Miniaturized Microstrip Lowpass Filter With Wide Stopband Using Double Equilateral U-Shaped Defected Ground Structure

Sio-Weng Ting, *Member, IEEE*, Kam-Weng Tam, *Senior Member, IEEE*, and R. P. Martins, *Senior Member, IEEE*

***Abstract*—A compact double equilateral U-shaped defected ground structure (DGS) unit is proposed. 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 the DGS lengths. A 2.4-GHz microstrip lowpass filter using five cascaded double U-shaped DGS units is designed and compared with conventional DGS lowpass filters. This lowpass filter achieves a wide stopband with overall 30-dB attenuation up-to 10 GHz and more than 42% size diminution.**

***Index Terms*—Attenuation pole, defected ground structure (DGS), size reduction, U-shaped, wide stopband.**

I. Introduction

APPLICATIONS of defected ground structure (DGS) in radio frequency/microwave (RF/MW) circuits find numerous advantages like circuitry size reduction and spurious response suppression. The conventional DGS element uses a dumbbell-shaped pattern etched in the ground plane [1]. This DGS element exhibits a bandgap characteristic at some frequency, which is mainly attributed by a finite attenuation pole. The relationship between attenuation pole frequency and the physical dimensions of the DGS unit was also explored. Recently, its usage in the lowpass filter for wide stopband implementation has been focused and demonstrated [2]–[7]. In fact, these DGS elements with uniform dimensions are cascaded in a one-dimensional (1-D) periodic pattern [2]–[4] in order to realize wider stopband even the passband ripple is concerned. To counteract this ripple problem, nonuniform configurations have been proposed to achieve much wider stopband and smaller passband ripple simultaneously [5]–[7]. It is found that the more DGS elements are used, the wider stopband is achieved.

Despite the different periodic DGS proposed in the past, the main laggard of these approaches is the excess circuitry size introduced due to the cascade DGS configuration. In order to realize simultaneously wide stopband and size minimization for the microstrip lowpass filter with DGS, a double equilateral U-shaped 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 2.4 GHz and wide stopband up-to 10 GHz has been designed and experimentally characterized to demonstrate the proposed DGS usefulness.

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The authors are with the Department of Electrical and Electronics Engineering, University of Macau, Macao, China (e-mail: tonyting@umac.mo).

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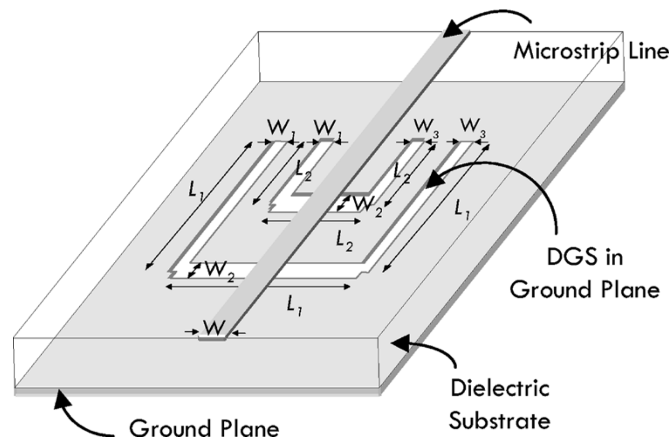

Fig. 1. Three-dimensional view of the proposed DGS unit.

II. Double Equilateral U-Shaped DGS Unit

The proposed double equilateral U-shaped DGS unit is shown in Fig. 1. It has a 50-Ω microstrip line on the top and two equilateral U-shaped patterns that are symmetrically etched in the ground plane. Each U-shaped pattern consists of three etched lines with the same length but different widths (W_1, W_2, and W_3). By setting these two U-shaped patterns with different lengths (L_1 and L_2, where $L_1 > L_2$), the smaller ones can easily be embedded inside the larger ones with the open-end alignment.

Similar to two nonuniform dumbbell-shaped DGS lines connected in cascade configuration, the proposed structure offers dual finite attenuation poles with reduced defected ground area. An example DGS unit has been simulated with IE3D [8] on the Rogers RO4003 substrate with a dielectric constant of 3.38 and a thickness of 1.524 mm. The simulation result, illustrated in Fig. 2, clearly shows that two finite poles with similar attenuation levels are exhibited at two different frequencies f_1 (lower attenuation pole frequency) and f_2 (upper attenuation pole frequency), respectively. When $W_1 = W_2 = W_3 = 1$ mm, $L_1 = 12$ mm and $L_2 = 7$ mm, the two poles are located at 3 GHz and 5.5 GHz and they yield two bandgaps having about 10% and 25% 10 dB-bandwidth. Like the effect of square lattice size or the gap size on the pole frequency of conventional dumbbell DGS unit, these two attenuation poles will be distanced to lower frequencies when larger widths W_1 and W_3 are used. Both the

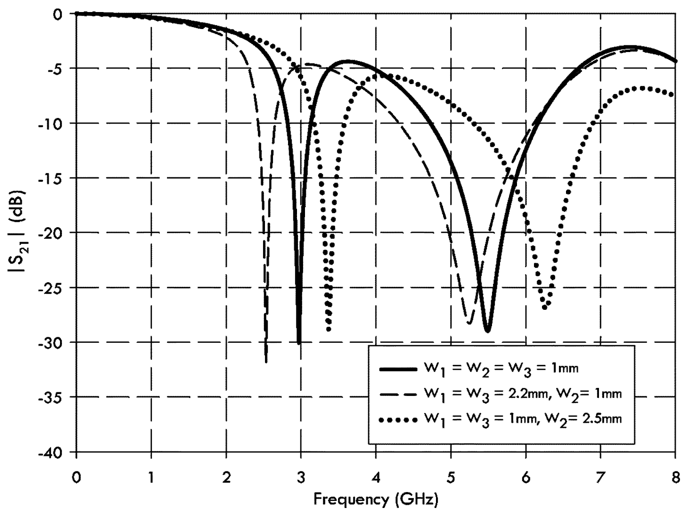

Fig. 2. Simulated $|S_{21}|$ parameter of double equilateral U-shaped DGS unit with $L_1 = 12$ mm, $L_2 = 7$ mm and different widths.

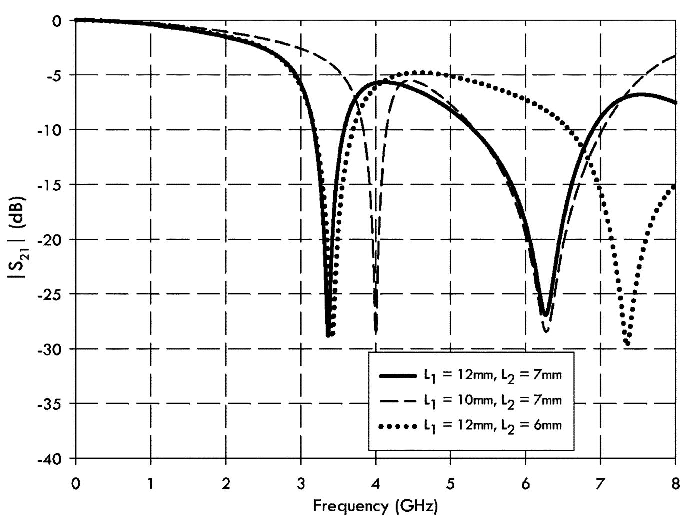

Fig. 3. Simulated $|S_{21}|$ parameter of double equilateral U-shaped DGS unit with $W_1 = W_3 = 1$ mm, $W_2 = 2.5$ mm and different lengths.

attenuation poles will be relocated to higher frequencies if only the width W_2 is increased.

On the other hand, when the widths are fixed and the lengths (L_1 and L_2) vary, the dual attenuation pole characteristic will be kept. Moreover, it is found that the lower attenuation pole results from the longer length L_1 whereas the upper attenuation pole is due to shorter length L_2. As shown in Fig. 3, only the frequency f_1 increases when the length L_1 is shorten. Similarly, a shorter L_2 will only lead f_2 to a higher frequency value. From Fig. 2 and Fig. 3, it is clear that the two attenuation poles can be relocated by adjusting either the DGS widths or lengths. The individual length adjustment can control these two poles independently, and thus will be more beneficial for the bandgap design and tuning. As such, attenuation poles at different frequencies can be simply designed with longer and shorter lengths (L_1 and L_2) in order that they are placed near the unwanted response of the lowpass filter stopband.

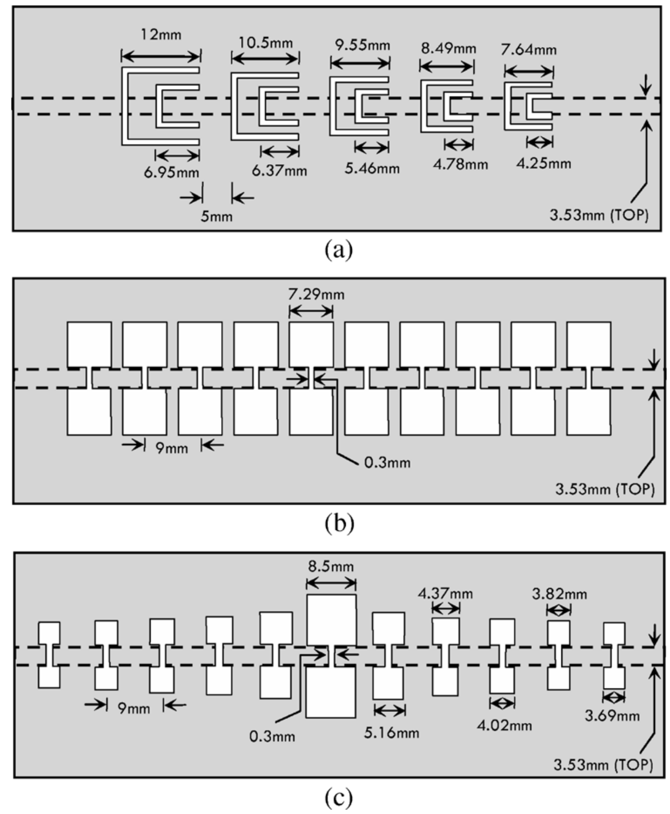

Fig. 4. Lowpass filter using cascade DGS (a) Type-I. (b) Type-II. (c) Type-III.

III. Microstrip Lowpass Filter With Wide Stopband

In order to demonstrate the effectiveness of this DGS unit, three microstrip DGS lowpass filters as shown in Fig. 4, by cascading the double equilateral U-shaped DGS units (called type-I), the uniform square-dumbbell DGS [1] (called type-II), and the exponentially resized square-dumbbell DGS [6] (called type-III) are designed and compared. All these three filters are designed for the same cutoff frequency at 2.4 GHz and are simulated on the Rogers RO4003 substrate with the same dielectric constant of 3.38 and thickness of 1.524 mm. A 50-Ω microstrip line is assumed on the top.

A lowpass filter with wide stopband can be designed by taking full advantages of the attenuation pole control as addressed in Section II. For example, to implement a wide stopband from 3 to 10 GHz by 10 attenuation poles, only five double equilateral U-shaped DGS units are needed to generate these attenuation poles at the frequencies (3 GHz, 5.5 GHz), (3.5 GHz, 6 GHz), (4 GHz, 7 GHz), (4.5 GHz, 8 GHz), and (5 GHz, 9 GHz), respectively. In addition, the lengths of the DGS units are adjusted individually according to the above attenuation pole frequencies. When the widths W_1, W_2, and W_3 are all selected as 1 mm and the separation between units is 5 mm, the lengths of the DGS units can be estimated based on the above inversely-proportional property. The optimized length parameters are shown in Fig. 4(a). Following the conventional approaches from [1] and [6], the 10-pole type-II and 11-pole type-III filters are designed and their dimensions are shown in Fig. 4(b) and (c). The simulation results of the above three filters are compared and plotted

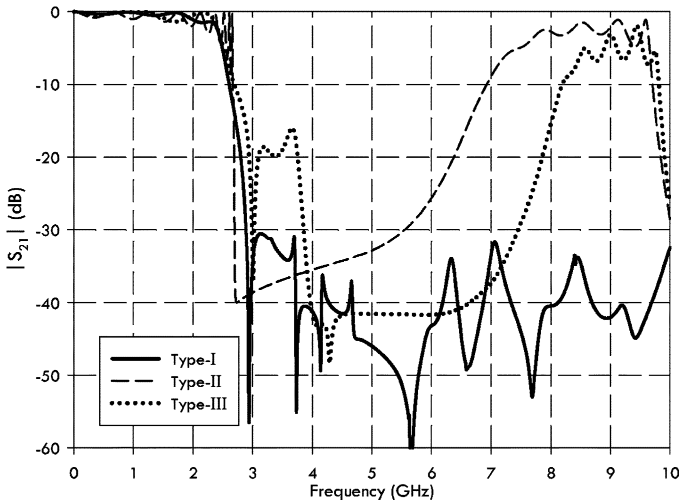

Fig. 5. Simulated $|S_{21}|$ parameter of the three DGS lowpass filters: type-I, type-II, and type-III.

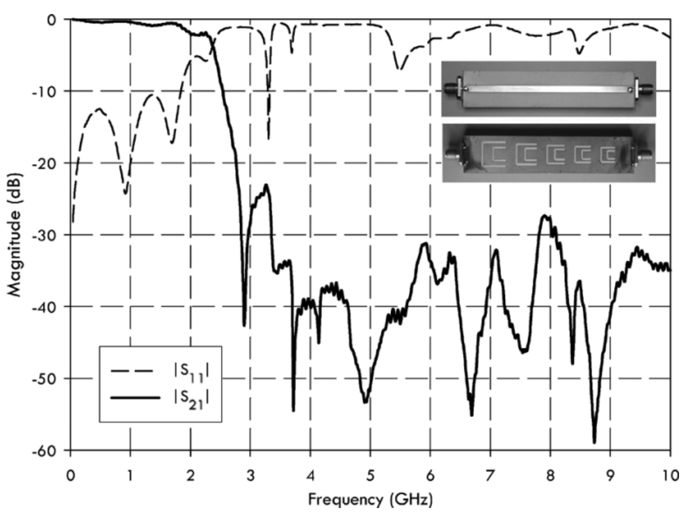

Fig. 6. Measured S-parameters of the type-I lowpass filter.

in Fig. 5. All three of these filters are with the cutoff frequency at 2.4 GHz and exhibit a similar passband performance.

Like the nonuniform type-III filter, the maximum passband ripple of the proposed structure is as low as 1.5 dB whereas 8.41 dB is obtained in the uniform type-II filters. For the proposed structure, a wide stopband with 30-dB attenuation until four times its cutoff frequency is obtained. However, for type-II and III filters, two spurious passbands ranging from 5.55 to 10 GHz and 7.45 to 10 GHz are observed. Thus, the proposed structure offers these spurious response suppressions close to 30 dB. The type-I filter was also fabricated and its measured results are reported in Fig. 6. A very good agreement with the simulation results is observed in both passband and stopband response. The measured passband shows a cutoff frequency of 2.4 GHz and its maximum ripple is 2.26 dB. The peak matching level is 10.52 dB. The measured stopband with the overall 30-dB attenuation is observed till 10 GHz. In the stopband, only two attenuation fluctuations bounded by -23 dB are recorded at 3.26 GHz and 7.9 GHz. Besides the wide stopband characteristic, the proposed filter with the overall defected ground area of 70.68×13 mm^2, as shown in the inset of Fig. 6, provides 42.5% and 52.2% size reduction against the type-II and type-III filters, respectively.

IV. Conclusion

The proposed double equilateral U-shaped DGS unit offers a dual-finite-attenuation-pole characteristic. These two attenuation-pole frequencies are inversely-proportional to the lengths of the interior and exterior U-shaped patterns. Using this structure for lowpass filter design, the attenuation poles can be designed at desired frequencies to suppress the filter spurious response. From the simulated and experimental results, the lowpass filter based on the proposed DGS unit offers significant improvement of the stopband attenuation and size reduction when compared with the conventional DGS lowpass filters.

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