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NEW U-SHAPED DGS BANDSTOP FILTERS

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Abstract—In this paper, new microstrip bandstop filters with single band, dual-band and tri-band by using U-shaped defected ground structures are presented without the assistance of coupled lines or certain resonators, and the application of DGS is developed. The proposed bandstop filters have good performances of low loss, multi-band operation, transmission zeros which improve the filter frequency selectivity, and miniaturization because of the cascade of DGS and minimum defected patterns which reduce the circuit size. The new designs are demonstrated by measurement.

1. INTRODUCTION

In recent years, there is growing interest in defected ground structures (DGS), and many microwave circuits, such as filter [1, 2], power divider and power amplifier, etc., have been implemented by using DGS. Similar to the PBG (photonic bandgap) or EBG (electromagnetic bandgap) structure, defected ground structure is formed by etching a defected pattern on the metallic ground plane, which enhances the effective capacitance and inductance of microstrip line, and as a result, DGS has slow-wave characteristics and restrains the spurious responses by rejecting harmonic in microwave circuits, so the performances of filters or other microwave components are effectively improved. DGS exhibits the properties of rejecting electromagnetic waves in certain

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frequencies and directions, and the most interesting applications for these structures are the filtering of frequency bands or the suppression of undesired spurious passbands and harmonics in microwave or millimeter wave circuits.

Currently, the most applied DGSs are all kinds of dumbbell and spiral-shaped ones, however, these structures hardly satisfy the requirement of narrow band. [2] reports the dual-mode DGS resonator and filter, [3] designs a dual-mode bandpass filter which assisted by U-shaped DGS to obtain a improved stopband performance and smaller size, and [4] designed dual-band bandstop filter with the assistance of DGS and stepped impedance resonator. The most reported works on DGS filters are the implementation of low pass filters [5–9] by using new DGS unit [7–9] or periodical DGS [10], and the reports on DGS bandstop filters especially the DGS assisted dual-band bandstop filters are very limited. We have also noticed that most of the DGS assisted microwave filters including lowpass, bandpass and bandstop filters consist of certain resonators or lines, and the DGS only plays a role of improving filter performances. The dual and tri-band bandstop filters only using DGS patterns have not been reported.

RF bandstop filters are highly desired for their effective suppression of spurious signals. With the rapid development of modern wireless communication, bandstop filters with more operation bands are attractive due to their ability to treat the unwanted signals of RF circuits by using one single filter, which decrease the circuit size and cost. Dual-band bandstop filters can filtrate the unwanted double-sideband spectrum of high power amplifiers and mixers. In this article, new technique of developing U-shaped DGS assisted dual and tri-band bandstop filters are presented without the assistance of resonators or coupled lines, and the U-shaped DGS shows a better stopband performance compared with conventional dumbbell ones. The ground plane of a standard 50-ohm microstrip line (ML) and a stepped-impedance microstrip line are perturbed by cascaded U-shaped DGSs to generate multi-band that is beneficial to narrow band performance and mutual coupling of this new DGS which creates multiple-resonance characteristics in the frequency response. The new bandstop filters have more operation bands compared with relative reported works [4, 11, 12], and have advantages of novel structures, miniature size for the DGS cascade and reduced defection cells, and good performances of transmission zeros and low loss. The designs are verified by experiment.

2. BANDSTOP FILTERS WITH SINGLE AND DUAL-BAND

Currently, DGS plays important roles in RF circuits design. Conventional dumbbell-shaped DGS can be equivalent by a parallel LC circuit [13]. Inductance L denotes the operation of rectangular lattice in the defected unit, and capacitance C denotes the operation of slit between two rectangular lattices. L increases with the area of rectangular lattice increasing, while C decreases with the width of slit increasing. U-shaped DGS can be seen as a transformation of the conventional dumbbell DGS, as shown in Fig. 1, and the calculated performance variation of dumbbell DGS transform to the U-shaped DGS is shown in Table 1, which shows the center frequency and 3 dB bandwidth decrease with parameter a_1 increasing. When $a_1 = a_2$, it is a dumbbell DGS, and when a_1 increased to a certain value as $a_2 = 0$, it is a U-shaped DGS. Simulated S parameters of the dumbbell-shaped DGS and U-shaped DGS are plotted in Fig. 2, and it can be seen that U-shaped DGS has more obvious and narrow stopband performance, and a single DGS can't create transmission zero. The equivalent circuit of U-shaped DGS can be expressed as a parallel LC circuit because it has similar frequency characteristics to that of the dumbbell DGS. The above calculations are got by using microstrip material with relative dielectric constant of 10.2 and thickness of 1.27 mm. Q values and frequency responses versus different parameters for the U-shaped DGS are analyzed in literature [14].

We know that U-shaped DGS has better stopband performance than the traditional dumbbell DGS from the above analysis. Here, a single band bandstop filter using double U-shaped DGSs is designed,

Table 1. Performance variation of dumbbell DGS transform to the U-shaped DGS. $a = 6\,\text{mm}$, $b = 0.4\,\text{mm}$, $c = 1\,\text{mm}$, $n = 2\,\text{mm}$.

a_1 (mm)	Center frequency f_0 (GHz)	3 dB bandwidth (GHz)
2.8	6.15	2.5
3.2	6.07	2.37
3.6	5.91	2.21
4.0	5.5	1.86
4.4	5.3	1.71
4.8	5.05	1.56
5.2	4.72	1.39
5.6	4.5	1.27

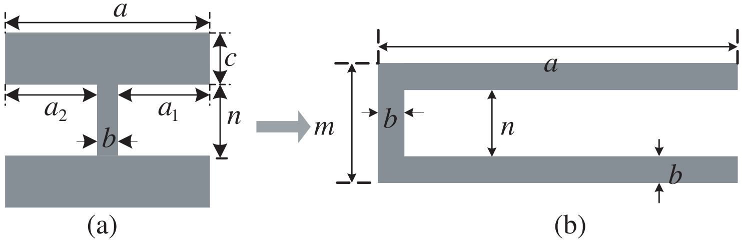


Figure 1. DGS unit. (a) Dumbbell DGS. (b) U-shaped DGS.

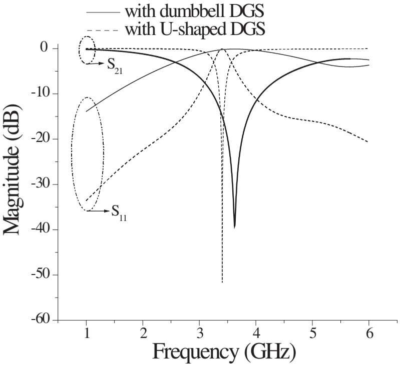


Figure 2. Simulated S-Parameters of the DGSs, U-shaped DGS: $a = 9\,\text{mm}$, $b = 0.4\,\text{mm}$, $m = 1.8\,\text{mm}$, $n = 1\,\text{mm}$, Dumbbell DGS: $a = 9\,\text{mm}$, $b = 0.4\,\text{mm}$, $c = 4\,\text{mm}$, $n = 1\,\text{mm}$.

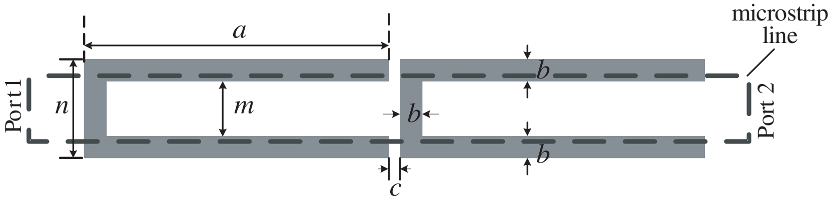


Figure 3. U-shaped DGS bandstop filter with single band, $a = 9\,\text{mm}$, $b = 0.4\,\text{mm}$, $c = 0.2\,\text{mm}$, $m = 1\,\text{mm}$, $n = 1.8\,\text{mm}$.

as shown in Fig. 3, and simulated frequency responses are shown in Fig. 4. It can be seen that the filter operates at 3.36 GHz with a relative bandwidth of 12.5%, and has a pair of transmission zeros which bring good frequency selectivity. It is also shown that the designed bandstop filter has better performance than that with a single U-shaped DGS

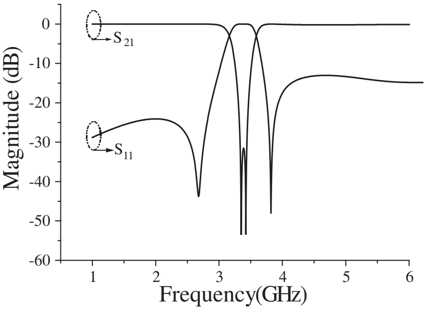
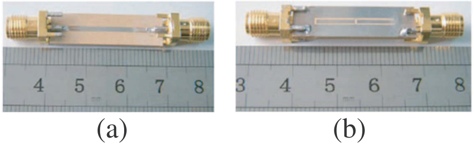


Figure 4. Simulated frequency responses of the single band U-shaped DGS bandstop filter.



(a) (b)

Figure 5. Photograph of the fabricated hardware. (a) Top view. (b) Bottom view.

as shown in Fig. 2, and a much wider bandwidth of stopband and smaller circuit size (circuit size reduction of about 34.5%) than the results shown in [14]. All of the filters in this paper are designed on ceramic substrate with relative dielectric constant of 10.2 and thickness of 1.27 mm. Input port and output port are microstrip lines with characteristic impedance of 50 Ω. In order to verify the design, the bandstop filter with double U-shaped DGS is fabricated and tested, and photograph of the hardware is shown in Fig. 5, and the measured results are shown in Fig. 6. The measurements which are got by Agilent E5071C vector network analyzer are in agreement with the simulation.

A dual-band bandstop filter is presented, as shown in Fig. 7, and the simulated frequency responses are shown in Fig. 8. Here, four U-shaped DGSs with identical dimensions are used to form two cascaded pairs to create dual-resonance characteristics in the frequency response. We know that the U-shaped DGSs including the uniform periodical ones only generate a single stopband in a certain frequency band, such as 1–5 GHz, and the 2nd and 3rd stopbands appear in the frequency band which is more than 5 GHz, but the cascaded U-shaped DGSs can generate more stopbands in a certain band of 1–5 GHz because the action of DGS coupling and, simultaneously, the cascaded U-shaped DGS increases the electric length of microstrip line

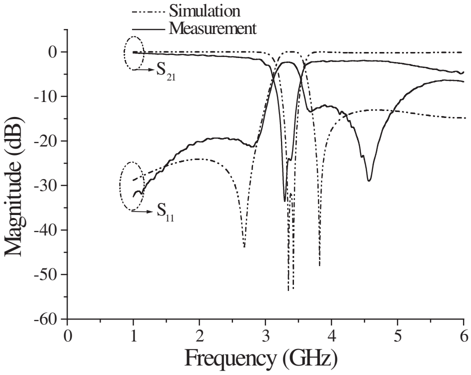


Figure 6. Simulation and measurement comparison.

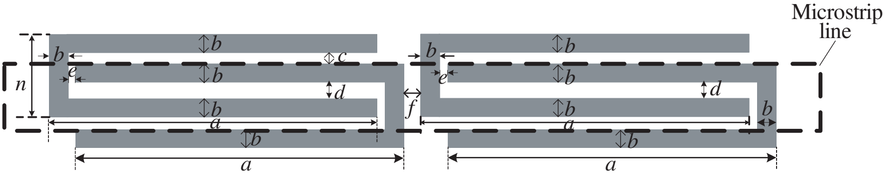


Figure 7. U-shaped DGS bandstop filter with dual-band, $a = 9\,\text{mm}$, $b = d = f = 0.4\,\text{mm}$, $c = e = 0.2\,\text{mm}$, $n = 1.8\,\text{mm}$.

and introduces additional inductance and capacitance. It can be seen that the dual-band bandstop filter operates at 2.73 GHz and 4.02 GHz with relative bandwidth of 15.7% and 2.48%, respectively, and has a max. loss of no more than 0.2 dB at center frequency, and the multiple transmission zeros with attenuation of more than 30 dB help improve the frequency selectivity greatly. For the first stopband, it is generated by the intrinsic characteristic of U-shaped DGS. But for the second stopband, it has a much narrower bandwidth because it is created by DGS coupling, not the intrinsic characteristic of U-shaped DGS. It also can be seen from Fig. 8 that the bandstop filter with two cascaded DGS pairs has much better performance than that with single cascaded DGS pattern. Calculated variation curves of the cascaded DGS parameters versus center frequency and bandwidth of the dual-band bandstop filter are plotted in Figs. 9(a)–(e). It is shown that parameters a and d control the filter center frequency and bandwidth and that parameter e dominantly affects the filter 3 dB bandwidth. It can be seen that center frequency of the dual-stopband decrease with increasing a and that the variation for the second stopband versus parameter d has the same case, but the center frequency of the first stopband increases

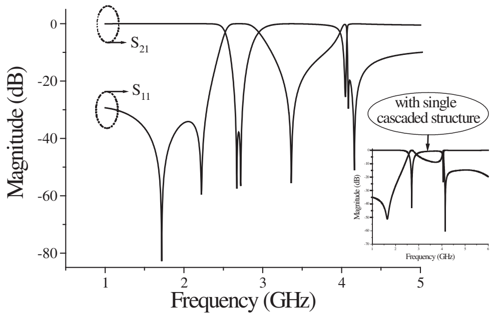


Figure 8. Simulated frequency responses of the dual-band DGS bandstop filter.

with parameter d increasing. Where, f_{0i} is the i-th center frequency of the dual-stopband, $i = 1, 2$. The figures also show that the 3-dB bandwidth of the dual-stopband decreases with parameters a and d increasing. However, the bandwidth of the first and second stopbands have the opposite variation trends with increasing parameter e.

In order to analyze the proposed dual-band bandstop filter in detail, comparison of the bandstop filter with normal arrayed and stagger arrayed DGS patterns is given in Fig. 10, and comparison of the bandstop filter with different periodic structures is shown in Fig. 11. It can be seen that with stagger arrayed DGS patterns, bandwidth of the first stopband is decreased and controllable by the coupling between the two DGS patterns. It can be seen from Fig. 11 that filter bandwidth has no obvious changes with three and four periodic DGS patterns. In the research, we find that the bandwidth of the rejection band will be extended by using 2 periodical cascaded patterns compared with a single cascaded pattern. However, more periodic DGS patterns have nearly no effect on filter bandwidth but introduce more transmission zeros, which increases the circuit size. Fig. 12 shows the photograph of the fabricated dual-band hardware, which has a circuit size reduction of about 93% compared with the reported dual-band bandstop filter in [15]. Fig. 13 shows the measured results, which are similar to the simulation.

3. BANDSTOP FILTERS WITH TRI-BAND

In order to show the effectiveness of the U-shaped DGS in bandstop filter design, tri-band bandstop filters are also designed, as shown in Fig. 14. Where, $50\,\Omega$ ML and stepped impedance ML are used as comparison, and six U-shaped DGS cells with cascade coupling

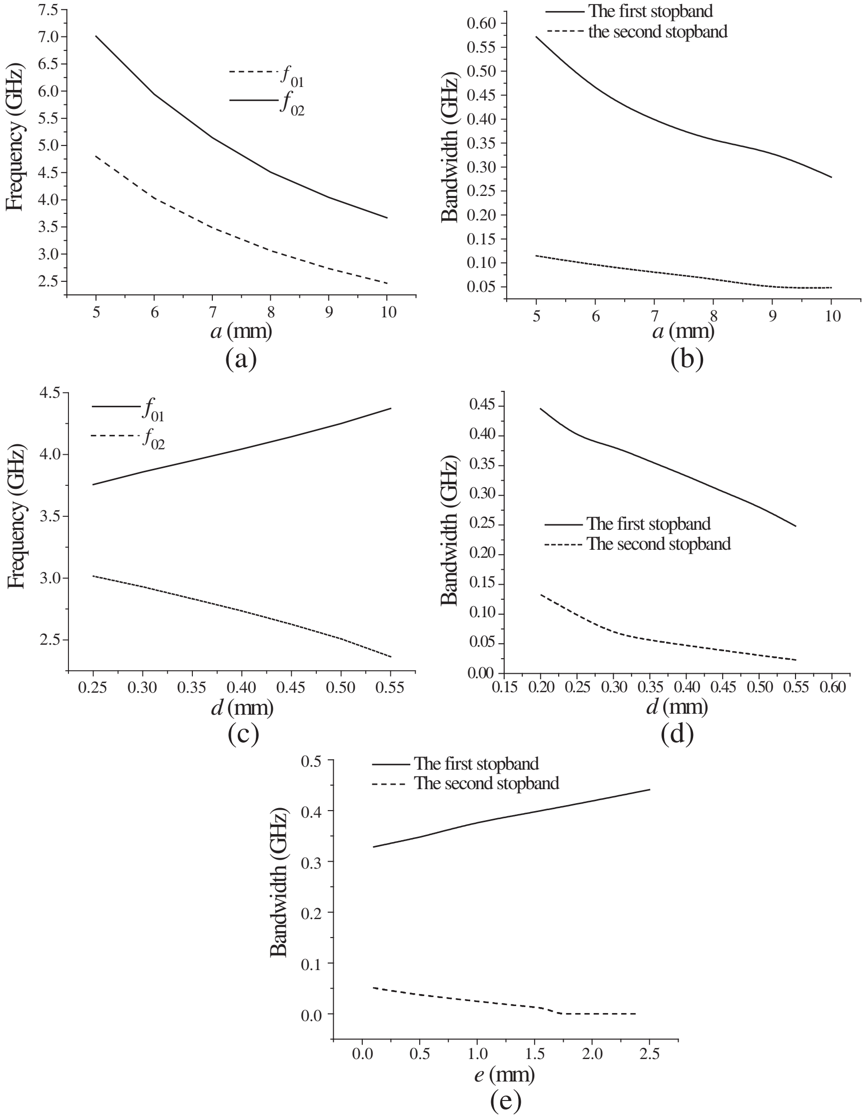


Figure 9. Calculated variation curves of filter center frequency and 3 dB bandwidth versus filter physical parameters. (a) Variation curves of center frequency versus parameter a. (b) Variation curves of 3 dB bandwidth versus parameter a. (c) Variation curves of center frequency versus parameter d. (d) Variation curves of 3 dB bandwidth versus parameter d. (e) Variation curves of 3 dB bandwidth versus parameter e.

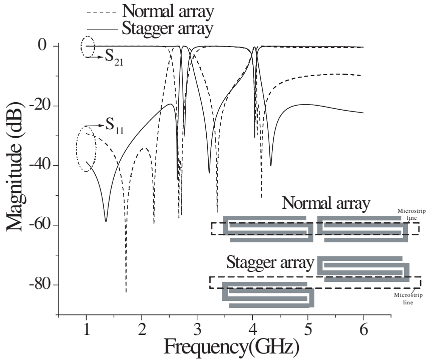


Figure 10. Simulated frequency responses of the bandstop filter with normal arrayed and stagger arrayed DGS patterns.

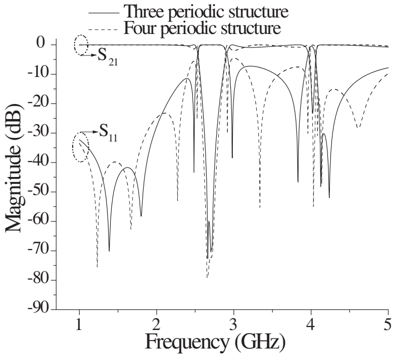
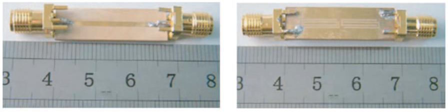


Figure 11. Simulated frequency responses of the dual-band bandstop filter with three and four periodic DGS patterns.



(a) (b)

Figure 12. Photograph of the fabricated hardware. (a) Top view. (b) Bottom view.

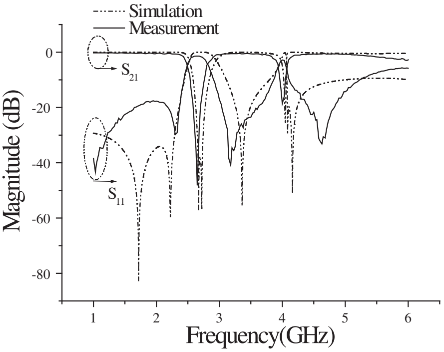


Figure 13. Simulation and measurement comparison.

are used to introduce a required tri-stopband. It also can be seen that combination of double U-shaped DGS constructs the E-shaped DGS. In the research, we find U and E-shaped DGS have similar frequency responses, and they nearly possess the same performance

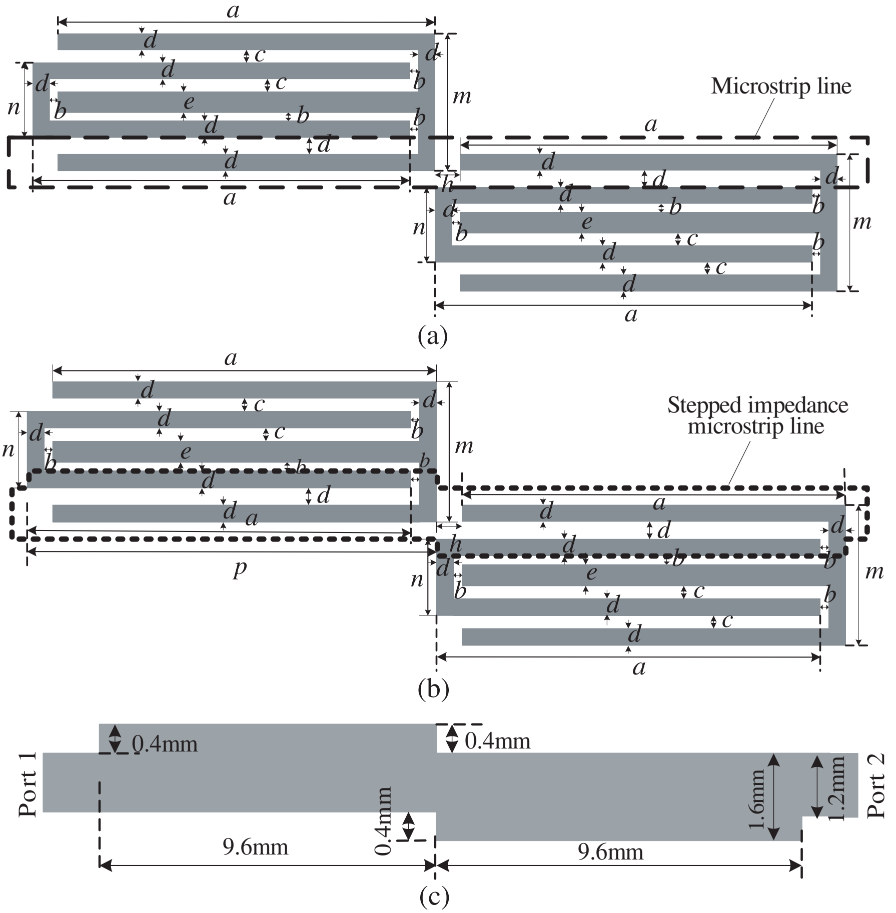


Figure 14. U-shaped DGS bandstop filter with tri-band, $a = 9\,\text{mm}$, $b = 0.2\,\text{mm}$, $c = 0.3\,\text{mm}$, $d = 0.4\,\text{mm}$, $e = 0.5\,\text{mm}$, $h = 0.6\,\text{mm}$, $m = 3.3\,\text{mm}$, $n = 1.8\,\text{mm}$. (a) With 50-ohm standard microstrip line. (b) With stepped impedance microstrip line. (c) Stepped impedance microstrip line.

if have the same dimension. Simulated filter frequency responses are shown in Fig. 15, and it can be seen that with stepped impedance microstrip line, the tri-band bandstop filter centers at 2.56 GHz, 3.42 GHz and 4.08 GHz with relative bandwidth of 12.1%, 2.93% and 2.45%, respectively, and also implements low loss and transmission zeros, as the real line shows. It also can be seen that the bandstop filter with stepped impedance microstrip line has nearly the same performance for the second and the third stopbands but a wider bandwidth for the first stopband than the 50 Ω microstrip line, so, it may be concluded that the bandwidth of the dominant mode can be enhanced with the assistance of stepped impedance ML as shown in Fig. 14(c). Photograph of the fabricated tri-band hardware and the measured results are shown in Figs. 16 and 17, respectively. It is shown

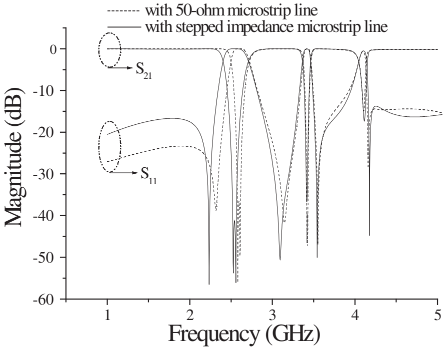
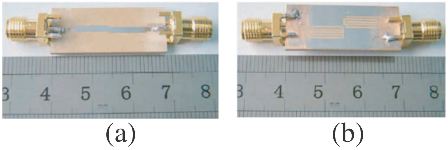


Figure 15. Simulated frequency responses of the tri-band DGS bandstop filter.



(a) (b)

Figure 16. Photograph of the fabricated hardware. (a) Top view. (b) Bottom view.

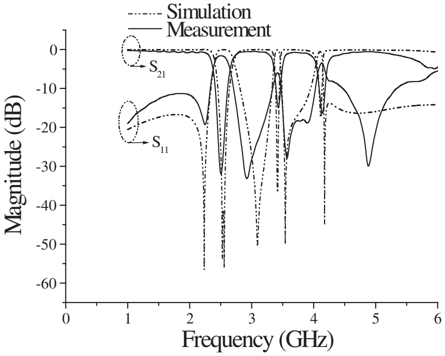


Figure 17. Simulation and measurement comparison.

that the measurement is similar to the simulation, which demonstrates the correctness of our design. The measured discrepancies are due to the precision of EM simulation and fabrication uncertainty.

4. CONCLUSION

New multiple-band microstrip bandstop filters with good performances of low loss and transmission zeros by using cascaded U-shaped DGS are developed, and the cascading creates dual and tri-resonance characteristics in the frequency response. A tri-band bandstop filter with standard 50 Ω microstrip line and stepped-impedance microstrip line are compared, which shows that the latter introduces a wider bandwidth for the first stopband. Compared with the other DGS assisted microwave filters including lowpass, bandpass and bandstop filters which consist of certain resonators or lines, our new design develops the DGS cascade structures without the assistance of resonators or lines to realize multi-stopband, which not only introduces the desired stopbands, but also implements miniaturization. The new designs are fabricated and measured, and the experiment demonstrates the design.

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