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COMPACT WIDEBAND BANDPASS FILTER USING OPEN SLOT SPLIT RING RESONATOR AND CMRC

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Abstract—In this paper, a compact, wide fractional bandwidth bandpass filter using a new open slot split ring resonator (OSSRR) defected ground structure and compact microstrip resonating cell (CMRC) is presented. OSSRR is the modified and dual version of the open split ring resonator (OSRR). The band pass filter (BPF) is constructed by cascading lowpass and highpass sections designed using CMRCs and OSSRR respectively. The designed BPF has wide fractional bandwidth of 74%, sharp passband to stopband transition and low passband insertion loss of less than 1 dB. The simulated results are well validated by the experimental results.

1. INTRODUCTION

Bandpass filter (BPF) having wide fractional bandwidth (FBW) is needed to cope with the present day wideband RF/wireless communication systems. But the BPF implemented using parallel coupled microstrip line (PCML) is suitable for obtaining FBW of only up to 20%. This is mainly due to the weak coupling between the parallel coupled lines. To achieve large FBW, microstrip width and spacing between the coupled lines have to be very small, which is difficult to fabricate. Many researchers have proposed various techniques to obtain a wide bandpass filter response [1–7]. A ground plane aperture technique was used to obtain the fractional bandwidth of 60% in multipole bandpass filter [1]. Cascaded lowpass and highpass sections are utilized to construct ultra wideband (UWB) bandpass filter in [2] and [3]. Using complementary split ring resonator (CSRR), bandpass filters with wide controllable fractional bandwidth

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are achieved in [4]. In [5], the authors utilized the defected ground structure (DGS) and high pass filter to obtain the wide bandpass response. But this filter involves via holes, which are difficult to achieve from fabrication point of view. Ultra wideband filter using DGS and fractal shape slot is reported in [6]. Recently wide passband of about 61% fractional bandwidth is obtained using transversal resonator and asymmetrical interdigital coupled lines in [7].

In this work, a new type of defected ground structure called open slot split ring resonator (OSSRR) is proposed. The OSSRR is a modified and negative image of the open split ring resonator (OSRR) [8]. Bandpass filter is designed by cascading highpass (HPF) and lowpass (LPF) filters realized using OSSRR and CMRC respectively. The designed filter has a wide FBW and compact size when compared to the conventional PCML BPF.

2. OPEN SLOT SPLIT RING RESONATOR DEFECTED GROUND STRUCTURE

Defected ground structure or defected ground plane (DGP) is obtained by etching periodic or non-periodic patterns in the ground plane of a microstrip line. Due to the defects in the ground plane, changes in the shield current take place and can change the capacitance and inductance of the microstrip line, thereby introducing a bandstop effect. Various types of DGS have been discussed in [9]. Over the past few years, slot split ring resonators (SSRR) defected ground structure [10] have been widely used in microwave technology for size miniaturization and performance enhancement of microwave components. SSRR is the negative image of the split ring resonator (SRR). Recently, circular shape open complementary split ring resonator suitable for coplanar waveguide technology was proposed in [11]. These resonators are called sub wavelength resonators because of their smaller size in the order of $\lambda/10$ at the resonance frequency.

In this paper, we propose a new DGS structure called open slot split ring resonator (OSSRR) suitable for microstrip technology exhibiting bandstop effect near its resonance frequency. The shape of OSRR is slightly modified, and its negative image is etched out from the ground plane to obtain OSSRR.

OSSRR is formed by two concentric square slots having openings at the same side and connected to another set of concentric square slots. At resonance it produces a narrow stop band similar to CSRR. The OSSRR with the dimensions $a = 12\,\text{mm}$, $c = 0.5\,\text{mm}$, $d = 0.5\,\text{mm}$, $g = 0.5\,\text{mm}$, and $l = 3\,\text{mm}$ is placed under a $50\,\Omega$ microstrip line and simulated using full wave simulator IE3D [12]. FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and height $h = 1.6$ mm is used for all simulations. At the resonance frequency $f_r = 0.74$ GHz a sharp stopband is observed. Unlike conventional dumbbell and arrow head shape structures [13], OSSRR DGS has sharp passband to stopband transition, but it has narrow stop bandwidth. To validate the proposed OSSRR to a practical circuit design, it is necessary to model the DGS. So the lumped element equivalent circuit of the OSSRR is constructed, and parameter values are obtained using [14]. We can model the proposed DGS as a parallel resonance circuit attached to the equivalent circuit of the transmission line. The geometry and equivalent circuit of OSSRR DGS are shown in Fig. 1. L_1 and C_1 are the inductance and capacitance of the microstrip line, and L_2 and C_2 are the inductance and capacitance of the OSSRR.

The equivalent circuit parameter values are listed in Table 1. Fig. 1(c) shows the simulated scattering parameters of OSSRR. The resonant frequency of the DGS is mainly determined by the dimensions

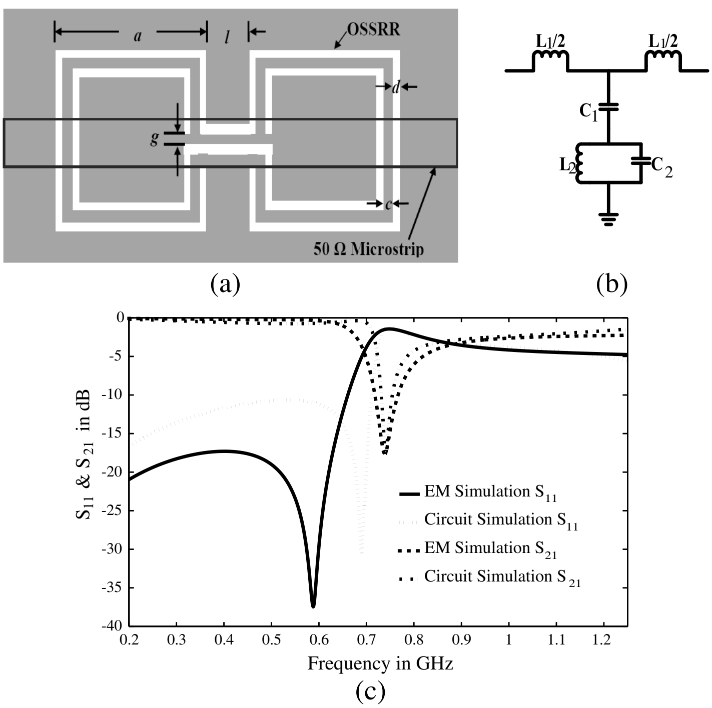


Figure 1. Open slot split ring resonator DGS. (a) Geometry. (b) Equivalent circuit. (c) Simulated scattering parameters of OSSRR.

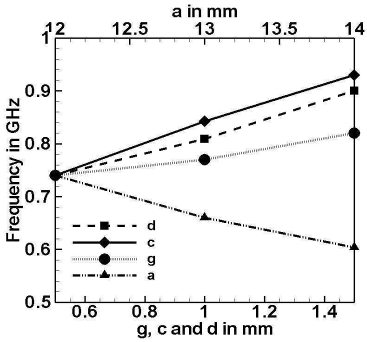


Figure 2. Variation of resonance frequency vs dimensions of OSSRR. (Side length varied from 12–14 mm and c, g, d varied from 0.5–1.5 mm.)

Table 1. Extracted equivalent circuit parameters of the OSSRR $a = 12\,\text{mm}$, $l = 3\,\text{mm}$, $c = g = d = 0.5\,\text{mm}$.

L_1 (nH)	C_1 (pF)	L_2 (nH)	C_2 (pF)
22.04	1.9584	4.3538	8.6949

Table 2. Extracted equivalent circuit parameters of the OSSRR with interdigital capacitor $a = 12\,\text{mm}$, $l = 3\,\text{mm}$, $c = g = d = 0.5\,\text{mm}$, $w_1 = 0.6\,\text{mm}$, and $w_2 = 1\,\text{mm}$.

L_1 (nH)	C_1 (pF)	L_2 (nH)	C_2 (pF)	C_3 (pF)
6.67	6.983	4.8797	3.6109	2.45

of the physical parameters. Change in resonance frequency with respect to these parameters is plotted in Fig. 2. Increase in side length of OSSRR decreases its resonance frequency and vice versa. Similarly, increase in g, c, and d will increase the resonance frequency.

3. DESIGN OF HIGHPASS FILTER

The stopband produced by the CSRR can be converted into a passband by introducing a interdigital capacitor in the microstrip line [15]. Here, we have used the two finger interdigital capacitor for suppressing low frequencies. Geometry of high pass filter and its equivalent circuit are presented in Fig. 3(a) and Fig. 3(b). The extracted equivalent circuit parameter values are listed in Table 2. The insertion loss of high pass filter using circuit and EM simulations are plotted in Fig. 3(c). The

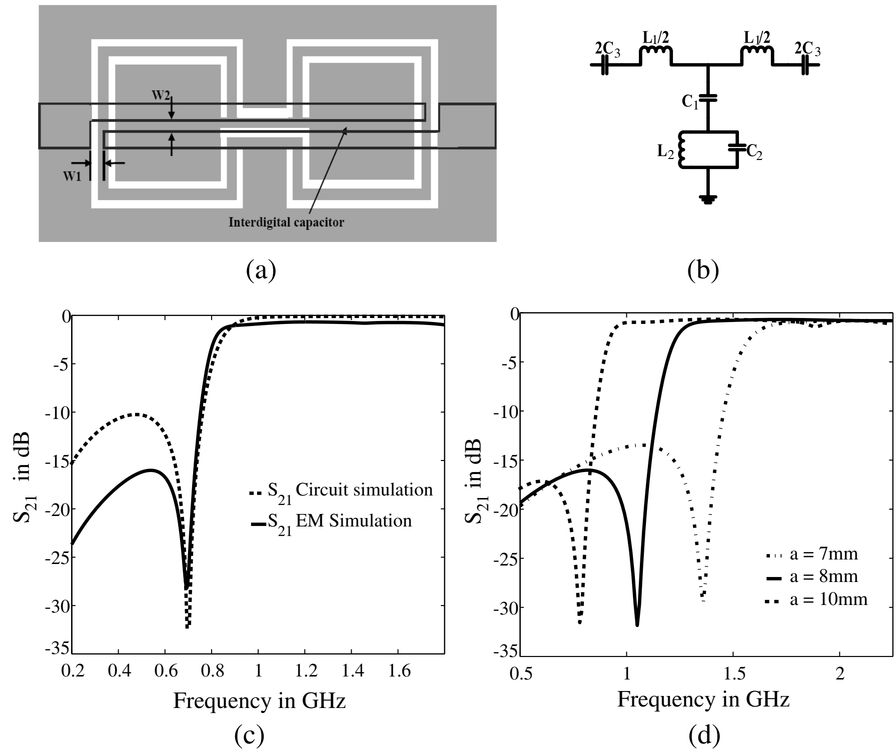
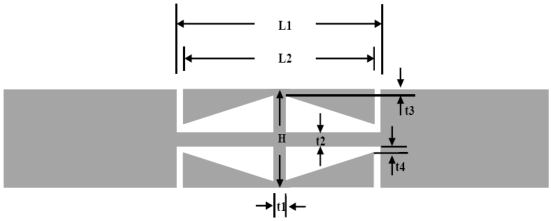


Figure 3. Highpass filter. (a) Geometry. (b) Equivalent circuit. (c) Insertion loss. (d) Transmission response for various 'a'.

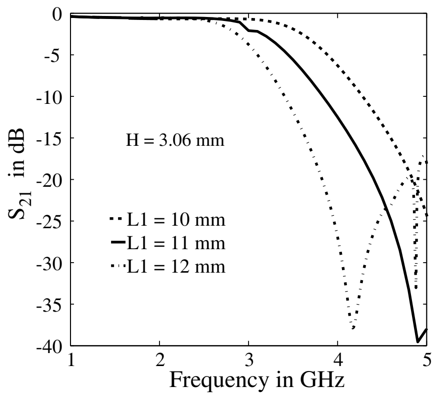
cut off frequency of the HPF can be controlled by the side length '*a*' of the OSSRR. The transmission response for various values of '*a*' is plotted in Fig. 3(d).

4. DESIGN OF LOWPASS FILTER

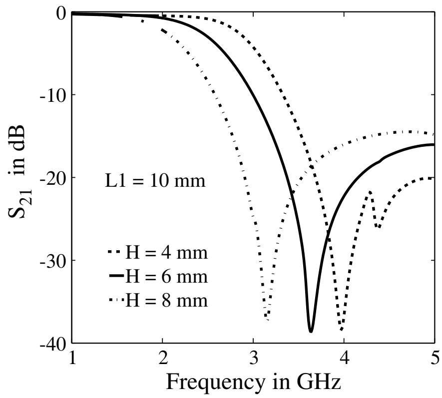
Lowpass filter is constructed by periodic arrangement of compact microstrip resonating cell (CMRC). We have utilized the structure presented in [16, 17] for designing lowpass filters. Propagation constant of a lossless transmission line is a function of distributed shunt capacitance and series inductance. So by increasing the value of inductance and capacitance of the transmission line periodically, slow wave effect can be achieved. Structure of a single CMRC cell is shown in Fig. 4(a). The narrow connecting lines result in increased inductance, and the gaps between the width of the lines are responsible



(a)



(b)



(c)

Figure 4. (a) Geometry of single CMRC. (b) Frequency response for various lengths. (c) Frequency response for various widths.

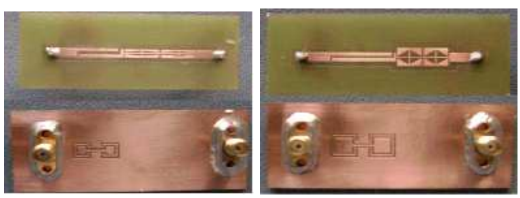
for increased capacitance. The dimensions of CMRC cell are as follows $L_1 = 10\,\text{mm}$, $L_2 = 9.2\,\text{mm}$, $H = 3.06\,\text{mm}$, and $t_1 = t_2 = t_3 = t_4 = 0.4\,\text{mm}$. By changing the size of the cell, stopband frequency can be easily varied. Fig. 4(b) shows the simulated frequency response of the cell for various lengths. As the length of the cell is increased, stopband frequency moves towards the lower end. So to avoid the increase in cell length for lower frequency, width of the cell is increased. Fig. 4(c) illustrates the characteristics of EBG cell for various widths. As width increases, stopband frequency moves towards the lower end without increasing the length of the device. Wide stopband can be achieved by cascading many cells.

5. DESIGN OF BANDPASS FILTER

As mentioned earlier, BPF is constructed by cascading lowpass and highpass sections. Two BPFs are designed and simulated for obtaining different fractional bandwidths. To obtain the sharp passband to stopband transition and wide rejection band, two CMRC cells are used in the LPF section. Dimensions of two types of proposed filters are listed in Table 3. Photograph of fabricated filters are shown in Fig. 5. In Type 1 filter, CMRC cell width is the same as the width of the microstrip line, and in Type 2 filter, CMRC cell width (H) is different from the microstrip width to reduce the length of the filter. Cutoff frequency of BPF can be varied by varying the cutoff frequency of either LPF or HPF. Simulated scattering parameters of both filters

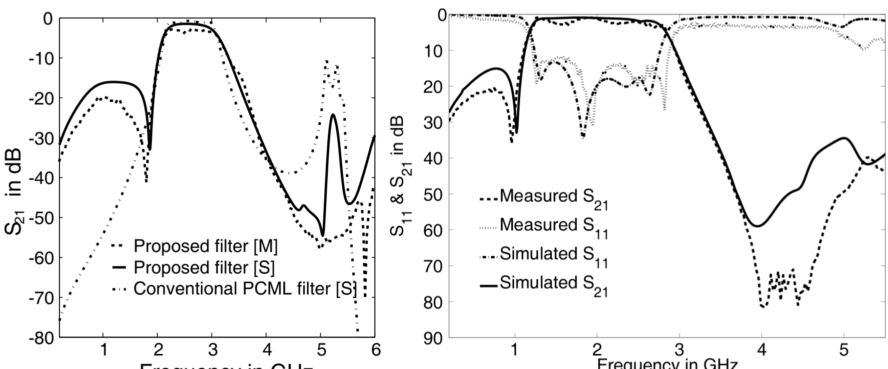
Table 3. Physical parameters of BPFs. All dimensions are in mm.

	a	c, d, g	l	W_1	W_2	L_1	L_2	H	t_1	t_2	t_3	t_4
Type 1	5.5	0.5	3	0.8	1.5	12	11.2	3.06	0.3	0.3	0.4	0.4
Type 2	8	0.5	3	0.6	1	8	7.2	6	0.3	0.3	0.4	0.4



(a) (b)

Figure 5. Fabricated proposed BPFs. (a) Type 1. (b) Type 2.



(a) (b)

Figure 6. Scattering parameters of proposed BPFs. (a) Type 1. (b) Type 2. (M→ measurement, S→ simulation.)

are plotted in Fig. 6. It can be observed that Type 1 filter has 29.2% FBW and is 20% smaller in size than the conventional third order PCML bandpass filter. Type 2 BPF has 76% FBW and occupies 47% smaller area than the traditional PCML BPF with the same center frequency at 2 GHz. The insertion loss of Type 1 and Type 2 filters are less than 1.48 dB and 1 dB respectively. In PCML bandpass filter, due to the difference in odd and even mode phase velocities, spurious pass band is present at the second harmonic of center frequency. Since the proposed filter involves cascaded stages of LPF and HPF sections instead of parallel coupled lines, it is free from second harmonic.

6. CONCLUSION

A new defected ground structure suitable for microstrip technology called open slot split ring resonator is proposed, and its resonance frequency variation versus physical dimensions are investigated. Wide bandpass filter is designed by cascading the LPF and HPF. Highpass response is obtained by interdigital capacitor and OSSRR. Low pass filter is constructed using cascaded stages of CMRCs. This idea was implemented and verified using fabricated prototype. The measured results show that the proposed filter has wider fractional bandwith and smaller size than the conventional PCML BPF. Additionally the designed BPF has the advantages of no second harmonic passband, low insertion loss, small size, and sharp cutoff.

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REFERENCES

1. Zhu, L., H. Bu, and K. Wu, "Broadband and compact multi-pole microstrip bandpass filters using ground plane aperture technique," *IEE Proceedings on Microwave, Antennas and Propagation*, Vol. 149, No. 1, 71–77, 2002.
2. Hsu, C.-L., F.-C. Hsu, and J.-T. Kuo, "Microstrip bandpass filters for ultra-wideband (UWB) wireless communications," *Proceedings of IEEE MTT-S International Conference*, 679–682, 2005.
3. Yang, G. M., R. H. Jin, and J. P. Geng, "Planar microstrip

UWB bandpass filter using U-shaped slot coupling structure," *Electronics Letters*, Vol. 42, No. 25, 1461–1463, 2006.

4. Mondal, P., M. K. Mandal, A. Chakrabarty, and S. Sanyal, "Compact bandpass filters with wide controllable fractional bandwidth," *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 10, 540–542, 2006.
5. Shobeyri, M. and M. H. Vadjed-Samiei, "Compact ultra-wideband bandpass filter with defected ground structure," *Progress In Electromagnetics Research Letters*, Vol. 4, 25–31, 2008.
6. An, J., G.-M. Wang, W.-D. Zeng, and L.-X. Ma, "UWB filter using defected ground structure of von Koch fractal shape slot," *Progress In Electromagnetics Research Letters*, Vol. 6, 61–66, 2009.
7. Sun, S., L. Zhu, and H.-H. Tan, "A compact wideband bandpass filter using transversal resonator and asymmetrical interdigital coupled lines," *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 3, 173–175, 2008.
8. Martel, J., R. Marques, F. Falcone, J. D. Baena, F. Medina, F. Martin, and M. Sorolla, "A new LC series element for compact bandpass filter design," *IEEE Microwave and Wireless Components Letters*, Vol. 14, No. 14, 210–212, 2004.
9. Weng, L. H., Y.-C. Guo, X.-W. Shi, and X.-Q. Chen, "An overview on defected ground structure," *Progress In Electromagnetics Research B*, Vol. 7, 173–189, 2008.
10. Burokur, S. N., M. Latrach, and S. Toutain, "A novel type of microstrip coupler utilizing a slot split ring resonators defected ground plane," *Microwave and Optical Technology Letters*, Vol. 48, No. 1, 138–141, 2006.
11. Velez, A., F. Aznar, J. Bonache, M. C. Velazquez-Ahumada, J. Martel, and F. Martin, "Open complementary split ring resonators (OCSRRs) and their application to wideband CPW band pass filters," *IEEE Microwave and Wireless Components Letters*, Vol. 19, No. 4, 197–199, 2009.
12. IE3D, version 10.2, Zeland Corp, Freemont, CA.
13. Abdel-Rahman, A. V., A. K. Verma, A. Boutejdar, and A. S. Omar, "Control of bandstop response of Hi-Lo microstrip low-pass filter using slot in ground plane," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 52, No. 3, 1008–1013, 2004.
14. Bonache, J., M. Gil, I. Gil, J. Garcia-Garcia, and F. Martin, "On the electrical characteristics of complementary metamaterial resonators," *IEEE Microwave and Wireless Components Letters*,

Vol. 16, No. 10, 543–545, 2006.

15. Li, C., K.-Y. Liu, and F. Li, "Design of microstrip highpass filters with complementary split ring resonators," *Electronics Letters*, Vol. 43, No. 1, 35–36, 2007.
16. Xue, Q., K. M. Shum, and C. H. Chan, "Novel 1-D microstrip PBG cells," *IEEE Microwave and Wireless Components Letters*, Vol. 10, No. 10, 403–405, 2000.
17. Xue, Q., K. M. Shum, and C. H. Chan, "Low conversion-loss fourth sub harmonic mixers incorporating CMRC for millimeter-wave applications," *IEEE Transcations on Microwave Theory and Techniques*, Vol. 51, No. 5, 1449–1454, 2003.