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Research Article

Wideband Microstrip 90° Hybrid Coupler Using High Pass Network

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A wideband 90° hybrid coupler has been presented and implemented in planar microstrip circuit. With similar structure of conversional 2-section branch-line coupler, the proposed coupler consists of a lumped high-pass network but not the quarter wavelength transmission at the center. The values of all lumped elements were optimized to replace a quarter-wavelength transmission line with a phase inverter. To demonstrate the proposed concept, a 1-GHz prototype was fabricated and tested. It achieves 90% impedance bandwidth with magnitude of $S11$ less than −10 dB. Within this bandwidth, more than 13 dB port-to-port isolation, less than 5.0 degree phase imbalance, and less than 4.5 dB magnitude imbalance are achieved, simultaneously. The proposed coupler not only achieves much wider bandwidth but also occupies less circuit area than that of the conversional 2-section branch-line coupler.

1. Introduction

Branch-line coupler is one of the fundamental components in RF/microwave front-end systems. It is a 4-port device that divides and/or combines power simultaneously with port-to-port isolation and 90° phase shift. These features make the branch-line coupler extremely useful in various applications such as antenna feeding network, phase shifter, balanced amplifier, and mixer. Bandwidth and compactness are two important design issues to meet the demand of the high performance systems. The bandwidth can be enhanced by increasing the number of sections, but the size will be increased. With the restriction of the line width, the characteristic impedance of the transmission line is limited to about 400 Ω; hence, the number of sections is limited to 3 or 4.

Recently, various wideband and/or compact couplers have been proposed. Multisection technique is conventional and effective way to enhance bandwidth of the branch-line coupler. Several multisection branch-line couplers integrated with pattern ground structure [1], coupled line [2], and loaded line [3] were demonstrated. These works achieve more than 70% bandwidth. Series stub matching presents a simple way to broaden bandwidth with limited improvement [4]. A quadrature hybrid coupler using metamaterial transmission line, which achieves 67%, was proposed in [5]. However, a crossover is required for the coupler and the coupler introduces 6 dB insertion loss instead of 3 dB for the signal division.

Figure 1 shows the schematic diagram of the wideband 90° hybrid coupler using phase inverter, which was firstly proposed in [6] and analyzed in [7]. The physical size of the proposed design is close to a conventional 2-section branch-line coupler, but its performance is similar to a 4-section branch-line coupler. The nature of parallel strip circuit requires double sided printed circuit broad fabrication technique, which increases the cost of the entire system. In this paper, a simple and lumped high pass network is used to replace the transmission line with phase inverter such that the proposed concept can be realized by pure microstrip circuit with keeping the advantages of being compact and wideband. Besides, the conventional SMA connector can be used for measurement of microstrip circuit; hence, no additional transition is required.

2. Proposed Design

The previously proposed wideband 90° hybrid coupler using phase inverter consists of 7 quarter-wavelength transmission

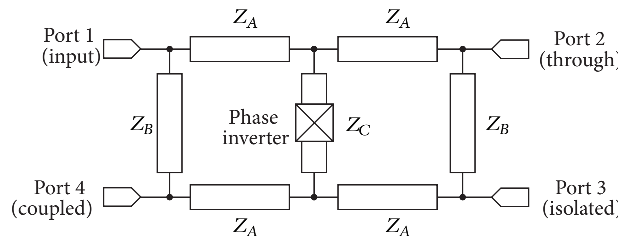

FIGURE 1: Schematic diagrams of proposed 90° hybrid coupler with various schemes, where Z_A, Z_B, and Z_C are the characteristic impedances of the quarter-wavelength transmission lines.

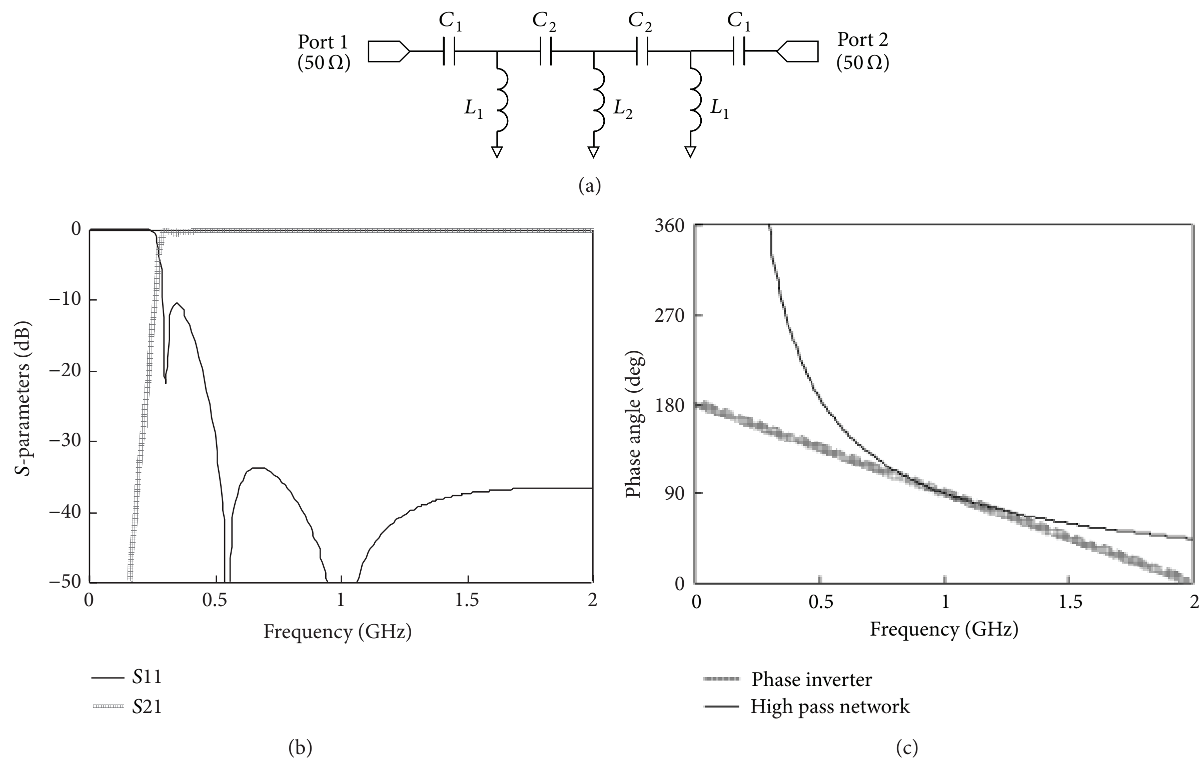

FIGURE 2: (a) Schematic diagrams of high pass network with 4 series capacitors and 3 shunt inductors. (b) Simulated frequency responses of the magnitudes of the S-parameters. (c) Simulated phase angles of the high pass network and the quarter-wavelength transmission line with phase inverter.

lines and a phase inverter as shown in Figure 1. Design equations based on the even- and odd-mode analysis are presented in [7], and they are

$$Z_A = Z_0$$
$$Z_B = \left(\sqrt{k} + \sqrt{k+1}\right) Z_0, \quad (1)$$
$$Z_C = \sqrt{k} Z_0,$$

where Z_A, Z_B, and Z_C are the characteristic impedances of the quarter-wavelength transmission lines, k is the power division ratio, and Z_0 is the port impedance. According to (1), the circuit parameters of the proposed coupler with equal power division ($k = 1$) are

$$Z_A = 50.0\,\Omega, \qquad Z_B = 120.7\,\Omega, \qquad Z_C = 50.0\,\Omega. \quad (2)$$

Phase inverter is the key of the previously proposed coupler, and it introduces a 180° phase delay without increasing the transmission line length. However, the phase inverter cannot be realized by the microstrip line, which is an unbalanced transmission line.

To replace the quarter-wavelength transmission line with characteristic impedance of $Z_C = 50\,\Omega$ and the phase inverter, a lumped high pass network with perfect passband and +90° phase shift at 1 GHz is designed in this paper. Higher-order high pass network will have better approximation to a quarter-wavelength transmission line with 50 Ω characteristic impedance and the phase inverter theoretically; however, higher-order high pass network introduces more insertion loss and more tolerance due to the lumped elements and soldering. To balance this trade-off, the high pass network consisting of 4 series capacitors and 3 shunt inductors as

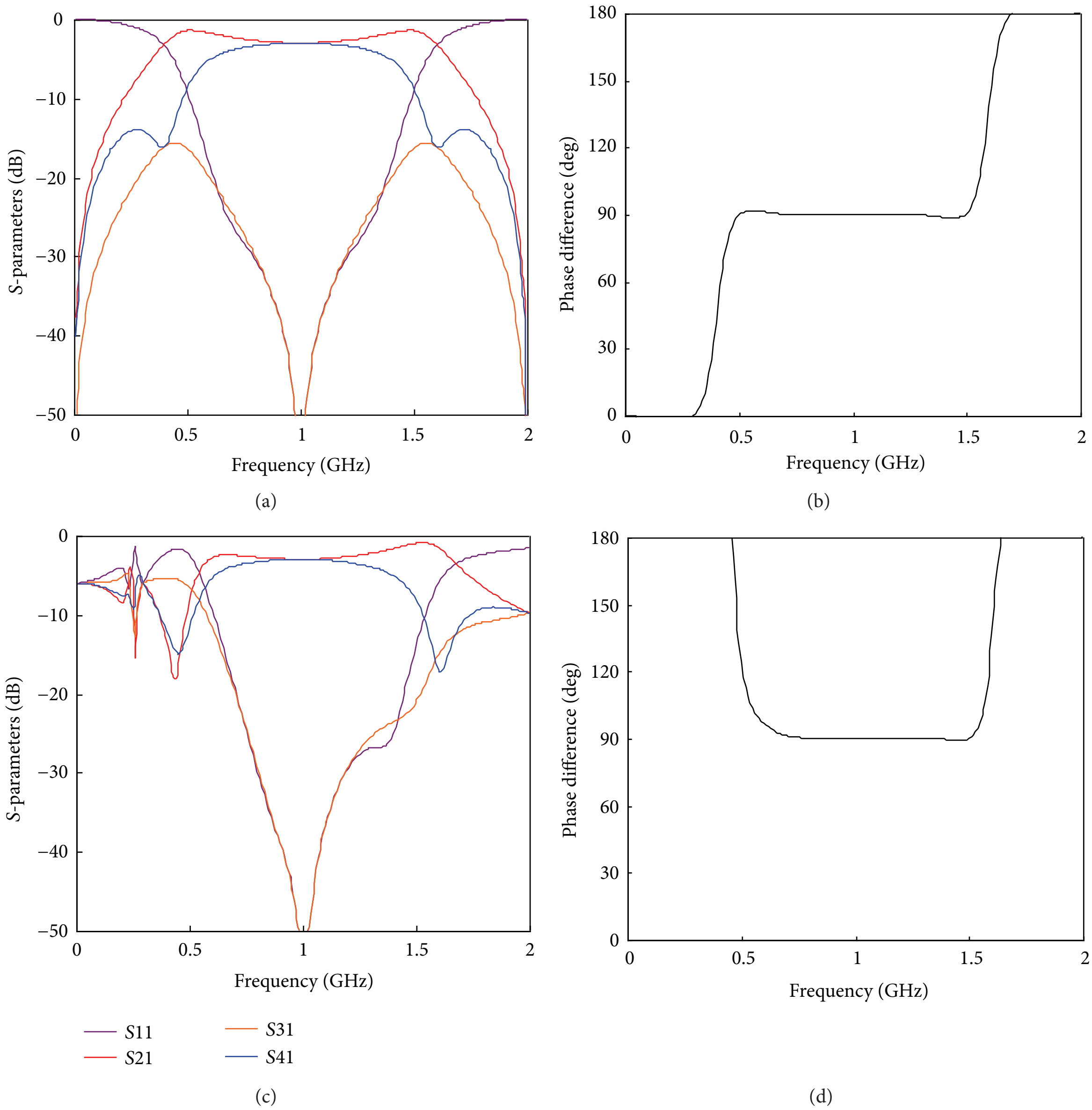

Figure 3: (a) Simulated magnitudes of the S-parameters of the wideband 90° hybrid coupler reported in [7] using ideal transmission lines and ideal phase inverter. (b) Simulated phase difference of the S-parameters of the wideband 90° hybrid coupler reported in [7] using ideal transmission lines and ideal phase inverter. (c) Simulated magnitudes of the S-parameters of the proposed coupler using ideal transmission lines and ideal lumped elements. (d) Simulated phase difference of the S-parameters of the proposed coupler reported using ideal transmission lines and ideal lumped elements.

shown in Figure 2(a) is chosen. The values of the capacitances and the inductances are

$$\begin{aligned} C_1 &= 12.4\,\text{pF}, \quad C_2 = 5.87\,\text{pF}, \\ L_1 &= 15.9\,\text{nH}, \quad L_2 = 15.6\,\text{nH}. \end{aligned} \tag{3}$$

These values are optimized using circuit simulator, Agilent Advanced Design System [8], with goals of $|S_{11}| = |S_{22}| = 0$, $|S_{21}| = |S_{12}| = 1$, and $\angle S_{21} = \angle S_{12} = +90^\circ$ at centre frequency of 1 GHz. The simulated magnitude and phase angle of the S-parameters of the high pass network with 50 Ω port impedance are shown in Figures 2(b) and 2(c), respectively. A distinct cut-off frequency is observed at about 0.3 GHz. The phase gradient is close to that of the conventional quarter-wavelength transmission line with phase inverter at around 1 GHz.

Figure 3 shows the simulated S-parameters of the previously proposed coupler with phase inverter and proposed coupler with high pass network. Both magnitude and phase responses are simulated from DC to 2 GHz. For ideal case, the two couplers have similar magnitude of the S-parameters over the simulated frequency range. The responses of the phase

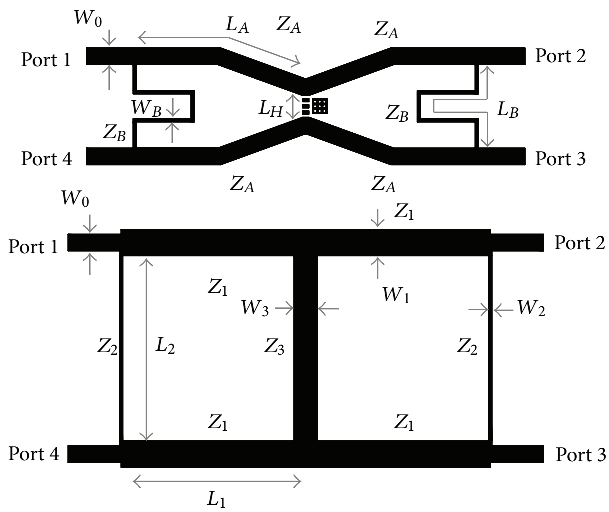

FIGURE 4: Layouts of the proposed coupler and the conventional 2-section branch-line coupler with same scale: $W_0 = 5.32$ mm, $L_A = 56.5$ mm, $L_B = 62.8$ mm, $W_B = 1.00$ mm, and $L_H = 7.0$ mm. $L_1 = 59.4$ mm, $W_1 = 8.42$ mm, $L_2 = 59.6$ mm, $W_2 = 0.99$ mm, and $W_3 = 7.52$ mm.

FIGURE 5: Photograph of the fabricated coupler.

difference are different at the lower frequency range, which is out of the range of working frequency band. The direct replacement is possible and it makes the circuit smaller.

The electromagnetic model of the proposed coupler was built in the electromagnetic simulation software, Zeland IE3D Version 10.1 [9], with the dielectric substrate of 1.57 mm thickness and a dielectric constant of 2.2. Figure 4 shows the layout with physical dimensions of the proposed coupler. All dimensions of the coupler were finely tuned by using electromagnetic simulation software to take into account the effect of the discontinuities introduced by all T-junctions and the high pass network. The occupied area of layout of the proposed coupler is 4107 mm^2 (111 m × 38 mm).

A conventional 2-section branch-line coupler is designed and simulated as a reference for comparison. The layout with physical dimensions is shown in Figure 4, where the circuit parameters are

$$Z_1 = 36.22\,\Omega, \quad Z_2 = 118.9\,\Omega, \quad Z_3 = 39.34\,\Omega. \quad (4)$$

The occupied area of layout of the conventional 2-section branch-line coupler is 9163 mm^2 (119 m × 77 mm).

The lumped high pass network occupies a relatively small area with the length of $L_H = 7.0$ mm. The occupied area of layout of the proposed coupler is just 45% of that of the conventional 2-section branch-line coupler.

3. Experimental Results

The proposed couplers were fabricated on the RT/Duroid 5880 substrate with metal thickness of 0.02 mm, substrate thickness of 1.57 mm, and dielectric constant of 2.2 by a standard printed circuit board fabrication technique. Figure 5 shows the photograph of the fabricated proposed coupler. The S-parameters of the coupler were measured by a vector network analyzer.

Figures 6(a) and 6(b) show that magnitudes of the S-parameters of the proposed coupler and the conventional 2-section branch-line coupler, respectively. Significant improvement on impedance bandwidth is observed. The simulated impedance bandwidths with $|S_{11}| < -10$ dB of the proposed coupler and the conventional 2-section branch-line coupler are 50% and 87%, respectively. The measured relative impedance bandwidth is 87% (0.55 GHz–1.40 GHz) as shown in Figure 6(c). Within this bandwidth, more than 13 dB port-to-port isolation, less than 3° phase imbalance, and less than 4.5 dB magnitude imbalance are achieved.

The simulated frequency responses of the proposed coupler and the conventional 2-section branch-line coupler are shown in Figure 7(a). The simulated phase bandwidths with phase imbalance less than 5° of the proposed coupler and the conventional 2-section branch-line coupler are 53% and 81%, respectively. Figure 7(b) shows the measured phase imbalance of the fabricated proposed coupler. The measured phase

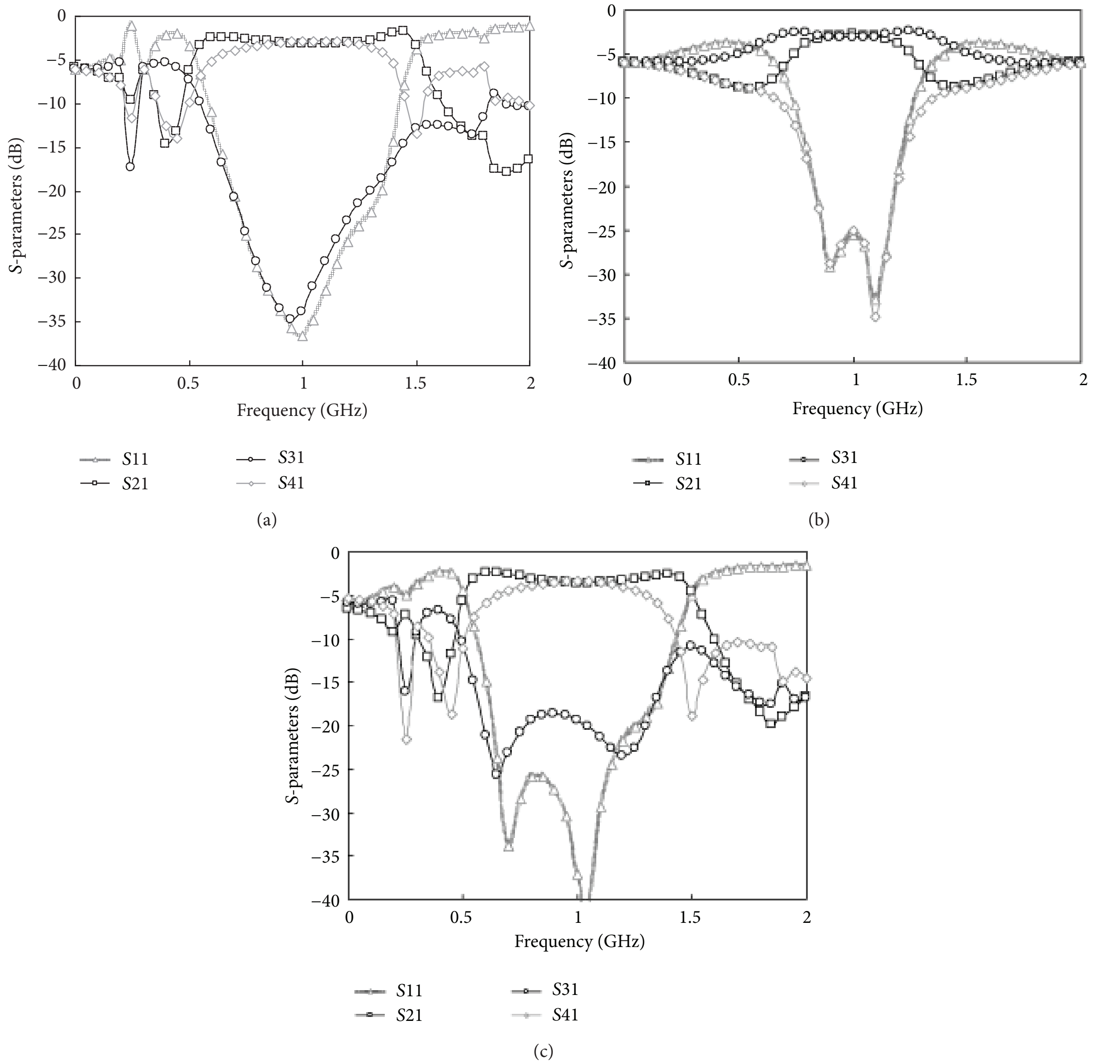

Figure 6: (a) Simulated magnitude of S-parameters of the proposed coupler. (b) Simulated magnitude of S-parameters of the conventional 2-section branch-line coupler. (b) Measured magnitude of S-parameters of the proposed coupler.

Table 1: Performance comparison of the previously reported branch-line coupler.

	Impedance bandwidth	Relative bandwidth with ±5 dB magnitude imbalance	Relative bandwidth with ±5° phase imbalance	Circuit size reduction
[1]	100%	75%	70%	Nil
[2]	70%	60%	56%	Nil
[3]	82%	75%	65%	52%
[4]	57%	63%	46%	65.4%
2-section branch-line coupler	50%	75%	50%	Nil
This work	90%	94%	88%	45%

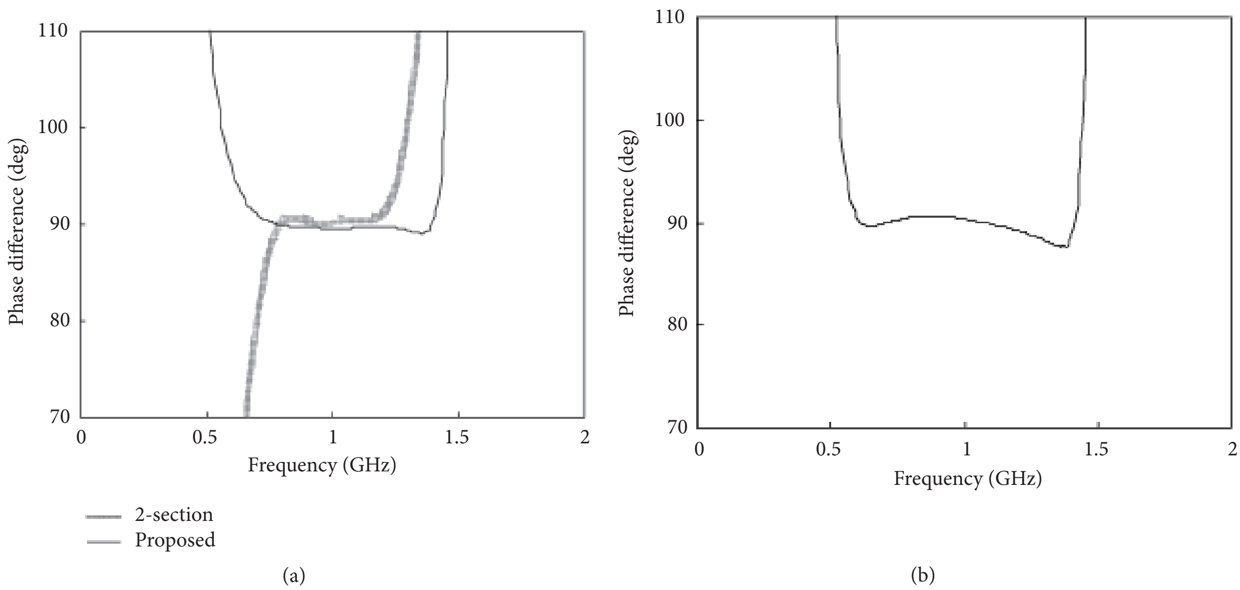

Figure 7: (a) Simulated phase differences between through and coupled signals magnitude of the proposed coupler and conventional 2-section branch-line coupler. (b) Measured phase differences between through and coupled signals magnitude of the proposed coupler.

bandwidth of fabricated proposed coupler is 83% (0.58 GHz–1.41 GHz). The mismatch of the simulation and measurement is due to the inaccurate values of the capacitances and inductances and the neglect of physical sizes of the lumped elements and parasitic effect of soldering. The comparison of some previously published branch-line couplers and this work is summarized in Table 1.

4. Conclusion

A wideband and compact 90° hybrid coupler integrated with high pass network has been proposed. The proposed coupler achieves smaller circuit area and wider bandwidth than that of the conventional two-section branch-line coupler. The lumped high pass network replaces the phase inverter in our previously proposed concept of the wideband hybrid coupler. Most importantly, the proposed concept is realized on the planar microstrip circuit; hence the proposed coupler can be fabricated by the single-layer printed circuit board fabrication technique.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

References

[1] C. W. Tang, M. G. Chen, Y. S. Lin, and J. W. Wu, "Broadband microstrip branch-line coupler with defected ground structure," *IET Electronics Letters*, vol. 42, no. 25, pp. 1458–1460, 2006.

[2] W. M. Fathelbab, "The synthesis of a class of branch-line directional couplers," *IEEE Transactions on Microwave Theory and Techniques*, vol. 56, no. 8, pp. 1985–1994, 2008.

[3] Y. H. Chun and J. S. Hong, "Compact wide-band branch-line hybrids," *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 2, pp. 704–709, 2006.

[4] B. M. Alqahtani, A. F. Sheta, and M. A. Alkanhal, "New compact wide-band branch-line couplers," in *Proceedings of the 39th European Microwave Conference (EuMC '09)*, pp. 1159–1162, Rome, Italy, October 2009.

[5] C.-J. Lee, K. M. K. H. Leong, and T. Itoh, "Broadband quadrature hybrid design using metamaterial transmission line and its application in the broadband continuous phase shifter," in *Proceedings of the IEEE International Microwave Symposium (IMS '07)*, pp. 1745–1748, Los Angeles, Calif, USA, June 2007.

[6] L. Chiu and Q. Xue, "Wideband parallel-strip 90° hybrid coupler with swap," *IEt Electronics Letters*, vol. 44, no. 11, pp. 687–688, 2008.

[7] L. Chiu and Q. Xue, "Investigation of a wideband 90° hybrid coupler with an arbitrary coupling level," *IEEE Transactions on Microwave Theory and Techniques*, vol. 58, no. 4, pp. 1022–1029, 2010.

[8] Agilent Headquarters, 395 Page Hill Road, P. O. Box 10395, Palo Alto, California, 94303, USA, http://eesof.tm.agilent.com/.

[9] IE3D 10.1, Zeland Software, Fremont, Calif, USA.