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# Stop Band Characteristics for Periodic Patterns of CSRRs in the Ground Plane

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***Abstract*-Stop band filters are designed by etching periodic patterns of complementary split ring resonators (CSRRs) in the ground plane of a microstrip line. CSRRs, being sub-wavelength resonators, their size are much smaller than the conventional microstrip resonators. As a resonator, it has been observed that a single CSRR in the ground plane has a very high Q factor and gives a very low insertion loss in the stop band. It has also been observed that the period of the CSRR loaded microstrip line can be made as small as λ/10 of the operating wavelength thereby extensive size miniaturization is possible. With the increased number of CSRRs etching and decreased period of the periodic structure loaded with CSRRs in the ground plane of the microstrip line, the stop bandwidth increases and side by side the insertion loss level in the mid stop band frequency decreases significantly thereby further enhancing the stop band filter performance along with the extensive size miniaturization.**

***Index Terms*- Stop band, Periodic Structures, Complementary Split Ring Resonators (CSRRs)**

## I. INTRODUCTION

Size miniaturization of microwave filters is of much demand in the today's rapid changing communication world. Even though end-coupled band pass filters and parallel-coupled band pass filters [1] with the half wavelength resonators are prevalent, they are much larger in size. There exist filters with quarter wavelength resonators. Even these filters also occupy a large amount of device area at lower range of microwave frequencies. Many microstrip filter designs have been proposed in the past few decades but there are rooms for improvements. Recently, metamaterials [2] are gaining a lot of interest to researchers across the globe because such artificial materials produce negative-ε and negative-μ electromagnetic properties, which do not occur in naturally occurring electromagnetic materials. Split Ring Resonators (SRRs) and Complementary Split Ring Resonators (CSRRs) also called as Sub Wavelength Resonators [3]-[4], whose size are much smaller than the operational frequency wavelength, are the component particles for such exotic artificial materials. These components for metamaterials can design filter with improved filter characteristics and size miniaturization. Preliminary results have been reported in [5]. In this paper, we will do a detailed investigation of CSRR based stop band filters: starting with a single CSRR etching in the ground plane, finding its stop band characteristics and quality factor. Then the effect of number of CSRRs etching and periodicity on the stop band filter performance will be investigated.

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## II. CSRR BASED STOP BAND FILTERS

SRR and its complementary structure, CSRR depicted in Fig. 1(a) and (b) respectively are small resonant particles with high quality factor [6]. CSRR essentially behaves as an electric dipole that can be excited by an axial electric field. The CSRR behaves as an externally driven parallel LC resonant circuit [7]. The resonant frequency of these particles can be tuned with the help of dimensions: $r_{ext}$, *c* and *d* depicted in Fig. 2. In our case, CSRR is formed by etching out the metallic portion of the ground plane of microstrip line in the shape of SRR. Both SRR and CSRR with the same dimensions resonate at the same frequency. Complementary split ring resonators (CSRRs) are used in the ground plane instead of SRRs in the same plane of the microstrip line to achieve the stop band characteristics. One of the major advantage is that for applications like harmonic suppression of a band pass filter, we can construct the band pass filter in upper part of the substrate and etch CSRR structures in the ground plane of the substrate hence there is more degrees of freedom for designing the filter as well as the technique used for harmonic suppression. Besides, there are no additional requirements in the area for harmonic suppression of filters.

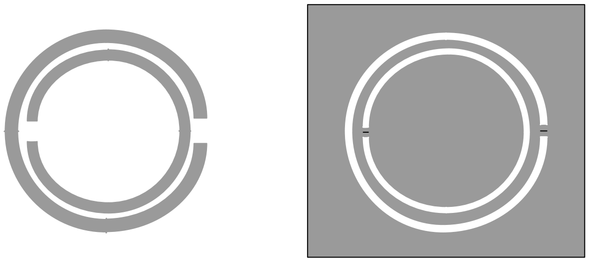

(a) (b)

Fig.1. (a) SRR and (b) CSRR

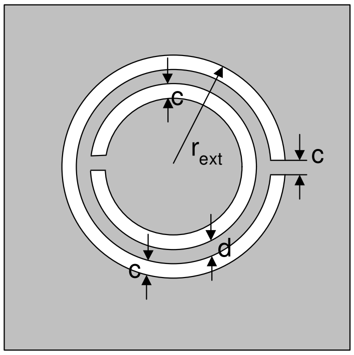
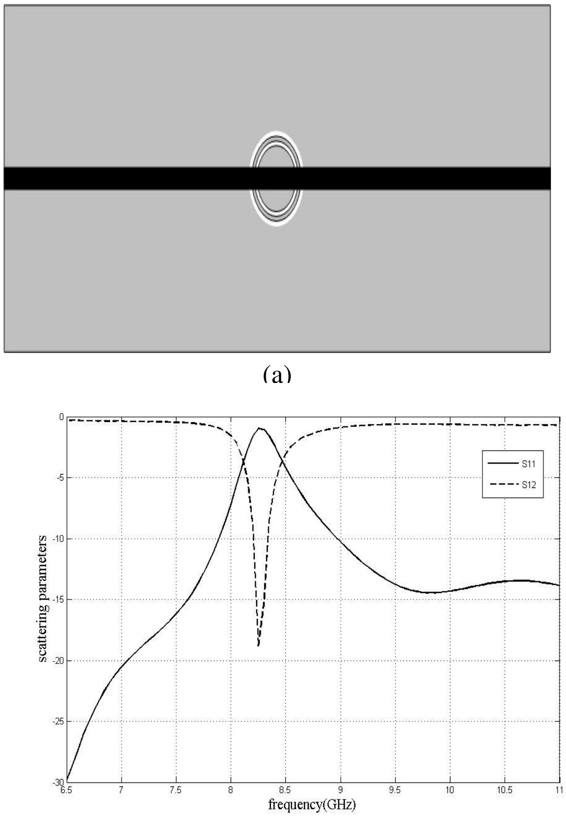


Fig.2. Structure of the CSRR showing the physical dimensions

## III. RESULTS AND DISCUSSION

A CSRR structure is designed to resonate at 8.3 GHz of the X-band microwave frequency region. The dimensions of the CSRR structure chosen for this frequency of operation are $r_{ext}$=1.0mm, $c$=0.2mm and $d$=0.2mm respectively. The dependence on dimensions of the CSRR structure for the resonant frequency is observed as follows: with the increase of external radius ($r_{ext}$) resonant frequency decreases and with the increase of the ring width ($c$) and gap width ($d$) resonant frequency increases. The CSRR structure is placed in the ground plane exactly below the center of a microstrip line of width 2.89mm for a FR4 dielectric substrate of $\varepsilon_r$=4.4 and height ($h$) 1.6mm as shown in Fig. 3(a). Same substrate is used for all other later designs. All the designs are simulated using Zeland IE3D software [8]. The simulation results for a single CSRR etching in the ground plane of a microstrip line are shown in Fig. 3(b).

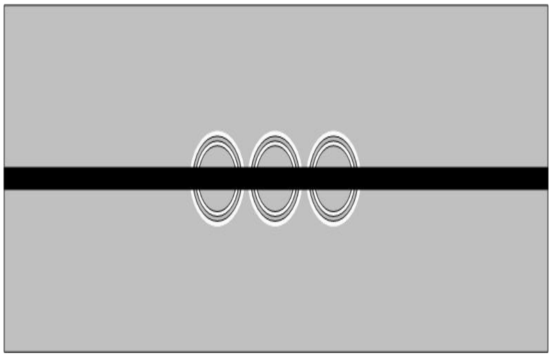


(a)

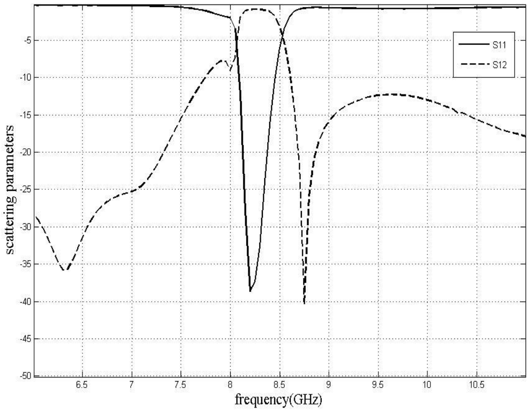
(b)

Fig.3. Single CSSR in the ground plane (a) Front view (b) Scattering parameters

The results of scattering parameters versus frequency (GHz) show narrow stop band characteristics at the resonant frequency of CSRR at 8.3 GHz. By placing a single CSRR structure in the ground plane, we can obtain a narrow stop band with a very low insertion loss level, which is not possible with conventional microstrip resonators. It is difficult to achieve such a good narrowband stop band response with a single element of conventional resonators. Stop bandwidth of the above single CRRR loaded microstrip line filter is approximately 150MHz and it has a very high quality factor of 12546 at the resonant frequency of 8.3 GHz.



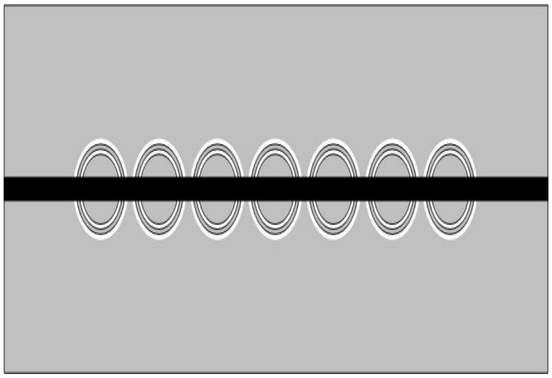
(a)



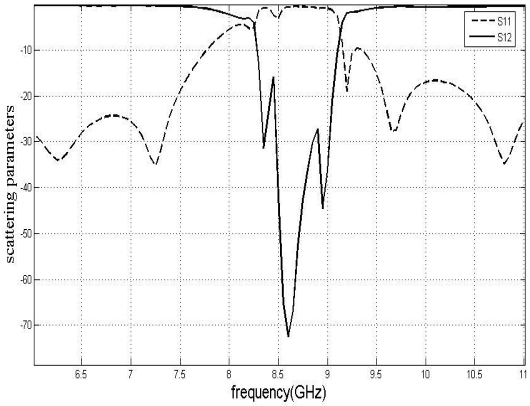
(b)

Fig.4. Stop band filter having 3 CSSRs in the ground plane (a) Front view (b) Scattering parameters

Here our concern is to enhance the stop band filter characteristics by increasing the number of CSRR structures in the ground plane. This is achieved by placing more CSRRs with the same resonant frequencies periodically. Such a stop band filter structure is shown in Fig. 4(a), which has three CSRR structures in the ground plane and all the CSRRs are resonating at the same frequency of 8.3 GHz. The distance between the centers of any two adjacent CSRRs is known as period and it is 3mm for this filter. The simulation results are shown in Fig. 4(b). The simulation results depicted in Fig. 4(b) shows a stop band at 8.3 GHz with a stop bandwidth of approximately 400MHz.



(a)

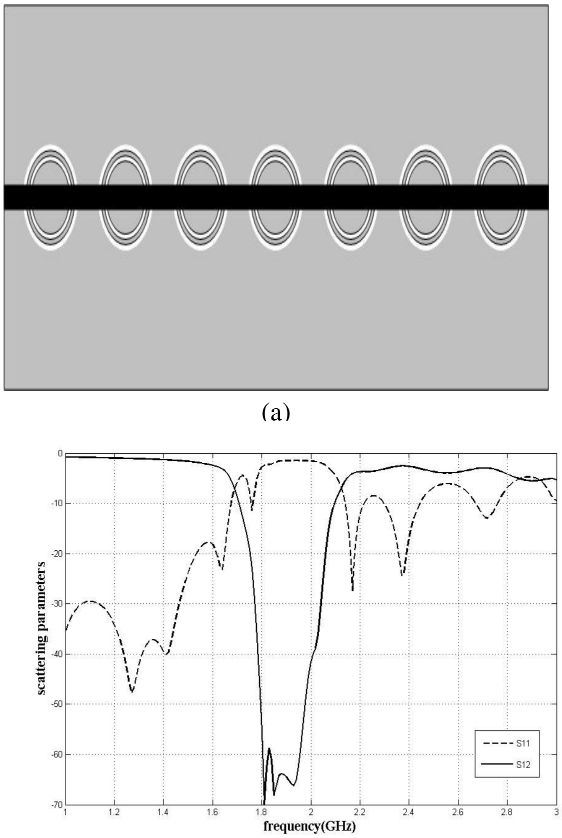


(b)

Fig.5. Stop band filter having 7 CSSRs in the ground plane (a) Front view (b) Scattering parameters

Comparing Fig. 3(b) and Fig. 4(b), we can observe an improvement in the stop bandwidth of nearly 250MHz. We can also observe a significant lowering in the insertion loss levels in the stop band. At resonant frequency, the insertion loss level is maintained at 18dB for the stop band filter with single CSRR and it is at 38dB for the stop band filter with three CSRR structures.

The CSRR structures in the ground plane is further increased to seven as shown in Fig. 5(a) and simulated in the same frequency range of 6GHz to 11GHz. Fig. 5(b) shows the simulation results of the design shown in Fig. 5(a) with seven CSRRs in the ground plane. The results show a large stop band from 8.3 GHz to 9.15GHz with a stop bandwidth of 850MHz, which is a significant improvement compared to the previous results of single CSRR and three CSRR structures in the ground plane.



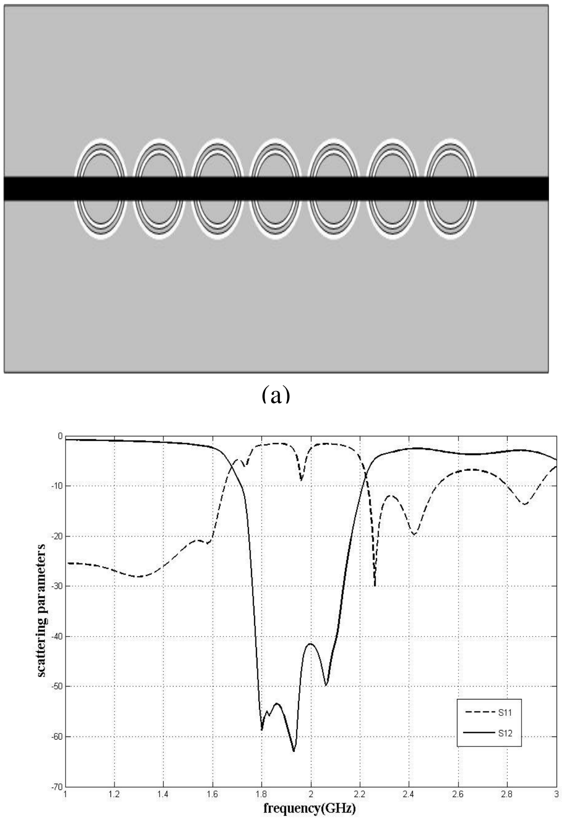
(a)

(b)

Fig.6. Stop band filter having period 20.6mm (a) Front view (b) Scattering parameters

From all these three stop band filters, we observe a significant increase in the stop bandwidth with the increased number of CSRR structures in the ground plane and decreased level of insertion loss in the stop band of the filter.

Period of the stop band structure is also a great concern for enhancing the properties of the filter response. A stop band filter is designed to operate at 1.9GHz with 7 CSRR structures in the ground plane as shown in Fig. 6(a). The dimensions of the CSRR structure are chosen to have resonant frequency at 1.9GHz. They are $r_{ext}$=5.0mm, $c$=0.2mm and $d$=0.2mm for an FR4 dielectric substrate having dielectric constant $\varepsilon_r$ = 4.4 and thickness of 1.6mm. Seven CSRR structures are placed in the ground plane exactly below a microstrip line of width 2.89mm having characteristic impedance ($Z_0$) of 50Ω. The period of the CSRR based stop band filter structure shown in Fig. 6(a) is maintained at 20.6mm.



(a)

(b)

Fig.7. Stop band filter having period 15.6mm (a) Front view (b) Scattering parameters

Fig. 6(b) shows the simulation results of the stop band filter structure shown in Fig. 6(a). The results are plotted for the scattering parameters

($S_{11}$ and $S_{12}$) against frequency from 1GHz to 3GHz. These results show a stop band mid band frequency of 1.9GHz, stop bandwidth ranges from 1.7GHz to 2.1 GHz approximately 400MHz. The period of the CSRRs based stop band filter is changed to 15.6mm. The number of CSRRs in the ground plane is same as in the previous design. The CSRR dimensions and dielectric substrate properties are also the same. The simulated results of the stop band filter design of Fig. 7(a) are shown in Fig. 7(b). Results of scattering parameters ($S_{11}$ and $S_{12}$) are plotted against frequency from 1GHz to 3GHz, which show a stop band from 1.7GHz to 2.2GHz (approximate band width 500MHz). Decreasing the period of the filter by 5.0mm increases the stop bandwidth of the filter by 100MHz. The insertion loss level at the mid frequency of the stop band is increased by 10dB and it is at a significant level of 60dB now.

All the above designs and their simulation results show that with the increase of number of CSRR structures in the ground plane and with small period between them gives more stop band width and lower insertion loss levels in the stop band. The stop bandwidth increases to the right of the resonant frequency of the CSRR particle. Using these two advantages of CSRR based stop band filter design; spurious pass bands in microstrip line filters can be eliminated. Since all the CSRR structures are in the ground plane of the dielectric substrate, we do not need extra device area for the design of stop band filter to remove unwanted spurious pass bands in band pass filters unlike other microstrip line stop band filters which require extra device area. The size of these resonant particles is very small with a very high quality factor and the period of these structures can be maintained at a very low fraction of operating wavelength compared to the conventional filters.

## IV. CONCLUSION

Using the sub-wavelength resonator components of left handed metamaterials namely CSRR, more compact planar microstrip stop band filters have been designed. It is very compact having the size smaller than one tenth of the wavelength at its operating frequency. The dimensions of these particles and the substrate parameters decide their resonant frequency. These types of particles provide an attractive means for developing very compact filters with fully planar fabrication techniques. This is especially benefit for the growing numbers of microwave circuits required for compact integrated circuit (IC) technology and wireless communications. Single CSSR particle in the ground plane gives a very narrow stop band at its resonant frequency with an extremely high Q factor but periodically placing these CSRR structures gives wide stop bands. As the number of etching of these structures increases in the ground plane of the dielectric substrate, the width of the stop band increases at a great extent. Stop bandwidth also depends on the period between the structures. It has been observed that as the period of etching such structures in the ground plane of the dielectric substrate decreases the stop bandwidth increases. One of the main advantages of these particles is unlike the other conventional filter components/structures, which require large period between them they can be placed very close (period can be smaller than one tenth of the operating frequency wavelength) and consequently the filter performances are also enhanced/improved. Because of this property of these particles the device areas are reduced drastically. Since they are placed in the ground plane they will not occupy extra device area in the design of microwave devices for applications like harmonic suppression.

## ACKNOWLEDGMENT

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