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A New Miniaturized Microstrip Branch-Line Coupler with Wide Suppression Band

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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 19.1% of the conventional branch-line coupler at 0.90 GHz, but also has high 7th harmonic suppression performance. The measured results indicate that a fractional bandwidth of more than 15.6% has been achieved while the phase difference between S_{21} and S_{31} is within $90^\circ \pm 0.8^\circ$. The measured fractional bandwidths of $|S_{21}|$ and $|S_{31}|$ within 3 ± 0.3 dB are 16.1% and 16.7%, 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, the 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 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 branch-line couplers [2–17].

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 and Ong proposed a branch-line coupler with a size reduction of 37% to the conventional design at 1.8 GHz [5]. Based on the similar idea, Mondal and Chakrabarty presented a branch-line coupler, which has the properties of 42% size reduction at 2.4 GHz and 5th harmonics suppression [6]. 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, 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 [7]. 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 [8]. Size reduction methods were

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also reported in [9–17]. These couplers achieve compact size, but the harmonic suppressions still need improvement.

The motivation of this paper is to design a new microstrip branch-line coupler with compact size and wideband harmonic suppression. For this purpose, one branch-line coupler with operation central frequency located at 0.90 GHz is designed, fabricated, and measured. Measured results indicate that the proposed branch coupler not only effectively reduces the occupied area to 19.1% of the conventional branch-line coupler at the same operation frequency, but also has high 7th harmonic suppression performance. Furthermore, the proposed new coupler has a fractional bandwidth of more than 15.6%, while the phase difference between S_{21} and S_{31} is within $90^\circ \pm 0.8^\circ$. The organizations of the paper are as follows: 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 eight ring resonators loaded inside the free area of a conventional branch-line coupler. Each ring resonator is composed of a short high-impedance line and a long ring low-impedance line. As the length of the high-impedance line is very short, less than $\lambda/10$, where λ is the guided wavelength at the operation frequency, each high-impedance line can be deemed as a lumped element with negligibly small value, and its inductance effect on 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 to 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.

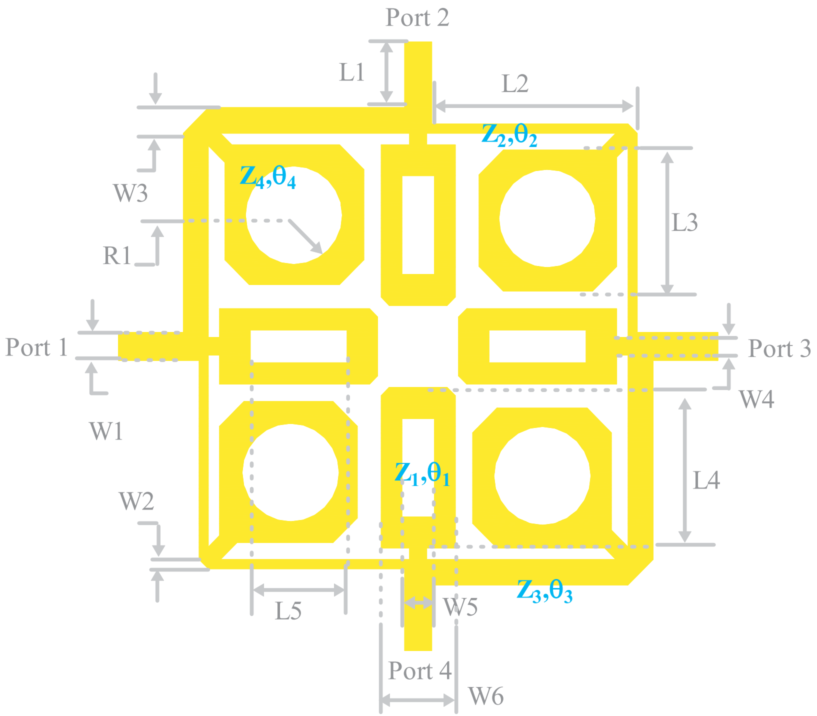


Figure 1. Topology of the proposed branch-line coupler.

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 ground. Thus, this type of loading can increase the shunt capacitance

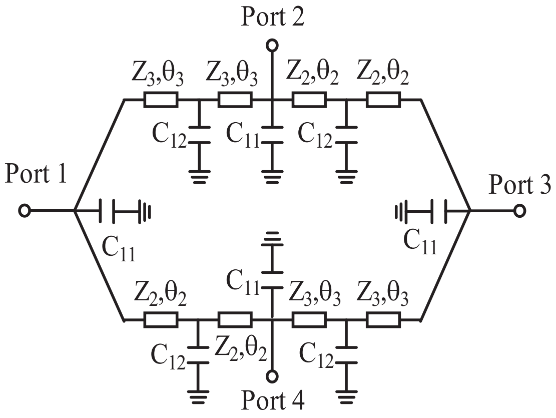


Figure 2. Equivalent circuit of the proposed branch-line coupler.

in the coupler. The propagation constant β is given by:

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

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 capacitances 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 than a conventional transmission line. This new type of slow-wave loading dose 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 λ 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: $W1 = 1.7\,\text{mm}$, $W2 = 0.6\,\text{mm}$,

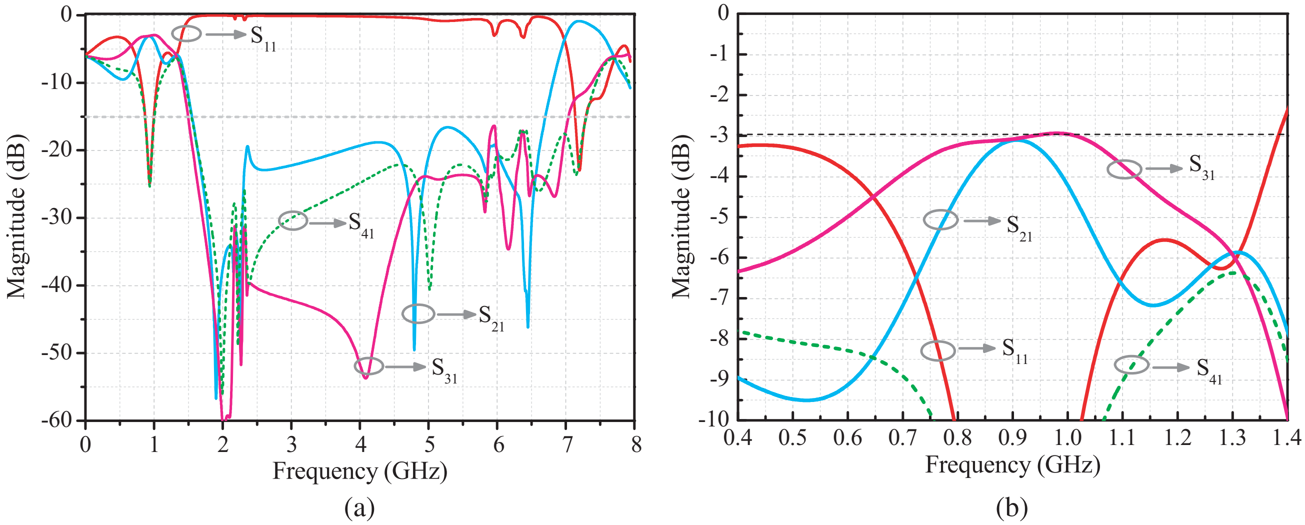


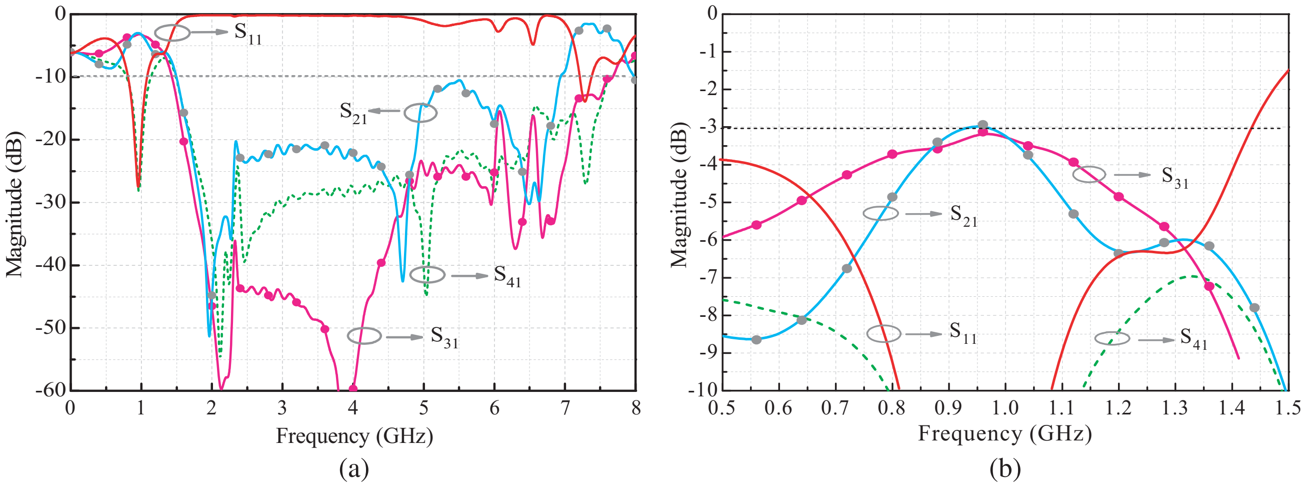
Figure 3. Simulated S-parameters of the proposed branch-line coupler. (a) Frequency range of 0.1 to 8 GHz. (b) Frequency range of 0.4 to 1.4 GHz.

$W3 = 1.1\,\text{mm}$, $W4 = 0.7\,\text{mm}$, $W5 = 1.6\,\text{mm}$, $W6 = 4.6\,\text{mm}$, $L1 = 8.3\,\text{mm}$, $L2 = 4.2\,\text{mm}$, $L3 = 7.8\,\text{mm}$, $L4 = 1.9\,\text{mm}$, $R1 = 3.0\,\text{mm}$. 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 590.2 mm^2.

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 0.90 GHz can be clearly observed. At this central frequency, the measured S_{21} is 3.0 dB, and S_{31} is 3.0 dB, while the measured fractional bandwidths of $|S_{21}|$ and $|S_{31}|$ within 3 ± 0.5 dB are 16.1% and 16.7%, respectively.

From Fig. 4(a) we can also observe that the 7th 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



(a) (b)

Figure 4. Measured S-parameters of the proposed branch-line coupler. (a) Frequency range of 0.1 to 8 GHz. (b) Frequency range of 0.4 to 1.4 GHz.

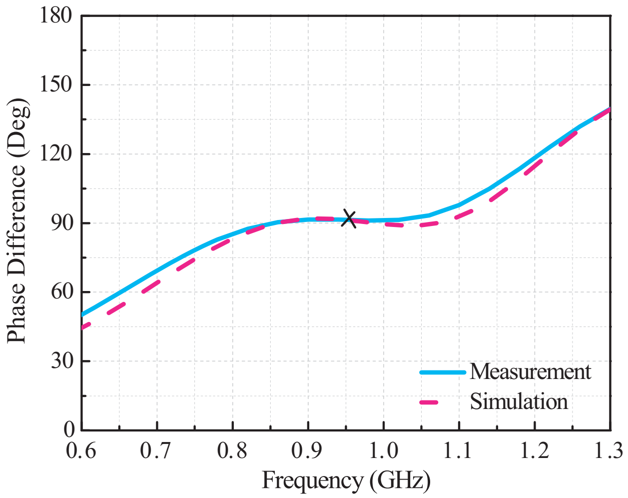


Figure 5. Phase difference between S_{21} and S_{31}.

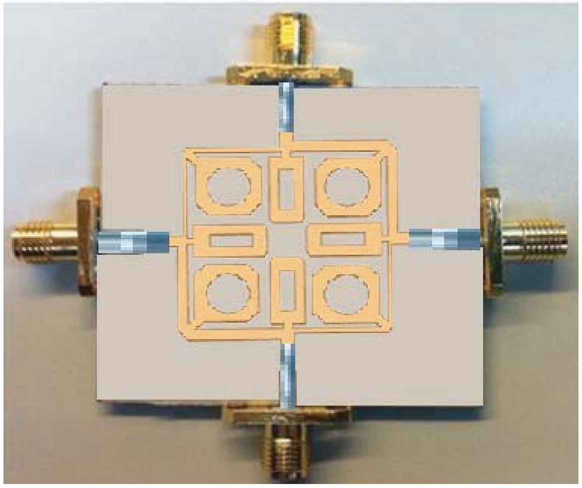


Figure 6. Proposed branch-line coupler.

a specialized communication system from the interference of unwanted signals from 1.5 GHz to 6.9 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 operate in high performance. In order to study size reduction performance, we investigated the circuit area of conventional one at the same frequency and found that the cost area was 3090 mm^2. This means that the proposed branch-line coupler can effectively reduce the occupied area to 19.1% of the conventional coupler.

Figure 5 shows the phase difference between S_{21} and S_{31}. According to a criterion of ±1° around the optimum 90° phase difference, the frequency range is from 0.83 GHz to 0.97 GHz corresponding to a bandwidth of 15.6%. To demonstrate the superior performance of the proposed coupler, Table 1 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.

Table 1. Performance comparison of couplers.

Ref.	Relative Area	Harmonic Suppression
Conventional	100%	No.
[5]	63.0%	N/A
[6]	58.0%	5th
[7]	24.0%	3rd
[8]	28.0%	2nd
[9]	29.3%	4th
[10]	26.8%	2nd
[11]	25.0%	4th
[12]	90.4%	2nd
[13]	60.0%	N/A
[14]	74.0%	N/A
[16]	56.8%	2nd
This Work	19.1%	7th

4. CONCLUSION

A new miniaturized microstrip branch-line coupler with good harmonic suppression has been presented in this paper. Due to eight ring resonators placed inside the free area of a conventional branch-line coupler, the new structure has effectively reduced the occupied area to 19.1% of the conventional design at 0.90 GHz and has high 7th harmonic suppression performance. One sample microstrip branch-line coupler has been fabricated, measured, and compared with the previous designs. Results indicate that the proposed 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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