A Compact Planar 90° Branch Line Coupler Using S-Shaped Structure Loading for Wideband Application

M. Maleki [1], J. Nourinia [2], Y. Zehforoosh [3], and V. Rafii [3]

[1] Department of Electrical Engineering
Ahar Branch, Islamic Azad University, Ahar, Iran
mostafa.maleki.k@gmail.com

[2] Department of Electrical Engineering
Urmia University, Urmia, Iran
j.nourinia@urmia.ac.ir

[3] Department of Electrical Engineering
Urmia Branch, Islamic Azad University, Urmia, Iran
y.zehforoosh@srbiau.ac.ir, vhd.rafii@gmail.com

Abstract **─** This paper presents the design of a wideband microstrip branched branch line coupler (BLC). The wideband performance of the BLC means that it possesses equal coupling and difference of phases throughout the operating frequency band, from 4 GHz to 6 GHz (based on a 10 dB, i.e., VSWR ≤ 2). The compactness of the proposed design is depending on the replacement of the branched transmission lines (TL) instead of the ordinary TLs. Small and easy to fabricate microstrip layout topology for the BLC has been designed and constructed relying on a low cost dielectric material, the well-known FR4. In addition, the proposed coupler can be easily fabricated on the printed circuit board without any lumped element. The proposed BLC exhibits couplings and phase errors within −3.75 ± 1 dB and 4° over a 60 % bandwidth (BW) with a center frequency of 5 GHz (based on 15 dB).

Index Terms **─** Compact, coupler, microstrip, planar, and wideband.

I. INTRODUCTION

The compact BLC is an important circuit in microwave integrated circuits and can be used as a power divider/combiner or a part of a mixer [1]. The conventional BLC was composed of four quarter-wavelength TLs [2]. However, adopting the quarter-wavelength TL to design the coupler takes too much space; therefore, larger circuit area may result in higher cost. In addition, the broadband BLC takes two times more space than the normal type.

Numerous methods have been proposed to reduce the circuit size [3-7]. A number of proposed methods are as follows: based on a methodology, the asymmetrical T-structure can be exactly synthesized and then applied to implement compact planar couplers [3]. A class of the novel compact-size BLCs using the quasi-lumped elements approach with symmetrical or nonsymmetrical T-shaped structures is proposed in [5, 6]. Nevertheless, using the lumped element in the circuit design requires an empirical model, such as an inductor model, attained via precise measurement. Based on another methodology, discontinuous microstrip lines whose size is significantly reduced relative to the standard design can be used to implement a compact planar coupler [3]. By using the inter digitized capacitors shunt with the TLs, further minimization of the 3 dB branch-line hybrid coupler can be achieved compared with previously reported techniques [4].

In [3-8] microstrip lines are employed to design the compact BLC. However, only a few studies provide detailed discussion on design

Submitted On: Feb. 4, 2013
Accepted On: May 14, 2013

procedures or formulations. In this paper, a new method for designing the microstrip BLCs with predetermined compact size and BW has been proposed and implemented. Utilizing the proposed multiple shunted open stubs shown in Fig. 1 (e), which can be realized with either high or low impedance, that can easily miniaturize the TLs of branch-line. The fabricated couplers not only occupy small space, but also reveal good circuit performances compared with that of the conventional branch-line type, and it can be used as an element of broadband Butler matrix networks to feed an array antenna. Good agreements between the results of the conventional and proposed BLC are observed.

In the next section, we will provide the transformed equation, which can synthesize the equivalent quarter-wavelength TL. Then the comparison between the theoretical predictions and measurements. Finally, conclusions are given in the last section.

II. DESIGN PROCEDURE

The desired 90° BLC should have a good performance such as return loss and isolation better than 20 dB over 50 % or wider BW (total BW measured based on 10 dB), and a small size on a single-layer circuit without using any air-bridges (planar structures) [7].

In order to enhance the BW, we choose cascaded branch line, broadband BLC as a quadrature hybrid circuit. However, it requires a large circuit area. The loaded line is a popular method to reduce the size of TL circuits such as branch-line and ring hybrids, which is important for planar integrated circuits. The results using a loaded line show good efficiency with regard to size reduction [7].

A TL and its π-equivalent circuit are shown in Fig. 1, and the design equations can be defined as follows [7],

$$\frac{\tan\theta_P}{Z_P} = \frac{\cos\theta_S - \cos\theta_0}{Z_0 \sin\theta_S} \tag{1}$$

$$Z_S = \frac{Z_0 \sin\theta_0}{\sin\theta_S}, \tag{2}$$

where $0 \leq \theta_S \leq \theta_0 \leq 90°$.

For demonstration, we select a TL of Fig. 1 (a) with the characteristic impedance Z_0 and electrical length θ_0 as a unit line section, and it can be replaced by a π-equivalent circuit in Fig. 1 (b). Then each open stub can be replaced by a folded open stub with equal characteristic impedance Z_P and total electrical length θ_P (i.e., $\theta_P = \theta_P' + \theta_P''$) as shown in Fig. 1 (c) and d, and in order to approach more size reduction one of the folded stubs can be flipped vertically (with a 45° corner) as shown in Fig. 1 (d). Finally, the approached structure is a balanced π-equivalent with S-shaped stubs as called S-shaped equivalent as shown in Fig. 1 (e). Due to the simulated and measured results, which are presented in the next section, this structure has an acceptable frequency response within the operating band width with regard to size reduction.

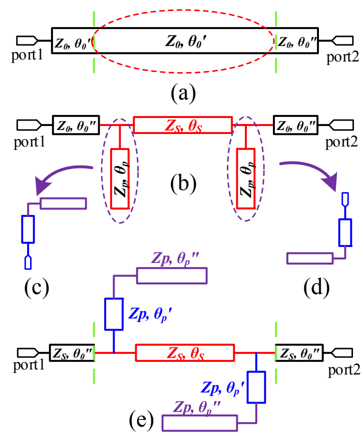

Fig. 1. Conventional TL and its S-shaped equivalent structure for (a) a conventional TL, (b) quasi π-equivalent TL of the conventional type, (c) folded equivalent structure of the open stub, (d) flipped vertically and folded equivalent structure of the open stub, and (e) the S-shaped equivalent structure of the conventional TL.

If the TLs of the conventional (broadband) BLC shown in Fig. 1 (a) are replaced by S-shaped equivalent structure shown in Fig. 1 (e). The open stubs on the corners should be merged together, in order to avoid being the stubs on the corner, one can replace a fraction of the conventional TLs of the couplers by the S-shaped equivalent structure as shown in Fig. 1 (e). Due to simulation results, presented in the next section, by an acceptable approximation, the rest fraction of each TL can be replaced by the conventional TL with the same electrical length, but with the characteristic impedance Z_S instead of Z_0. This replacement results in a flatter structure as shown in Fig. 1 (e).

The proposed circuit has been shown in Fig. 2 and each conventional TL has been replaced by an S-shaped equivalent structure. Length and width of each intersection transmission line lettered in Fig. 2 are listed in Table 1.

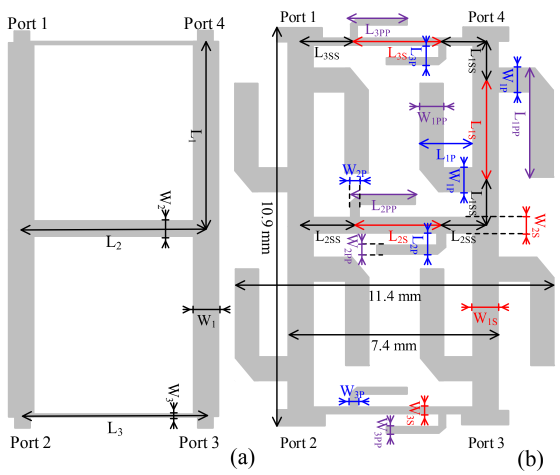

Fig. 2. (a) The conventional broadband BLC and (b) the proposed broadband BLC with S-shaped equivalent structure. (The figures are not scaled to the real size, the conventional type is larger.)

Table 1: Length and width of each intersection lettered in Fig. 2 (all values are in mm).

	L_i	W_i	L_{iSS}	L_{iS}	W_{iS}	L_{iP}	W_{iP}	L_{iPP}	W_{iPP}
i=1	8.10	1.70	0.85	3.40	0.70	2.05	0.80	3.75	0.80
i=2	10.6	0.80	1.75	3.20	0.30	0.65	0.20	2.43	0.20
i=3	10.6	0.25	1.75	3.20	0.10	0.30	0.10	1.85	0.10

III. SIMULATION AND EXPERIMENTAL RESULTS

Simulation was accomplished using EM simulation software Agilent Advanced Design System (ADS), which is an electromagnetic wave simulator that provides an integrated design environment to the designers of RF electronic products. The proposed BLC is designed on an FR4 substrate with a thickness of 0.8 mm, a dielectric constant of 4.4, and a loss tangent of 0.022. Figure 2 presents the layout of the proposed microstrip BLC with S-shaped TLs and its effective size is 10.90 mm × 7.40 mm (outer stubs are neglected [7], total size is 10.90 mm × 11.40 mm). The simulation results of the return loss, isolation, and coupling and insertion loss of the proposed BLC are shown in Fig. 4 and the phase division is shown in Fig. 5. At the designed frequency, 5 GHz, the insertion loss is -3.5 ± 0.1 dB, the isolation is about 20 dB, and the phase difference is 90°. In addition, these figures show that the performance of the proposed coupler has approximately couplings and phase errors within −3.75 ± 1 dB and 4° and return loss and isolation better than 15 dB over a 60 % BW. Table 2 summarizes the recently published branch-line hybrid couplers with reduced wavelength in TL and this work. In addition, it shows significant improvement in size reduction with regard to wide band performance.

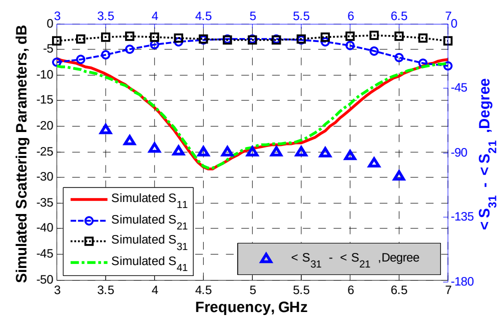

Fig. 3. Scattering parameters of the conventional BLC.

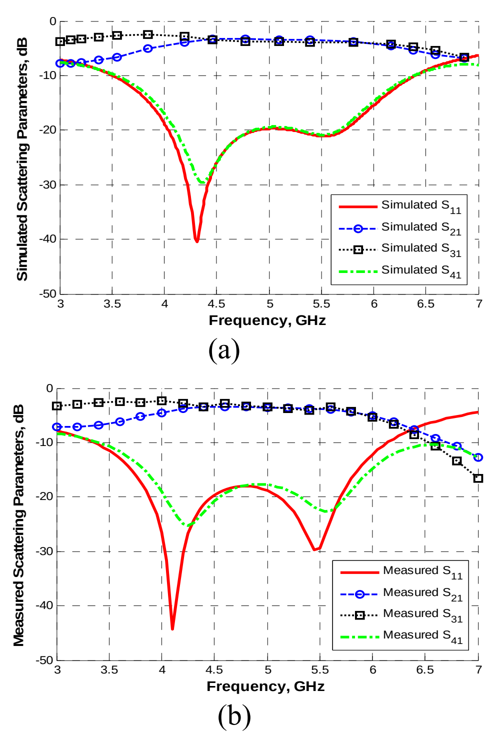

Fig. 4. Scattering parameters of the proposed BLC, (a) simulated scattering parameters and (b) measured scattering parameters.

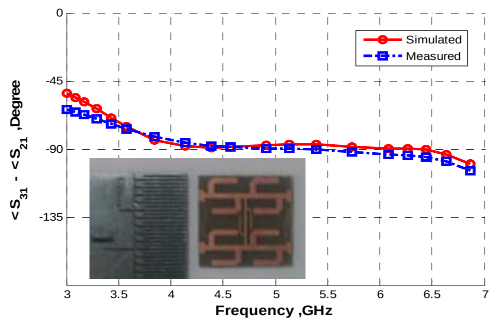

Fig. 5. Measured and simulated phase difference between S_{31} and S_{21} of the proposed BLC, and its photograph.

Table 2: Comparison of published compact BLC and this work.

Ref.	Phase Error	Substrate	f_0 (GHz)	B.W. (GHz) (based on 10dB)	Reduction Ratio
[3]	~5	RO4003	0.9	0.3 (0.75~1.05)	0.12
[4]	~2	FR4	0.825	0.15 (0.75~0.9)	0.26
[5]	>5	RO4003	2.4	0.4 (2.2~2.6)	0.76
[6]	>5	FR4	2.4	0.8 (2~2.8)	0.29
[7]	~5	RO4003	5	2 (4~6)	0.5
This Work	4	FR4	5	2 (4~6)	0.39

IV. CONCLUSION

This paper, the conventional broadband BLC (cascaded BLC) with seven sections of the quarter-wavelength TLs has been miniaturized easily by using the proposed S-shaped equivalent structure. The corresponding design equations, equivalent structures, and their simulated and measured results are presented as well. Table 2 reveals that using the proposed S-shaped equivalent structure is an effective approach to miniaturize the circuit size of a BLC (i.e., the reduction size is 61 %) with regard to wideband performance. The proposed BLC exhibits couplings and phase errors within −3.75 ± 1 dB and 4° and return loss and isolation better than 15 dB over a 60 % BW with a center frequency at 5 GHz. Moreover, these couplers can be fabricated using a standard printed circuit board process, which is easily applicable to the design of microwave integrated circuits, such as broadband Butler matrix networks.

REFERENCES

[1] S. A. Maas, *Microwave Mixers*, Norwood, MA: Artech House, 1986.

[2] D. M. Pozar, *Microwave Engineering,* 3rd Ed, New York: John Wiley & Sons, 2005.

[3] C. H. Tseng and C. L. Chang, "A rigorous design methodology for compact planar branch-line and rat-race couplers with asymmetrical T-structures," *IEEE Transactions on Microwave Theory and Techniques*, vol. 60, no. 7, pp. 2085-2092, July 2012.

[4] K. Y. Tsai, H. S. Yang, J. H. Chen, and Y. J. E. Chen, "A miniaturized 3 dB branch-line hybrid coupler with harmonics suppression," *IEEE Microwave and Wireless Components Letters,* vol. 21, no. 10, pp. 537-539, Oct. 2011.

[5] C. W. Tang, M. G. Chen, and J. W. Wu "Realization of ultra-compact planar microstrip BLCs with high-impedance open stubs," *IEEE Microwave Symposium, 2007.*

[6] S. S. Liao and J. T. Peng "Compact planar microstrip BLCs using the quasi-lumped elements approach with nonsymmetrical and symmetrical T-shaped structure," *IEEE Transactions on Microwave Theory and Techniques,* vol. 54, no. 9, Sep. 2006.

[7] C. Chen, H. Wu, and W. Wu "Design and implementation of a compact planar 4×4 microstrip Butler matrix for wideband application," *Progress in Electromagnetics Research C,* vol. 24, pp. 43-55, 2011.

[8] A. Yilmaz, E. Cetiner, and M. Hasanovic, "Sonnet modelling and simulation of broadband branchline coupler," *27th Annual Review of Progress in Applied Computational Electromagnetics (ACES),* Williamsburg, Virginia, pp. 398-402, March 2011.

Mostafa Maleki was born in Urmia, Iran, in 1985. He received the B.Sc. degree in Electrical and Communications Engineering from Urmia Azad University, Urmia, Iran, in 2008 and M.Sc. degree in Electrical Engineering from Ahar Azad University,Ahar,Iran, in 2013. He is with the Northwest Antenna and Microwave Research Laboratory (NAMRL). His current research interests include RF amplifiers, RF filters, microwave components and high-frequency networks.

Javad Nourinia was born in Urmia, Iran, in 1969. He received the M.Sc. and Ph.D. degree in Electrical Engineering from Iran University of Science and Technology, Tehran in 1995 and 2000, respectively. He is now a Professor of Electrical Engineering at the university of Urmia and head of Electronics and Communication Department.

Yashar Zehforoosh was born in Urmia, Iran, in 1981. He received his Ph.D. degree from Science and Research Branch of Islamic Azad University Tehran, Iran in 2012. His research interests include broadband antennas, electromagnetic structures and UWB systems.

Vahid Rafii was born in Urmia, Iran, in 1986. He received the B.Sc. degree in Communication Engineering from the Urmia Azad University, in 2008 and M.Sc. degree in Communication Engineering from Urmia University, Urmia, Iran, in 2013. His research interests include antenna array, array feed networks, and their antenna applications.