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COMPACT, DEEP, AND WIDE REJECTION BANDWIDTH LOW-PASS FILTER USING OPEN COMPLEMENTARY SPLIT RING RESONATOR

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ABSTRACT: *A deep and wide rejection bandwidth, sharp cutoff and compact low-pass filter design using open complementary split ring resonator (OCSRR), and open stub is presented in this article. OCSRR is counterpart of the open split ring resonator. The proposed low-pass filter consist of two OCSRR connected in series. The open stubs are attached on both sides of the OCSRR. At the 3 dB cutoff frequency of 1.08 GHz, the proposed filter offers a sharp rejection and wide rejection bandwidth of more than 20 dB up to six times the cutoff frequency. The filter size is very small as 0.22 $\lambda_g \times 0.18\ \lambda_g$, where λ_g is the guided wavelength at the cutoff frequency. The proposed filter is fabricated and tested; the experimental results are found to be in good agreement with the simulation results.* © 2011 Wiley Periodicals, Inc. Microwave Opt Technol Lett 53:845–848, 2011; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.25874

Key words: *microstrip filter; open complementary split ring resonator; low-pass filter*

1. INTRODUCTION

The rapid development of commercial markets for wireless communication products over the past decade has generated an increasing research interest in size miniaturization and performance improvement of microwave circuit designs. The design of compact low-pass filters with sharp cutoff and wide stopband is required for the elimination of unwanted harmonics or spurious passband in microwave and wireless communication systems. Low-pass filter design using conventional structures such as stepped impedance and open stubs are suffering from either spurious passband or poor cutoff performance. Hence, many novel types of low-pass filter using defected ground structures (DGSs) and compact microstrip resonating cell (CMRC) have been proposed by many researchers [1–9] in recent years. Various DGSs [1–6] such as dumbbell, arrowhead, H-shape, elliptical, complementary split ring resonator, and open slot split ring resonator are used to design compact LPF

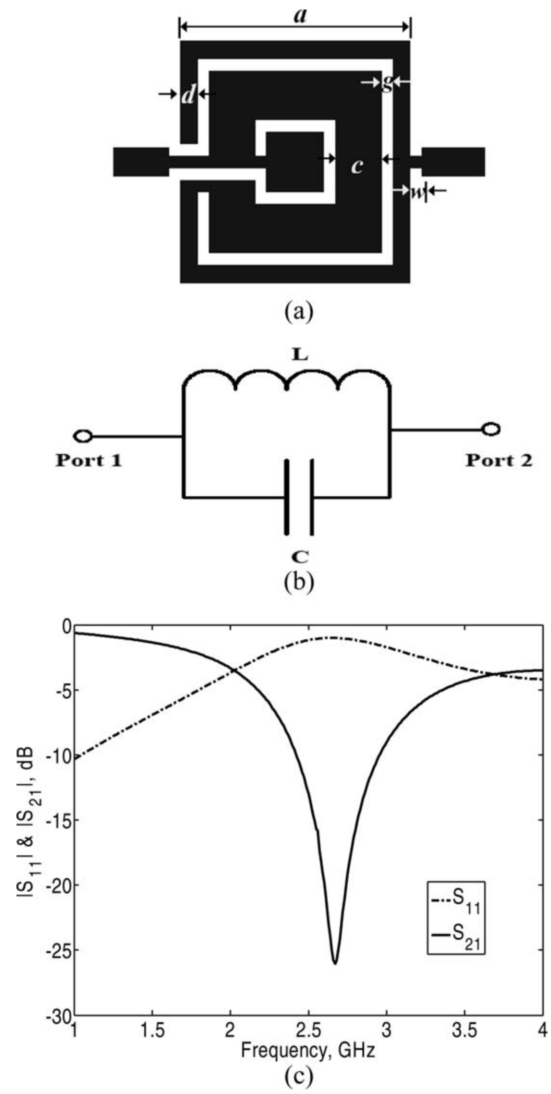


Figure 1 Open complementary split ring resonator (a) layout, (b) equivalent circuit, and (c) simulated scattering parameters

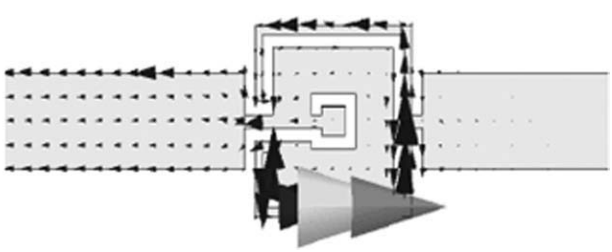


Figure 2 Current distribution of OCSRR at the resonant frequency

and bandpass filter. Fractal shape DGS and modulated microstrip line [7] is used to obtain a good out-of-band filter performance and sharp cutoff in LPF design. Tapered CMRC and modified CMRC have been proposed to design LPF with wide stopband [8, 9]. Even though the performance of filter is good, length is long due to periodic arrangement of CMRC. Recently, open complementary split ring resonator (OCSRR) has been proposed to design a compact low-pass filter in microstrip technology [10].

In this work, a compact, sharp cutoff and improved wide stopband low-pass filter is designed using OCSRR and open-stub arrangement. The proposed filter offers a deep and wide rejection bandwidth than the existing low-pass filters such as cascaded stages of OCSRR. Besides, the size of the filter is comparatively smaller than the existing low-pass filters.

2. OPEN COMPLEMENTARY SPLIT RING RESONATOR

OCSRR is a negative image of the open split ring resonator (OSRR). It was first proposed in coplanar waveguide (CPW) technology by Velez [11] for size miniaturization of microwave devices and components. The OSRR consists of two concentric copper rings having openings at the same side and are connected to the access lines; hence, the resonator is left open. The OCSRR is counterpart of the OSRR. The layout and equivalent circuit of the OCSRR is shown in Figures 1(a) and 1(b), respectively. We can model the OCSRR as a parallel resonant circuit, where "L" is the inductance of the rings, and "C" is the capacitance between the rings. At the resonant frequency of OCSRR, the line is left open, and the energy is reflected back to the source, thereby, causing an attenuation pole. To study the frequency response of the OCSRR, this structure is designed on a FR4 substrate having a dielectric constant of $\varepsilon_r = 4.4$ and a thickness of 1.6 mm. The dimensions of OCSRR are as follows: $a = 6$ mm, $d = 0.4$ mm, $c = 1.45$ mm, $g = 0.4$ mm, and $w =$

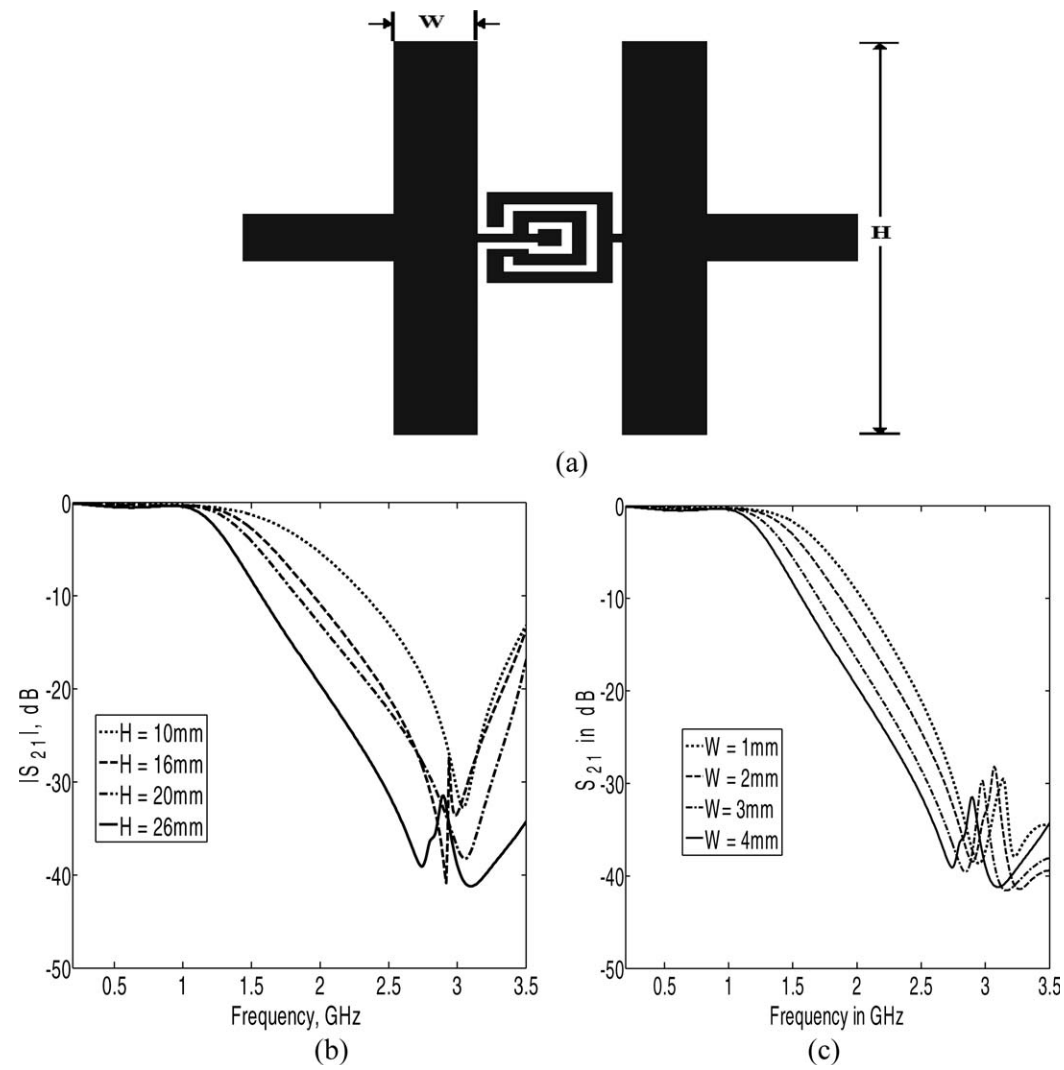
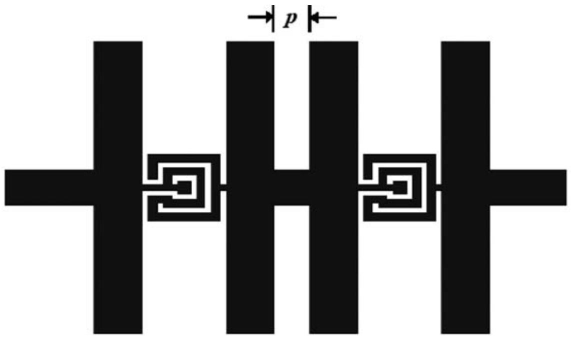
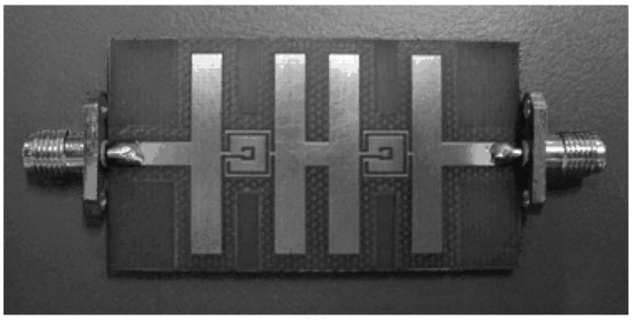


Figure 3 Proposed low-pass filter (a) layout, (b) transmission response for various heights "H" for fixed width "W" = 4 mm, and (c) transmission response for various widths "W" for fixed height "H" = 26 mm



(a)



(b)

Figure 4 Proposed low-pass filter (a) layout and (b) photograph

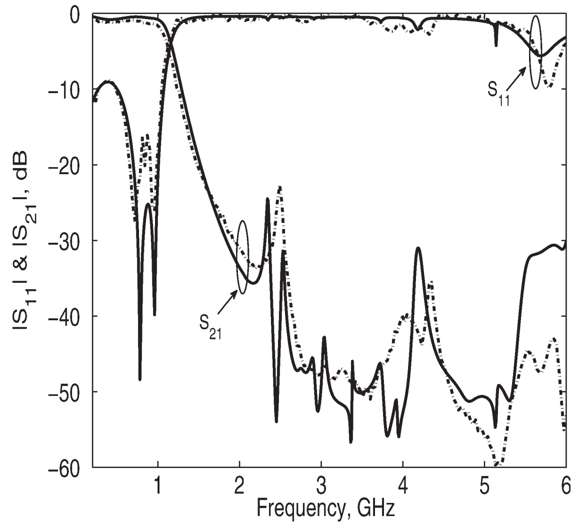


Figure 5 Simulated (solid line) and measured (dashed line) scattering parameters of proposed low-pass filter

0.4 mm. To achieve sharp rejection, capacitance of the OCSRR should be high, so the value of "*c*" is kept more than "*d*." Simulated scattering parameters are plotted in Figure 1(c). At the resonant frequency $f_r = 2.67$ GHz, an attenuation pole is observed. The current distribution of the OCSRR at the resonance frequency of OCSRR is shown in Figure 2. From the figure, it can be observed that at resonance, the transmitted energy is reflected back to the source and causing an attenuation pole.

3. LOW-PASS FILTER DESIGN USING OCSRR

As discussed in [10], the OCSRR-based filter characteristic does not fall in any standard approximations such as Chebyshev and elliptic. So the low-pass filter is constructed using the cascaded stages of OCSRR. To obtain a spurious free stopband, many cascaded stages of OCSRR tuned to the spurious passband frequency are used. This will increase the length of the filter. In our proposed design, two open-ended stubs are attached on both sides of the OCSRR, and the number of cascaded stages has been reduced to just two to get a very good filter performance. The layout of the proposed structure is shown in Figure 3(a). By keeping the width of the open stub as constant, simulated transmission responses for stub lengths $H = 10$, 16, 20, and 26 mm are shown in Figure 3(b). It is observed that by increasing the length of the stub, the cutoff frequency move toward the lower end and sharp roll off rate is also achieved. Similarly, transmission responses of the structure for various stub widths $W = 1$ to 4 mm are plotted in Figure 3(c). The increase in width of the stub increases capacitance due to which sharp transition from passband to stopband is achieved. Hence, suitable choice of device dimension leads to a low-pass filter with the required cutoff frequency. For demonstration purpose, we have designed a low-pass filter with 3-dB cutoff frequency of 1 GHz and more than 20-dB rejection levels at 1.5 GHz. The length and width of the stub are chosen as 26 and 4 mm, respectively. The dimensions of OCSRR are same as mentioned above. However, the spurious passband is present near the cutoff frequency, and the transition from passband to stopband performance is poor. So, we have cascaded the two cells of OCSRR and open-stub arrangement. The distances between the two cells are 3 mm, which is optimized using electromagnetic simulation. The geometry and photograph of the proposed low-pass filter is shown in Figures 4(a) and 4(b), respectively. The prototype of the proposed filter is fabricated on a FR4 substrate and tested using Agilent 8753ES Network analyzer. Simulated and experimental results of the proposed low-pass filter are illustrated in Figure 5. The proposed filter has 3 dB cutoff frequency of 1.08 GHz and low insertion loss of less than 0.66 dB in the passband. The insertion loss suddenly drops to -20 dB at 1.45 GHz that means the transition bandwidth is only 0.37 GHz. The selectivity of the proposed filter is 46 dB/GHz. The measured stopband rejection of the filter is better than 30 dB up to 6 GHz, which is nearly six times the cutoff frequency. The length of the filter is 32.6 mm excluding the access line, which is 73% shorter than the Aznar's low-pass filter reported in [10]. The proposed low-pass filter result is compared with the some of the efficient and related filters already existing in literature and tabulated in Table 1. Note that λ_g is the guided wavelength of the 50 Ω microstrip line at the

TABLE 1 Performance Comparison of LPFs

Low-Pass Filter	Cutoff Frequency (f_c) (GHz)	Size	Stop Bandwidth Up To	Stopband Rejection (More than 30 dB)
Wu et al. [4]	1.1	$0.32\ \lambda_g \times 0.18\ \lambda_g$	$5f_c$	Upto $4.4f_c$
Li et al. [8]	1.3	$0.62\ \lambda_g \times 0.19\ \lambda_g$	$10f_c$	Upto $6f_c$
Aznar et al. [10]	1.33	$0.81\ \lambda_g \times 0.09\ \lambda_g$	$4f_c$	Upto $2f_c$
Proposed work	1.08	$0.22\ \lambda_g \times 0.18\ \lambda_g$	$6f_c$	Upto $6f_c$

cutoff frequency. Wu's low-pass filters [4] using novel split-ring resonator DGS could achieve harmonic suppression up to five times the cutoff frequency, and it is 0.1 λ_g longer than the proposed filter. Li's low-pass filter [8] using tapered compact microstrip resonant cells could achieve harmonic suppression up to 10 times the cutoff frequency, but it is 0.4 λ_g broader and 0.01 λ_g longer than the proposed filter. However, the stopband rejection level of more than 30 dB is up to six times the cutoff frequency, which is comparable to the proposed low-pass filter.

4. CONCLUSIONS

This paper presents a novel low-pass filter with improved stopband performance and compact size using OCSRR. To obtain the sharp rejection, cascaded stages of two cell OCSRR and open-ended stubs are utilized. The proposed filter shows a very good performance in terms of low-insertion loss in the passband, deep and wide rejection bandwidth, and compact design. The proposed filter is verified with the experimental results. This filter is simple from fabrication point of view as well, because it does not involve any via holes.

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MINIATURIZED ZEROTH-ORDER RESONATOR BASED ON SIMPLIFIED CRLH TL STRUCTURE

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ABSTRACT: *A novel miniaturized zeroth-order resonator (ZOR) using a simplified composite right/left-handed transmission line structure is proposed. The ZOR consists of only microstrip line and grounded stub. Compared with the conventional half-wavelength resonator, the superiority of the ZOR proposed here mainly lies in its compact size. In addition, it is easy to tune the zeroth-order resonant frequency, thanks to its simple structure and easy fabrication. The full-wave simulation and experiment are carried out on a four-cell ZOR and a one-cell ZOR. A good agreement between the simulated and experimental results verifies that the proposed method is feasible.*

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Key words: *simplified composite right/left-handed (SCRLH); transmission line (TL); zeroth-order resonator (ZOR); infinite wavelength; dimension reduction*

1. INTRODUCTION

Electromagnetic metamaterials may be classified into two different categories: resonant and transmission line (TL) metamaterials [1]. Compared with the resonant metamaterials, TL metamaterials exhibit several advantages such as broad bandwidth, low loss, and compatibility with planar circuits. So, after the concept of composite right/left-handed (CRLH) TL metamaterials was independently introduced by Caloz et al. [2], Iyer and Eleftheriades [3], and Oliner [4], it quickly led to a large number of novel applications [5].

An intriguing zeroth-order resonator (ZOR) based on CRLH TL was first reported in [6] and extensively developed in [7]. The zeroth-order resonant frequency and unloaded Q of the ZORs are independent of their physical lengths. More importantly, it has a unique property of supporting an infinite-wavelength wave at a specific nonzero frequency [6–9]. Therefore, ZORs have wide applications in microwave dividers [10], couplers [11], filters [12], and antennas [13, 14]. Most of the reported ZORs were basically achieved using CRLH TL structures. However, there are still some disadvantages in designing and processing the series capacitors or shunt inductors of CRLH TL structures such as complex configuration, difficult implementing, and bothersome equivalent circuit, which, to some extent, increase the applied difficulty and cost of the CRLH TL devices [15–17].

Some researchers proposed a simplified composite right/left-handed (SCRLH) TL, by means of taking away the series capacitance of the CRLH TL, to replace the CRLH TL in some application cases [18, 19].

Although the TL metamaterials can provide new insights into the design of microwave components and antennas, there is still some controversy [20]. Proponents suggest that the concepts and theory of TL metamaterials provide new insights that have resulted in novel microwave applications. Detractors point out the physical problem in realizing a true CRLH TL and suggest that in practical cases it would be better to handle with CRLH TL problem using filter theory. Despite the continuing controversy, this article still explores the concept of SCRLH TL in the design of ZOR.

In this article, a novel approach to design ZORs based on a SCRLH TL structures is proposed. The principle is theoretically analyzed. The performances of a four-cell ZOR and a one-cell ZOR are simulated and experimentally tested. The simulated