Miniaturization of Branch-Line Coupler Using Composite Right/Left-Handed Transmission Lines with Novel Meander-shaped-slots CSSRR

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Abstract. *A novel compact-size branch-line coupler using composite right/left-handed transmission lines is proposed in this paper. In order to obtain miniaturization, composite right/left-handed transmission lines with novel complementary split single ring resonators which are realized by loading a pair of meander-shaped-slots in the split of the ring are designed. This novel coupler occupies only 22.8% of the area of the conventional approach at 0.7 GHz. The proposed coupler can be implemented by using the standard printed-circuit-board etching processes without any implementation of lumped elements and via-holes, making it very useful for wireless communication systems. The agreement between measured and stimulated results validates the feasible configuration of the proposed coupler.*

Keywords

Branch-line coupler, complementary split single ring resonators, composite right/left-handed transmission lines, meander-shaped-slots, miniaturization.

1. Introduction

Branch-line couplers are one of the most popular passive circuits used for microwave and millimeter-wave applications [1]. They offer equal magnitude and quadrature phase outputs at the operating frequency band. They have been used extensively in the design of balanced mixers, image-rejection mixers, antenna array feed networks, balanced amplifiers, power combiners, and power dividers. However, at the lower frequencies of the microwave band, the size of conventional branch-line couplers is too large for practical use. In modern communication systems, various characteristics such as miniaturization and low-cost fabrication are required for passive circuit design. Therefore, compact branch-line couplers are important passive components that need to be enhanced.

In the past years, there has been great improvement in various reports concerning the size reduction [2-5]. In [2], the miniaturization is achieved by using artificial transmission lines consisting of microstriplines periodically loaded with open-circuit shunt stubs in place of transmission lines, and this method has a size reduction about 51%. Size reduction about 71% is achieved using symmetrical T-shaped structure with quasi-lumped elements approach in [3]. Sizes of fabricated couplers can be reduced about 54% of conventional ones in [4]. The fractal-shaped couplers of second iteration orders achieved 72.7% size reduction in [5].

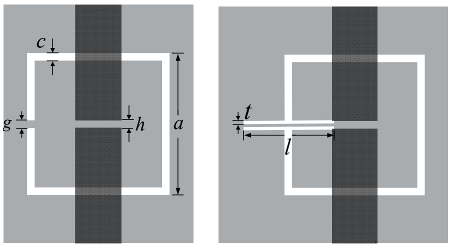
As we know, the conventional lumped components, such as lumped inductances, are frequency dispersive in higher microwave frequencies and have the limited choice of the available values. On the other hand, the distributed structures are more complicated to design and possess larger sizes at low frequency. In this paper, a new method without lumped components to design the compact branch-line coupler at low frequency has been proposed and implemented. Recently, composite right/left handed transmission lines (CRLH-TL) [6, 7] has been an important tool to design microwave circuit components. The first distributed CRLH-TL is implemented by loading complementary split ring resonators (CSRRs) [8] combined with series gaps. Complementary single split ring resonator (CSSRR) [9] presents the same characteristics as CSRRs, but it is easier to design than CSRRs.

In this paper, a new method without lumped components to design the compact branch-line coupler at low frequency has been proposed and implemented. Firstly, a novel CSSRR is used to substitute conventional CSSRR in the design of the CRLH-TL, and the resonant frequency can be reduced by 52%. Then, the proposed CRLH-TL is used to design the compact branch-line coupler operating at 0.7 GHz. The measurement result shows that, the area of branch-line coupler with the new method can be reduced by 77.2% compared with traditional one.

2. Proposed CSSRR Structures and Equivalent Circuit Model

In Fig. 1 (a), the conventional CSSRR is etched in the ground plane. The dark grey denotes the conductor strip and the light grey denotes the ground plane. Based on this, the proposed design is achieved by loading a pair of narrow slots in the split of the ring, shown in Fig. 1(b). The TP-2 substrate with relative dielectric constant 6 and thickness 1 mm is used. The dimensions are given as follows: $a = 8.8$ mm, $c = 0.4$ mm, $g = 0.25$ mm, $h = 0.4$ mm, $l = 14$ mm, $t = 0.25$ mm. The simulated S parameters of the conventional and the proposed CSSRR are shown in Fig. 2, which indicate that a lower resonant frequency can be realized obviously.

The proposed cell can be modeled by the equivalent circuit shown in Fig. 3. This model is valid under the assumption that the size is electrically small. In this model, L is the line inductance, Cg is the gap capacitance. The CSSRR is modeled by the parallel resonant circuit (with inductance Lc and capacitance Cc), while its coupling to the host line is modeled by the capacitance C.



(a) (b)

Fig. 1. CRLH-TL cell with (a) the conventional CSSRR and (b) the proposed CSSRR.

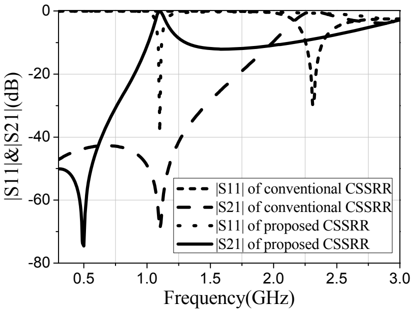


Fig. 2. The simulated S parameters of CRLH-TL cell.

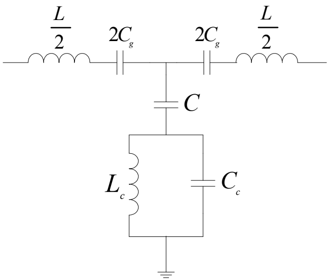
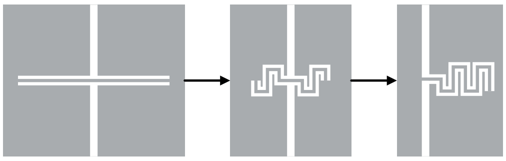


Fig. 3. Equivalent circuit of CSSRR.

To reduce the size of the proposed CSSRR more, the slots are altered as meander-shaped shown in Fig. 4. The total length of the slots is fixed.



(a) (b) (c)

Fig. 4. The different shaped slots with the length fixed: (a) structure 1, (b) structure 2, (c) structure 3.

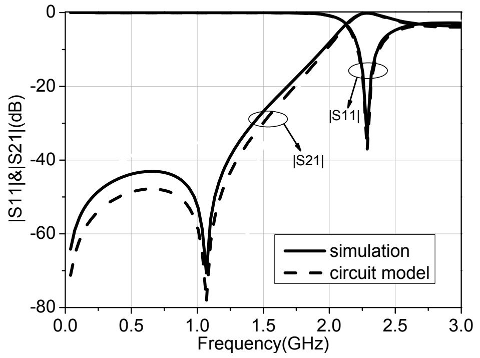
In order to demonstrate the correctness of the equivalent circuit model and analyze the reason why the resonant frequency is lower than the conventional cell, circuit simulation parameters are extracted by *Serenade* software as follows in Tab. 1.

	Con.	Str.1	Str.2	Str.3
C [pF]	10	26.87	40.32	45.41
Cc [pF]	1.75	5.31	8.12	10.72
Cg [pF]	0.17	0.30	0.35	0.30
L [nH]	13.9	13.9	11.14	7.08
Lc [nH]	1.75	3.14	1.95	1.63
fr [GHz]	2.31	1.1	1.16	1.14
fz [GHz]	1.1	0.5	0.5	0.51

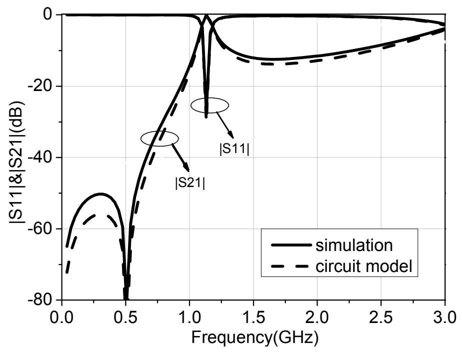
Tab. 1. Extracted parameters and *fr*, *fz* of CRLH-TL.

Two specific frequencies are used in the process: the resonant frequency f_r, and the transmission zero frequency f_z ($f_Z = 1/2\pi\sqrt{L_C(C+C_C)}$) at which the impedance of the shunt branch is equal to zero. By comparing results in Tab. 1, f_r and f_z of the proposed structures can be both lowered remarkably with respect to the Conventional CSSRR, while the proposed Structure 1, 2, 3 are almost the same. The C and C_c are increased largely due to the significant increase of the coupling between the CSSRR and the host line, which is the reason why resonant frequency is lower than the conventional case.

Because the f_r and f_z of the proposed Str. 1, 2, 3 are almost the same, we only compare Conventional case and Str.3, and the simulated and circuit model results of S parameters are shown in Fig. 5. It is observed that the simulation and circuit model results are consistent, and the resonant frequency can be reduced by 52% when substitutes the Con. CSSRR for the Str.3 CSSRR.



(a)



(b)

Fig. 5. The simulated and circuit model S parameters of CRLH-TL using (a) Con. CSSRR, (b) proposed Str. 3 CSSRR.

3. Design of Compact Branch-Line Coupler

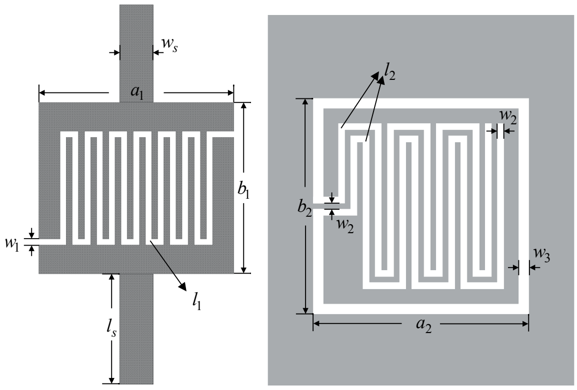
A traditional branch-line coupler is composed of four quarter-wavelength transmission-line sections at a designated frequency. If phase advance characteristic of CRLH-TL is used to design branch-line coupler, the phase of the operating frequency can be designed +90°, and the 90° electrical length is no longer restricted by quarter-wavelength. The coupler can be miniaturized when the total length of CRLH-TL is shorter than quarter-wavelength transmission-line.

Based on the analysis above and for verification, a compact-size branch-line coupler operating at 0.7 GHz is designed, simulated, and fabricated. Ansoft Designer simulator is used for all simulations, and the coupler is constructed using F4B-2 substrate with relative dielectric constant 2.65 and thickness 0.5 mm.

Fig. 6 presents the novel CRLH–TL based on the proposed meander-shaped CSSRR. As shown in Fig. 6(a), microstrip-interdigital structure is used to implement series capacitance in order to reduce radiation loss, and in Fig. 6(b), the Str.3 CSSRR is selected. In order to reduce the number of simulated parameter, keep all the width of slots fixed ($w_1 = 0.25$ mm, $w_2 = 0.25$ mm, $w_3 = 0.4$ mm). The characteristic impedances of the branch-line coupler are 35 Ω and 50 Ω, whose parameter results are shown in Tab. 2. As shown in Tab. 2. take 50 Ω transmission line with +90 electrical length for example, the simulated results of S parameters are shown in Fig. 7. As can be seen from Fig. 7, the CRLH-TL has energy transmission at operating frequency only, which determines that the bandwidth of the designed branch-line coupler will be narrow.

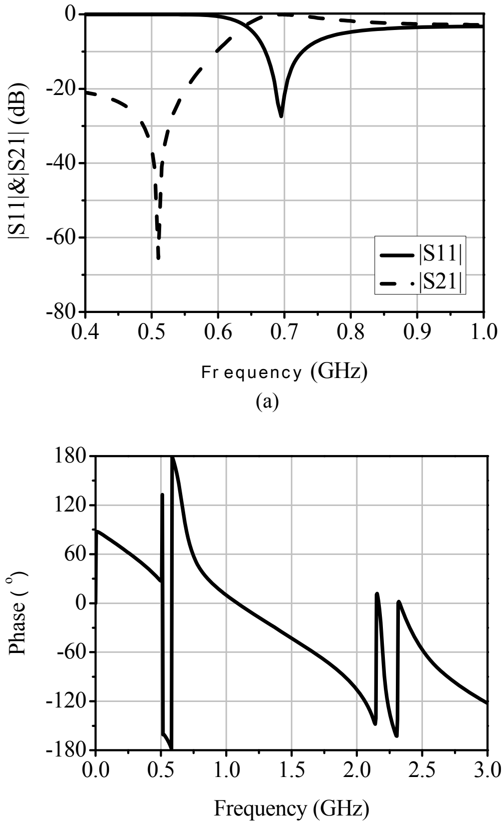
TL	l_s	w_s	a_1	b_1	l_1	a_2	b_2	l_2
35 Ω	9.45	2.25	8	7.5	98	8.8	8.8	43.4
50 Ω	9	1.34	8	7	65.2	8.8	8.8	46.78

Tab. 2. The parameter results for the designed 35 Ω and 50 Ω CRLH-TL (Unit: mm).



(a) (b)

Fig. 6. Topology of the proposed CRLH–TL. (a) top view, (b) bottom view.



(a)

(b)

Fig. 7. Simulated results of 50 Ω CRLH-TL. (a)S parameters, (b)transmission phase.

Fig. 8 shows the simulated S-parameters and phase differences between the output ports of the proposed branch-line coupler based on the parameter in Tab. 2. As can be seen from Fig. 8, the branch-line couplers were operated at 0.7 GHz.

Prototype of the designed branch-line coupler is fabricated. Fig. 9 shows the photograph of the fabricated prototype. The measurements are made using HP 8720ET Vector Network Analyzer, and Fig. 10 shows the measured results. Fig. 8 and Fig. 10 show that the measured and simulated S-parameters agree very well. The main difference between the measurements and simulations is a slight shift of center frequency (of less than 0.5%).

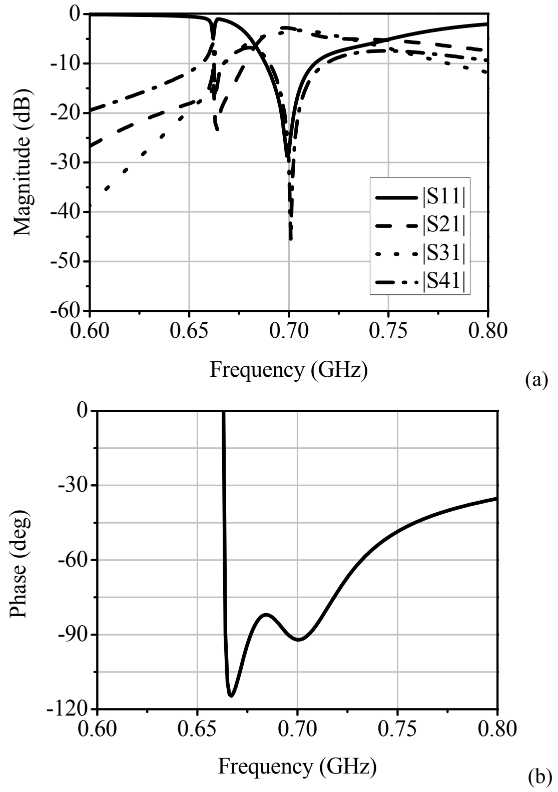


Fig. 8. Simulated results of the proposed branch-line coupler: (a) S-parameters, (b) phase differences between the output ports.

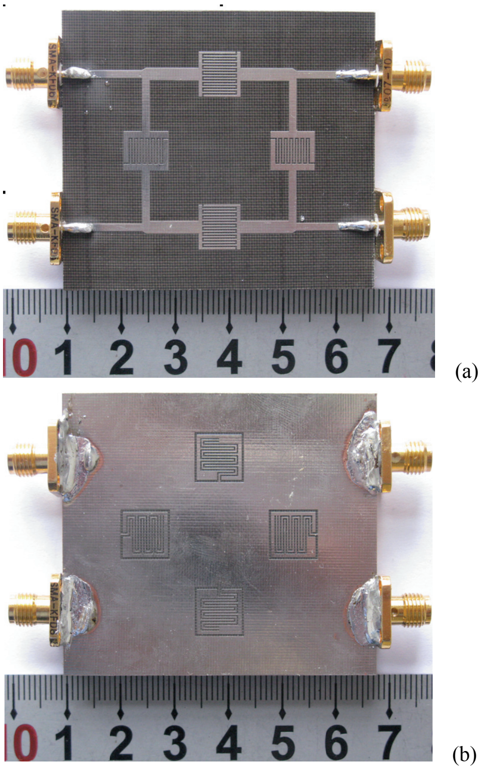


Fig. 9. Photograph of the proposed branch-line coupler: (a) top view, (b) bottom view.

Fig. 11 shows the photographs of the proposed and conventional branch-line couples. As can be seen from Fig. 11, the overall circuit size of the proposed and conventional branch-line coupler operating at 0.7 GHz is 36×35.2 mm^2 and 72.37×76.82 mm^2, respectively. That is, the proposed branch-line coupler achieved 77.2% circuit size reduction, and the size reduction is better than the structures reported in literature [2-5].

As can be seen from Fig. 8, Fig. 10 and Fig. 11, the proposed branch-line coupler without any lumped elements, bonding wires and via-holes can be easily fabricated. In addition, good agreement between the measured and simulated results is observed.

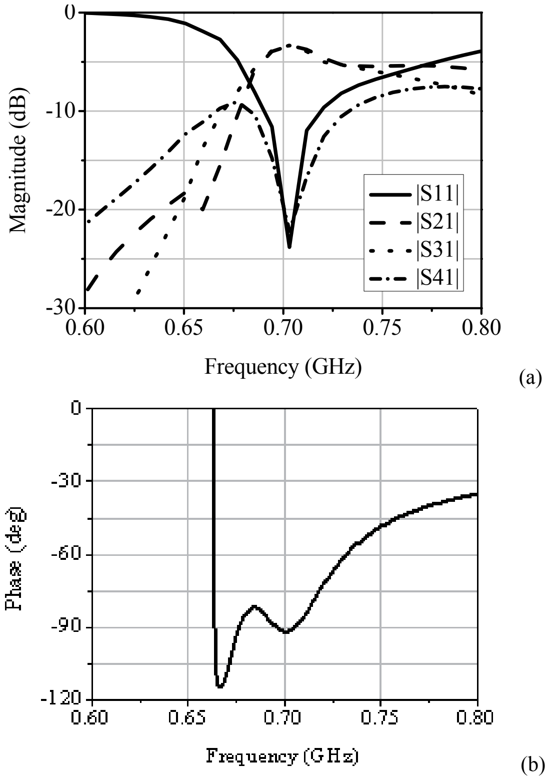


Fig.10. Measured results of the proposed branch-line coupler: (a) S-parameters, (b) phase differences between the output ports.

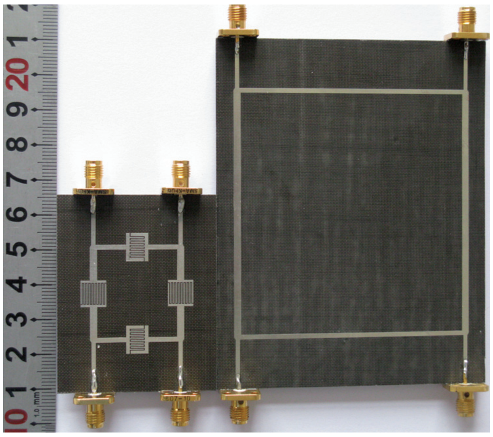


Fig. 11. Photographs of the proposed and conventional branch-line couples.

4. Conclusions

In this paper, a new method without lumped components to design the compact branch-line coupler at low frequency has been proposed and implemented. The proposed coupler can be easily obtained using CRLH-TL. The corresponding design process and their responses are provided as well. Moreover, this coupler can be fabricated easily with a standard printed circuit board process, which is applicable to the design of microwave integrated circuits. However, the proposed compact microstrip branch-line coupler is only suitable for narrowband systems.

Acknowledgements

This research has been supported by National Natural Science Foundation of China under Grant 60971118. The authors would like to thank the China North Electronic Engineering Research Institute for the fabrication and measurement supports. They also extend their gratefulness to the reviewers for their valuable comments.

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