

## **A NOVEL WIDEBAND BANDPASS FILTER BASED ON COMPLEMENTARY SPLIT-RING RESONATOR**

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**Abstract**—This paper presents a novel wideband bandpass filter making use of complementary split-ring resonator (CSRR) as the basic resonant unit. The resonant characteristic of CSRR is carefully studied through full wave analysis. The coupling of CSRR structure is very strong that can be used to realize wideband filter with small insertion loss. A filter with center frequency at 3.5 GHz, passband from 3.1 GHz to 3.8 GHz is designed and fabricated. The measured results are in good consistent with simulated results.

### **1. INTRODUCTION**

Rapid development of wireless communications present extraordinary demand for wideband bandpass filters with highly selectivity and low insertion loss. The traditional cavity or coaxial structure filters usually have large size and heavy weight in the communication systems [1]. In recently, many people have focused on filter design with split-ring resonator (SRR) or improved SRR structures, which are feasible to realize cross couplings [2–4]. The complementary split-ring resonator (CSRR) structure is achieved by etching SRR in the background, which can also realize resonance effect and has found great application in the design of wideband bandpass filter [5–15].

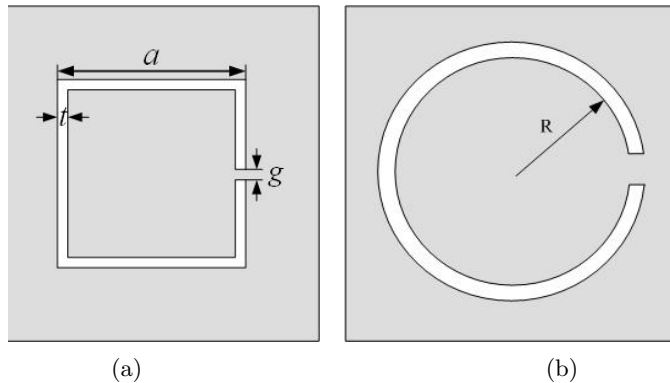
The SRRs are very easy to introduce coupling in their resonant frequency, the synthesis method which was presented by Revy has been improved and some SRR bandpass filters have also been designed and fabricated [2]. And a novel dual-band bandpass filter is designed based on Equal-Length SRR [3]. Recently, CSRR is presented and investigated on the basis of defected ground structure (DGS), then it is used in the filter design [5–7]. In [9], CSRR is introduced and accompanied with open-stubs to form lowpass filter with wide

stopband. And also, CSRR is sometimes combined with means of transmission line sections to realize resonate structure which is used to design bandpass filter [10–14]. The CSRR is also used in Substrate Integrated Waveguide (SIW) to realize bandpass filter [15]. Though it is difficult to give an accurate synthesis for CSRR filter, this structure still has wide application for its advantages such as compact size, strong coupling and so on.

In this paper, the resonant properties of CSRR are carefully studied, and the rules of the change of resonant frequency are obtained. Use the rule as guide line, a filter of center frequency 3.5 GHz, passband from 3.1–3.8 GHz are designed and fabricated, in which CSRRs are used as resonant units.

## 2. THE RESONANT PROPERTY OF CSRR

CSRR structure is achieved by etching SRR structure in the background. As shown in Fig. 1, there are two different kinds of CSRR structure. In addition, there are also many improved forms, such as stud loaded and double ring CSRR, etc., which are not included in this paper. Compared with the circular structure, the square one is widely used because its facility in adjusting resonant frequency and realizing inner coupling.



**Figure 1.** Two different kinds of CSRR (a) square CSRR and (b) circular CSRR.

The CSRR structure resonates at a constant frequency when its dimension is confirmed. To investigate the resonant property of CSRR, we use a simple model as shown in Fig. 2. A single ring CSRR is etched in the ground and a transmission line is placed cross the center of the CSRR on the top layer of the substrate. For all cases in this paper,

the microstrip with relative permittivity 2.65 and thickness 1 mm is considered. By adjusting the dimension parameters of the CSRR, the resonant frequency of this unit is shifted correspondingly.

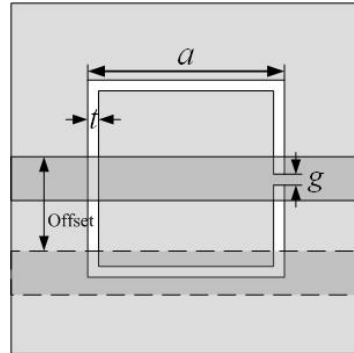


Figure 2. A simple CSRR unit model.

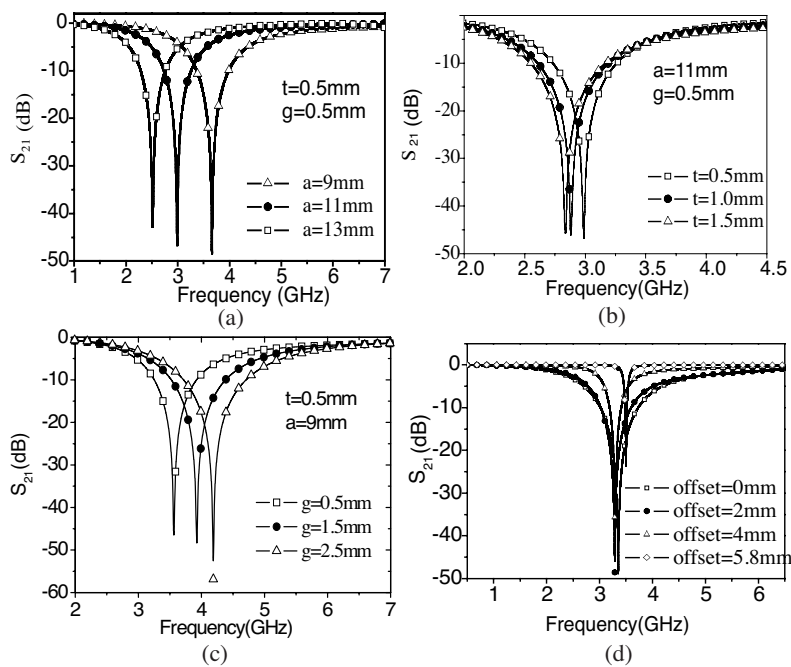


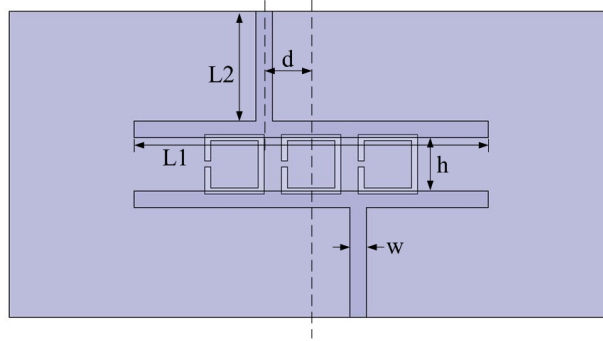
Figure 3. Transmission curves with different (a) side-length, (b) strip-width, (c) gap width, (d) offset.

From the above figures, the basic rule of resonant frequency is achieved. For the single ring CSRR, the resonant frequency is mainly determined by the side-length of the CSRR. Fig. 3(a) depicts that the resonant frequency is rapidly decreasing while the side-length is slightly increased. From Fig. 3(b) and Fig. 3(c) we can see that, by increasing the strip-width of the CSRR, the resonant frequency will decrease, and the wider the gap-width is, the higher the resonant frequency. The coupling between the feed line and the CSRR mainly concentrates at the edge of the CSRR which is estimated by considering the field density at resonant frequency. If we put the feed line above the edge of the CSRR, stronger coupling will be obtained with a little change of resonant frequency. The resonant frequency has little change with increasing offset, as shown in Fig. 3(d). It is important that the coupling is sensitive to the location of the feed transmission line while it is placed above the edge of the CSRR, which will bring some difficulties in the filter design. In order to maintain a stable resonant property, it is better to set the ring width of CSRR little than the width of the transmission line, as shown in Fig. 2.

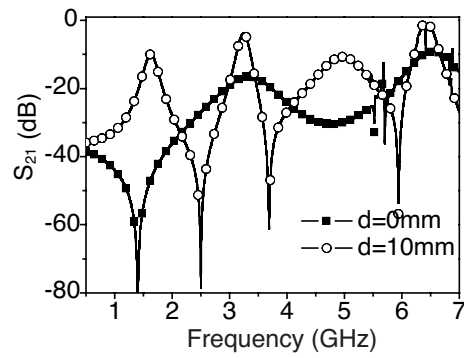
### 3. FILTER DESIGN

The filter structure is shown in Fig. 4. Without the CSRR structure, the model is a pair of parallel couple microstrip line. Stronger coupling will be achieved if the couple lines are put closer, and some energy will be coupled to output, which lead to a narrow passband. It is interesting to find that there is little transmission response when parameter “ $d$ ” is zero, because the couple lines are under the isolation case while analyzed by even-odd-mode theory. The unparallel feed structure will destroy this isolation and will form some transmission response while the two transmission phase of the two pass are equal. A comparison of transmission response with two different values of  $d$  is given in Fig. 5, the dimension parameters are  $L_1 = 60$  mm,  $w = 2.8$  mm, and  $h = 9$  mm.

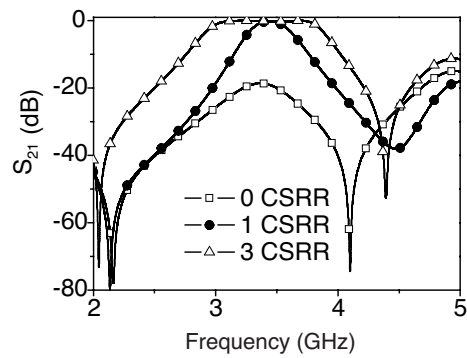
The couple line can not form transmission while  $h$  is larger enough. We choose the CSRR with proper dimension, where  $a = 10$  mm,  $t = 1$  mm and  $g = 1$  mm. The resonant frequency is about 3.5 GHz, and the distance between the two couple line is 9 mm, which means the coupling between the feed line and CSRR are kept constant. And the other parameters are  $L_1 = 60$  mm,  $L_2 = 18.6$  mm,  $w = 2.8$  mm,  $d = 6.5$  mm. Because the energy are coupled by the CSRR, so its resonant frequency is close to the center frequency of the passband. Adjusting the feed structure offset “ $d$ ” to a proper value, the coupling introduced by the CSRRs has form transmission response from 3.1 GHz



**Figure 4.** Bandpass filter based on CSRR.

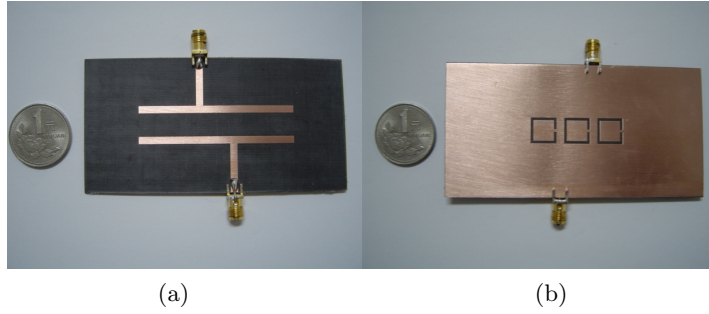


**Figure 5.** Transmission responses without CSRR.

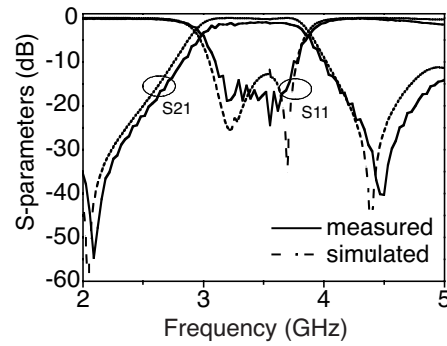


**Figure 6.** Transmission responses with different number of CSRR.

to 3.8 GHz, as depicted in Fig. 6. Adjusting the dimension of the CSRR to form a different resonant frequency, with the same feeding structure, we also can design other bandpass filter with different passband. And we have also give the results while there is a single CSRR, the bandwidth of which is much smaller and the insertion loss is larger.



**Figure 7.** Bandpass filter based on CSRR (a) top view and (b) bottom view.



**Figure 8.** Comparison of measured results and simulated results.

The fabricated filter is shown as Fig. 7. The dimensions of the filter are the same as above, and the total dimension is  $102 \text{ mm} \times 60 \text{ mm}$ . The simulated results and measured results are shown in Fig. 8. From the measured results, the response are in good accord with that of the simulated and the insertion loss is very small. And in the measured results, the passband is from 3.1 GHz to 3.8 GHz, with maximal insertion loss 1.3 dB in all passband.

#### 4. CONCLUSION

This paper presents a novel bandpass filter based on CSRR, which is characterized by wide band and small insertion loss. The resonant property of the single ring CSRR is carefully studied, which is useful to determine the CSRR dimension. A bandpass filter is designed and fabricated to confirm the design procedure.

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