [6], dumbbell [11,12], spiral [11], and fractal [13]. In [14], an H-shaped DGS was proposed, with

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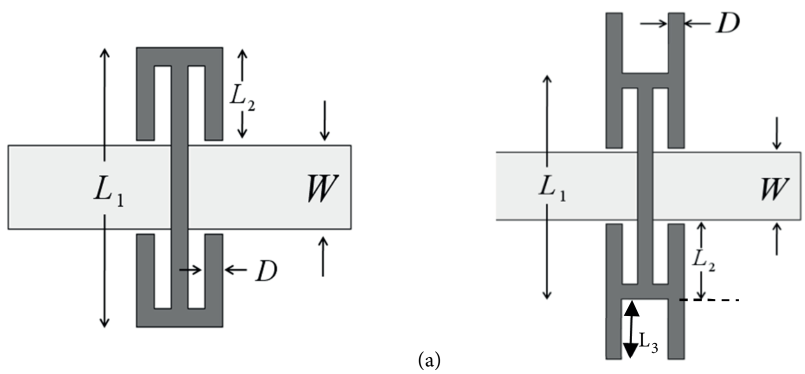
dimensions about 26% smaller than a dumbbell DGS. In [15], a new DGS was proposed by removing the narrow slots of a dumbbell DGS and it was shown that this new structure has a wider range of gap capacitance than the dumbbell DGS. In [16], the application of a dumbbell DGS (proposed in previous papers) in mutual coupling reduction just in the E-plane in microstrip antennas was investigated. In this paper, a novel compact DGS has been proposed for microstrip array application in order to reduce mutual coupling and surface waves between elements in both E-plane and H-plane arrangement.

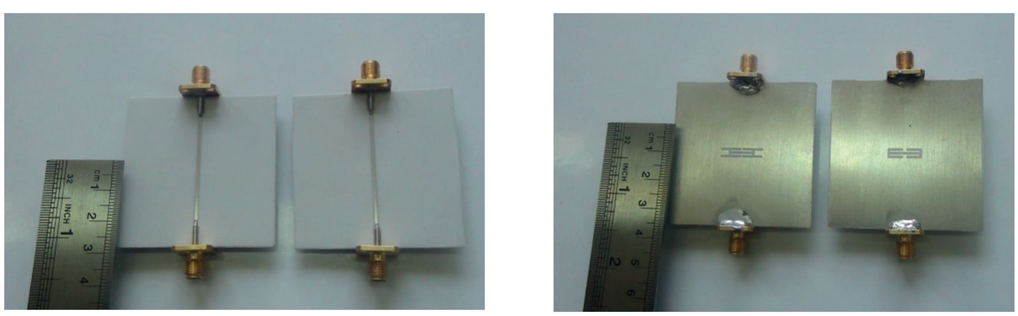
2. DGS configuration and characteristics

2.1. Structure

In Figures 1a and 1b, the proposed T-shaped DGS and conventional H-shaped DGS geometry are shown. The reference characteristic impedance of the transmission line is 50 Ω. The designed structure was fabricated on a Rogers 4003 substrate with a relative permittivity of $\varepsilon_r = 3.55$ and thickness of 1.02 mm. The length of the DGS main slot was $L_1 = 11.23$ mm; T-shaped slots with lengths of $L_2 = 4.95$ mm were etched on both tops of the main slot. Widths of all slots and the spaces between slot branches were D = 0.64 mm. The maximum length and width of the whole DGS were L_1 and $5 \times D$, respectively.



(a)



(b)

Figure 1. a) T-shaped and H-shaped DGS and b) fabricated T-shaped and H-shaped DGS top and bottom views.

As we know, the main slot adds a capacitive effect and the T-shaped slot adds an inductive effect that can be modeled by a parallel LC resonator in series with the transmission line, as shown in Figure 2. The dimensions of the H-shaped DGSs were $L_1 = 8.41$ mm, $L_2 = 3.86$ mm, and $L_3 = 3.24$ mm, with the same width of D.

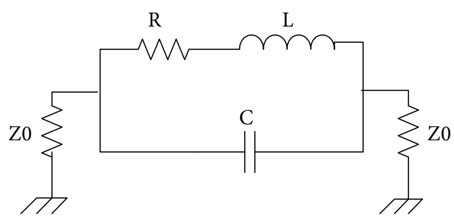


Figure 2. Equivalent circuit of T-shaped DGS.

2.2. Accommodation comparison

One of the problems with implementing DGSs is the space limitation, which is related to the circuit size and the occupation area of the DGS slots. This makes the DGS inappropriate for high-frequency applications such as dual band printed antennas. By minimizing the DGS, it could have more usages in high-frequency applications. Therefore, the more compact the DGS is, the more usages it will have in high-frequency applications. Here, by designing the slots with the dimensions mentioned in Section 2.1, the proposed DGS is about 24% more compact compared to an H-shaped DGS at the same resonant frequency. Finally, the conventional H-shaped DGS and our proposed T-shaped DGS S-parameters were simulated using EM FEM-based simulation software (HFSS 10) at the same resonant frequency of 5 GHz, as shown in Figure 3a. Then they were fabricated. After fabrication, the measurement results agreed with the simulated results shown in Figure 3b. In addition to compactness, the T-shaped DGS has a slightly higher Q factor than the H-shaped DGS, which results in a deeper stop band.

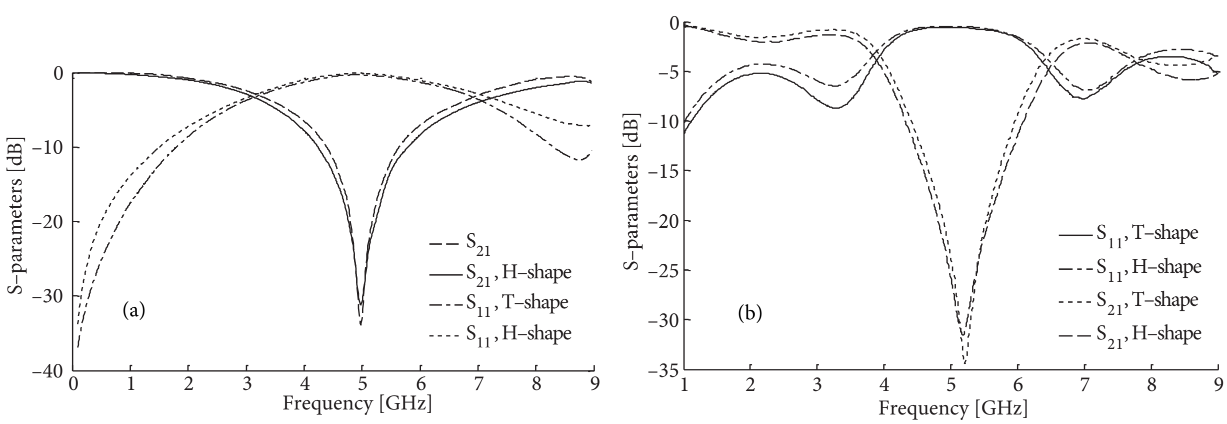


Figure 3. a) T-shaped and H-shaped DGS S-parameters simulation results. b) Measurement results.

3. Mutual coupling reduction and results

One of the problems in planar printed circuits, especially in microstrip array antennas, is the surface wave, which is the dominant factor in producing mutual coupling between array elements. Previously, the effect of DGS in reduction of mutual coupling between elements was just studied in the E-plane [17], but in this paper the effects of DGS both in the E-plane and the H-plane were studied; there was a good improvement in reduction of mutual coupling in both the E-plane and the H-plane. In addition, the proposed DGS has a more compact structure in comparison with the previous DGS structure [17], which facilitates its usage in microstrip antenna arrays.

The implementation of the T-shaped DGS in the E-plane between two adjacent elements of an array is shown in Figure 4a. The dimension of the patch elements are W_p and L_p, with a resonant frequency of 2.39

GHz. The distance between the two adjacent patch elements was 0.5 λ and the DGS was located exactly in the middle of them. It should be noted that unlike microstrip transmission line application, in the microstrip patch array there would be a shift in the stop band of the DGS. Therefore, DGS slot dimensions should be adjusted in order to obtain the required stop band frequency. Figure 4b shows the geometry of two adjacent elements of an array with the T-shaped DGS in the H-plane. The insertion of a DGS in the H-plane differs with the E-plane in order to reduce mutual coupling. Placing the two DGS slots near the radiation edges of the patches in the H-plane as well as in the middle of them would result in a greater reduction of mutual coupling. The reason is that on the array patches, the current distribution is minimal near the center of the patch and maximal near the radiation edges of the patch. Thus, the DGS should be located near the radiation edges of the patch in order to have an impressive effect on the mutual coupling in the H-plane. The dimensions of the E-plane DGS are L_1 = 26.2 mm, L_2 = 9.1 mm, and D = 2.6 mm and the dimensions of both H-plane DGS structures are L_1 = 24.3 mm, L_2 = 9 mm, and D = 2.5 mm. The distance between these two H-plane DGS structures is 54 mm.

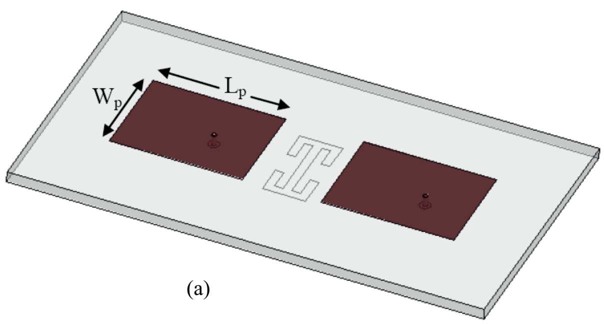


Figure 4. a) T-shaped DGS geometry between antenna patches for E-plane arrangement. b) T-shaped DGS geometry between antenna patches for H-plane arrangement.

Figures 5a and 5b illustrate the S_{21} parameter of the two adjacent patches with T-shaped DGS in both the E-plane and the H-plane. Both are compared to the case without DGS. As shown in Figure 5a, mutual coupling between two adjacent patch elements is reduced by about –8 dB in the E-plane with respect to the non-DGS patches. In the same procedure, in the H-plane the result shows that at the resonant frequency of the antenna, a reduction of –9 dB was achieved in mutual coupling in comparison with the non-DGS structure.

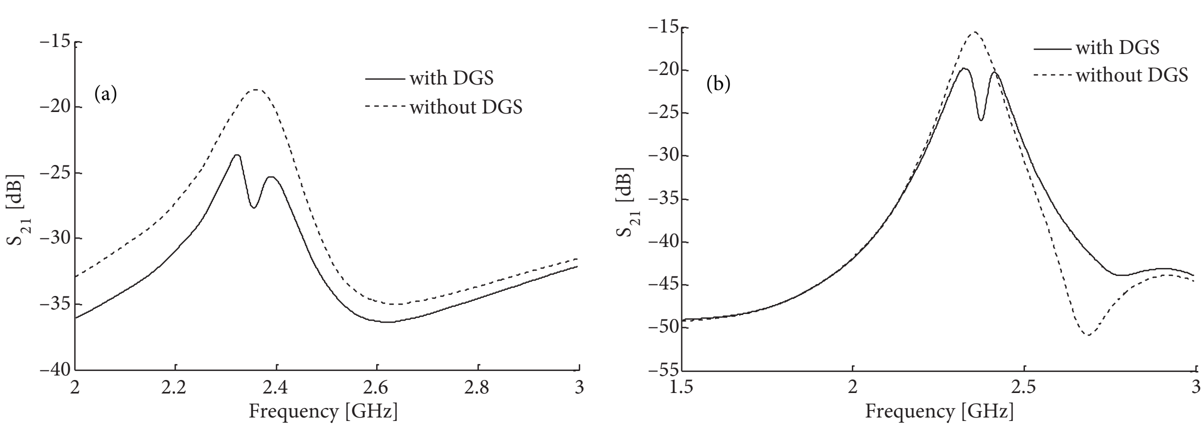


Figure 5. a) Simulated S_{21} of two-element array with and without DGS for E-plane arrangement. b) Simulated S_{21} of two-element array with and without DGS for H-plane arrangement.

Figures 6a and 6b illustrate the S_{11} parameter of the two adjacent patches with the T-shaped DGS in both the E-plane and the H-plane and without the DGS. There was a slight shift in the resonant frequency between the DGS antenna and the conventional antenna, which was due to the slow-wave effects of DGS.

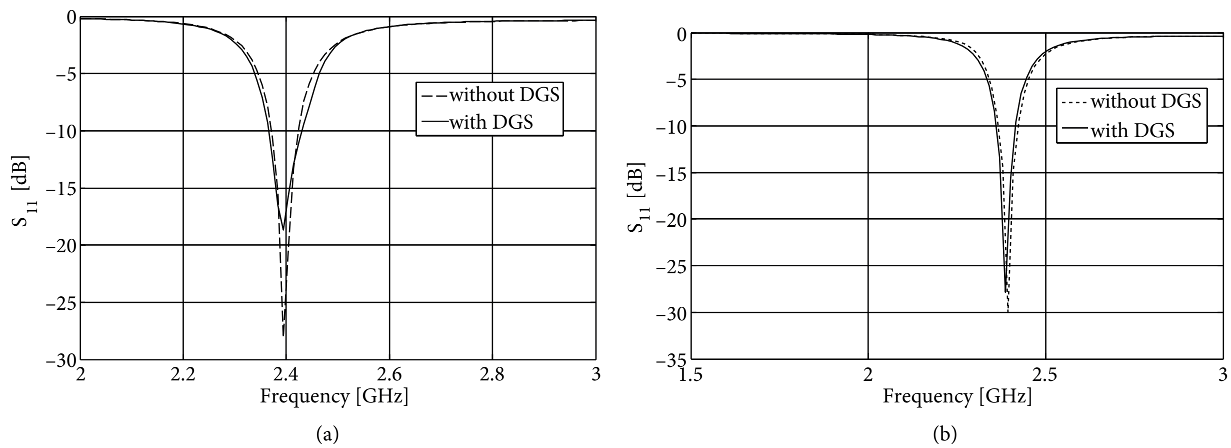


Figure 6. a) Simulated S_{11} of two-element array with and without DGS for E-plane arrangement. b) Simulated S_{11} of two-element array with and without DGS for H-plane arrangement.

Simulated radiation patterns of two-element arrays with and without DGS for both the E-plane and the H-plane at 2.39 GHz are shown in Figure 7. In the case with DGS, the back lobe level is increased slightly due to the existence of the DGS, which acts as a slot radiator.

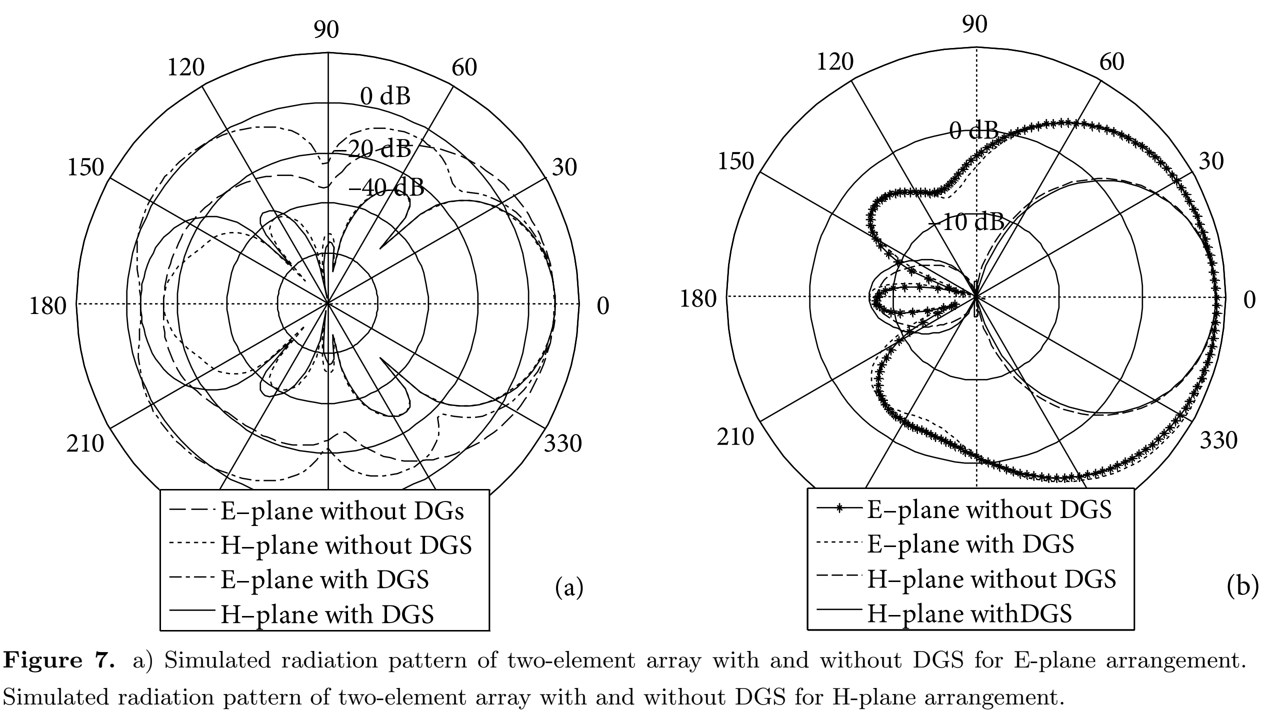


Figure 7. a) Simulated radiation pattern of two-element array with and without DGS for E-plane arrangement. b) Simulated radiation pattern of two-element array with and without DGS for H-plane arrangement.

As mentioned in [18], mutual coupling could increase the side lobe level of the unequally spaced patch arrays. Thus, in order to reduce the side lobe level, a linear 8-element uniform amplitude unequally spaced microstrip array was designed based on [19] (Figure 8a). The synthesized element positions of the patch array are given in Figure 8a (with assumption of a symmetric array structure). The operating frequency of the designed patch is 2.39 GHz. As mentioned above, the mutual coupling effect on the side lobe level can be reduced by using a T-shaped DGS. In Figure 8b, the pattern is illustrated for the arrays with and without DGS. First and second side lobe level decreases, while third and fourth side lobe level increases. As can be seen, implementation of the DGS reduces the maximum side lobe level by 2 dB.

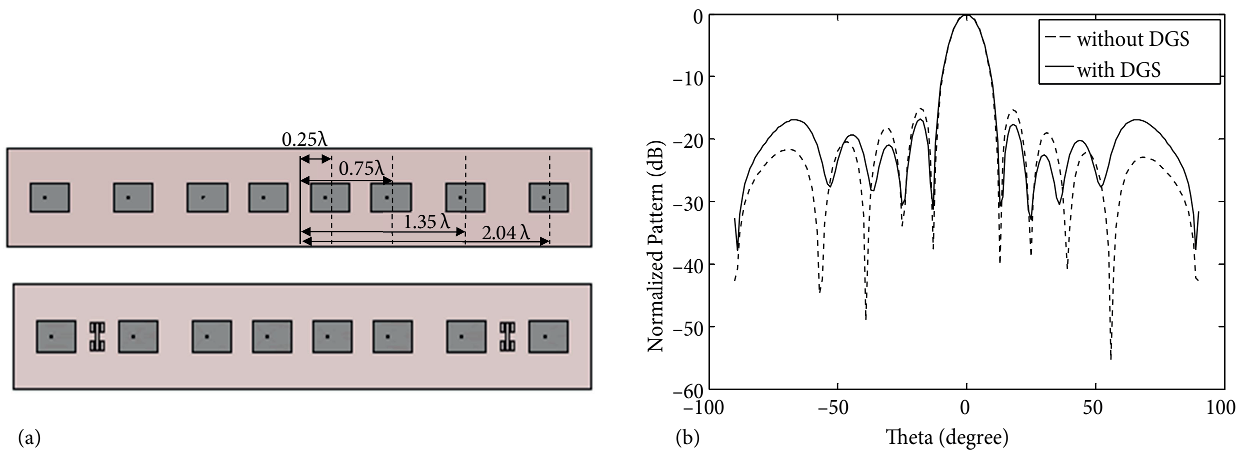


Figure 8. a) Structure of linear array with and without DGS. b) Normalized pattern of unequally spaced linear array with and without DGS.

4. Conclusion

A novel compact T-shaped DGS was proposed and applied to two adjacent microstrip elements. This proposed DGS has the advantage of occupying less area compared to conventional DGSs. Next, it was shown that mutual coupling was reduced both in the E-plane and the H-plane. The reasoning behind the DGS configuration for the H-plane is that the current distribution is minimal at the center of the patch and it would increase approaching the radiation edges (regarding the feed position). Therefore, the DGS must be placed near the radiation edges, instead of the centerline of the patch, in the H-plane in order to have an appropriate effect. Finally the DGS was used in an unequally spaced array in order to reduce its side lobe level.

Acknowledgments

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