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A compact branch-line coupler design using low-pass resonators and meandered lines open stubs

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Abstract: A compact 1.5 GHz microstrip branch-line coupler with harmonic suppression, using low-pass resonators and meandered lines open stubs, is designed and fabricated in this paper. Both significant size reduction and harmonics suppression are achieved in the proposed structure using U-shape low-pass resonators and meandered lines open stubs. The proposed coupler shows more than 24 dB suppression for harmonics (2nd up to 10th). The proposed coupler size has been reduced by almost up to 81% compared to the typical one. The designed coupler is simulated using Advanced Design System software. The measured results verify the simulation data of the designed coupler.

Key words: Branch-line coupler, harmonic suppression, microstrip, resonators, size reduction

1. Introduction

Branch-line couplers (BLCs) are microwave devices that divide or combine power with 90° phase shifts between two output ports. BLCs are widely used in communication and microwave applications. BLCs are the main blocks in many microwave devices, such as Doherty power amplifiers, balanced power amplifiers, antenna feeding networks, mixers and matched attenuators, and RFID reader modules [1–4].

Several techniques such as defected ground structures [5], shunt open stubs [6], and resonators [7–9] have been presented to design couplers with reduction of unwanted harmonic suppression and size.

A compact coupler with discontinuous microstrip lines was reported in [10]. Conventional quarter wavelength lines of this coupler are replaced with compact discontinuous microstrip lines and 60% size reduction is achieved in this work; however, the obtained insertion loss in the pass band is worse than in a conventional coupler. In [11], a BLC with uniplanar composite right-left-handed transmission lines was reported. Size reduction of 67.5% is achieved in this work but the response of this coupler could not suppress the unwanted harmonics. In [12], a dual-band microstrip BLC using bended lines was reported. The obtained phase difference in both frequencies of this coupler is not accurate according to the ideal coupler.

A wide band coupler with arbitrary coupling level was reported in [1]. Harmonic suppression is achieved in this work, but the coupler is large.

A compact harmonic suppressed coupler with meander t-shaped line was presented in [13], but only two harmonics are suppressed and the size reduction is not satisfactory.

Recently, several couplers have been presented with size reduction or harmonics suppression. However, few of them have achieved both size reduction and harmonics suppression.

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In this paper a BLC with harmonics suppression and size reduction is designed and fabricated. U-shape resonators and meandered lines open stubs are used to achieve suppression and size reduction in the proposed BLC.

2. Design of the basic resonator

Four series U-shaped resonators are used to construct the basic resonator for the presented coupler. The proposed layout of the basic resonator is illustrated in Figure 1 [14].

The basic resonator dimensions are as follows: d = 2 mm, d_1 = 3.5 mm, d_2 = 12 mm, d_3 = 1 mm, d_4 = 0.9 mm, W = 1.5 mm, W_1 = 1 mm, W_2 = 0.7 mm, W_3 = 0.1 mm. The frequency response of the basic resonator is illustrated in Figure 2. As seen in this figure, the basic resonator is a sharp low-pass filter, and it has a wide suppression band from about 3.5 GHz up to 12 GHz, which is suitable for harmonics suppression.

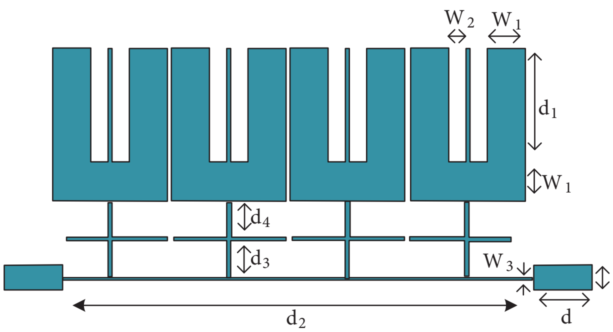

Figure 1. The proposed layout of the basic resonator.

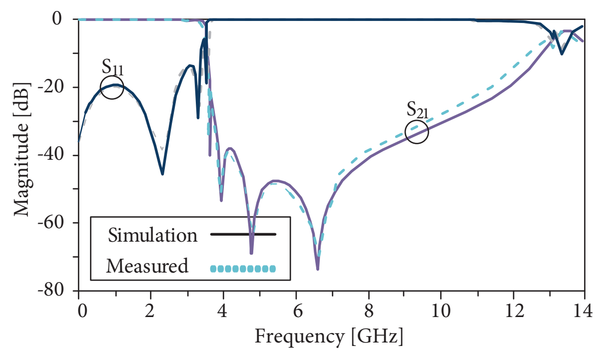

Figure 2. Frequency response of the basic resonator.

3. Design of the branch line coupler

The conventional BLC, also called a quadrature hybrid, includes four ports and four quarter wavelength transmission lines. In the BLC, the phase difference between two output ports should be 90° and the ideal insertion losses of the output ports are 3 dB. The conventional BLC has a large size. Replacing two quarter wavelength transmission lines ($\lambda/4$) with the proposed basic resonators results in a strong miniaturization and suppression of the 3rd to 10th harmonics. Meandered lines open stubs are used to provide suppression of the second harmonic, as illustrated in Figure 3. As seen, this open stub is a meandered line; therefore, this stub could be allocated in the designed BLC and also causes size reduction of the proposed BLC.

In order to suppress the nth order of harmonics the length of the open stub line must be calculated as below:

$$\theta_n = \pi/2n. \tag{1}$$

This open circuit is used to suppressed the second harmonic; therefore, the electrical length of the open stub must be equal to ($\pi/4$) 45°. With the applied substrate (RT/Duroid 5880, with 31 mil (0.787 mm) thickness and ε_r = 2.2), the physical length of this stub can be calculated as below:

$$\lambda_g = (\frac{C}{f\sqrt{\varepsilon_{re}}}), \tag{2}$$

$$\varepsilon_{re} = (\frac{\varepsilon_r+1}{2}) \quad + (\frac{\varepsilon_r-1}{2}).(1+12\frac{h}{W})^{-0.5} \tag{3}$$

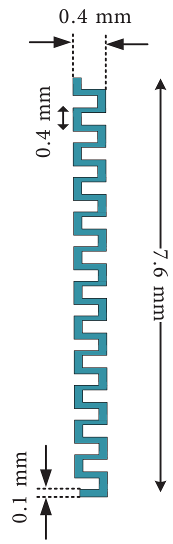

Figure 3. Structure of the meandered line open stub.

With the applied substrate the ε_{re} parameter is obtained from Eq, (3) and equal to $\varepsilon_{re} = 1.871$. Therefore, the λ_g parameter is obtained from Eq. (3) and equal to $\lambda_g = 146.3$ mm. The corresponding physical length of $\pi/4$ is equal to 18.3 mm. The open stop with this length suppresses the second harmonic, but this length is too long and not placed correctly in the coupler structure. Therefore, to reduce the length of this stub, the meandered line is applied. The length of the meandered line (7.6 mm) is less than half the size of the typical open stub without meandering.

The final layout of the proposed BLC is depicted in Figure 4. Two basic resonators and four meandered lines open stubs are used in the designed BLC to achieve the desired specifications.

The basic dimensions of the proposed coupler are as follows: $W_{c1} = 1$ mm, $W_{c2} = 1.5$ mm, $W_{c3} = 0.1$ mm, $G = 1.25$ mm, $l_{c1} = 7.5$ mm, $l_{c2} = 15$ mm.

In the proposed coupler the characteristic impedance of four horizontal transmission lines is 84 Ω (1 mm) and the characteristic impedance of two transmission vertical lines is 67.4 Ω (1.5 mm). Two proposed filters are connected with high impedance lines with 188.2 Ω (0.1 mm).

A conventional BLC is designed in the operating frequency of 1.5 GHz to compare the obtained size reduction. Four typical quarter wavelength transmission lines are used in the conventional BLC. According to Eq. (3), the quarter wavelength ($\lambda_g/4$) is equal to 36.6 mm. The conventional BLC has a large size. This structure consists of two quarter wavelength transmission lines ($\lambda_g/4$), with 50 Ω characteristic impedances and two quarter wavelength transmission lines ($\lambda_g/4$), with 35.35 Ω impedances. With the applied substrate 50 Ω characteristic impedance is equal to 2.42 mm width and with 35.35 Ω impedance is equal to 3.94 mm width. The final size of the conventional BLC is obtained as 39.8 mm $\times$ 43 mm, while the final size of the designed BLC is 17 mm $\times$ 19.4 mm, both in the main frequency of 1.5 GHz. According to the obtained dimensions of the proposed and the conventional BLC, about 81% size reduction is achieved for the proposed BLC. A comparison between the obtained size of the conventional and the proposed BLC is illustrated in Figure 5.

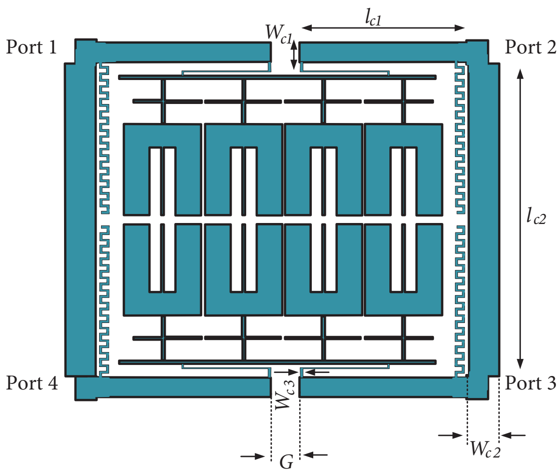

Figure 4. Final layout of the proposed BLC.

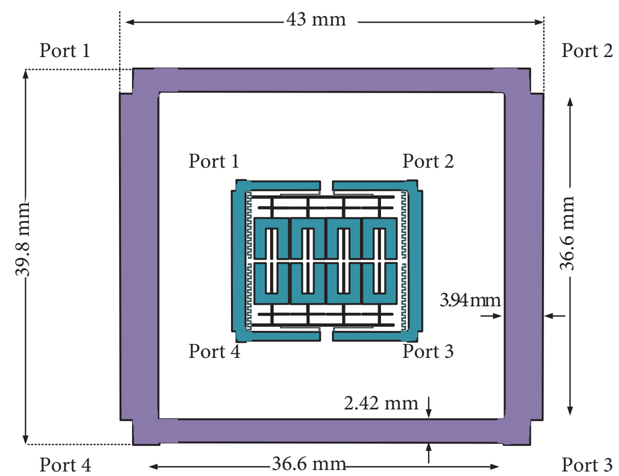

Figure 5. Comparison between size of the conventional and the proposed BLC.

4. Results of the proposed BLC

RT/Duroid 5880 substrate with 31 mil thickness and $\varepsilon_r = 2.2$ is used for fabrication of the proposed BLC. A photograph of the fabricated BLC is shown in Figure 6. Simulation and measured results of the presented BLC are illustrated in Figures 7a–7d. In order to have better results, both EM simulation and circuit simulation are performed.

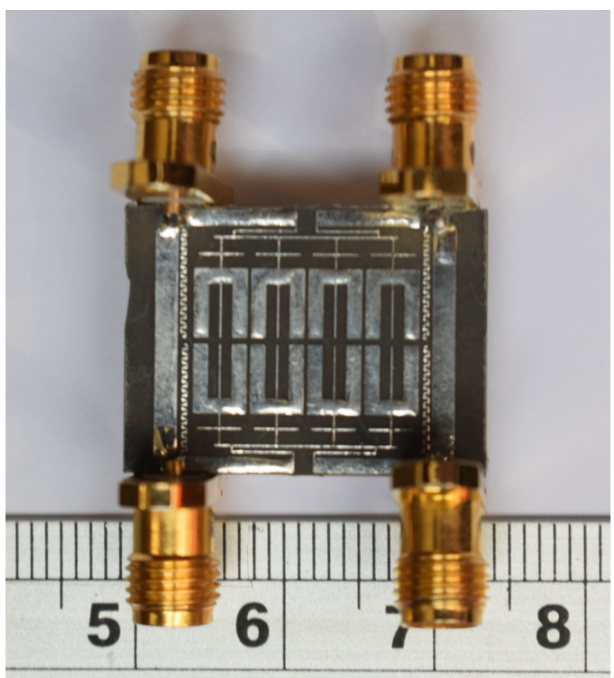

Figure 6. Fabricated BLC photograph.

According to the measured results, as seen in Figure 7b, the proposed BLC shows about 28 dB attenuation in the second harmonic, 48 dB attenuation in the third harmonic, 42 dB attenuation in the fourth harmonic,

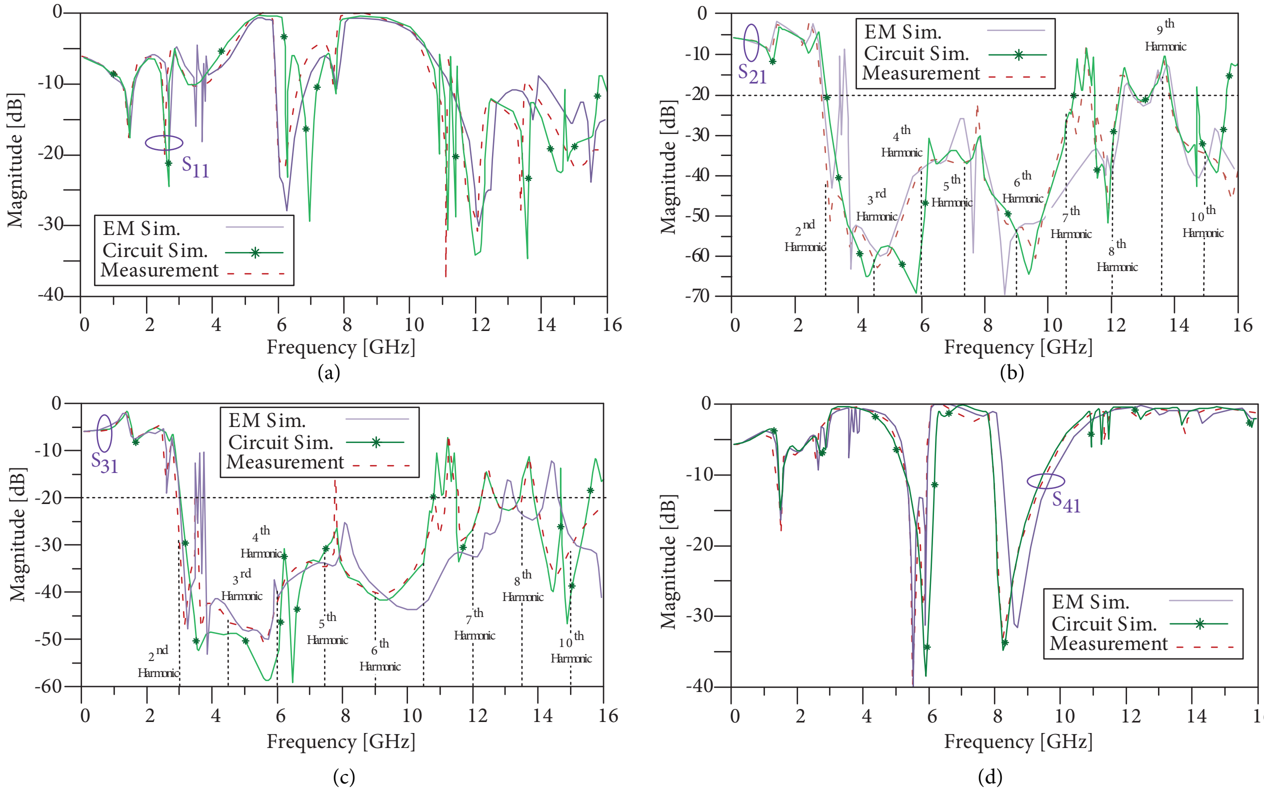

Figure 7. Frequency responses of the proposed BLC: (a) S_{11}, (b) S_{21}, (c) S_{31}, and (d) S_{41}.

about 35 dB attenuation in the fifth harmonic, 41 dB attenuation in the sixth harmonic, 31 dB attenuation in the seventh harmonic, about 22 dB attenuation in the eighth harmonic, 16 dB attenuation in the ninth harmonic, and 33 dB attenuation in the tenth harmonic. The harmonics suppression levels of the proposed coupler (S21 and S31) for circuit simulation, EM simulation, and measurement results are listed in Table 1.

Table 1. Harmonics suppression level.

Harmonic suppression level																		
	2nd (dB)		3rd (dB)		4th (dB)		5th (dB)		6th (dB)		7th (dB)		8th (dB)		9th (dB)		10th (dB)	
	S21	S31	S21	S31	S21	S31	S21	S31	S21	S31	S21	S31	S21	S31	S21	S31	S21	S31
Circuit simulation	30	28	62	50	68	54	37	32	54	42	33	31	37	22	16	20	35	40
EM simulation	45	29	60	46	40	45	36	35	52	41	40	34	37	24	15	22	36	31
Measured	45	28	62	48	42	46	36	35	51	41	33	31	37	22	16	20	36	33

Figure 8 shows the output phase difference between ports two and three. As shown in this figure, the phase difference between output ports of the proposed BLC is about 89.5°.

There is good agreement between the measured and simulated parameters at low frequencies, but at high frequencies the measured parameters are shifted from the design goal, which represents that error for simulation and fabrication is due to the high-frequency parasitic effect.

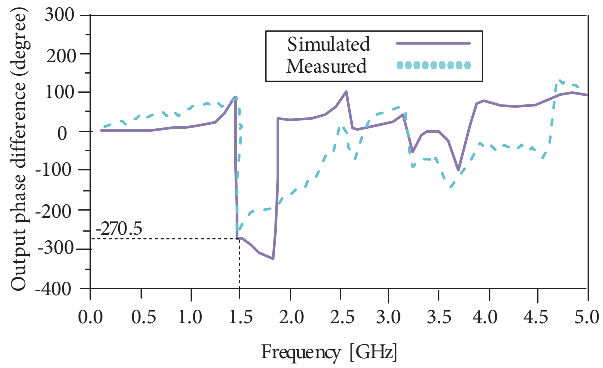

Figure 8. The phase differences between output ports 2 and 3.

A comparison between the presented BLC and other works is reported in Table 2. As seen, the proposed BLC shows excellent size reduction and harmonic suppression compared with other studies.

Table 2. Comparison between proposed BLC and the other works.

Refs.	Main frequency	Circuit size	Size reduction	Harmonic suppression
[15]	1.8 GHz	0.03 λ^2	52%	
[10]	1 GHz	0.025 λ^2	60%	
[16]	2.45 GHz	0.018 λ^2	70%	2nd and 3rd
[17]	2.4 GHz	0.028 λ^2	55%	
[18]	0.836 GHz	0.016 λ^2	73%	2nd
Proposed BLC	1.5 GHz	0.012 λ^2	81%	2nd up to 10th

5. Conclusions

A compact harmonic suppressed BLC is proposed in this paper. Two low-pass filters and four meandered lines open stubs are applied to miniaturize the size and suppress the harmonics. For verification, the designed BLC is fabricated and the measurement results are compared with the simulation data, which show good agreement. The results show excellent size reduction and harmonic suppression compared with other couplers.

References

[1] Alshamaileh KA, Devabhaktuni VK, Dib NI. Impedance-varying broadband 90° branch-line coupler with arbitrary coupling levels and higher order harmonic suppression. IEEE T Comp Pack Man 2015; 10: 1507-1515.

[2] Chiu L. Wideband microstrip 90° hybrid coupler using high pass network. Int J Microw Wirel T 2014; 7: 1-6.

[3] Kurt E, Palamutçuoğullari O. An adaptive feedforward amplifier application for 5.8 GHz. Turk J Elec Eng & Comp Sci 2007; 14: 437-43.

[4] Bostan Ö, Aydoğmuş HU, Topaloğlu S. Design of a low-power, low-cost UHF RFID reader module. Turk J Elec Eng & Comp Sci 2016; 24: 2747-2755.

5 Dwari S, Sanyal S. Size reduction and harmonic suppression of microstrip branch-line coupler using defected ground structure. Microw Opt Techn Let 2006; 48: 1966-1969.

[5] Mondal P, Chakrabarty A. Design of miniaturised branch-line and rat-race hybrid couplers with harmonics suppression. IET Microw Antenna P 2009; 3: 109-116.

[6] Zhang J, Sun XW. Harmonic suppression of branch-line and rat-race coupler using complementary spilt ring resonators (CSRR) cell. Progress in Electromagnetic Research Letters 2008; 2: 73-79.

[7] Gu J, Sun X. Miniaturization and harmonic suppression rat-race coupler using C-SCMRC resonators with distributive equivalent circuit. IEEE Microw Wirel Co 2005; 15: 880-882.

[8] Hou JA, Wang YH. Design of compact 90° and 180° couplers with harmonic suppression using lumped-element bandstop resonators. IEEE T Microw Theory 2010; 58: 2932-2939.

[9] Sun KO, Ho SJ, Yen CC, van der Weide D. A compact branch-line coupler using discontinuous microstrip lines. IEEE Microw Wirel Co 2005;15: 519-520.

[10] Zhang J, Tao J, Zong B, Zhou C. Compact branch-line coupler using uniplanar spiral based CRLH-TL. Progress in Electromagnetic Research Letters 2015; 52: 113-119.

[11] Koziel S, Bekasiewicz A. Fast simulation driven feature based design optimization of compact dual band microstrip branch line coupler. Int J RF Microw C E 2016; 26: 13-20.

[12] Choi KS, Yoon KC, Lee JY, Lee CK, Kim SC, Kim KB, Lee JC. Compact branch line coupler with harmonics suppression using meander T shaped line. Microw Opt Techn Let 2014; 56: 1382-1384.

[13] Roshani S, Hayati M, Setayeshi S, Roshani S, Mohamadpour G. A miniaturized harmonic suppressed power amplifier integrated with lowpass filter for long term evolution application. Analog Integr Circ S 2016; 89: 197-204.

[14] Eccleston KW, Ong SH. Compact planar microstrip line branch-line and rat-race couplers. IEEE T Microw Theory 2003; 51: 2119-2125.

[15] Gu J, Sun X. Miniaturization and harmonic suppression of branch-line and rat-race hybrid coupler using compensated spiral compact microstrip resonant cell. In: IEEE 2005 MTT-S International Microwave Symposium Digest Conference; 17 June 2005; Long Beach, CA, USA. New York, NY, USA: IEEE. pp. 1211-1214.

[16] Liao SS, Sun PT, Chin NC, Peng JT. A novel compact-size branch-line coupler. IEEE Microw Wirel Co 2005; 15: 588-590.

[17] Tsai KY, Yang HS, Chen JH, Chen YJ. A miniaturized 3 dB branch-line hybrid coupler with harmonics suppression. IEEE Microw Wirel Co 2011; 21: 537-539.