Progress In Electromagnetics Research Letters, Vol. 41, 185–191, 2013

LOWPASS FILTER WITH WIDE STOPBAND AND SHARP SKIRT USING NOVEL DEFECTED GROUND STRUCTURE

Yang Li*, **Hong-Chun Yang, and Shao-Qiu Xiao**

School of Physical Electronics, University of Electronic Science and Technology of China, Chengdu 610054, China

Abstract—A novel defected ground structure unit is presented in this paper. This structure is composed of a traditional dumbbell DGS and a pair of coupling stubs in the aperture. In contrast to a single finite attenuation pole characteristic offered by the conventional dumbbell DGS, the proposed DGS unit provides dual finite attenuation poles that can be independently controlled. By adjusting the position of the two attenuation poles, a much sharper skirt and wider stopband could be achieved. A lowpass filter with a cut off frequency of 3.2 GHz utilizing four cascaded novel DGS units is designed, fabricated and measured. This lowpass filter achieves a wide stopband with over 30-dB attenuation up to 30 GHz. The results obtained from simulation and measurement have good agreement.

1. INTRODUCTION

A lowpass filter is commonly used in many microwave communication and radar systems to suppress harmonics and spurious frequencies. Therefore, wide stopband and sharp cutoff response are important factors in the design of the lowpass filter. Usually, the conventional method to implement lowpass filters is using stepped impedance structures and shunt stubs [1, 2]. The disadvantage of these structures is narrow stopband and poor cutoff response. Recently, numerous research works have been carried out to design high performance LPFs using defected ground structures (DGSs) [3–5]. In general, there are two effects of DGS; the bandgap effect, which stops wave propagating at the centre frequency of attenuation pole, and the slow-wave effect,

Received 15 June 2013, Accepted 29 July 2013, Scheduled 31 July 2013
* Corresponding author: Yang Li (liyang8311@gmail.com).

which provides the size reduction of microwave circuits. A traditional DGS element uses a dumbbell-shaped pattern etched in the ground plane and can provide only one attenuation pole [6], which limits the bandwidth of the stopband and the cut off frequency responses. Although it can be overcome by cascading several DGS units in one-dimensional period pattern [7, 8], the increased circuit size will become another problem. In order to realize simultaneously wide stopband and size minimization for the microstrip lowpass filter with DGS, a novel DGS unit that can offer dual attenuation poles is proposed. The proper control of these two attenuation poles can significantly suppress the spurious responses in the stopband with much smaller defected ground area. A microstrip lowpass filter prototype with a cutoff frequency of 3.2 GHz and wide stopband up to 30 GHz has been designed and experimentally characterized to demonstrate the proposed DGS usefulness.

2. DGS UNIT DESIGN

In this letter, a novel defected ground structure with two attenuation poles is provided. The position of the two attenuation poles can be adjusted independently, so a lowpass filter with ultra-wide stopband and sharp skirt can be realized by optimizing the parameters of the DGS.

Figure 1 shows the structure of a traditional DGS and the proposed DGSs. The dashed line outlines the microstrip line. The shape filled with grey color denotes the DGS pattern etched in the ground plane. From the schematic, one can notice that the only difference is that a pair of coupling stub is added in the aperture of the traditional DGS. The coupling length is w_4, the width of the coupling stub w_5, and the gap between two stubs w_6.

Two structures, both the traditional one and the one proposed in this letter, are simulated with a commercial EM simulation software IE3D. In simulation, the substrate used is Rogers RT6010 with relative permittivity 10.2 and thickness 1 mm. Associated parameters: $w_1 = 1\,\text{mm}$, $w_2 = 4\,\text{mm}$, $w_3 = 1.5\,\text{mm}$, $w_4 = 2.8\,\text{mm}$, $w_5 = 0.1\,\text{mm}$, $w_6 = 0.1\,\text{mm}$, $l_1 = 0.9\,\text{mm}$, $l_2 = 2.9\,\text{mm}$. The simulated results are shown in Fig. 2.

Figure 2 shows the comparison of the frequency responses of traditional DGS unit and proposed DGS unit. It can be observed that the proposed DGS pattern has two attenuation poles while the traditional one has only one. The position of attenuation pole 2 of the novel DGS pattern located at 13 GHz, basically the same as the traditional DGS unit. Additionally, there is another attenuation pole

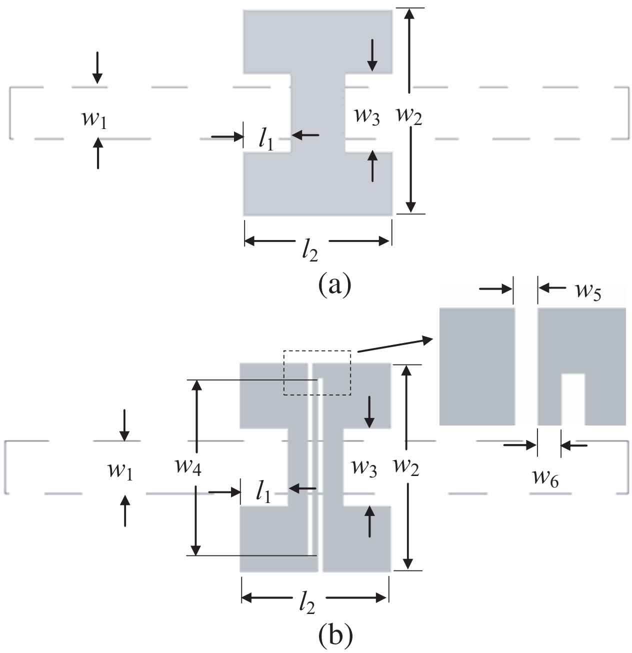

Figure 1. (a) Structure of the traditional DGS pattern and (b) the proposed DGS pattern.

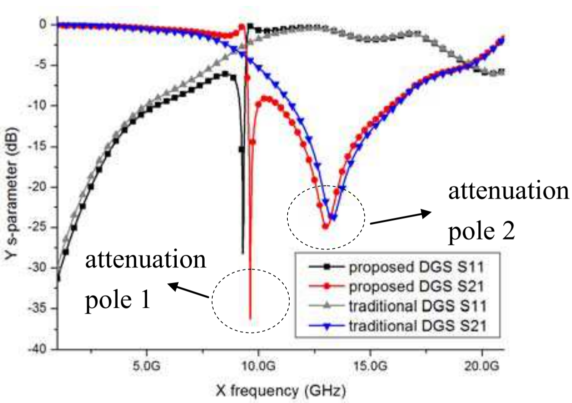

Figure 2. Simulated S-parameters of the traditional DGS and the novel DGS.

located at about 10 GHz. Because of the existence of attenuation pole 1, a much sharper selectivity than the traditional DGS pattern can be achieved. By arranging the two attenuation poles properly, a lowpass filter with ultra-wideband stopband and sharp skirt could be implemented.

3. PARAMETRIC STUDY

During the parameter research, it is found that the positions of the two attenuation poles can be tuned independently by adjusting w_3 and w_4. Fig. 3 shows the simulated S_{21} with different values of w_3 and w_4. Other parameters are the same as the ones given above.

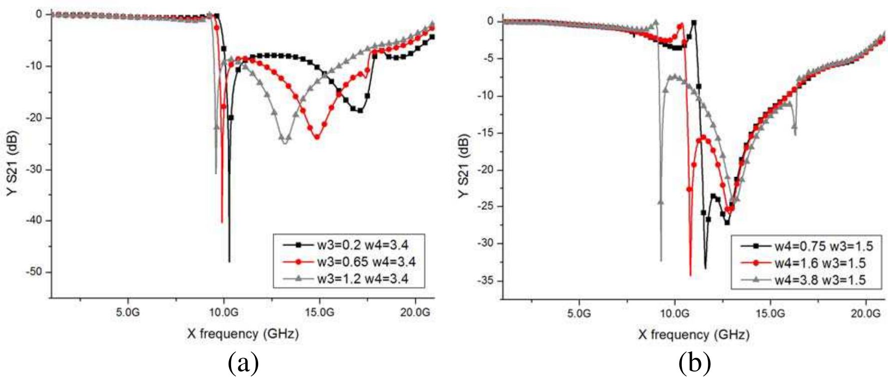

Figure 3. Simulated S_{21} with different (a) w_3 and (b) w_4.

From Fig. 3, it can be seen that when w_4 is fixed and w_3 increased, the second attenuation pole decreases from 17 GHz to 13.17 GHz while the first attenuation pole decreases from 10.27 GHz to 9.57 GHz. On the other hand, when w_3 is fixed and w_4 increased, the first attenuation pole decreases from 11.6 GHz to 9.275 GHz while the second attenuation pole increases from 12.725 GHz to 13.125 GHz. So we can conclude that the first attenuation pole is mainly controlled by w_4 and the second attenuation pole mainly controlled by w_3. This independence will be beneficial for the filter design and tuning.

4. LOWPASS FILTER DESIGN

A lowpass filter with ultra-wide stopband and sharp skirt utilizing the proposed DGS pattern is designed, fabricated and measured.

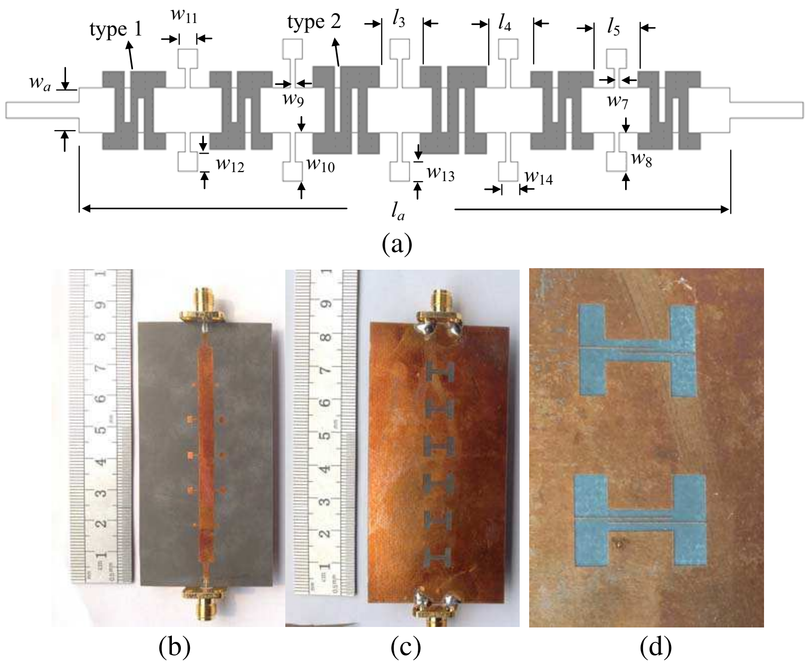

Figure 4. (a) Dimensions of the fabricated filter and photograph of (b) the prototype front view, (c) back view, (d) detailed view of the DGS.

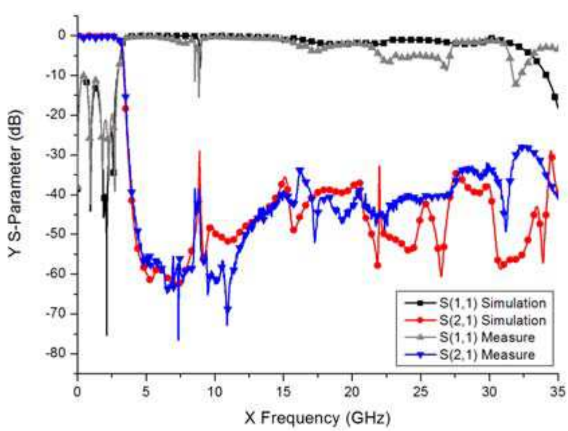

Figure 5. Results obtained from simulation and measurement.

In order to further suppress the harmonic responses, pairs of semi-lumped LC resonant stubs are added to improve the performance. The substrate used in the simulation and fabrication is Rogers RT5880 with relative permittivity 2.2 and thickness 0.508 mm. The parameters and photograph of the fabricated prototype is shown in Fig. 4. The simulated and measured results are depicted in Fig. 5.

In this filter, two kinds of novel DGS unit with different dimensions are used, named type 1 and type 2. The parameters of type 1 are: $w_2 = 8$ mm, $w_3 = 4.5$ mm, $w_4 = 2.4$ mm, $w_5 = 0.1$ mm, $w_6 = 0.1$ mm, $l_1 = 2.25$ mm, $l_2 = 5.9$ mm. The parameters of type 2 are: $w_2 = 9$ mm, $w_3 = 4.5$ mm, $w_4 = 4.4$ mm, $w_5 = 0.1$ mm, $w_6 = 0.1$ mm, $l_1 = 2.25$ mm, $l_2 = 5.9$ mm. Other parameters are: $w_7 = 0.2$ mm, $w_8 = 0.8$ mm, $w_9 = 0.2$ mm, $w_{10} = 1.8$ mm, $w_{11} = 1$ mm, $w_{12} = 1$ mm, $w_{13} = 1.5$ mm, $w_{14} = 2$ mm, $l_a = 67$ mm, $w_a = 4.5$ mm.

From Fig. 5, it is observed that the proposed DGS lowpass filter has a great harmonic suppression and selectivity performance. The fabricated filter has a 3 dB cutoff frequency at 3.25 GHz, and suppression levels are greater than 30 dB from 3.75 to over 30 GHz. The square factor of $\mathrm{BW}_{3\,\mathrm{dB}}/\mathrm{BW}_{30\,\mathrm{dB}}$ is 0.87.

5. CONCLUSIONS

A novel DGS pattern with two attenuation poles is proposed in this letter. The novel DGS has two independently tunable attenuation poles. By finely adjusting the positions of the attenuation poles, wide stopband and sharp skirt characteristics can be achieved. In order to validate the proposed DGS pattern, a lowpass filter based on the new structure has been designed, fabricated and measured. This filter exhibits a sharp selectivity and a very wide stopband. The simulated results are in good agreement with the measured one.

ACKNOWLEDGMENT

This work was supported by the Fundamental Research Funds for the Central Universities.

REFERENCES

1. Matthaei, G. L., L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-matching Networks, and Coupling Structures*, Artech House, Dedham, MA, 1980.

2. Makimoto, M. and S. Yamashita, *Microwave Resonators and Filters for Wireless Communication: Theory, Design and Application*, Springer, Berlin, 2001.
3. Ahn, D., 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 Trans. on Microw. Theory and Tech.*, Vol. 49, No. 1, 86–93, 2001.
4. Song, K., Y. Z. Yin, et al., "Compact LPF with pair of coupling slots for wide stopband suppression," *Electronics Letters*, Vol. 46, No. 13, 922–924, 2010.
5. Taher, H., "High-performance low-pass filter using complementary square split ring resonators defected ground structure," *IET Microwaves, Antennas & Propagation*, Vol. 5, No. 7, 771–775, 2011.
6. Mandal, M. K. and S. Sanyal, "A novel defected ground structure for planar circuits," *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 2, 93–95, 2006.
7. Verma, A. K. and A. Kumar, "Synthesis of microstrip lowpass filter using defected ground structures," *IET Microwaves, Antennas & Propagation*, Vol. 5, No. 12, 1431–1439, 2011.
8. Kufa, M. and Z. Raida, "Lowpass filter with reduced fractal defected ground structure," *Electronics Letters*, Vol. 49, No. 3, 199–201, 2013.