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具有諧波抑制特性應用之微型化分支線耦合器設計

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摘要

在本文中，提出了一種具有多層陶瓷電容器（MLCC）元件和平面人造傳輸線（ATL）的小型化和諧波抑制特性集總元件分支線耦合器（BLC），於超高頻帶（UHF）之操作應用。新的結構不僅有效地將佔用面積比傳統分支線耦合器減少到 4.8%於 0.925 GHz 的操作設計，而且具有高諧波抑制性能。實驗結果表明，提出的分支線耦合器(BLC)設計具有插入損耗小，體積小的優點。在 UHF 系統的中心頻率下，所提出的微型分支線耦合器(BLC)的佔用尺寸僅為 13.7（L）×10.55（W）mm^2，也相當於等效為 0.06λ$_g$×0.05λ$_g$。測量結果表明，S$_{21}$和 S$_{31}$之間的相位差在 90˚±1˚之內，已達到超過 225MHz 的帶寬。此外，測量的插入損耗與常規分支線耦合器的插入損耗相當。通過使用具有多層陶瓷電容（MLCC）元件的標準印刷電路板蝕刻工藝，可以輕鬆實現新的耦合器，對於無線通信系統非常有用。模擬和測量結果非常一致，從而驗證了設計理念。

關鍵詞：分支線耦合器，人造傳輸線，UHF 頻帶，多層陶瓷電容器

A Miniaturized Branch-Line Coupler Design With Harmonic Suppression Characteristics Application

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Abstract

In this paper, a miniaturized and harmonic suppression characteristics lumped-element branch-line coupler (BLC) with multi-layer ceramic capacitor (MLCC) elements and planar artificial transmission lines (ATLs) is proposed for ultra-high-frequency (UHF) applications. The new structure not only effectively reduces the occupied area to 4.8% of the conventional branch-line coupler at 0.925 GHz, but also has high harmonic suppression performance. The experimental results reveal that the proposed BLC features low insertion loss and compact size.

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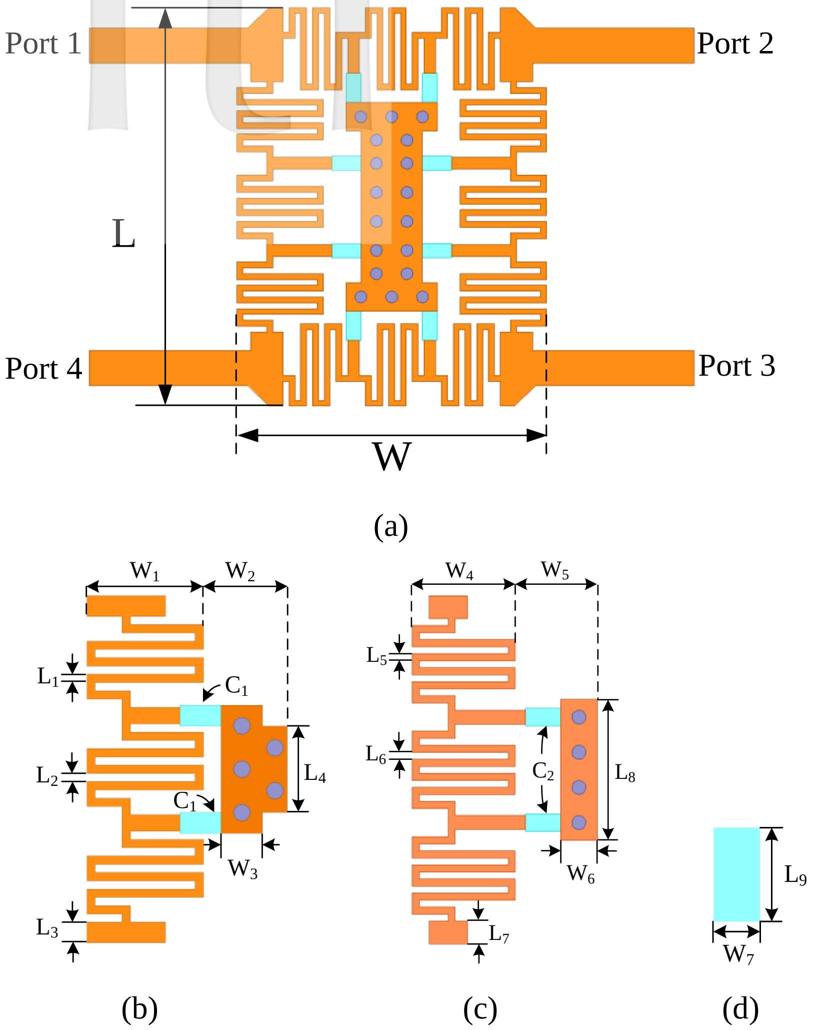
At the center frequency of the UHF system, the occupied size of the proposed miniaturized BLC is merely 13.7(L) ×10.55(W) mm^2, or equivalently $0.06\lambda_g \times 0.05\lambda_g$. The measured results indicate a bandwidth of more than 225MHz has been achieved while the phase difference between S_{21} and S_{31} is within 90°± 1°. 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 with multi-layer ceramic capacitor (MLCC) elements and is very useful for wireless communication systems. The simulated and measured results are in good agreement, thereby verifying the design concept.

Keywords：Branch-Line Coupler, Artificial Transmission Line, UHF Band, Multi-Layer Ceramic Capacitor

I. INTRODUCTION

Wireless communication is continuously evolving through the introduction of different communication standards, which are included LTE, WCDMA, WLAN, WIMAX, and CDMA2000 systems to meet a continuing demand for higher data throughput and multimedia services. To develop a radio frequency (RF) front-end which meets different requirements of modern dissimilar standards, the RF building blocks (low noise amplifier, power amplifier, filters, couplers…) should accommodate different discrete frequencies. The branch-line coupler (BLC) is a fundamental component in planar microwave-integrated circuit that has many applications in devices such as phase shifters, vector modulators, amplifiers, and mixers. The compact size and high-performance of this element are highly demanded in many communication systems. The conventional branch-line coupler is composed of four quarter-wavelength transmission sections on designing frequency, which result in a large occupied area, especially at low frequencies [1].However, nowadays, portable devices require compact and cost-efficient components. Therefore, high performances, compact size and low cost are often the stringent requirements that should be driven forward in order to fulfill the demand of modern microwave communication systems. To shrink the size of the coupler, there are several techniques which have been proposed and developed [2-6]. In addition, other BLCs with harmonic suppression characteristics to further achieve better operational performance have been recently reported in [7-8].

In this letter, a novel design for a compact branch-line directional coupler using multi-layer ceramic capacitor (MLCC) elements and planar artificial transmission lines (ATLs) is presented. The multi-layer ceramic capacitor (MLCC) elements and planar artificial transmission lines (ATLs) are implemented using lumped elements to replace the four quarter-wavelength transmission lines of a conventional branch-line directional coupler. The novel synthesized lumped element BLC, composed of a pair of series LC tanks and two meander line inductors, is proposed and investigated by utilizing a similar synthesis procedure but different circuit topology. The proposed BLC not only effectively reduces the occupied area to 4.8% of the conventional case, but also has high second harmonic suppression performance from 2.44 to 7.1 GHz. It is demonstrated and experimentally validated at a center frequency of 0.925 GHz. This BLC is designed and fabricated for validation. From the measurement results, the performance in terms of isolation and phase/magnitude difference between ports is comparable to the conventional one. Compared to prior works presented in [5]-[9], the proposed coupler features an even more compact size and also provides a wider operating bandwidth more than 225 MHz for practical application. Details of the coupler design are then carefully described and analyzed. The performance of the prototype for the coupler will be verified and discussed as well.



(a)

(b) (c) (d)

Fig. 1 Geometry of proposed miniaturized branch-line coupler. (a) Proposed branch-line coupler circuit layout structure (b) 35.4-Ω horizontal branch lines (c) 50-Ω vertical branch lines (d) MLCC element.

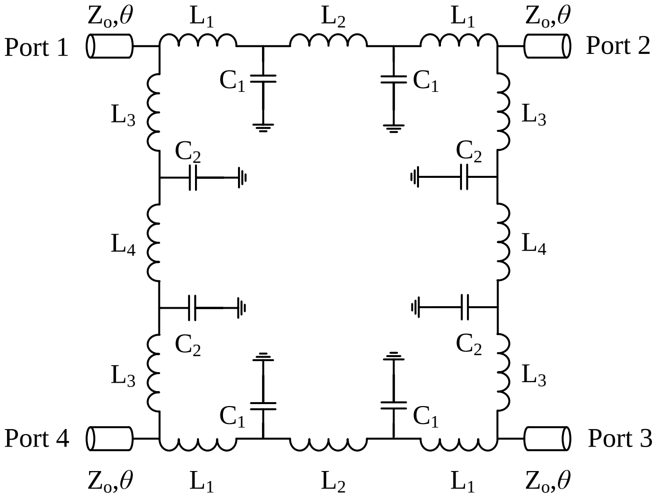


Fig. 2 Equivalent lumped circuit model.

II. BRANCH-LINE COUPLER STRUCTURE AND DESIGN

A conventional branch-line directional coupler consists of four transmission lines in a square shape. The two horizontal transmission lines, known as the horizontal branch lines, have a characteristic impendence of 35.4Ω, while the two vertical transmission lines, known as the vertical branch lines, have a characteristic impendence of 50Ω. The four ports are designed to have a characteristic impendence of 50Ω. These four transmission lines have a length of λ/4 long, resulting in a phase shift of 90° at the other ends. As a result, there will be no signal at port 4. The signal input to port 1 will be divided equally at ports 2 and 3.Due to the branch lines need to be λ/4 long, the overall dimensions of the coupler will be quite large for low operating frequency.

Therefore, we propose to use lumped elements implemented using ATLs and MLCC elements to replace these branch lines. The ATLs and MLCC elements used to replace the 50Ω vertical branch line and 35.4Ω horizontal branch line in the conventional branch-line directional coupler is shown in Figure 1, where the stubs are connected to the ground plane on the other side of the substrate using vias. The proposed coupler is fabricated using a 20 mil-thick RO4003C substrate with dielectric constant ε_r = 3.38 and loss tangent tanδ = 0.0027, which occupies a small size of only 13.7(L) ×10.55(W) mm^2, corresponding to $0.06\lambda_g \times 0.05\lambda_g$ at 925 MHz. Utilizing EM simulation and design optimization, the dimensions of the proposed branch-line coupler at 925 MHz are obtained and shown in TABLE I. The 50Ω vertical and 35.4Ω horizontal branch lines are designed with the required values for the components of L_3 =5.1 nH, L_4 = 1 nH and C_2 = 1.2 pF for 50Ω branch line and L_1 =4.5 nH, L_2 = 1 nH and C_1 = 2.2 pF for 35.4Ω branch line as shown in Figure 2. The proposed coupler design has low harmonic band resistance characteristics. When the LC tank has a suitable value, the proposed coupler design can have good band resistance performance in practical applications. The lumped equivalents of the meander line inductors and LC tanks can be extracted using standard matrix conversions, with the assistance of the EM full-wave simulator Ansoft HFSS and circuit emulator Agilent ADS.

III. RESULTS AND DISCUSSIONS

The photograph of the conventional and the proposed miniaturized branch-line hybrid couplers are fabricated, as shown in Figure 3. The coupler is measured using a vector network analyzer and corrected using TRL. The performances of three conditions are including the simulated with the ideal equivalent lumped circuit and the proposed EM structure and the measured with the practical circuit are shown in the Figure 4. The phase difference between the quadrate ports is illustrated in Figure 5. The measured insertion losses S21 and S31 have been respectively evaluated to be about 3.4 and 3.82 dB at the center operating frequency of 925 MHz. There are with a small difference about 0.42 dB. We can also observe that the proposed operating range of the coupler in the ±1 dB range varies from 770 to 1085 MHz, which is equivalent to 33.9% as shown in Figure 4. In addition, the phase shit of the proposed design is measured about 89.87° at 925 MHz between the ports 2 and 3 as shown in Figure 5. The proposed coupler is with the bandwidth of 23.35% from 850 to 1080 MHz when the phase shift is around the range from +1° to -1°. The above results are obtained a wide bandwidth for the proposed coupler with UHF application.

The proposed branch-line coupler has the dimension with 13.7(L) ×10.55(W) mm^2.The dimension of the proposed design is far less than the conventional coupler about the compaction ratio of 95.2% when both couplers are with the similar performance. The measured result is including the three parts of the return loss (S_{11}), isolation (S_{41}), and insertion loss at the quadrate output ports (S_{21}, S_{31}) that compare the two structures between proposed and conventional types as shown in Figure 6. The phase shift responses between proposed and conventional types are shown in Figure 7. The performance of the proposed hybrid is approximately the same as the conventional one when the center operation frequency at 925MHz as shown in TABLE II.

The structure of the ideal model with capacitive and inductive and the combination of the artificial transmission lines, practical capacitance and inductance components are shown in figures 4 and 5. The simulated results are with a similar trend. The measured result also displays the same trend with the simulated. From the review of the simulated result, the ideal model type doesn't consider the parasitic spurious effects. Therefore, there are shown slightly different results between the ideal model type and the practical artificial transmission lines with capacitance and inductance components. Furthermore, the phenomenon of the frequency offset between the simulation and the measurement result is caused by a slight error in the soldering of the connector and the component. There are agreement trend results between the propose design and the traditional design as shown in figure 6. Moreover, the proposed coupler also achieves small size capability, as shown in Figure 3.

The second harmonic suppression is also measured and compared with the proposed and conventional couplers. The performance of the proposed coupler is shown and obtained better than the conventional type when the frequency range from 2.44 to 7.1 GHz, so that the power loss can be further improved for practical application.

The physical sizes are compared with the proposed and the conventional couplers as the TABLE II. The size of the proposed design has a significant small size and is dense.

TABLE I DIMENSIONS OF THE PROPOSED BRANCE-LINE COUPLER (UNIT:MM)

W	W_1	W_2	W_3	W_4	W_5
10.55	2.82	2.03	1	2.935	2.34
W_6	W_7	L	L_1	L_2	L_3
1	0.5	13.7	0.2	0.2	0.5
L_4	L_5	L_6	L_7	L_8	L_9
2.08	0.2	0.2	0.65	4	1

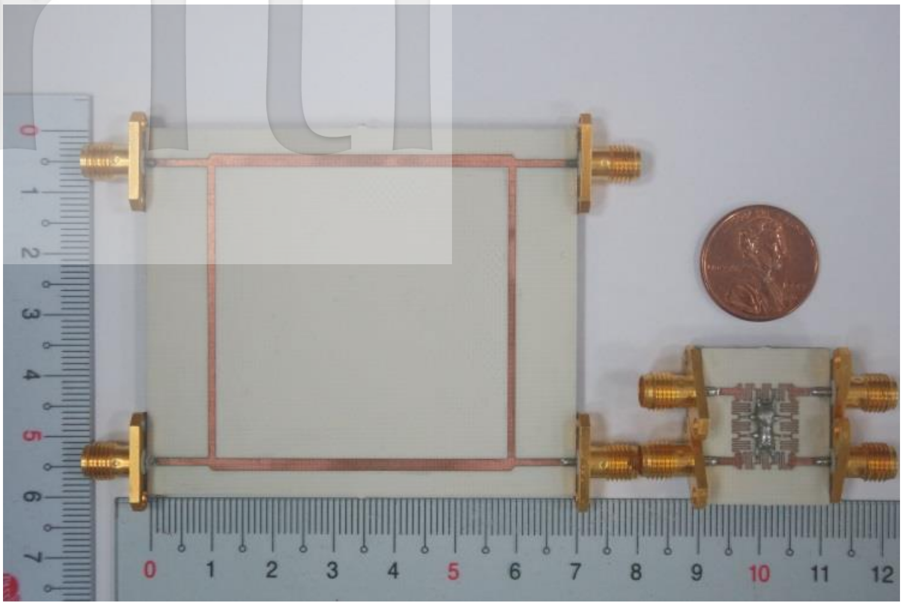
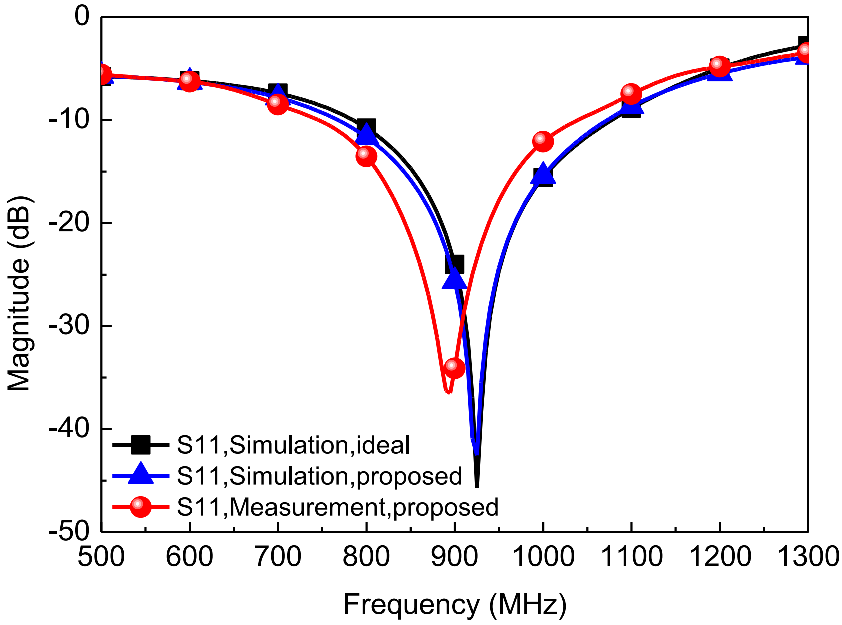
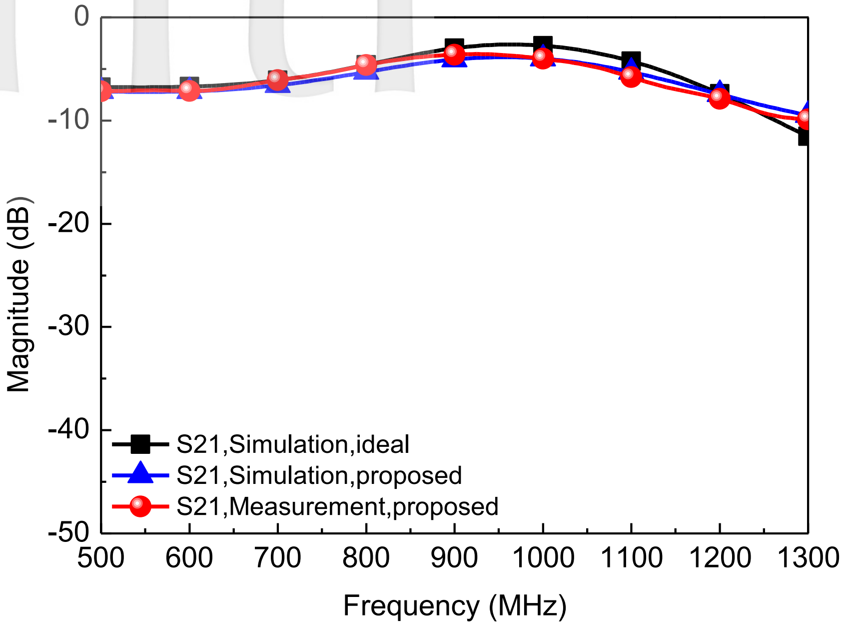


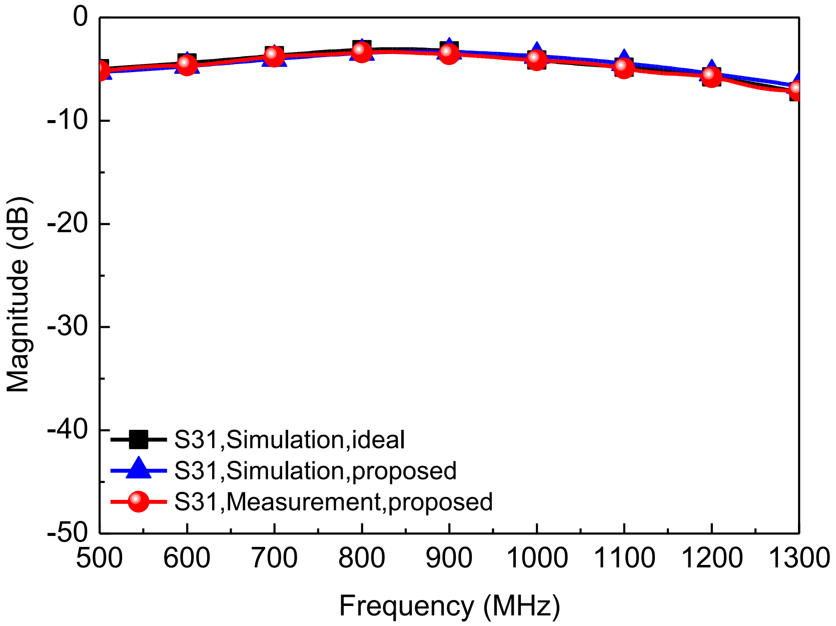
Fig. 3 Size comparisons of the new (right) and conventional branch line (left) couplers.



(a)


0
-10
-20
-30
-40
-50
Magnitude (dB)
500
600
700
800
900
1000
1100
1200
1300
Frequency (MHz)
S21,Simulation,ideal
S21,Simulation,proposed
S21,Measurement,proposed

(b)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Magnitude (dB)
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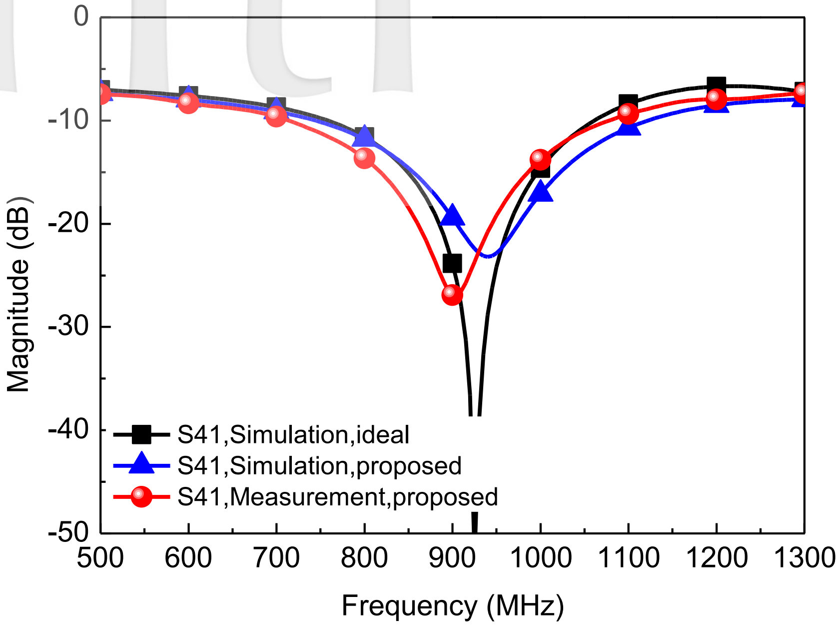
Frequency (MHz)
S31,Simulation,ideal
S31,Simulation,proposed
S31,Measurement,proposed

(c)



(d)

Fig. 4 Simulated and measured S-parameters of the proposed miniaturized branch-line coupler. (a) Return loss (S_{11}), (b) Insertion loss (S_{21}), (c) Insertion loss (S_{31}) and (d). Isolation (S_{41})

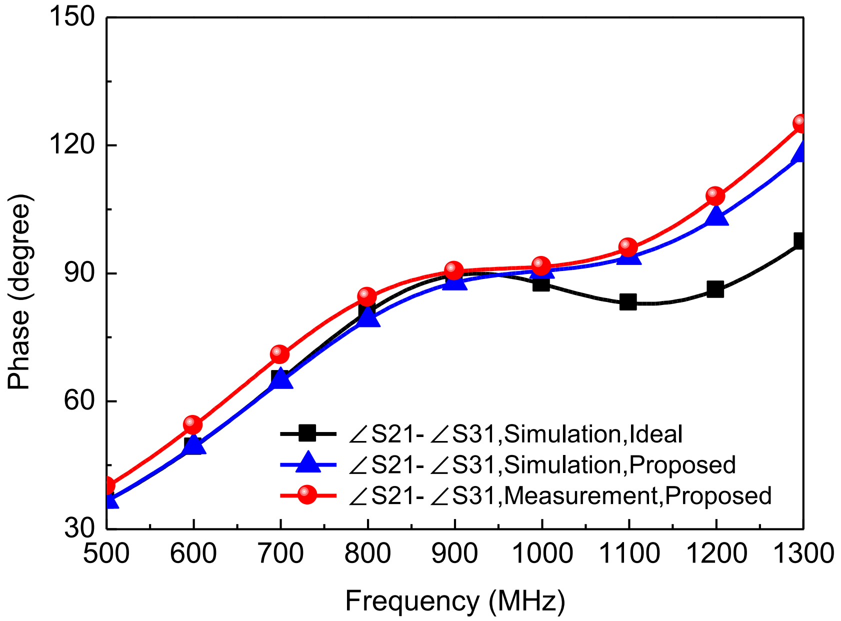
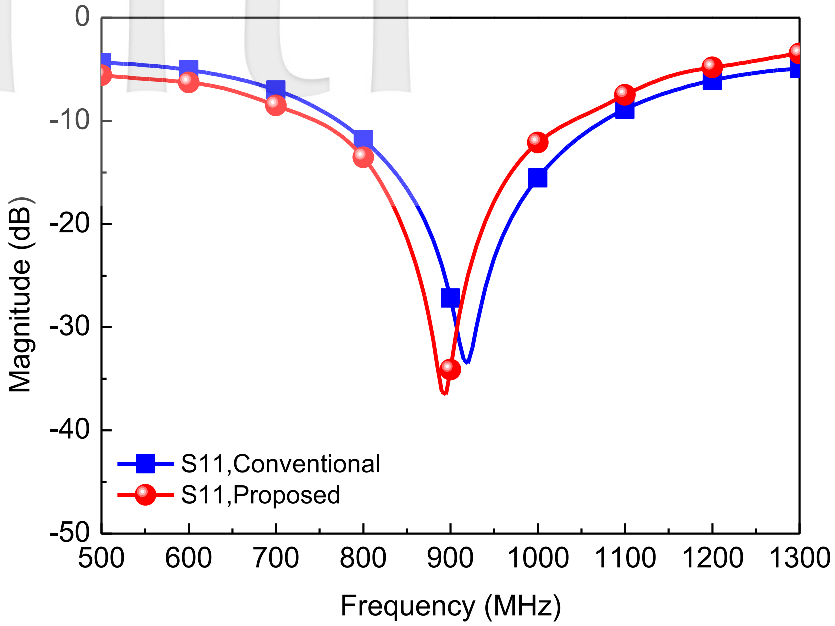
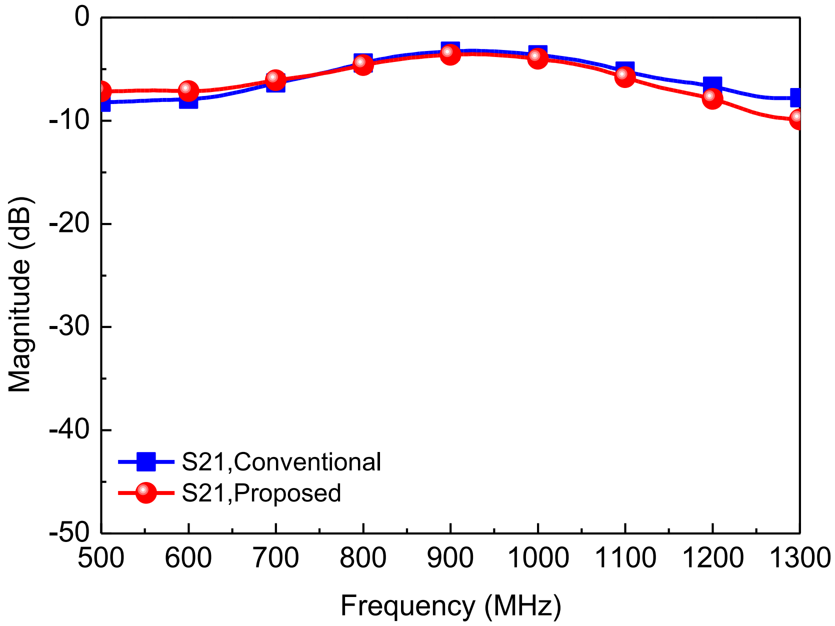


Fig. 5 Simulated and measured of phase difference response for the proposed branch-line coupler.



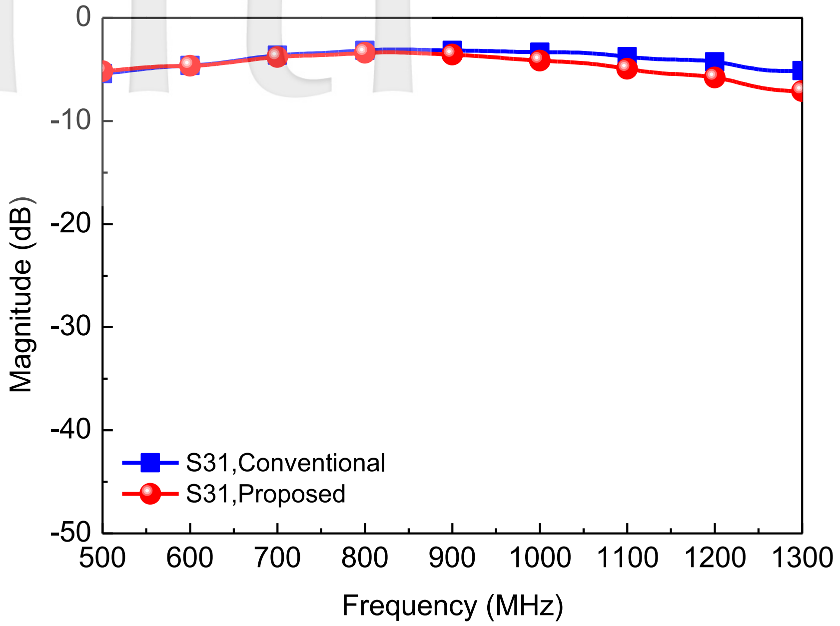
Magnitude (dB)
0
-10
-20
-30
-40
-50
500
600
700
800
900
1000
1100
1200
1300
Frequency (MHz)
S11,Conventional
S11,Proposed

(a)

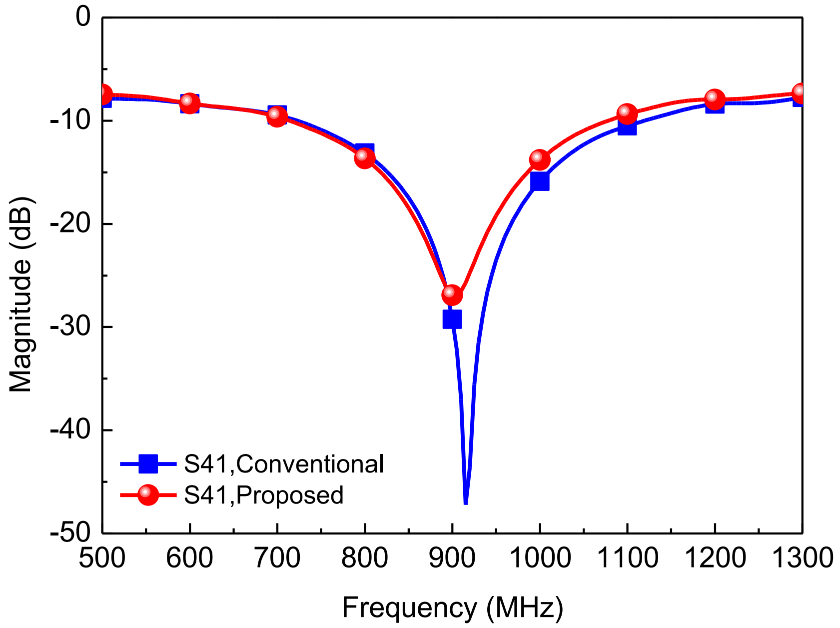


Magnitude (dB)
0
-10
-20
-30
-40
-50
500
600
700
800
900
1000
1100
1200
1300
Frequency (MHz)
S21,Conventional
S21,Proposed

(b)



(c)



(d)

Fig. 6 Measured S-parameters of the branch-line couplers between proposed and conventional types. (a) Return loss (S_{11}), (b) Insertion loss (S_{21}), (c) Insertion loss (S_{31}) and (d) Isolation (S_{41}).

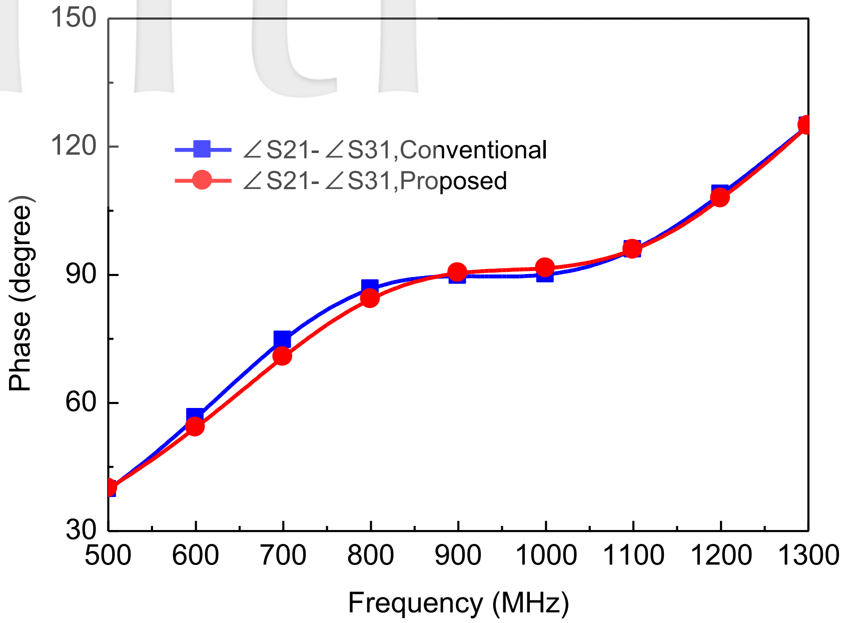


Fig. 7 Measured S-parameters of phase difference response between proposed and conventional branch-line coupler types.

TABLE II Performance Comparison Of The Conventional And The Proposed Branch-Line Coupler

Coupler Type	*Area (mm^2)*	*Relative Size*	*Harmonic Suppression*	*Operating Frequency (GHz)*
Conventional	3003.04	100%	yes	0.925
proposed	144.535	4.8%	yes	0.925

Coupler Type	*Insertion Loss (dB)*	*Return Loss (dB)*	*Isolation (dB)*	*90^o Phase error*
Conventional	-3.36	-31.96	-35.55	-0.36°
proposed	-3.40	-23.42	-23.71	-0.13

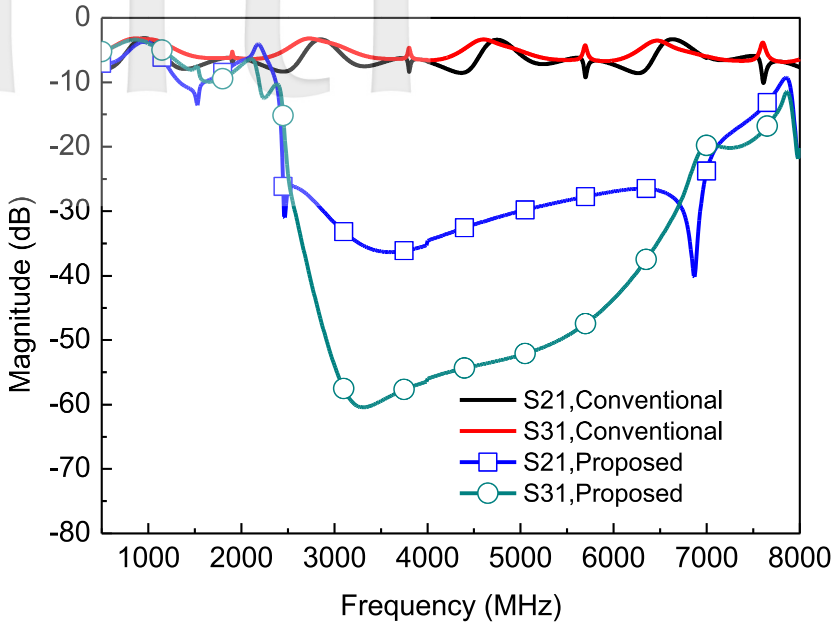


Fig. 8 Measured magnitudes against the frequency for analyzing harmonic suppression performance.

IV. CONCLUSION

In this paper, a new miniaturized BLC operating at 0.925 GHz with an extremely compact structure and low fabrication cost is introduced, and the results are verified by simulation and measurement. It has been shown that the new coupler, with a 95.2% size reduction, works as well as a conventional BLC. Moreover, the proposed coupler shows a wide upper stopband from 2.44 to 7.1 GHz. In a word, the proposed coupler features not only a miniaturized size, but well-behaved in-band and out-of-band electrifying performances. For these reasons, the proposed miniaturized branch-line coupler will be a promising solution for integration into various communication systems for power division.

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