Introducing a Novel Defected Ground Structure For Microstrip Applications

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***Abstract*—A novel compact and simple shape of defected ground structure (DGS) is introduced for microstrip applications. The DGS cell is etched on the ground plane between the array elements or in filter applications. Three shapes of DGSs, namely narrow strip, symmetric comb and asymmetric comb, are proposed, analyzed and compared. Parametric studies of DGS parameters for a transmission line loaded with unit cell DGS are presented. The results indicate that the asymmetric comb shaped DGS is better at suppressing propagation of surface waves in microstrip substrate.**

Keywords-component; antenna; microstrip; mutual coupling; DGS ; filter.

I. INTRODUCTION

DURING recent years, microstrip array antennas have been used widely because of their simple manufacturing, small size, light weight and low cost [1-4]. They are used in phased array antennas applications such as pattern beam forming, smart antennas and electronic scanning radars [4]. Also they are used in microwave components like filters, power dividers and other things.

In a patch antenna array structure surface waves and near fields can lead to coupling between the elements [5, 6]. The near-field coupling arises when an antenna element is placed in the near-field zone of another element. In a microstrip phased array, the surface waves increase the mutual coupling between array elements, which cause impedance and pattern anomalies associated with the blind scan angle [5]. In such scenarios, the coupling can result in severe degradation to the antenna's radiation characteristics.

One of the techniques to reduce mutual coupling between patch array elements is by cutting a slot inside the ground plane, referred to as DGS [7]. Most of the works reported so far include DGS shapes such as rectangle [8], dumbbell [9], spiral [10], H-shape [11], L-shape [12], and complementary split-ring resonator [13]. To increase the mutual coupling reduction one needs to place several of such simple DGS structures near to each other in between the array elements. Due to the limit in the space between the patch array elements one can only place a few of such DGS unit cells, thus, limiting the overall reduction in mutual coupling.

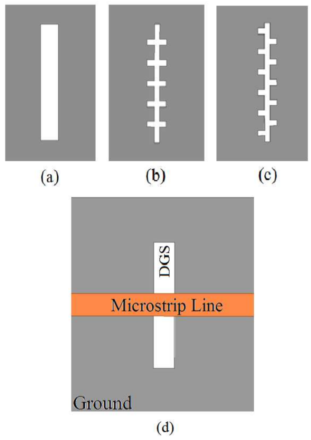

Fig. 1. Configuration of the proposed DGS cells (a) Narrow strip, (b) Symmetric comb and (c) Asymmetric comb. (d) A microstrip transmission line placed on top of a typical proposed DGS cell.

In this paper, introducing a novel compact and simple DGS shape for microstrip applications is proposed. The shape and size of the slot used in the DGS is such that several of them can be placed in series in various microwave applications.

The simulation is carried out through the commercial software Ansoft HFSS. A prototype is fabricated and measured results are compared with simulation.

II. CHARACTERISTIC ANALYSIS OF THE PROPOSED DGS

A. *Introducing the new DGS cells*

The DGS cell is etched on the ground plane between the array elements. Three types of DGS shapes namely narrow strip, symmetric comb and asymmetric comb as shown in Fig. 1 are proposed. All three proposed DGS cells have the same overall slot length and width.

To see the filtering performance of the proposed DGS cells, a 50 Ω microstrip transmission line can be placed on top of each of the proposed DGS cells, as shown in Fig. 1d.

As shown in Fig. 2, the simulated result of S_{12} for the three DGS cells show that for a resonant frequency of 5 GHz the dimensions of the DGS structures should be optimized. The optimization show that for the proposed resonant frequency the dimension of the narrow strip shaped DGS should be very narrow. Array of such cells will not result in a good mutual coupling reduction. For the symmetric comb shaped DGS the length of arms should be large and thus many of them cannot be placed in series in a limited space between array elements to produce large reduction in mutual coupling.

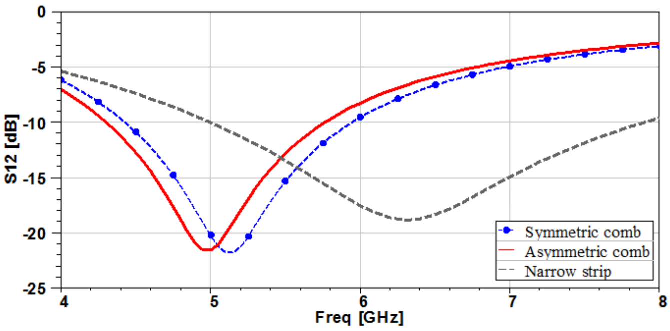

Fig. 2. S_{12} of various DGS cell shapes

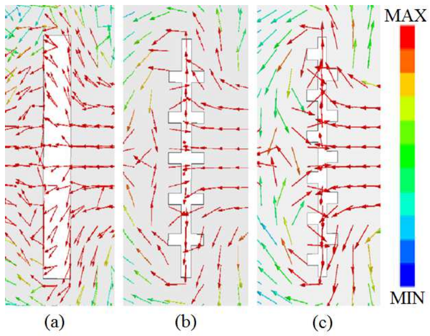

Fig. 3. Poynting vector distribution in the ground plane of the microstrip line with various DGS cells

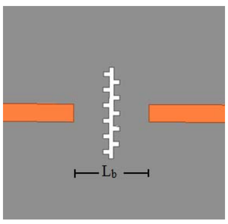

Fig. 4. The DGS structure with two weakly coupled microstrip lines

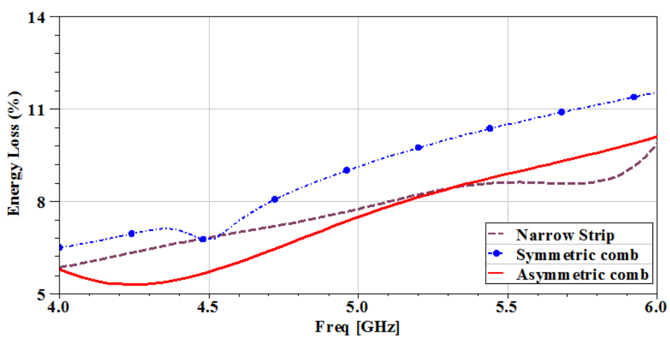

Fig. 5. Energy loss for various types of DGS unit cells

From Fig. 2, the asymmetric comb shaped DGS seems to provide low mutual coupling with the smallest arms. This is suitable for placing several of such cells in series between array elements.

To see the performance of the three DGS cells even further, Fig. 3 shows the Poynting vector behavior in the ground plane of the structure shown in Fig. 1d. It can be seen that the asymmetric comb shaped DGS has lower power transmission than the other two cells.

To see how much energy is coupled between two patch antennas, one can use the transmission line structure of Fig. 4, where the DGS structure is laid on the center of the ground plane between two weakly coupled microstrip lines with 50 Ω characteristic impedance, this method has been successfully used in ultra wide band filter design to study the property of the microstrip stepped-impedance resonators [14]. In our studies, the distance L_b between two open ports of the weakly coupled microstrip lines is 16 mm, which is enough to avoid a strong coupling between DGS and the open microstrip lines. The energy loss, EL, is calculated from the following [15]

$$\mathrm{EL}(\%) = \left[1 - \left(|S_{11}|^2 + |S_{12}|^2\right)\right] \times 100 \tag{1}$$

Fig. 5 shows the calculated energy loss for different DGS cells. The asymmetric comb shaped DGS exhibits a lower energy loss within a wider bandpass.

From the above consideration it can be concluded that from the three DGS cells proposed the asymmetric comb DGS provides the lowest mutual coupling.

B. *Asymmetric comb shaped DGS unit cell parametric study*

Fig. 6 shows the unit cell of the asymmetric comb DGS structure, which will be referred to as the ACDGS cell. The optimized dimensions of the ACDGS structure are: L = 21 mm, $a = b = f$ = 1 mm, c = 1.25 mm, d = 2.6 mm, and e = 2.5 mm. The ACDGS is etched in the ground plane of the substrate which has a dielectric constant of ε_r=3.38, $\tan\delta$=0.004, and a thickness of h=1.63 mm

The effect of varying the parameter d, of a unit cell ACDGS cut from the ground plane of a 50 Ω microstrip transmission line is shown in Fig. 7. The simulated S_{12} results show that when d is varied from 2.5 to 2.7 mm, the S_{12} remains almost constant around -22 dB while the cell resonance center frequency decreases from 5.15 GHz to 4.85 GHz and its bandwidth remains constant.

Fig. 8 shows the S_{12} of the microstrip transmission line loaded with unit ACDGS cell for various cell parameter c while d is set at 2.6 mm. The simulated results show that with an increase in c, the cell resonance frequency decreases while the S_{12} remains almost unchanged around -22 dB. Also this study shows that with decrease in c, bandwidth slightly increases. Thus, one can use parameter d and c to tune the resonant frequency finely.

C. *Equivalent circuit model of the ACDGS cell*

The DGS is a slot etched in the ground plane of the microstrip line. This slot disturbs the current distribution in the ground plane. The DGS unit cell can provide cutoff frequency and attenuation pole at certain frequency. The DGS structure increases the effective permittivity leading to an increase in the effective inductance and capacitance of the microstrip line. Therefore, the DGS can be modeled simply as a parallel RLC resonant circuit [7]. The etched gap area under the microstrip line corresponds to a capacitance and the space between the ACDGS-arms is equivalent to an inductance. In order to extract the values of the equivalent circuit elements, the S-parameters of the ACDGS unit cell are calculated using an EM simulator. By circuit and microwave theory [16], the inductance and capacitance of the equivalent parallel RLC circuit can be expressed by the following equation:

$$C = \frac{5f_c}{\pi.(f_p^2 - f_c^2)} \quad pF \tag{2}$$

$$L = \frac{250}{C.(\pi.f_p)^2} \quad nH \tag{3}$$

At the resonant point, the DGS cell behaves as a pure resistance R, and it can be expressed in (4):

$$R = 2Z_0\left(\frac{1}{|S_{21}|} - 1\right) \quad \Omega \tag{4}$$

Where f_c is the cutoff frequency and f_p is the resonant frequency that can be obtained from the EM-simulation result of Fig. 9, which are 3.2 GHz and 5 GHz respectively. Z_o is the characteristic impedance of the microstrip line which is set at 50 Ω. At this resonant frequency the value of S_{12} is -21.9 dB. Through equations (2) to (4) one can calculated C = 0.3452 pF, L = 2.937 nH and R = 1150 Ω. Thus, the equivalent circuit of Fig. 10 can be used. Through commercially available package, Microwave Office, the S_{11} and S_{12} of the equivalent circuit can be compared to those of simulation, Fig. 9. The equivalent circuit results show excellent agreement with those of the simulated results.

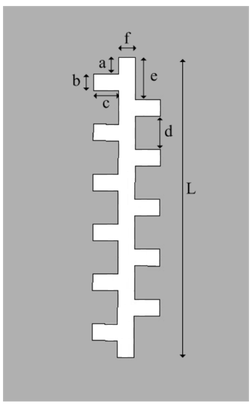

Fig. 6. The dimension of the asymmetric comb shaped DGS structure

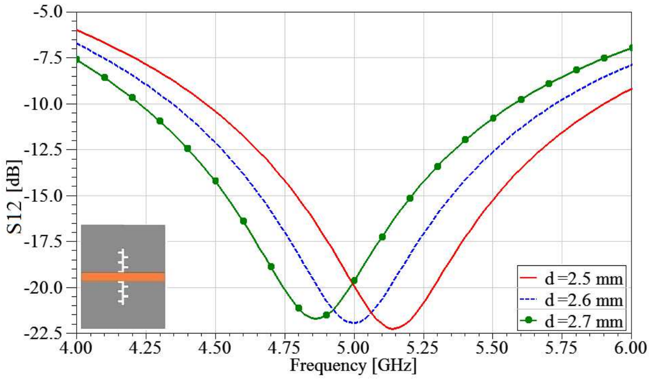

Fig. 7. S_{12} for various ACDGS parameter *d*.

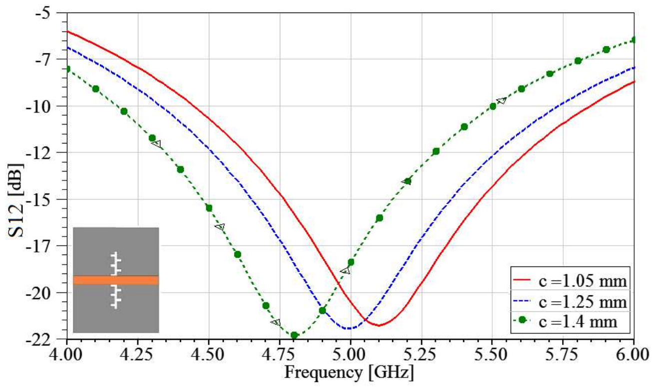

Fig. 8. S_{12} for various ACDGS parameter *c* with *d*=2.3 mm.

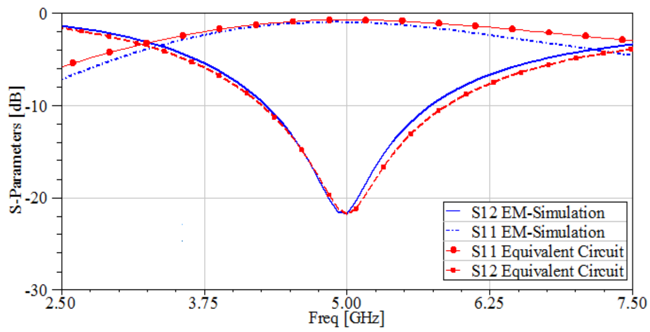

Fig. 9. The simulated and calculated (from equivalent circuit) S-parameters for the ACDGS unit cell

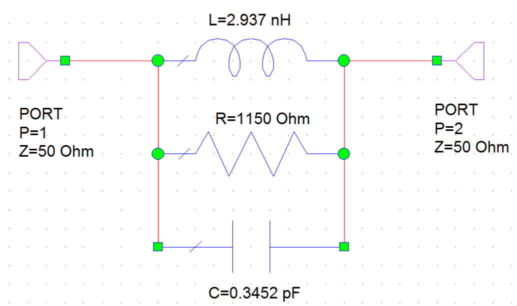

Fig. 10. Equivalent circuit model for the ACDGS unit cell

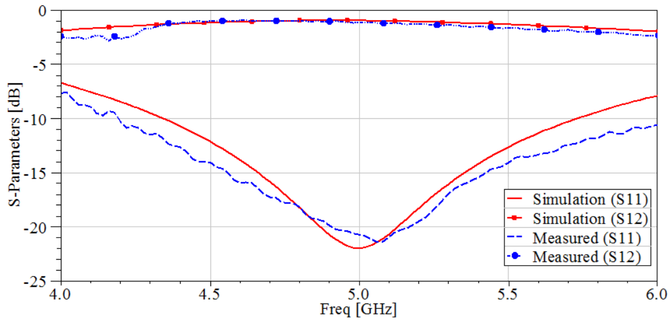

Fig. 11. Measured and simulated S-parameters for the ACDGS unit cell

The ACDGS structure shown in caption of Fig. 7 is fabricated and its measured results are shown in Fig. 11.

The proposed asymmetric comb shaped DGS unit cell, can be placed in between elements of patch antenna array. A two-element microstrip array with ACDGS is designed and the array characteristics against different element separations are studied. The results show that the degree of the mutual coupling suppression is increased when the element separation is reduced and also show that a relative reduction in mutual coupling of 23 dB as compared to the same structure without the DGS is obtained [17].

III. Conclusion

In this paper, three shapes of DGSs, namely narrow strip, symmetric comb and asymmetric comb, are proposed, analyzed and compared. Parametric studies of DGS parameters for a transmission line loaded with unit cell DGS are presented. The results indicate that the asymmetric comb shaped DGS (ACDGS) is better at suppressing propagation of surface waves in microstrip substrate. The equivalent circuit model of the ACDGS unit cell are proposed and in order to obtain the values of the equivalent circuit elements, the S-parameters of the ACDGS unit cell are calculated using an EM simulator and finally the measurement of the fabricated structure are compared and the results show good compatibility with the simulated results.

References

[1] David M. Pozar, “Microstrip antenna”, *Proceeding of the IEEE*, Vol.80, 1992.

[2] K. R. Carver and J. W. Mink, “Microstrip Antenna Technology”, *IEEE Transactions on Antennas and Propagation*, Vol. 29, NO. 1, 1981.

[3] N.Ghassemi and S. Mohanna, “Wideband Microstrip Antenna Array Using aperture Coupled Elements” , *Progress in Electromagnetics Research Symposium*, , Place: Russia, 18 August 2009.

[4] R. Osman, “Microstrip array antenna for automobile radar system”, MSc thesis, University Technology Malaysia, 2006.

[5] A. Bhattacharyya, “Characteristics of space and surface waves in a multilayered structure,” *IEEE Trans. Antennas Propag*., vol. 38, no. 8, pp. 1231–1238, Aug. 1990.

[6] M. Nikolic, A. Djordjevic, and A. Nehorai, “Microstrip antennas with suppressed radiation in horizontal directions and reduced coupling,” *IEEE Trans. Antennas Propag*., vol. 53, no. 11, pp. 3469–3476, Nov. 2005.

[7] D. Ahn, J. S. Park, C. S. Kim, J. Kim, Y. Qian, and T. Itoh,“A design of the low-pass filter using the novel microstrip defected ground structure,” *IEEE Transactions Microwave Theory Tech*., vol. 49, pp. 86–93, Jan. 2001.

[8] H. Liu, Z. Li, X. Sun, and J. Mao, “Harmonic suppression with photonic bandgap and defected ground structure for a microstrip patch antenna,” *IEEE Microw. Compon. Lett*., vol. 15, no. 2, pp. 55–56, Feb. 2005.

[9] Mohsen Salehi, Alireza Motevasselian, Ahad Tavakoli, and Teimur Heidari, “Mutual Coupling Reduction Of Microstrip Antennas Using Defected Ground Structure,”*IEEE Electronic letters*,2006.

[10] J.-S. Lim, C.-S. Kim, Y.-T. Lee, D. Ahn, and S. Nam, “A spiral shaped defected ground structure for coplanar waveguide,” *IEEE Microw. Compon. Lett*., vol. 12, no. 9, pp. 330–332, 2002.

[11] Mandal M.K., Sanyal S, “A novel defected ground structure for planar circuits,”*IEEE Microwave Wireless Lett.*, 16, (2), pp. 93–95., 2006.

[12] E. K. I. Hamad, A. M. E. Safwat, and A. S. Omar, “Controlled capacitance and inductance behavior of L-shaped defected ground structure for coplanar waveguide,” *in Proc. IEE Microwave Antennas Propagation*, vol. 152, pp. 299–304, Oct. 2005.

[13] Mohammed M. Bait-Suwailam, Omar F. Siddiqui, and Omar M. Ramahi, “Mutual Coupling Reduction Between Microstrip Patch Antennas Using Slotted-Complementary Split-Ring Resonators”, *IEEE Antennas Wireless Propag. Lett*, VOL. 9,pp. 876 – 878, 2010.

[14] Li, R., Zhu, L.: “Compact UWB bandpass filter using stub-loaded multiple-mode resonator”, *IEEE Microw. Wirel. Compon. Lett*., 17, (1), pp. 40–42,2007.

[15] S. Xiao M.-C. Tang Y.-Y. Bai S. Gao B.-Z. Wang. “Mutual coupling suppression in microstrip array using defected ground structure”, *IET Microw. Antennas Propag*., Vol. 5, Iss. 12, pp. 1488–1494, 2011.

[16] Hong, J.S., Lancaster, M.J. “Microwave filters for RF & microwave applications” Wiley, New York, 2001.

[17] Y. Hajilou, H. R. Hasani, B. Rahmati “Mutual Coupling Reduction Between Microstrip Patch Antennas,” accpeted for publication in coming 6th EUCAP Conference, Prague, 26-30 March 2012.