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Miniaturized Branch-Line Coupler with Wide Upper Stopband Using Right-Angled Triangle Artificial Transmission Line

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Abstract—Based on a novel right-angled triangle artificial line, a branch-line coupler is designed in this letter. The measured results indicate that the proposed branch-line operates at 0.975 GHz with a stopband bandwidth more than $15f_c$. Here, f_c is the center frequency of the coupler. Importantly, the suppression levels in the stopband are better than 15 dB. Besides, its occupied size is about $23.18 \times 22.5\,\text{mm}^2$, which is only 16.5% of a traditional one at the same operating band. In practice, the proposed branch-line coupler can be used in compact systems which require good high-order harmonic suppression.

1. INTRODUCTION

As a key device, branch-line couplers have been widely used in modern radio frequency systems such as beam-forming network, balanced amplifiers, phase shift and mixers [1]. However, the conventional type suffers from a large size and high-order harmonics. As we know, more occupied area is against the miniaturization, and high-order harmonics always introduce jamming. So, it is of great value to design a branch-line coupler with a compact size and good harmonic suppression levels simultaneously. Recently, artificial transmission lines (ATLs) have attracted more attention, and several branch-line couplers have been designed by means of ATLs. In [2], a branch-line coupler has been implemented using capacitively loaded slow wave transmission lines. Although its size is 46% compared with its ordinary counterpart, and it rejects the first and second harmonic bands effectively, it has no advantages in systems required high-order suppression. In [3], a compact size harmonic suppressed 3 dB branch line coupler operating at 0.9 GHz is designed using an H-shaped transmission line. It can suppress the unwanted spurious passband response up to third harmonic of the operating band, and the occupied area is 36% of the conventional one. Obviously, it has more excellent performances than that of [2]. However, it still leaves some spaces to be improved. In [4], a novel modified T-shaped transmission line is initially proposed, and then a branch line coupler with size reduction and unwanted harmonics suppression is implemented. The designed coupler is 74% smaller than that of the conventional, one and it achieves a wide harmonic suppression up to at least the eighth harmonic. However, its dimension is still a little large for compact systems.

In this letter, a novel ATL is initially proposed and analyzed. To reduce its dimension, the ATL is folded into a right-angled triangle shape. Then, a branch-line coupler is synthesized by combining $50\,\Omega$ and $35.35\,\Omega$ 90° ATLs. The measured results imply that the designed coupler has an ultra-wide harmonic suppression band (more than $15f_c$) in high levels. Moreover, it has merits of a miniaturized size and simple fabrication process.

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2. PROPOSED RIGHT/ANGLED TRIANGLE ATL

Figure 1 illustrates the geometry of the proposed ATL. It is composed of a meandered host line, a triangle patch, a rectangle patch, two right-angled trapezium patches, and two sections of uniform transmission lines connecting to input and output ports of Z_0. The patches are connected to the host line using four high-impedance lines. The trapezium patches are coupled with the triangle patch by interdigital structures. The microstrip line is designed on an F4B-2 substrate with a thickness of 0.5 mm, dielectric constant of 2.65, and loss tangent of 0.008. Fig. 2 shows the corresponding lumped equivalent circuit model of the proposed ATL. Based on the theory of transmission line, the uniform transmission line can be equivalent to series inductor L_1 and shunt capacitor C_1. L_1 and L_2 represent meandered line inductors. L_3 represents the inductor between the host line and right-angled trapezium patch. L_4 represents the inductor between the host line and triangle patch. C_2 represents the coupled interdigital capacitance between the triangle patch and trapezium patch. C_3 represents the capacitance between the right-angled trapezium patch and ground plane, and C_4 represents the capacitance between the triangle patch and ground plane. The series LC tank composed of L_5 and C_5 shunted on the host line mainly represents ahi-lo impedance line composed of the rectangle patch and corresponding connected line. Based on the theory of equivalent uniform transmission line, the characteristic impedance Z_c and guided wave number β_g of the proposed ATL can be expressed as:

$$Z_c = \sqrt{L_t/C_t} \tag{1}$$

$$\beta_g = \omega\sqrt{L_t C_t} \tag{2}$$

where ω is the operating frequency, and L_t and C_t are the total series inductance and total shunt capacitance, respectively. Referring to the lumped equivalent circuit model shown in Fig. 2, they can

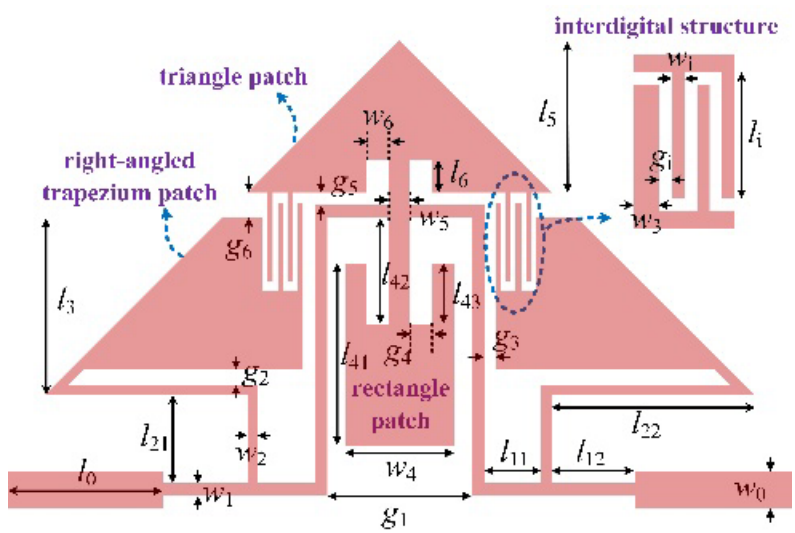

Figure 1. Geometry of the proposed right-angled triangle ATL.

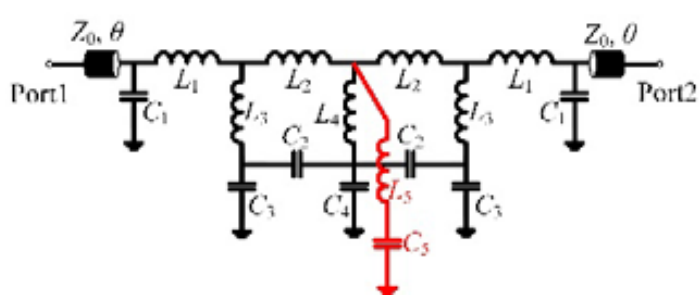

Figure 2. Corresponding lumped equivalent circuit model.

be achieved as $L_t = 2(L_1 + L_2)$, $C_t = 2C_1 + 2C_3 + C_4$. From Eqs. (1) and (2), it can be easily obtained that Z_c would remain unchanged, and β_g would increase while L_t and C_t increase proportionally. As a result, the length of the proposed ATL can be reduced obviously compared with that of the conventional one.

In our design, the center frequency is chosen as 1 GHz. The dimensions of the ATL with 50 Ω and 90° electrical length are optimized as $w_0 = 1.33$ mm, $l_0 = 1.5$ mm, $w_1 = 0.18$ mm, $g_1 = 4.4$ mm, $l_{11} = 4.6$ mm, $l_{12} = 0.8$ mm, $w_2 = 0.1$ mm, $g_2 = 0.5$ mm, $l_{21} = 1.07$ mm, $l_{22} = 1.03$ mm, $w_3 = 0.4$ mm, $g_3 = 0.2$ mm, $l_3 = 2.88$ mm, $w_4 = 3.1$ mm, $l_{41} = 4.38$ mm, $l_{42} = 1.2$ mm, $l_{43} = 0.7$ mm, $g_4 = 0.4$ mm, $w_5 = 0.4$ mm, $l_5 = 4.51$ mm, $g_5 = 0.3$ mm, $w_6 = 1$ mm, $l_6 = 0.3$ mm, $g_6 = 0.4$ mm, $w_i = 0.2$ mm, $l_i = 0.7$ mm, and $g_i = 0.12$ mm. The S-parameter shown in the upper part of Fig. 3 illustrates that the ATL with characteristic impedance of 50 Ω and electrical length of 90° has suppression better than 15 dB from 2.75 GHz to 14.5 GHz. The stopband effect of this ATL can be utilized to suppress the harmonics. From the lower part of Fig. 3, it can be observed that the simulated Z_c and phase delay at 1 GHz are 50.3 Ω and 90.2°, respectively. According to the theory of transmission line, the length of a 50 Ω conventional transmission line is more than 50 mm. In our design, the total length of the 50 Ω ATL is merely 22 mm, which indicates that the proposed ATL can be used for miniaturization compared with its conventional counterpart.

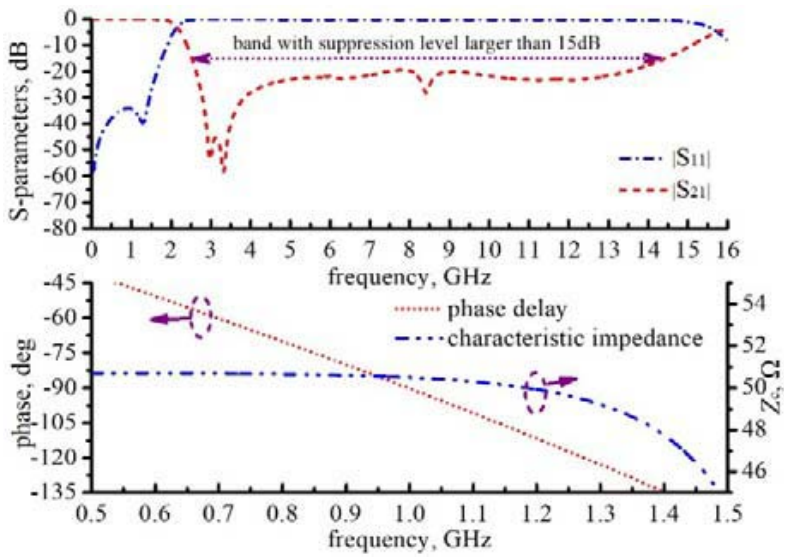

Figure 3. Frequency responses of the proposed ATLs.

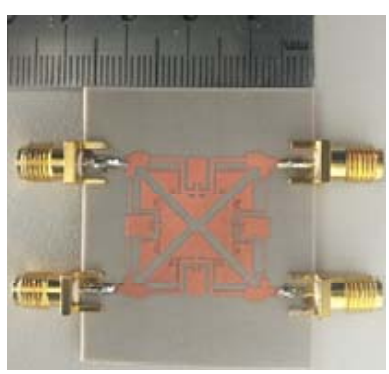

Figure 4. Photograph of the fabricated coupler.

3. BRANCH-LINE COUPLER DESIGN, FABRICATION AND MEASUREMENT

To design a miniaturized and harmonic suppressed branch-line coupler, the conventional transmission lines are replaced with the designed 50 Ω and 35.35 Ω 90° right-angled triangle ATLs. Here, it should be

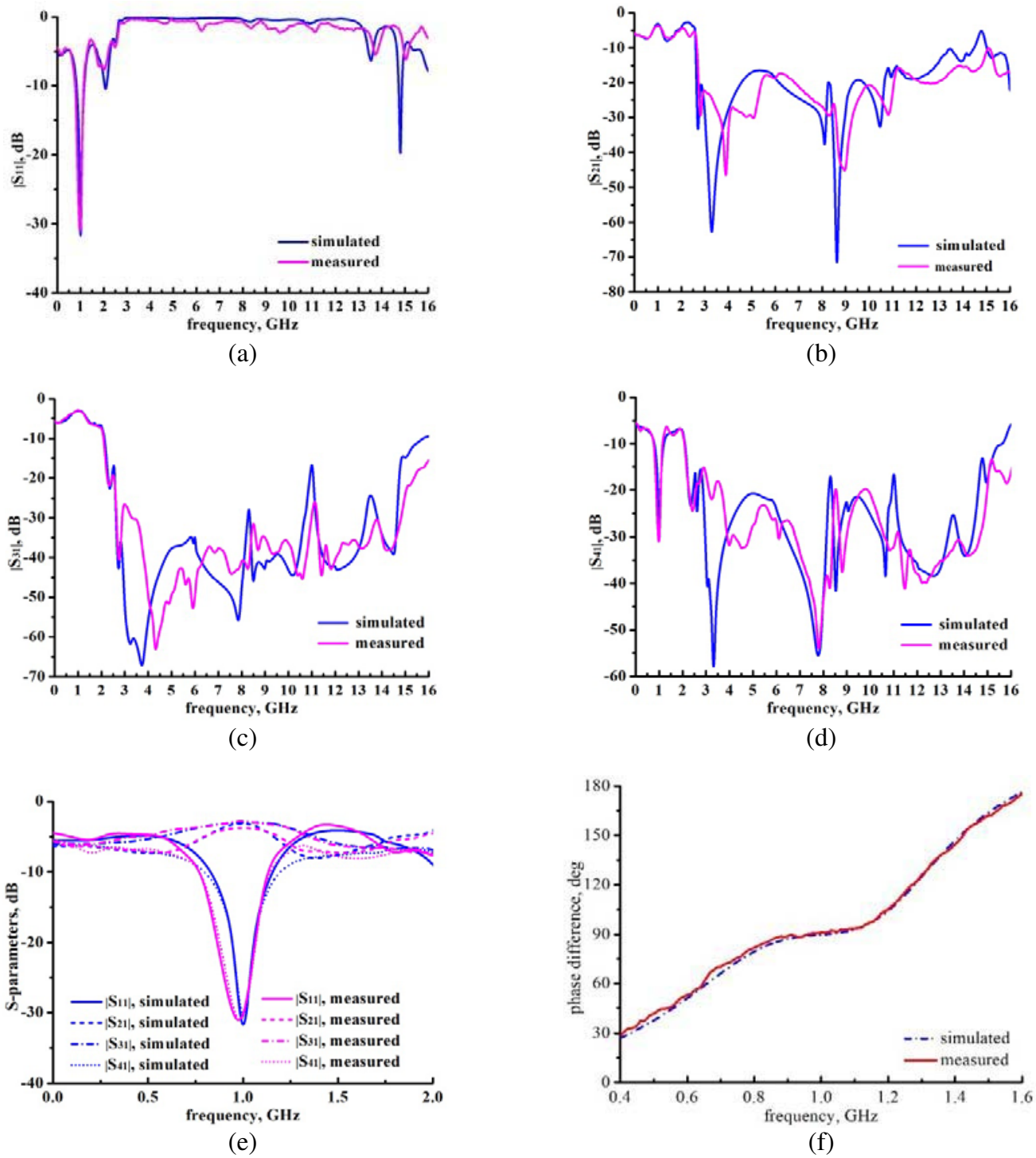

Figure 5. Frequency responses of the branch-line coupler. (a) The simulated and measured S_{11} results. (b) The simulated and measured S_{21} results. (c) The simulated and measured S_{31} results. (d) The simulated and measured S_{41} results. (e) S-parameters. (f) Phase difference between the output ports.

noted that the ATL with 35.35 Ω is designed using the same method for ATL with 50 Ω. Its dimension parameters are $w_0 = 2.21$ mm, $l_0 = 2.2$ mm, $w_1 = 0.15$ mm, $g_1 = 4.2$ mm, $l_{11} = 1.3$ mm, $l_{12} = 3.58$ mm, $w_2 = 0.12$ mm, $g_2 = 0.3$ mm, $l_{21} = 1.1$ mm, $l_{22} = 4.3$ mm, $w_3 = 0.35$ mm, $g_3 = 0.3$ mm, $l_3 = 3.58$ mm, $w_4 = 2.8$ mm, $l_{41} = 4.52$ mm, $l_{42} = 1.1$ mm, $l_{43} = 0.6$ mm, $g_4 = 0.4$ mm, $w_5 = 0.4$ mm, $l_5 = 4.29$ mm, $g_5 = 0.2$ mm, $w_6 = 1$ mm, $l_6 = 0.4$ mm, $g_6 = 0.12$ mm, $w_i = 0.15$ mm, $l_i = 1$ mm, and $g_i = 0.12$ mm. For better performances, a global optimization of the coupler is necessary. It should be noted that the width of the meandered lines is the crucial parts to be adjusted for good performances. After optimization, w_1 is adjusted towards 0.18 mm for the 50 Ω ATL and 0.62 mm for the 35.35 Ω ATL. A photograph of the fabricated branch-line coupler is depicted in Fig. 4. As shown in Fig. 4, the space between the host lines is used sufficiently, which results in compactness of the designed coupler.

The simulated and measured results of the coupler are plotted in Fig. 5. Ansoft HFSS15 is used for simulation, and an Anritus ME7808A network analyzer is carried out for measurement. The acceptable deviations between the simulated and measured results appear due to the fabrication and calculation error. The fabricated coupler exhibits a wide suppression band better than 15 dB and a good isolation from 2.75 GHz to 15 GHz. The harmonic suppression band is around $15f_c$. According to the measured results, the centre frequency of the fabricated coupler is 0.975 GHz, which deviates from that of the simulated result (1 GHz). At the measured centre frequency, the measured insertion losses at outputs (port 2 and port 3) are 3.63 dB and 3.14 dB, respectively. The return loss and isolation are 32.15 dB and 31.87 dB, respectively. The 3 dB bandwidth of the insertion losses is from 0.72 GHz to 1.23 GHz. Fig. 5(f) illustrates the phase difference between output ports. The phase difference between the output ports is 90° at 1.02 GHz, and the $90 \pm 5°$ phase imbalance of the proposed coupler ranges from 0.87 GHz to 1.13 GHz. As a result, the coupler has an operating band ranging from 0.87 GHz to 1.13 GHz (the relative frequency bandwidth is 26% of the central frequency) when both $90 \pm 5°$ phase imbalance and 3 dB bandwidth of the insertion losses are taken into consideration. The measured return loss $|S_{11}|$ and isolation coefficient $|S_{41}|$ are less than −10 dB ranging from 0.85 GHz to 1.15 GHz. The occupied size of the coupler is only $23.18 \times 22.5\,\text{mm}^2$, which is only 16.5% of its conventional counterpart. Compared with the reported coupler in [4], the proposed one has better performances, especially in the width of the suppression band and the total size of its dimension. Table 1 compares the size reduction and harmonic suppression of the designed branch-line coupler with those compact couplers in references. It can be seen that the designed coupler in this paper has better performances than those referenced ones. The proposed coupler can be used for synthesis systems with miniaturization requirements.

Table 1. Comparison of various compact couplers.

References	Size Reduction	Harmonic Suppression
[5]	71.5%	$3f_c$
[6]	78.6%	$2f_c$
[7]	82.2%	$4f_c$
[8]	79%	$5f_c$
This work	83.5%	$15f_c$

4. CONCLUSION

In this letter, a branch-line coupler using a novel right-angled triangle artificial transmission line has been presented. It has merits of miniaturized size and high-level wide-band suppression. On the one hand, the occupied dimension of the designed branch-line coupler is only 16.5% of its conventional counterpart. On the other hand, the coupler has a wide suppression band ranging from 2.75 GHz to 15 GHz. Both of the merits indicate that the proposed coupler has good potential in miniaturized systems with wide harmonic suppression requirements.

ACKNOWLEDGMENT

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