An Ultra-sharp Roll-off Lowpass Filter Using Coupled DGS

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Abstract

A compact low-pass filter using defected ground structure (DGS) resonator is proposed in this letter. The designed LPF with two cascaded coupled dumbbell-shaped DGS (DB-DGS) resonators are both simulated and measured. The simulatied and experimental results demonstrate that the designed LPF has a compact size compared with the other reported DGSs. By controlling the coupling distance, an ultra-sharp skirt performance can be achieved. The size of proposed LPF with two coupled DB-DGS is about 30mm×16mm, and the RO rate is about 242.8 with a cutoff frequency of about 3.08 GHz. The suppression of stopband is about -20dB at the frequencies up to 8.15GHz.

Keywords

Low-pass Filters, Defected Ground Structure, Coupling effect.

1. Introduction

Microwave lowpass filters (LPFs) with the demand for compact size, low insertion loss, excellent frequency selectivity, and wide stopband are highly desirable in modern wireless communication and signal processing systems. Microwave components with Defected Ground Structure (DGS) has gained popularity among all the techniques reported for enhancing the parameters due to its simple structural design. Initially dumbbell-shaped DGS(DB-DGS) was reported for LPFs underneath the microstrip line[1]. A repetition of a single defect with a finite spacing is referred to as a periodic structure. Periodic DGSs for planar microwave cir-cuits are earning major attraction of microwave researchers. Various DGS designs have been proposed, and explored, such as horizontally periodic DGS (HPDGS)[2], vertically periodic DGS (VPDGS)[3], interdigital DGS[4], split-ring resonator DGS[5] and so on. The shape of DGS unit, distance between two DGS units and the distribution of different DGSs are the main parameters that affect the performance. A repetition of a single defect with a finite spacing is referred to as a periodic structure. DGS unit shape, and distribution of the different distances between the DGS units are two main parameters affecting DGS cycle performance.

In this letter, a compact filter realized by combining two coupled DB-DGS is presented. By coupling DB-DGS units in a manner of mirror symmetry, the ultra-sharp RO is obtained thanks to the splitting of transmission zeros, which is due to the strong coupling between the two DB-DGSs. With the analysis and adjusting of the coupling distance, the smooth pass-bands are achieved. Based on the geometric property, stop-band with better rejection performance and sharper transition band can be designed, which facilitates the low-pass filter design. Finally, a compact low-pass filter with excellent skirt performance is optimally designed, fabricated and characterized.

2. Design Procedure

2.1 Coupled dumbbell DGS

As shown in Figure 1, the DB-DGS unit is obtained by etching a dumbbell-shaped defect pattern on the ground laye. The microstrip is on the top layer. Between the top and the ground plane is a substrate with a dielectric constant of 2.55 and loss tangent of 0.0015. The thickness of the substrate is h = 0.8 mm. All size parameters can be found in the caption, and they are compactable with common printed circuit board technology.

DGS has been combined with planar transmission lines on the ground, namely microstrip lines. Defects on the ground plane interfere with the current distribution on the ground plane. This current distribution changes the transmission line by including some parameters (slot resistance, slot capacitance, and slot inductance) to the line parameters (line resistance, line capacitance, and line conduction) (or the characteristics of any structure). In other words, any defects etched on the ground under the microstrip line will change the effective capacitance and inductance of the microstrip line by increasing the slot resistance, capacitance, and inductance. Because the impedance in the defect region is discontinuous, the electromagnetic resonance is obtained and the band gap is formed.

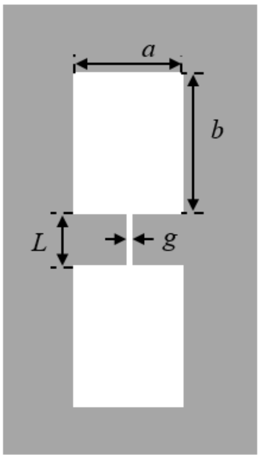


Fig.1 Layout of the DB-DGS on the bottom layer (with a=6mm, b=6mm, L=4mm, g=0.5mm)

By cascading the surface defects (resonance unit), according to the number of cycles, the return loss and bandwidth levels can be improved. As shown in Figure 2, the coupled DB-DGS unit is obtained by etching two dumbbell-shaped DGS patterns of the same size on the ground. Two dumbbell-shaped DGS patterns are arranged closed to each other in a manner of mirror symmetry. The distance parameter between the two dumbbell-shaped DGS is d=0.5mm.

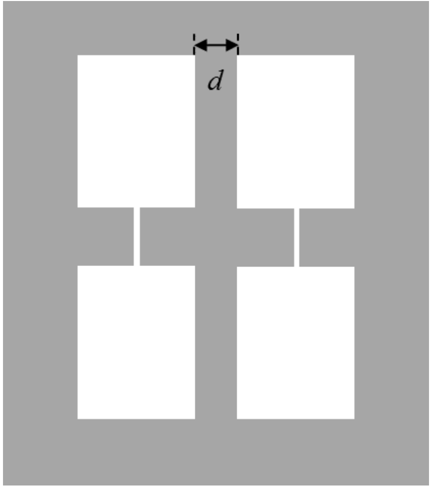


Fig.2 Layout of the coupled DB-DGS

Fig.3 shows the frequency response of a single DB-DGS and the couple DB-DGS. The contrast of simulated results between the two cases illustrates the advantage of coupled DB-DGS.The transmission-zero location of a single DB-DGS are at 5.42GHz, and the value of RO is only 6.7. The transmission-zero location of the coupled DB-DGS is at 3.71GHz, and the value of RO is 37. Coupled DB-DGS can realize transmission zeros at lower frequencies and better frequency selectivity than the single DB-DGS. It can also be found that the coupled DB-DGS has better suppression.

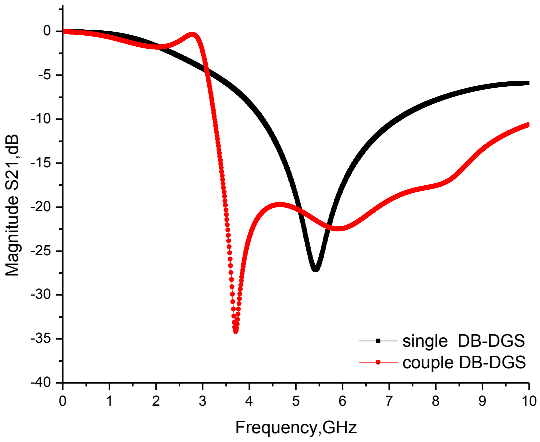


Fig.3 Simulated S parameters for a single DB-DGS and the couple DB-DGS

2.2 Effect of coupling distance d

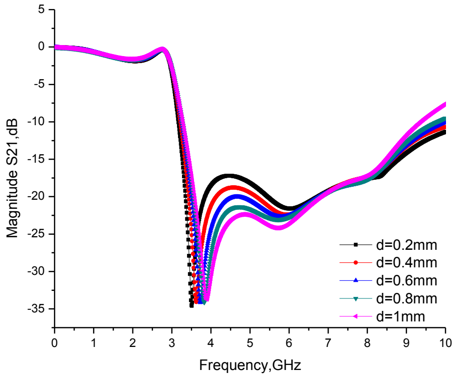


Fig.4 Layout of the coupled DB-DGS

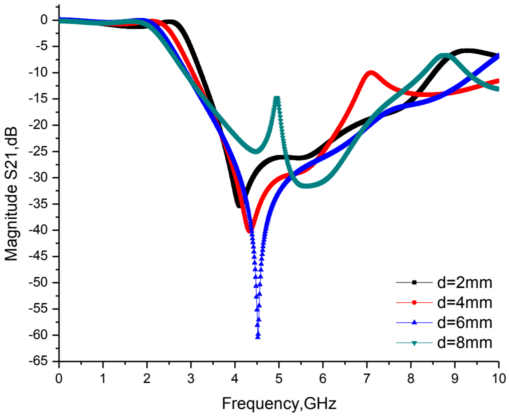
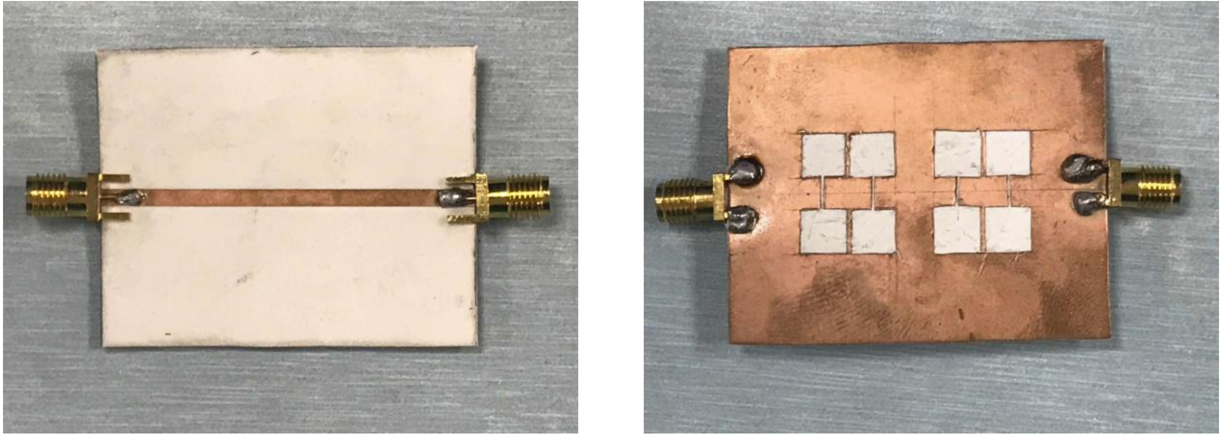


Fig.5 Layout of the coupled DB-DGS

The internal couplings of the coupled DB-DGS are provided by combining two single DB-DGS, which are controlled by the distance between two individual DB-DGSs. Setting two simulation ranges for comparison, namely, one from 0.2mm to 1mm with a step size of 0.2mm, and the other from 2mm to 8mm with a step size of 2mm, the simulation results are shown in Fig.4 and Fig.5. When the coupling distance range is 0.1 mm to 1 mm, the longer the couple distance is, the higher the resonance frequency is, and the worse the frequency selectivity is. When the coupling distance is 8mm, it can be found that frequency response has changed, and the previous changes can no longer be used to infer the subsequent changes. There are two modes of transmission characteristics for the two DGSs combinations. For coupled DB-DGS, the two DGSs can be considered as a coupled DGS mode within 8mm, and can be viewed as a cascaded DGS mode at 8mm.

3. Fabrication and measurement

A prototype of proposed LPF was fabricated with common standard printed circuit board technology, the top and bottom views of which are shown in Fig. 6(a) and (b), respectively. The proposed LPF is designed by cascading two couple DB-DGS between to minimise the mutual coupling[6].



(b)

Fig.6 Photographs of the tri-band filter. (a) Top view, (b) Bottom view

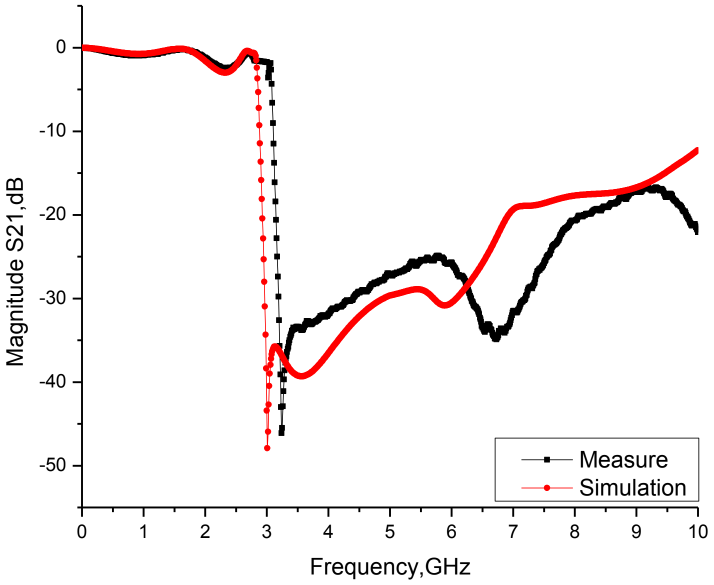


Fig.7 Simulated and measured results of the proposed filter

The relative dielectric constant and loss tangent of the substrate are the same with that used in the simulations. The simulation is accomplished by HFSS 15.0 software, and the measurement is performed with a vector network analyzer (R&S, ZNB40). As can be seen in Fig.7, there exists a little frequency shift between the simulated S parameters and the measured one. The variation may be caused by the inconsistent substrate material in the simulation and fabrication.

It is noted that the measured 3 dB cutoff frequency (fc) is around 3.08 GHz and the stopband with rejection better than 20 dB is from 3.15 to 8.15 GHz. Especially, the bandwidth of transition band between -3dB and -20dB is only about 0.07GHz, realizing an ultra-sharp RO of 242.8 and outstanding skirt performance. This is because the attenuation transmission zeros is located at 3.24 GHz near the cutoff frequency. The total size of the fabricated LFP is only about 30mm×16mm.

4. Conclusion

A novel compact low-pass filter is proposed and demonstrated based on the coupled dumbbell shaped defected ground structures. Both the resonant and coupling properties of the coupled dumbbell shaped defected ground structure are analyzed. The coupled dumbbell shaped ground structures can increase the effective induction and capacitance, leading to an ultra-sharp RO and compact size. Based on the analysis, a filter with excellent skirt performance and compactness is designed, fabricated and measured. Benefiting from these outstanding performances, the proposed low-pass filter can be applied in various modern wireless communication systems.

References

[1] Ahn D, Park J S, Kim C S, et al. A design of the low-pass filter using the novel microstrip defected ground structure[J]. IEEE transactions on microwave theory and techniques, 2001, 49(1): 86-93.

[2] Lim J S, Lee Y T, Kim C S, et al. A vertically periodic defected ground structure and its application in reducing the size of microwave circuits[J]. IEEE Microwave and Wireless Components Letters, 2002, 12(12): 479-481.

[3] Oskouei H D, Forooraghi K, Hakkak M. Guided and leaky wave characteristics of periodic defected ground structures[J]. Progress In Electromagnetics Research, 2007, 73: 15-27.

[4] Balalem A, Ali A R, Machac J, et al. Quasi-elliptic microstrip low-pass filters using an interdigital DGS slot[J]. IEEE Microwave and wireless Components letters, 2007, 17(8): 586-588.

[5] Hou Z Z. Novel wideband filter with a transmission zero based on split - ring resonator DGS[J]. Microwave and Optical Technology Letters, 2008, 50(6): 1691-1693.

[6] Xu S, Ma K, Meng F, et al. DGS embedded transformed radial stub for ultra-wide stopband lowpass filter[J].Electronics letters, 2012, 48(23): 1473-1475.