Progress In Electromagnetics Research Letters, Vol. 52, 93–97, 2015

A Novel Coupled-Defected Ground Structure with Enhanced Coupling-Coefficient and Its Application in Filter Design

Si-Si Chen[1], Lin Li[1, *], and Zhi-Yong Chen[2]

Abstract—A novel coupled-defected ground structure (C-DGS) with inductors inserted between the adjacent defected ground structure (DGS) cells is presented in this paper. In comparison to conventional C-DGS structure, the proposed C-DGS exhibits a larger coupling-coefficient, resulting in a wider stop-band. Moreover, the stopband can be adjusted flexibly without modification since the coupling-coefficient varies with the change of the inductance of the inserted inductor. Based on this new C-DGS, a low-pass filter (LPF) using cascaded C-DGS is constructed. The proposed structure is experimentally verified through the demonstration of a low-pass filter design.

1. INTRODUCTION

Defected ground structures (DGSs) are desirable because they exhibit lots of attractive characteristics including high impedance, wide stopband, simple structure and small size occupations. As a result, DGSs have been widely employed to develop new microwave and millimeter component with enhanced performance.

For band-stop filters, u-slot and v-slot DGSs can provide a band-rejection property with an improved Q factor [1]. What is more, an interdigital DGS which provides a higher capacitive coupling value has advantages in designing band-stop filters [2]. An etched lattice shape is used to design microstrip low-pass filters with extended stopband [3]. Expanded to the geometrical shapes of a DGS, they can be used to design a microstrip stub compact 3-pole bandpass filter (BPF) [4]. Besides, the Giuseppe Peano fractal geometry of DGS is applied for miniaturization of microstrip patch antennas [5].

Generally, DGSs with wider stopband are desirable in many components. However, single DGS always fails to provide wide stopband since only one transmission zero is created. To expand the stopband, a coupled-defected ground structure (C-DGS) has been proposed in [6]. By utilizing the inductive coupling between adjacent DGS cells, extra transmission zeros can be excited to create a wider stop-band. In that design, the coupling effect is mainly related to the distance between of two adjacent DGS cells and the lattice dimension. However, the distances between the cells are always limited by the fabrication tolerance.

In this paper, a novel coupled-defected ground structure with enhanced inductive coupling-coefficient is proposed. It is revealed in this paper that this new C-DGS exhibits a larger coupling effect and accordingly wider stopband as compared to the conventional C-DGS. Finally, the validity of the proposed C-DGS is verified by experiments of a new low-pass filter based on this new C-DGS.

2. THE NOVEL COUPLED-DEFECTED GROUND STRUCTURE

As shown in Figure 1, conventional C-DGS consists of two closely located dumbbell-shaped DGS cells. The dumbbell-shaped DGS unit is fully described by two parameters: the etched lattice

Received 5 February 2015, Accepted 19 March 2015, Scheduled 25 March 2015

* Corresponding author: Lin Li (lilin_door@hotmail.com).

[1] Department of Electronic Engineering, Zhejiang Sci-Tech University, Hangzhou, Zhejiang 310018, China. [2] Department of Communication Engineering, Zhejiang Sci-Tech University, Hangzhou, Zhejiang 310018, China.

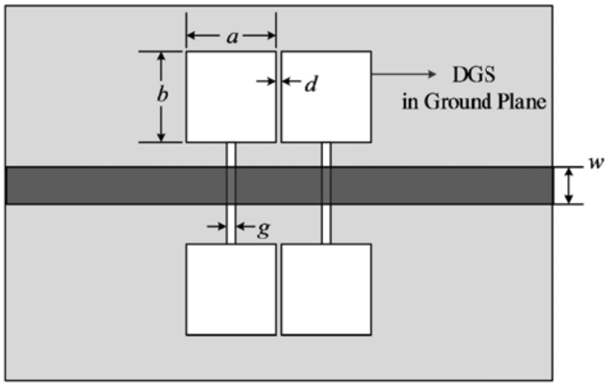

Figure 1. Schematic view of a conventional C-DGS.

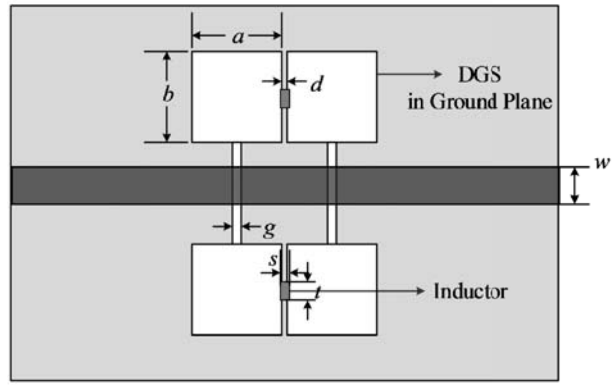

Figure 2. Schematic view of the proposed C-DGS.

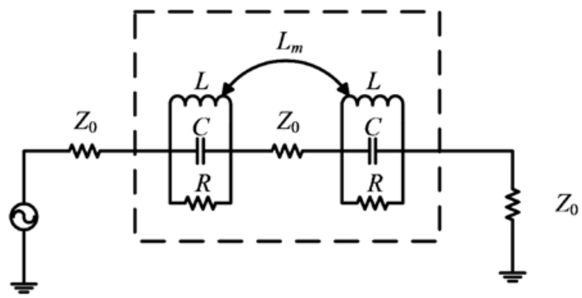

Figure 3. Equivalent circuit of the coupled-defected ground structure.

dimensions ($a \times b$) and gap distance (g) which can provide cutoff frequency and attenuation pole in some frequency [1]. The line width (w) is chosen for the characteristic impedance of 50-Ω microstrip line. And the distance between two adjacent DGS cells is represented by d, which has great influence on the coupling-coefficient [6].

Figure 2 shows the schematic of the proposed C-DGS which exhibit similar configuration to the conventional CDGS. And both of two C-DGSs can create the coupling of ground currents between adjacent DGS cells, and the coupling effect greatly improves the bandstop characteristic owing to an additional attenuation pole [6]. However, in comparison to the conventional C-DGS, two symmetrical inductors are introduced between the two adjacent DGSs.

According to [6], C-DGS can be represented by the equivalent RLC circuit in Figure 3.

Here, C, L, and R are the capacitance, inductance, and resistance extracted by (1), (2), and (3), respectively.

$$C = \frac{\omega_c}{2Z_0\left(\omega_0^2 - \omega_c^2\right)} \tag{1}$$

$$L = \frac{1}{4\pi^2 f_0^2 \cdot C} \tag{2}$$

$$R = \frac{2Z_0}{\sqrt{\frac{1}{|S_{11}(\omega_0)|^2} - \left[2Z_0\left(\omega_0 C - \frac{1}{\omega_0 L}\right)\right]^2 - 1}} \tag{3}$$

Here, ω_c is the 3-dB cutoff angular frequency, ω_0 the resonance angular frequency, Z_0 the characteristic impedance of the microstrip line, and $S_{11}(\omega_0)$ the S-parameter at the resonance angular frequency.

L_m represents the mutual inductance between two adjacent DGSs. And L_m can be obtained from the below equation:

$$L_m = Lk_M = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} L \quad (4)$$

where k_M is the coupling coefficient, and f_e and f_m are two resonance frequencies exhibited by C-DGS due to the coupling effect.

As demonstrated in [6], the distance of two spilt zeros mainly depends on the strength of coupling effect without dimension modification, which means the zeros will separate further while the coupling coefficient is enhanced. In conventional C-DGS, the distance (d) between two adjacent DGS cells plays a major role in enhancing the coupling coefficient. However, conventional C-DGS always fails to further improve the coupling coefficient on account of the limited distance.

With inserted inductors, the new C-DGS has an opportunity to further improve the stopband without any dimension changed. Figure 4 compares the simulated insertion loss of the conventional and the new C-DGS with the same dimension on a FR-4 substrate (a dielectric constant ε_r of 4.4 and a thickness of 1.5 mm). The data are obtained by using Ansoft High Frequency Structure Simulator (HFSS). The lattice dimension $a \times b$, the etched gap distance g, the line width w and the distance of two adjacent DGS cells d of the two C-DGSs are both set to be 5.5 mm × 5.5 mm, 0.2 mm, 2.4 mm and 0.8 mm. The value of inductance in the new C-DGS is 3.3 nH.

As displayed in Figure 4, the transmission zero separation can be observed evidently as the result of the coupling effect. Moreover, owing to the introduction of the inductor, the proposed C-DGS provide a much wider zero separation than the conventional C-DGS. According to the simulation results from HFSS, the coupling coefficient k_m of conventional C-DGS calculated by (4) is only −0.1948. For the proposed C-DGS, the coupling coefficient is increased to −0.4149, which verify the validity of the proposed C-DGS.

To further study the influence of the inductors on the coupling coefficient k_m, Figure 5 shows the numerical relationship between the coupling coefficient and the value of inductance. As seen from the graph, the inductors exert an enormous function on enhancing the coupling coefficient. And with the increase of inductance the inductors, the coupling coefficient k_m can be increased effectively, and thus an expanded stopband can be realized easily. In addition, the performance improvement is obtained by simply tuning the inductance of the inductors without the requirements to change the configuration of the DGSs, which provide much convenience and flexibility to the design.

In fact, the current distributions on the ground plane are significantly disturbed by the coupled-defected ground structures, and it is reasonable to consider the magnetic coupling between any two resonators is dominant [7]. Just as described in [6], the ground currents of two adjacent DGS cells move in opposite directions in shared ground to contribute the negative mutual inductance. And that

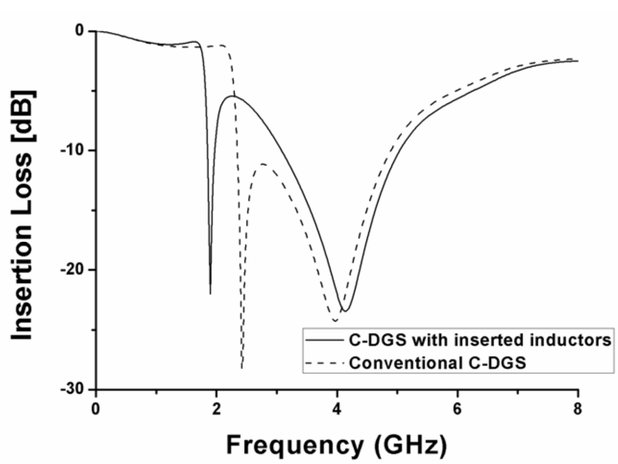

Figure 4. Simulation results for conventional C-DGS and proposed C-DGS.

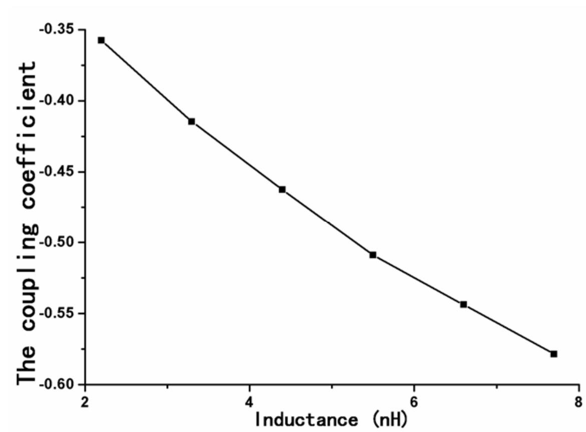

Figure 5. The relationship between the coupling coefficient and the inductance.

the coupling coefficient extracted by (4) is related to the coupling inductance which can be enhanced by inserted inductors remarkably in the shared ground of two adjacent DGS cells. Hence, the inserted inductors display great function in improving the coupling coefficient as a result.

The value of mutual inductance arises as the inductance of inserted inductors increase, which can explain the graph shown in Figure 5. In the result of the data above and the analysis of the novel structure, we assert that the proposed C-DGS exhibits a larger coupling-coefficient than conventional C-DGS.

3. DESIGN AND MEASUREMENT OF A LPF BASED ON THE PROPOSED C-DGS

The novel C-DGS LPF is composed of two cascaded novel C-DGS, which is shown in Figure 6. The fundamental parameters are set as the figure shown. A FR-4 substrate (a dielectric constant ε_r of 4.4 and a thickness of 1.5 mm) is attached under the ground metal. In addition, the value of inserted inductor with package of 0603 is 1.7 nH. Figure 7 shows photograph of the fabricated low-pass filter with the proposed C-DGS.

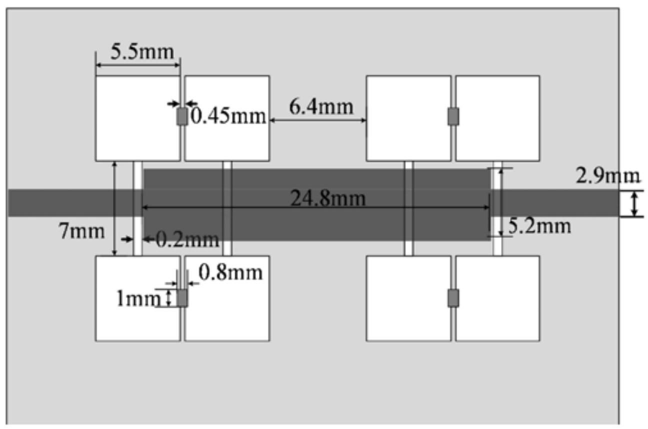

Figure 6. Proposed LPF using the novel C-DGS.

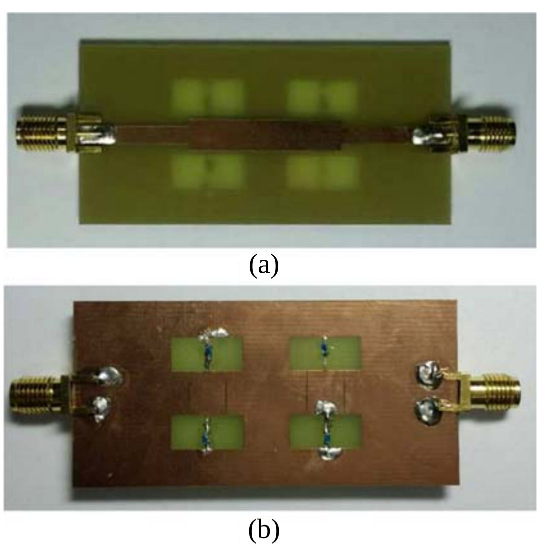

Figure 7. Fabricated LPF with proposed C-DGS. (a) Top view. (b) Bottom view.

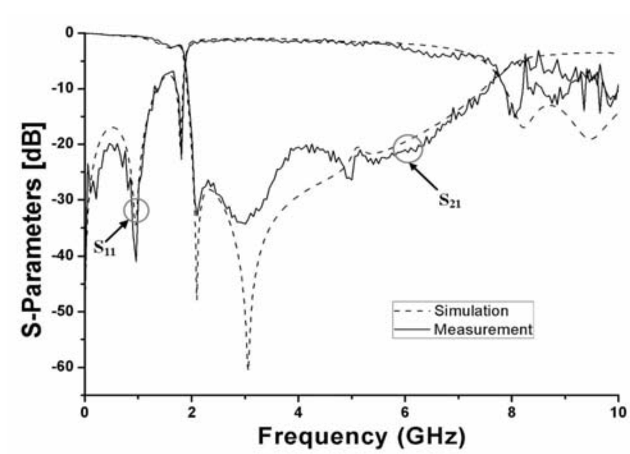

Figure 8. Simulated and measured S-parameter of the novel C-DGS LPF.

The simulated and measured insertion losses of the novel LPF are shown in Figure 8. This LPF has a measured 3 dB cutoff frequency of f_c at about 1.85 GHz. The measured passband insertion loss is within 0.5 dB including the SMA connector loss. As the result of the coupling effect of the C-DGS, the two transmission zeros can be observed to be located at 2.11 GHz with 32.8 dB, at 3.01 GHz with 34.3 dB respectively. With the aid of these transmission zeros, the 20 dB rejection stopband is extended from 2.02 GHz ($1.092f_c$) to 6.35 GHz ($3.432f_c$) over 20 dB, indicating a very wide 20 dB stopband bandwidth of $2.341f_c$. Moreover, these transmission zeros also create a sharp transition for the filter. The attenuation rates at the passband to stopband transition knees are 116 dB/GHz (the measured attenuations being 5 and 32.8 dB at 1.87 GHz and 2.11 GHz, respectively). In addition, the main circuit of filter occupies a compact size of 30.2 mm × 18 mm. By simply welding different values of the chip inductors, we can obtain a LPF with new characteristic and greatly improve the stopband characteristics without any structure modification.

4. CONCLUSIONS

In this paper, a novel coupled-defected ground structure with enhanced coupling-coefficient is proposed. The analysis based on the equivalent circuit reveals that the proposed C-DGS exhibits a much higher coupling coefficient than the conventional C-DGS. Moreover, the transmission characteristics of the new C-DGS can be tuned easily by changing the inductance of the inductors. With these advantages, the proposed C-DGS is promising in the microwave circuit design. Finally, the proposed C-DGS has been applied in the low-pass filter design. The measured results of the fabricated LPF demonstrate that the novel C-DGS improves the C-DGS characteristics performance and enlarge the range of C-DGS applications.

ACKNOWLEDGMENT

This work was supported by the program for Zhejiang leading team of science and technology innovation (2011R50004), the National Natural Science Foundation of China under grants (61101052) and 521 talent project of Zhejiang Sci-Tech University.

REFERENCES

1. Woo, D.-J., T.-K. Lee, J.-W. Lee, C.-S. Pyo, and W.-K. Choi, "Novel U-slot and V-slot DGSs for bandstop filter with improved Q factor," *IEEE Trans. on Microw. Theory and Tech.*, Vol. 54, No. 6, 2840–2847, Jun. 2006.
2. Balalem, A., A. R. Ali, J. Machac, and A. Omar, "Compact band-stop filter using an interdigital DGS structure," *IEEE 14th Microw. Tech. Conference*, 1–3, Prague, Apr. 2008.
3. Ahn, D., J.-S. Park, C.-S. Kim, J. Kim, Y.-X. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Trans. on Microw. Theory and Tech.*, Vol. 49, No. 1, 86–93, Jan. 2001.
4. Abdel-Rahman, A., A. K. Verma, A. Boutejdar, and A. S. Omar, "Compact stub type microstrip bandpass filter using defected ground plane," *IEEE Microw. and Wireless Compon. Lett.*, Vol. 14, No. 4, 136–138, Apr. 2004.
5. Oraizi, H. and S. Hedayati, "Miniaturization of microstrip antennas by the novel application of the Giuseppe Peano fractal geometries," *IEEE Trans. on Ante. and Propa.*, Vol. 60, No. 8, 3559–3567, Aug. 2012
6. Jung, S., Y.-K. Lim, and H.-Y. Lee, "A coupled-defected ground structure lowpass filter using inductive coupling for improved attenuation," *Microw. and Opt. Technol. Lett.*, Vol. 50, No. 6, 1541–1543, Jun. 2008.
7. Wu, S.-J., C.-H. Tsai, and T.-L. Wu, "A novel wideband common-mode suppression filter for GHz differential signals using coupled patterned ground structure," *IEEE Trans. on Microw. Theory and Tech.*, Vol. 57, No. 4, 848–855, Apr. 2009.