

## A New Miniaturized Microstrip Branch-Line Coupler with Good Harmonic Suppression

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**Abstract**—A new miniaturized microstrip branch-line coupler with good harmonic suppression is proposed in this paper. The new structure has two significant advantages, which not only effectively reduces the occupied area to 20.4% of the conventional branch-line coupler at 0.96 GHz, but also has high 6th harmonic suppression performance. The measured results indicate that a bandwidth of more than 120 MHz has been achieved while the phase difference between  $S_{21}$  and  $S_{31}$  is within  $90^\circ \pm 1^\circ$ . The measured bandwidth of  $|S_{21}|$  and  $|S_{31}|$  within  $3 \pm 0.3$  dB are 145 MHz and 150 MHz, respectively. Furthermore, the measured insertion loss is comparable to that of a conventional branch-line coupler. The new coupler can be easily implemented by using the standard printed-circuit-board etching processes and is very useful for wireless communication systems.

### 1. INTRODUCTION

Branch-line couplers are extensively used at microwave frequencies in the design of microwave circuits such as balanced mixers, image-rejection mixers, balanced amplifiers, power combiners, and power dividers [1]. There are currently two drawbacks for the conventional microstrip branch-line design. Firstly, conventional branch-line coupler is composed of four quarter-wavelength transmission-line sections at the designed frequency, which will result in a large occupied area especially at low frequency. Secondly, the conventional design also has harmonics that occur at the integral multiples of the fundamental operation frequency. These properties will degrade the performance of the coupler. Therefore, much work has been reported in recent years to achieve both compact design and harmonic suppression for the branch-line coupler [2–16].

Typically, there are two methods to design a compact planar microstrip branch-line coupler with harmonic suppression. The first method is to load the coupler with shunt open-stubs. By loading shunt open-stubs inside the free area of the branch-line coupler, Eccleston et al. designed a branch-line coupler with a size reduction of 37% to the conventional design at 1.8 GHz [10]. Based on a similar idea, Mondal and Chakrabarty proposed a branch-line coupler, which has the properties of 42% size reduction at 2.4 GHz and 5th harmonics suppression [11]. However, further improvement should be carried out on size reduction and harmonic suppression. The second design method is to introduce slow-wave resonators in the coupler structure. Using compensated spiral compact microstrip resonant cells (SCMRCs), Gu and Sun introduced a branch-line coupler with its area reduced to 24% of the conventional one together with 2nd and 3rd harmonics suppression at 2.4 GHz. However, the isolation performance is not ideal [12]. By introducing high-low impedance resonators inside the free area of the coupler, Wang et al. proposed a slow-wave branch-line coupler with its area reduced to 28% of the conventional one at 2.0 GHz. Even so, it only has 2nd harmonic suppression performance [13]. Size reduction methods were also reported in [14–16]. These couplers achieve compact size, but the harmonic suppressions still need improvement.

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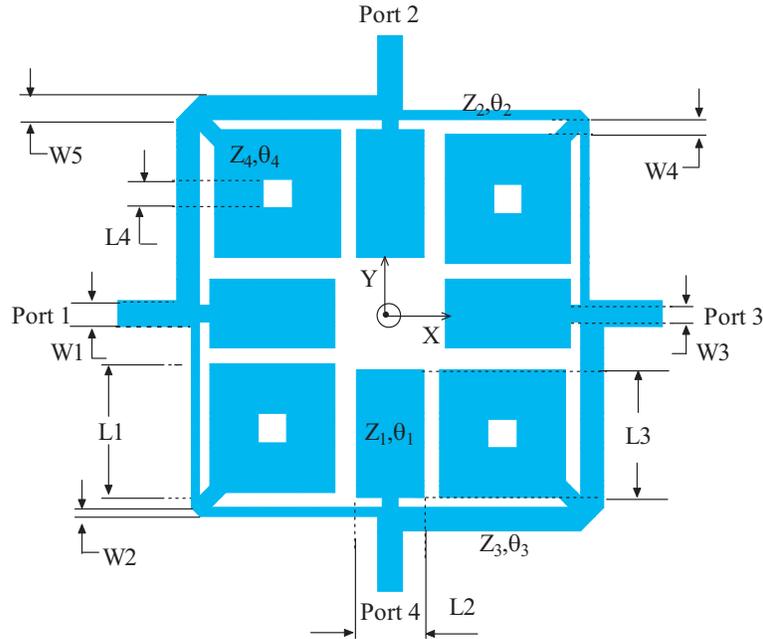
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The motivation of this work is to design a new microstrip branch-line coupler with compact size and wideband harmonic suppression. For this purpose, a branch-line coupler with operation central frequency located at 0.96 GHz is designed, fabricated, and measured. Measured results indicate that the proposed branch coupler not only effectively reduces the occupied area to 20.4% of the conventional branch-line coupler at the same operation frequency, but also has high 6th harmonic suppression performance. Furthermore, the proposed new coupler has a bandwidth of more than 120 MHz, while the phase difference between  $S_{21}$  and  $S_{31}$  is within  $90^\circ \pm 1^\circ$ . The organizations of the paper are as following: the design theory of the proposed branch-line coupler is given in Section 2; the simulated and measured results are given in Section 3, and the conclusions are given in Section 4.

## 2. CIRCUIT DESIGN

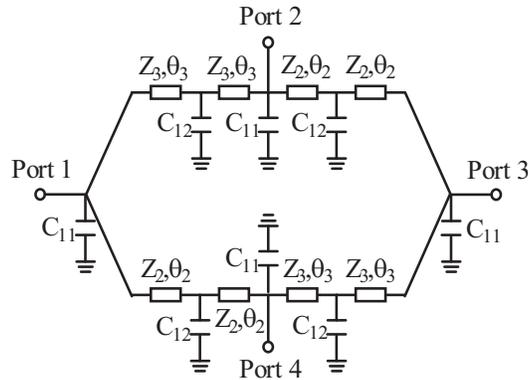
The schematic layout of the proposed branch-line coupler is shown in Fig. 1, which consists of only eight open-ended resonators loaded inside the free area of a conventional branch-line coupler. Each open-ended resonator is composed of a short high-impedance line and a long low-impedance line with open-end. The length of the high-impedance line is very short and less than  $\lambda/10$ , where  $\lambda$  is the guided wavelength at the operation frequency. Therefore, each high-impedance line is deemed as a lumped element with negligibly small value, and its inductance effect to the per unit length of the main transmission lines between two adjacent ports can be ignored since it is trivial. The capacitances caused by the low-impedance lines are loaded parallel with the main transmission lines in a distributed form. This will increase the per unit length capacitance of the main transmission lines between two adjacent ports. Here, the square slots etched in the square patches can introduce multiple-mode resonator, i.e., square ring multiple-mode resonator, for better harmonic suppression performance.



**Figure 1.** Topology of the proposed branch-line coupler.

Figure 2 shows the equivalent circuit of the proposed branch-line coupler. We can clearly see from this figure that the loaded high-low impedance resonators will introduce extra parallel capacitances denoted as  $C_{11}$  and  $C_{12}$  in the coupler, where  $C_{11}$  and  $C_{12}$  are the capacitances caused by the couplings between the loaded resonators and the ground. Notice that the shunt capacitors  $C_{11}$  represent square patches and that the shunt capacitors  $C_{12}$  represent rectangular patches, respectively. Thus, this type of loading can increase the shunt capacitance in the coupler. The propagation constant  $\beta$  is given by:

$$\beta = \omega \sqrt{L_0(C_0 + C_1)} \quad (1)$$



**Figure 2.** Equivalent circuit of the proposed branch-line coupler.

where  $L_0$  and  $C_0$  are the distributed inductance and capacitance for the main line of the branch-line coupler per unit length, respectively, and  $C_1$  is the effective distributed capacitance per unit length caused by the shunt capacitance  $C_{11}$  and  $C_{12}$ . Clearly, the propagation constant is increased by the periodic capacitive loading. An increased propagation constant means that a shorter physical structure can be used to yield a required electrical length compared with a conventional transmission line. This new type of slow-wave loading does not occupy extra area of the circuit as the periodic slow-wave loading is placed at the free area inside the branch-line coupler. We can get a desired slow-wave factor by adjusting the structure parameters of the proposed new branch-line coupler properly. On the other hand, when the electrical length of the loaded high-low impedance resonator is odd number times of  $\lambda/4$ , where  $\lambda$  is the guided wavelength at the spurious resonance frequency, harmonic signals that occur at the integral multiples of the fundamental operation frequency can be suppressed. The proposed branch-line coupler is designed based on the slow-wave loading mentioned above.

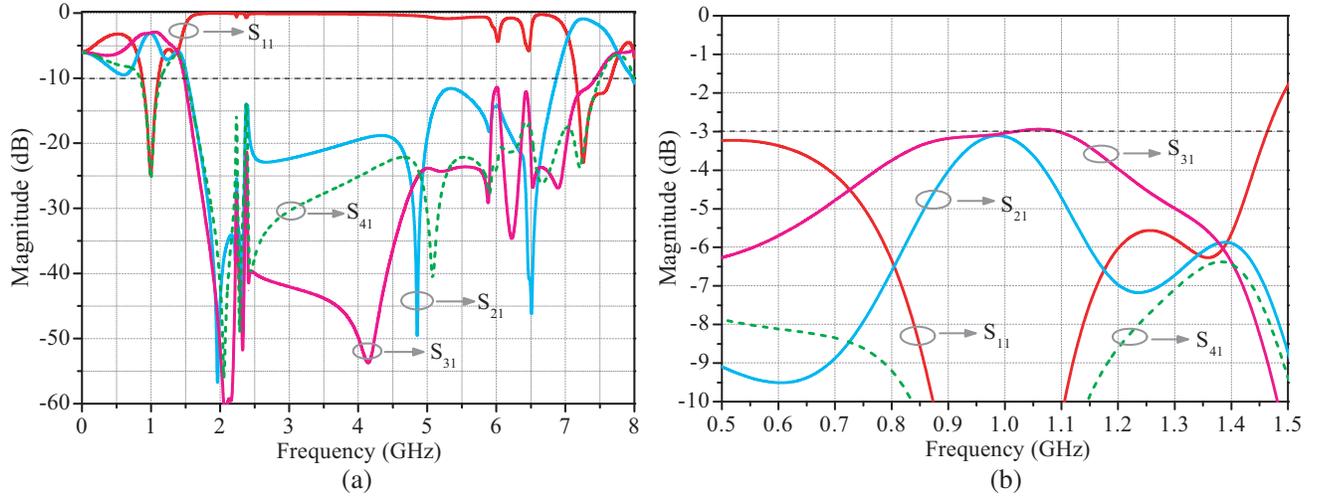
With further optimal design by the full-wave electronic magnetic (EM) simulation software, the final structure parameters of the proposed branch-line coupler are as follows:  $W1 = 1.7$  mm,  $W2 = 0.6$  mm,  $W3 = 1.1$  mm,  $W4 = 0.7$  mm,  $W5 = 1.6$  mm,  $L1 = 8.3$  mm,  $L2 = 4.2$  mm,  $L3 = 7.8$  mm,  $L4 = 1.9$  mm. They can be easily implemented by the standard printed-circuit-board etching processes. The substrate used here has a relative dielectric constant of 2.94 and thickness of 0.76 mm, and the total area of the proposed branch-line coupler is 630.33 mm<sup>2</sup>.

### 3. SIMULATION AND MEASUREMENT RESULTS

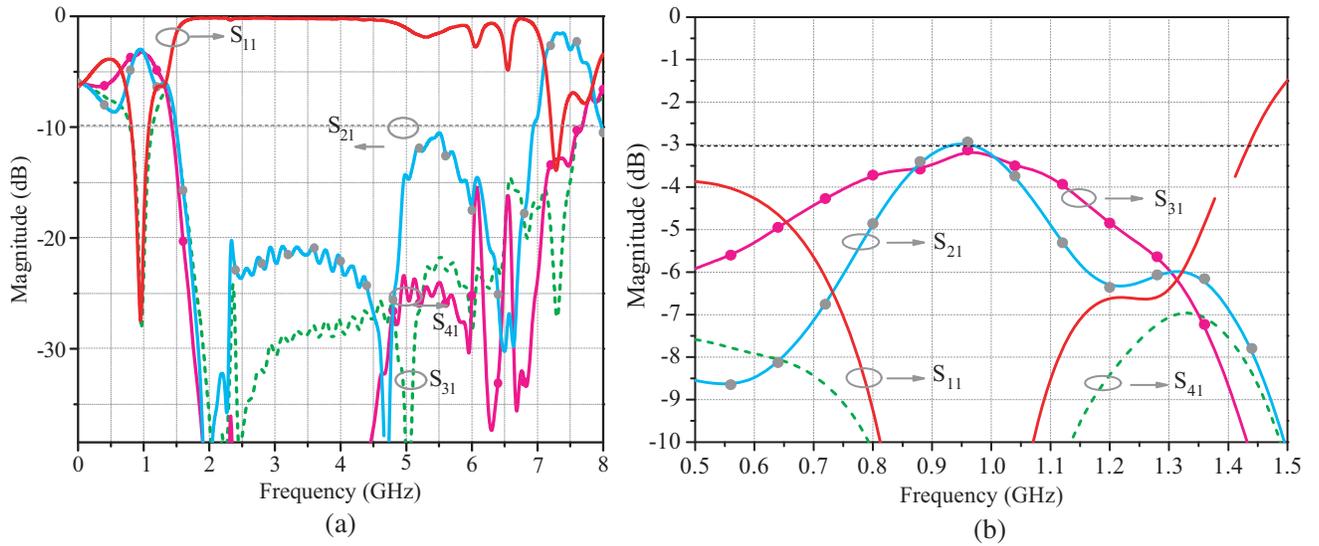
Simulation was accomplished with ANSOFT HFSS 13.0. Measurement was carried out on an Agilent 8531B network analyzer. Fig. 3 shows the simulated results of  $S$ -parameters. Fig. 4 shows the measured  $S$ -parameters of the proposed branch-line coupler. We can find that they are in good agreement. Referring to the measured results in Fig. 4, the central frequency located at 0.96 GHz can be clearly observed. At this central frequency, the measured  $S_{21}$  is 3.12 dB, and  $S_{31}$  is 3.10 dB, while the measured bandwidths of  $|S_{21}|$  and  $|S_{31}|$  within  $3 \pm 0.5$  dB are 145 MHz and 150 MHz, respectively.

From Fig. 4(a) we can also observe that the 6th harmonic signals have been effectively suppressed with  $S_{21}$  and  $S_{31}$  lower than a criterion of  $-10$  dB. This means that the proposed new coupler can protect specialized communication system from the interference of the unwanted signals from 1.5 GHz to 5.8 GHz, such as the signals in the IEEE 802.11 a/b/g standard specifications. This property is very useful for modern communication system to operation in high performance. In order to study the size reduction performance, we investigated the circuit area of conventional one at the same frequency and found that the cost area was 3089.88 mm<sup>2</sup>. This means that the proposed branch-line coupler can effectively reduce the occupied area to 20.4% of the conventional coupler.

Figure 5 shows the phase difference between  $S_{21}$  and  $S_{31}$ . According to a criterion of  $\pm 1^\circ$  around the optimum  $90^\circ$  phase difference, the frequency range is from 0.90 GHz to 1.02 GHz corresponding to a bandwidth is 12.5%. To demonstrate the superior performance of the proposed coupler, Table 1



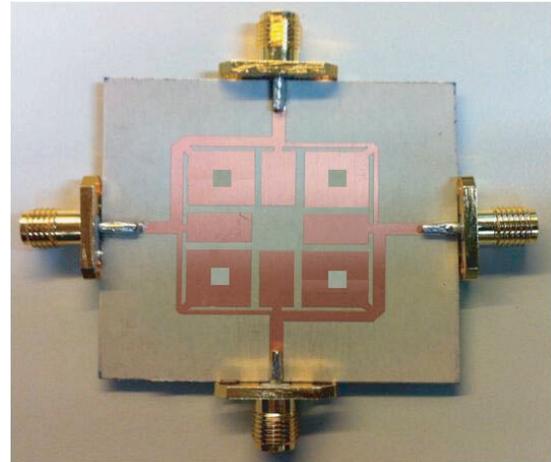
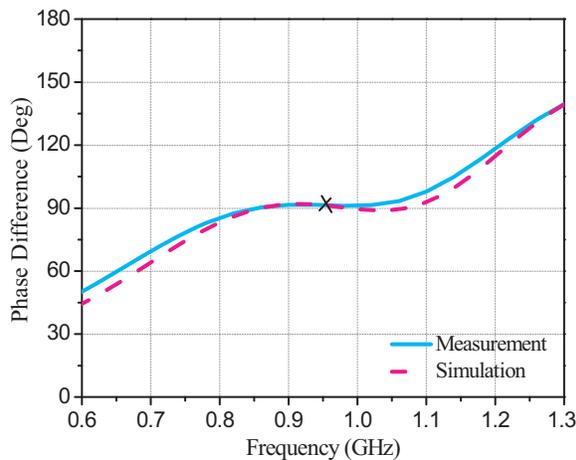
**Figure 3.** Simulated  $S$ -parameters of the proposed branch-line coupler. (a) Frequency range of 0 to 8 GHz. (b) Frequency range of 0.5 to 1.5 GHz.



**Figure 4.** Measured  $S$ -parameters of the proposed branch-line coupler. (a) Frequency range of 0 to 8 GHz. (b) Frequency range of 0.5 to 1.5 GHz.

**Table 1.** Performance comparison of couplers.

Ref.	Relative Area	Harmonic Suppression
Conventional	100%	No
[10]	63.0%	N/A
[11]	58.0%	5th
[12]	24.0%	3rd
[13]	28.0%	2nd
[14]	29.3%	4th
[15]	26.8%	2nd
[16]	25.0%	4th
This Work	20.4%	6th



**Figure 5.** Phase difference between  $S_{21}$  and  $S_{31}$ . **Figure 6.** Proposed branch-line coupler.

shows the performance comparison of the proposed design with several previous designs. Hence, the advantages of the proposed coupler can be clearly observed. A photograph of the fabricated branch-line coupler is shown in Fig. 6.

#### 4. CONCLUSION

A new miniaturized microstrip branch-line coupler with good harmonic suppression has been presented in this paper. Due to only eight open-ended resonators placed inside the free area of a conventional branch-line coupler, the new structure has effectively reduced the occupied area to 20.4% of the conventional design at 0.96 GHz and has high 6th harmonic suppression performance. One sample microstrip branch-line coupler has been fabricated, measured, and compared with the previous designs. Results indicate that the proposed new coupler has the properties of compact size, low insertion loss, and wideband harmonic suppression performance. With this good performance, the proposed branch-line coupler has potential applications in modern wireless communication systems.

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#### REFERENCES

1. Pozar, D. M., *Microwave Engineering*, Ch 7, 333–337, 3rd Edition, Wiley, New York, 2005.
2. Mohra, A., A. F. Sheta, and S. F. Mahmoud, “New compact 3 dB 0/180 microstrip coupler configurations,” *Applied Computational Electromagnetics Society (ACES) Journal*, Vol. 19, No. 2, 108–112, Jul. 2004.
3. Xiao, B., J. Hong, and B. Wang, “A novel UWB out-of-phase four-way power divider,” *Applied Computational Electromagnetics Society (ACES) Journal*, Vol. 26, No. 10, 863–867, Oct. 2011.
4. Shamaileh, K. A., A. Qaroot, N. Dib, and A. Sheta, “Design of miniaturized unequal split wilkinson power divider with harmonics suppression using non-uniform transmission lines,” *Applied Computational Electro-magnetics Society Journal*, Vol. 26, No. 6, 530–538, Jun. 2011.
5. Wu, Y. L., Z. J. Hou, and Y. A. Liu, “A novel single-layer microstrip coupler with arbitrary power division ratio and harmonics suppression,” *Electromagnetics*, Vol. 34, No. 6, 497–512, Aug. 2014.

6. Wu, Y. L., S. Y. Zhang, S. W. Leung, Y. A. Liu, and Q. Xue, "An analytical design method for a novel dual-band unequal coupler with four arbitrary terminated resistances," *IEEE Transactions on Industrial Electronics*, Vol. 61, No. 10, 5509–5516, Oct. 2014.
7. Wu, Y. L., W. N. Sun, S. W. Leung, Y. A. Liu, Y. L. Diao, and K. H. Chan, "Single-layer microstrip high-directivity coupled-line coupler with tight coupling," *IEEE Trans. Microw. Theory Tech.*, Vol. 61, No. 2, 746–753, Feb. 2013.
8. Wu, Y. L., Z. Zhuang, Y. A. Liu, L. Deng, and Z. Ghassemlooy, "Wideband filtering power divider with ultra-wideband harmonic suppression and isolation," *IEEE Access*, Vol. 4, 6876–6882, 2016.
9. Wu, Y. L., L. X. Jiao, Y. T. Du, and Y. A. Liu, "Wideband filter-integrated coupled-line coupler with unequal power division and inherent DC-block function," *Microwave and Optical Technology Letters*, Vol. 58, No. 1, 121–123, Jan. 2016.
10. Eccleston, K. W. and S. H. M. Ong, "Compact planar microstripline branch-line and rat-race couplers," *IEEE Trans. Microw. Theory Tech.*, Vol. 51, No. 10, 2119–2125, Oct. 2003.
11. Mondal, P. and A. Chakrabarty, "Design of miniaturized branch-line and rat-race hybrid couplers with harmonics suppression," *IET Microw. Antennas Propag.*, Vol. 3, No. 1, 109–116, Jan. 2009.
12. Gu, J. and X. Sun, "Miniaturization and harmonic suppression of branch-line and rat-race hybrid coupler using compensating spiral compact microstrip resonant cell," *IEEE MTT-S Int. Dig.*, 1211–1214, 2005.
13. Wang, J., B.-Z. Wang, Y. X. Guo, L. C. Ong, and S. Xiao, "A compact slow-wave microstrip branch-line coupler with high performance," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 17, No. 7, 501–503, Jul. 2007.
14. Velidi, V. K., B. Patel, and S. Sanval, "Harmonic suppressed compact wideband branch-line coupler using unequal length open-stub units," *International Journal of RF and Microwave Computer-Aided Engineering*, Vol. 21, No. 1, 115–119, Jan. 2011.
15. Tsai, K. Y., H. S. Yang, J. H. Chen, and Y. J. Chen, "A miniaturized 3 dB branch-line hybrid coupler with harmonics suppression," *IEEE Microw. Wirel. Compon. Lett.*, Vol. 21, No. 10, 537–539, Oct. 2011.
16. Velidi, V. K., A. Pal, and S. Sanyal, "Harmonics and size reduced microstrip branch-line baluns using shunt open-stubs," *International Journal of RF and Microwave Computer-aided Engineering*, Vol. 21, No. 2, 115–119, Mar. 2011.