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LETTER

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Novel design of substrate integrated waveguide filter employing broadside-coupled complementary split ring resonators

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Abstract: A novel design of filter based on substrate integrated waveguide (SIW) structure is presented in this letter, and a pair of broadside-coupled complementary split ring resonators (BC-CSRRs) are used in the filter. The filter has a very simple structure and a very compact size. Its characteristics are discussed. In order to verify the proposed design, an example of the proposed filter with a center frequency of 5 GHz is fabricated and measured, and good results obtained. Moreover, a way to make further use of the proposed structure to design dual-band filter is also discussed in this letter, and an example of dual-band filter has been fabricated and measured.

Keywords: substrate integrated waveguide, filter, BC-CSRR, split ring resonator, dual-band

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Substrate integrated waveguide (SIW) structure is evolved from traditional rectangular metal waveguide [1]. It succeeds most of the advantageous characteristics of traditional rectangular waveguide, but is much easier to connect with other planar structures such as microstrip line, so SIW is very convenient to integrate into microwave circuits.

The broadside-coupled split ring resonator (BC-SRR) is evolved from the edge-coupled split ring resonator (EC-SRR), which is first presented by Pendry in [2], as a possible unit cell of metamaterial. After that, SRR structure has gained much attention, and many researchers proposed some other shapes of SRR structure, including the BC-SRR [3]. The BC-SRR was proposed in order to avoid the EC-SRR bianisotropy. It has the additional advantage of a potentially much smaller electric size [4]. The main modification with regard to the EC-SRR is that both rings are printed at both sides of the dielectric board. This modification does not substantially affect the behavior of the resonator.

By invoking the concept of duality and complementarity [5, 6, 7], the BC-CSRR can be derived from the BC-SRR structure in a straightforward way. The benefit of this is that the BC-CSRR structure is especially suited to SIW structure, since they both are two-sided and symmetrical. Fig. 1 shows the basic configuration of the BC-CSRR structure. Please notice that circular SRR and rectangular SRR are basically the same, in this letter, rectangular BC-CSRRs are adopted. Two ring slots are respectively etched on the surface metal on the top and bottom side of the substrate.

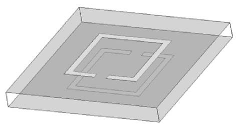

Fig. 1. Configuration of the BC-CSRR.

In [8] and [9], some kinds of SIW filters with BC-CSRRs are proposed, but they are not simple enough, since two pair of BC-CSRRs are contained in a single filter. In this letter, a novel SIW filter employing BC-CSRR is presented. The proposed filter contains only one pair of BC-CSRRs, which makes it more simple and compact. Plus, another advantage is that dual-band filter can be easily designed based on the proposed filter, using two pairs of BC-CSRRs of different size.

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2 Filter design and analysis

Fig. 2 shows the basic layout of proposed filter, it is designed on a 0.508 mm-thick Rogers RO4350 substrate with a relative permittivity of 3.66 and a loss tangent of 0.004.

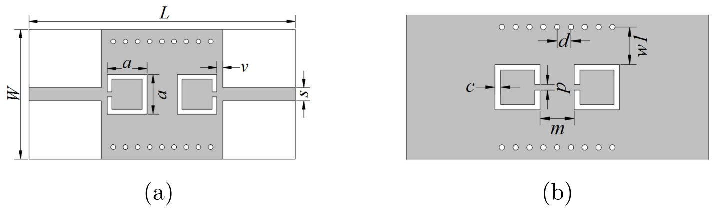

Fig. 2. (a) Configuration of the top of the proposed filter. (b) Configuration of the bottom of the proposed filter.

As is shown in Fig. 2, a pair of BC-CSRRs of the same size are placed at both sides of SIW part of the filter. The total size of this filter is 22.1 mm × 10.8 mm at 5 GHz, and it diminishes to only 10.1 mm × 10.8 mm disregard the feed lines. Parameters in Fig. 2 are as follows: $L = 22.1$, $W = 10.8$, $a = 3.3$, $c = 0.2$, $v = 0.5$, $m = 2.5$, $p = 0.2$, $d = 1$, $w1 = 2.65$, $s = 1.1$ (all in mm), and all metallic vias have the same diameter of 0.4 mm.

a and $w1$ are key parameters of the proposed filter. The center frequency can be altered by changing the value of a. Fig. 3(a) shows the simulated results of S_{21} when a changes. It can be seen that the center frequency would ascend if a goes down. The bandwidth of the proposed filter can be altered by changing the value of $w1$. Fig. 3(b) shows the simulated results of S_{21} when $w1$ changes. It can be seen that the passband would become wider when $w1$ increases.

The distance between two BC-CSRRs, namely m in Fig. 2(b), also has an important influence on the performance of the proposed filter. Fig. 3(c) shows the

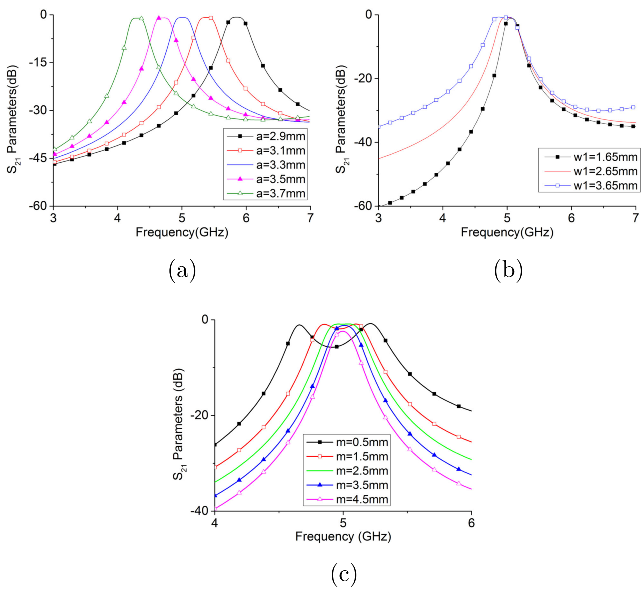

Fig. 3. (a) S_{21} parameter against frequency when a changes. (b) S_{21} parameter against frequency when $w1$ changes. (c) S_{21} parameter against frequency when m changes.

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simulated results of S_{21} when m changes. Obviously, either the value of m is too large or too small would bring a bad effect.

3 Measurement results

In order to verify the proposed design, a sample has been fabricated and measured. Fig. 4(a) and Fig. 4(b) shows the photograph of the fabricated filter, and Fig. 4(c) shows the comparison between simulated and measured S-parameters of the proposed filter.

From Fig. 4(c), it can be seen that the measured and simulated results show good agreement. The center frequency of the fabricated filter is 5 GHz. The selectivity of passband and the rejection of stopband are very good, and the insertion loss in passband is less than 2 dB. There is a very little frequency deviation between the simulated and measured results. This is probably due to simulation errors and fabrication errors.

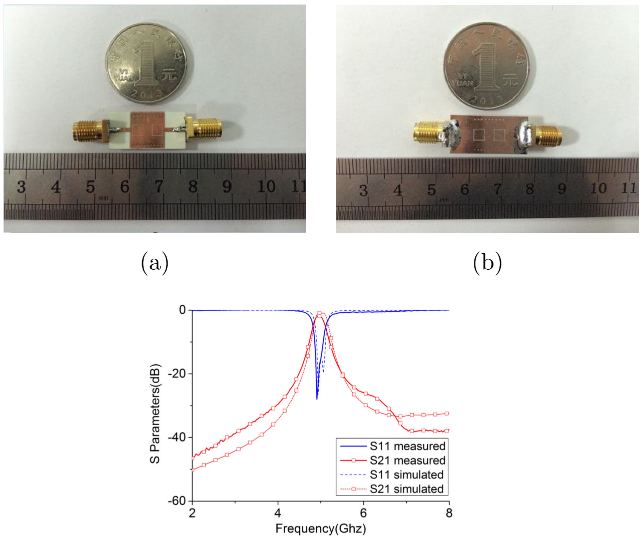

Fig. 4. (a) Photograph of the top of the fabricated filter. (b) Photograph of the bottom of the fabricated filter. (c) Simulated and measured S-parameters against frequency of the fabricated filter.

4 Design of dual-band filter

Based on the proposed filter, a dual-band filter can be very easily designed. Since the size of BC-CSRR is essential to the center frequency of the proposed filter, it is not hard to imagine that if add a pair of bigger or smaller BC-CSRRs to the original filter, a second passband would come out. Fig. 5 is an example of this kind of dual-band filter.

In order to verify the proposed dual-band filter design, a sample has been fabricated and measured, with main parameters as follows: $m = 2.5$, $v = 0.5$, $w1 = 9$, $a = 2.5$, $b1 = 2$, $b2 = 1.3$ (all in mm), and all metallic vias have the same diameter of 0.4 mm. Fig. 6(a) and Fig. 6(b) shows the photograph of the fabricated

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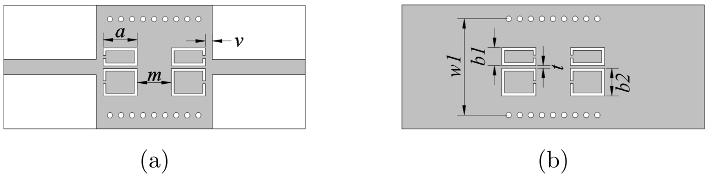

Fig. 5. (a) Configuration of the top of the proposed dual-band filter. (b) Configuration of the bottom of the proposed dual-band filter.

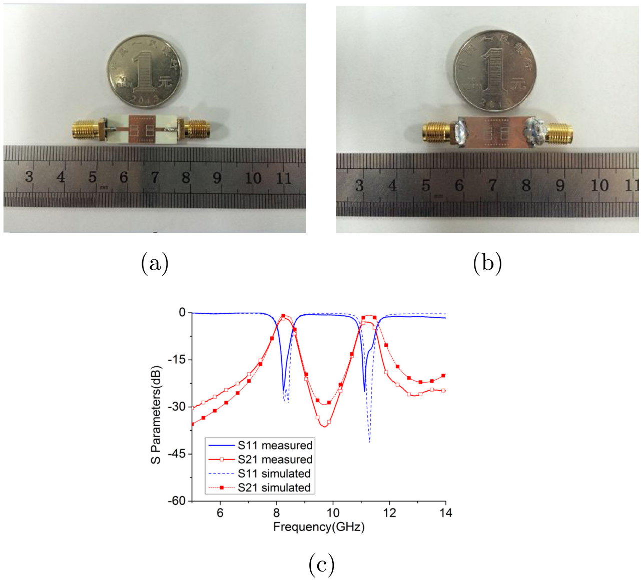

Fig. 6. (a) Photograph of the top of the fabricated dual-band filter. (b) Photograph of the bottom of the fabricated dual-band filter. (c) Simulated and measured S-parameters against frequency of the fabricated dual-band filter.

dual-band filter, and Fig. 6(c) shows the comparison between simulated and measured S-parameters of the proposed dual-band filter.

From Fig. 6(c), it can be seen that the fabricated dual-band filter has two passband respectively at 8.2 GHz and 11.2 GHz. Rejection between two passband is greater than 30 dB.

5 Conclusion

A novel compact SIW filter employing BC-CSRR is presented. The filter is easy to design. The center frequency and bandwidth of the proposed filter are very convenient to alter during designing. Measurement results of the proposed filter show a good selectivity and out-of-band rejection, and insertion loss is also reasonable. Besides, a way to design dual-band filter derived from the proposed original filter is also presented. Measurement results of the dual-band filter demonstrate that this way of designing dual-band filter is feasible. Two kinds of filter both have a very simple structure and compact size, and they both obtain good performance. And since they are designed on the SIW structure, they can be integrated into microwave circuits without any difficulties. Therefore, the proposed filters are suitable for various applications.

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