BRIEF PAPER Special Section on Microwave and Millimeter-Wave Technology

Size Miniaturized Rat-Race Coupler Using Open Complementary Split Ring Resonator

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SUMMARY In this paper, a rat-race hybrid coupler based on an open complementary split ring resonator (OCSRR) is presented. By embedding the OCSRR in the microstrip transmission line, slow-wave effect is introduced to achieve size reduction. The proposed rat-race coupler size is 37% smaller than the conventional rat-race coupler. Besides, the proposed coupler provides better third harmonic suppression up to 35 dB. The simulated results are compared with the measured data and good agreement is reported.
key words: *open complementary split ring resonator (OCSRR), rat-race coupler, harmonic suppression*

1. Introduction

The rat-race coupler or 180° hybrid is one of the important component in the microwave/millimeter wave circuits. It is widely used in various applications such as mixer, multiplier, amplifier etc. The important shortcoming of rat-race coupler is its size (1.5 λ_g, where λ_g is the guided wavelength at the design frequency). To overcome this limitation, several methods have been reported [1]–[5]. The slow-wave effect offered by defected ground structure (DGS) and photonic bandgap structure (PBG) is commonly used to achieve size reduction [1], [2]. Miniaturized spurious passband suppression rat-race coupler using compensated spiral compact microstrip resonant cell (C-SCMRC) resonator is demonstrated in [3]. Recently, metamaterial based subwavelength resonator known as complementary split ring resonator (CSRR) is utilized to design a compact ring hybrid [4], [5]. In this paper, we propose a compact and harmonic suppressed ring hybrid using open complementary split ring resonator (OCSRR) for the first time in microstrip technology.

2. Open Complementary Split Ring Resonator

Open complementary split ring resonator is a negative image of the open split ring resonator (OSRR). It was recently reported by some of the authors in [6]. The schematic of the OCSRR is shown in Fig. 1(a). As compared with the CSRR, the electrical size of the OCSRR is roughly half of the CSRR size [6] and hence size miniaturization is achieved. To study the frequency response characteristics of the microstrip line

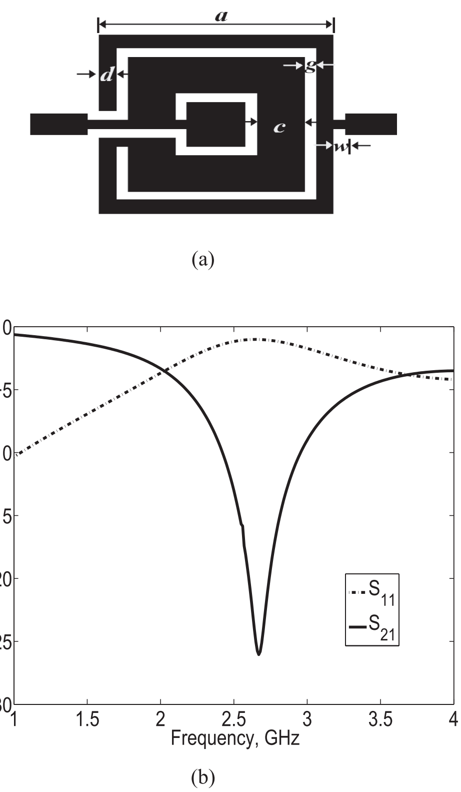

Fig. 1 OCSRR (a) Layout (b) Simulated scattering parameters.

loaded with the OCSRR, the OCSRR having the dimensions: a = 6 mm, c = 1.45 mm, d = 0.3 mm, g = 0.4 mm, and w = 0.4 mm is designed on the FR4 substrate with dielectric constant ε_r = 4.4 and substrate thickness h = 1.6 mm and simulated using full-wave simulator. The simulated results are shown in Fig. 1(b). During resonance, the OCSRR act as an open resonator and the total transmitted energy is reflected back to the source itself, thereby causing an attenuation pole at f_r = 2.67 GHz. Since the OCSRR is embedded in the microstrip line itself, it increases the inductance and capacitance of the microstrip line resulting in a slow-wave effect.

3. Design of Ring Hybrid

To design an OCSRR based rat-race coupler with 1.5 GHz center frequency, the OCSRR is embedded in a 50 Ω microstrip line. The length of the microstrip line is 20 mm,

Manuscript received February 1, 2011.
Manuscript revised May 6, 2011.
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DOI: 10.1587/transele.E94.C.1601

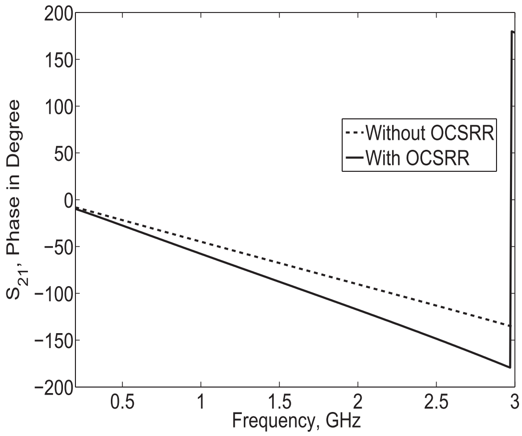


Fig. 2 Simulated phase response of microstrip line with and without OCSRR.

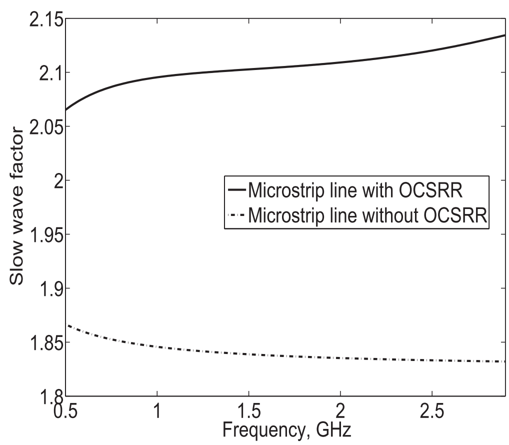
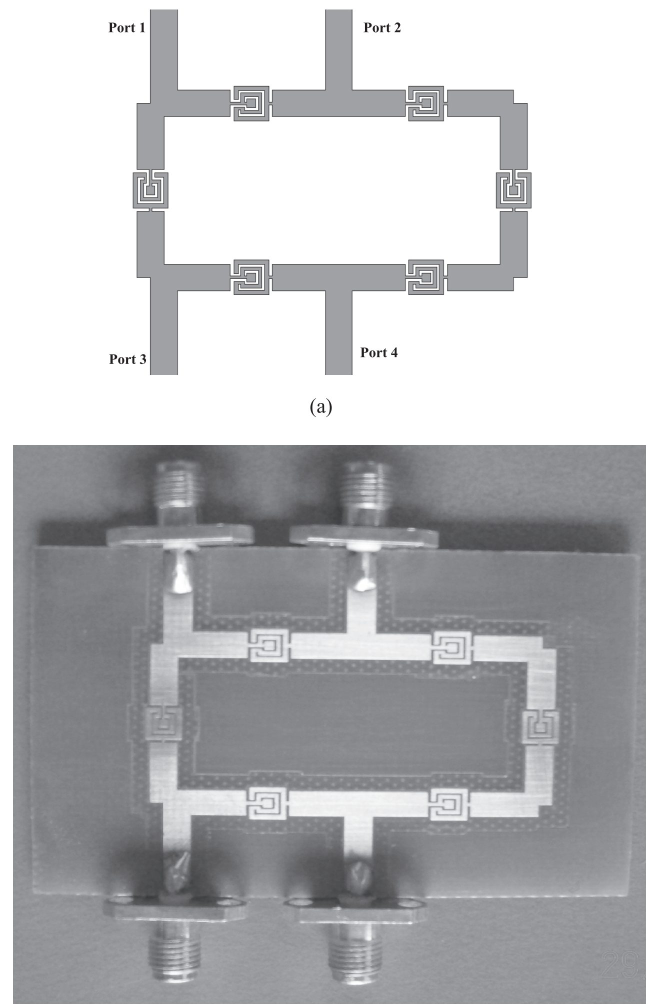


Fig. 3 Slow-wave factor of microstrip line with and without OCSRR.

which is approximately equal to the $\lambda_g/4$ at 2 GHz. The dimensions of the OCSRR are adjusted manually and optimized to obtain a 70.7 Ω line impedance and 90° phase shift at the center frequency. The characteristics impedance of the OCSRR embedded microstrip line is calculated using the method described in [7]. The optimized dimensions of the OCSRR are as follows: $a = 4$ mm, $c = 0.4$ mm, $d = 0.5$ mm, $g = 0.3$ mm, and $w = 0.4$ mm. The attenuation pole (f_r) observed for these dimensions is 4.54 GHz, which is useful for obtaining the third harmonic suppression. The simulated phase response of the microstrip line with OCSRR and without OCSRR is shown in Fig. 2. From the diagram, it is observed that the phase of the OCSRR embedded microstrip line is −90° at 1.5 GHz, where as 2 GHz in microstrip line without OCSRR. The slow wave factor (SWF) of the line loaded with the OCSRR is calculated by the method described in [8] using Eq. (1) and plotted in Fig. 3.

$$SWF = \frac{\lambda_0.\Delta\theta}{360L} + \sqrt{\varepsilon_{eff}} \quad (1)$$

where 'L' is the physical length of the line and Δθ is the phase difference between the microstrip line with OCSRR and without OCSRR. From the plot, it is observed that the SWF of the microstrip line loaded with OCSRR is increased compared to the microstrip line without OCSRR. So the increase in SWF validates the size reduction capability of the OCSRR for microwave applications.



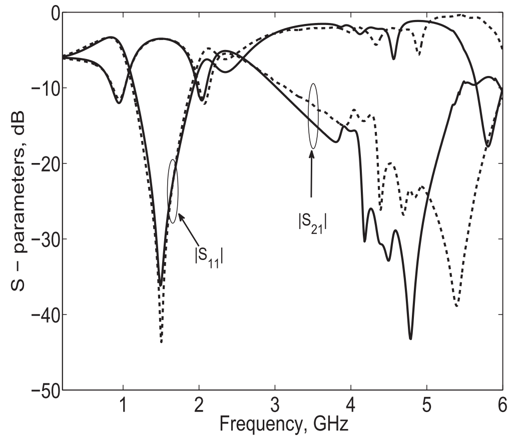
(a)

(b)

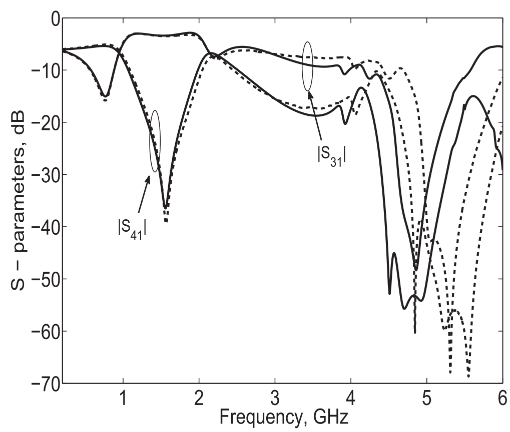
Fig. 4 Proposed RRC (a) Layout (b) Photograph of fabricated prototype.

This property helps us to design a size reduced ring hybrid. The configuration of the proposed rectangular shaped ring hybrid operating at 1.5 GHz is shown in Fig. 4(a). The conventional 70.7 Ω microstrip line is replaced with the OCSRR embedded microstrip line. The photograph of the fabricated ring hybrid is shown in Fig. 4(b). Simulated and measured S-parameters of the proposed ring hybrid are shown in Fig. 5(a) & Fig. 5(b) respectively. Simulation and measurement are in good agreement. In Fig. 5(a), frequency variation of the input matching S_{11} and the output at port 2 S_{21} are shown, while in Fig. 5(b), the output at port 3 S_{31} and the isolation S_{41} are shown. Measurements have been carried out using Rohde & Schwarz vector network analyzer. The measured output $|S_{21}|$ is −3.508 dB and $|S_{31}|$ is −3.398 dB at 1.5 GHz. The measured return loss $|S_{11}|$ is −43.53 dB and isolation $|S_{41}|$ is better than −39 dB.

The measured phase response of the proposed ring hy-



(a)



(b)

Fig. 5 Proposed rat-race coupler (a) Simulated (solid line) and measured (dashed line) scattering parameters ($|S_{11}|$, $|S_{21}|$) (b) Simulated (solid line) and measured (dashed line) scattering parameters ($|S_{31}|$, $|S_{41}|$).

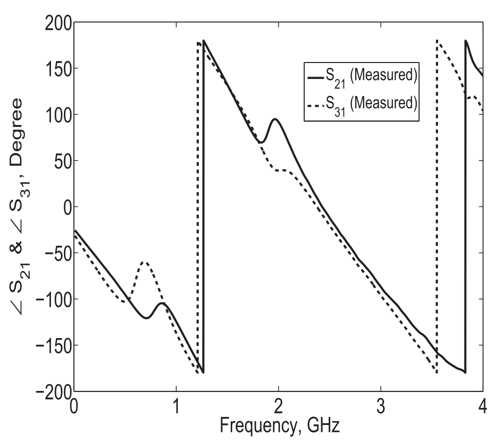


Fig. 6 Phase response for the sum port excitation.

brid for the port 1 and port 4 excitations are shown in Fig. 6 and Fig. 7 respectively. The phase difference between S_{21} and S_{31} is 0.9°. The phase difference between S_{34} and S_{24} is 183.15°. The proposed coupler offers the third harmonic

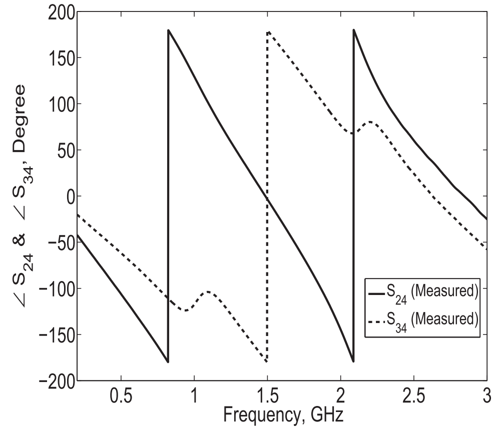


Fig. 7 Phase response for the difference port excitation.

Table 1 Performances of the proposed ring hybrid.

	Simulation	Measurement
Operating frequency	1.5 GHz	1.544 GHz
Return loss (S_{11})	36.08 dB	43.53 dB
Isolation (S_{41})	36.5 dB	39 dB
Output 1 (S_{21})	3.506 dB	3.508 dB
Output 2 (S_{31})	3.39 dB	3.398 dB
Amplitude imbalance	0.116 dB	0.11 dB
Phase difference (Sum port)	1.6°	0.9°
Phase difference (Difference port)	184.4°	183.15°

suppression up to 35 dB and 37% smaller than the conventional ring hybrid. The measured amplitude imbalance for the ring hybrid is 0.11 dB. The performances of the proposed ring hybrid are summarized in Table 1.

4. Conclusion

Size reduction is the major concern for the design of microwave devices operating in the low frequency range. Hence in this communication, the slow-wave effect and the stopband effect of the OCSRR have been utilized for the size miniaturization and harmonic suppression of the ring hybrid respectively. The proposed rat-race coupler size is 37% smaller than the conventional coupler and the third harmonic suppression is achieved without adding any additional structure. The measured results are in good agreement with the simulated results and small differences found may be due to the fabrication tolerance and connector losses.

Acknowledgements

Authors are grateful to the Science and Engineering Research Council, Department of Science and Technology, Government of India for supporting this study (Project No: ECE/P/KRS/DST/01).

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