A novel directional coupler from composite right/left-handed transmission line and artificial transmission line

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A Novel Directional Coupler from Composite Right/Left-Handed Transmission Line and Artificial Transmission Line

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***Abstract*-A novel directional coupler from composite right/left-handed transmission line and artificial transmission line is presented in this paper. The proposed couplers with 6 dB, 10 dB, and 20 dB coupling coefficients are implemented with printed circuit board. The simulated and measured results are compared and analyzed. Simulated results agree well with measured results. The experimental results show that this coupler works well from 1.3 GHz to 1.8 GHz. Meanwhile, the backward and tight coupling characteristics of the coupler are demonstrated in the operational band. In addition, the coupling coefficients can be adjusted easily with a large dynamic range.**

I. INTRODUCTION

In 1968, the Russian physicist Veselago proposed left-hand materials (LHMs) [1], which are artificial materials characterized by simultaneously negative electric permittivity and magnetic permeability. He predicted LHMs distinctive electromagnetic properties, such as the reversals of Snell's Law, the Doppler Effect, the Vavilov Cerenkov Effect and so on, in his paper. In recent years, the research on LHMs has lead to the development of new microwave concepts and applications. In 2004, a transmission line (TL) approach of composite right/left-handed (CRLH) materials was proposed and CRLH−TL structures were applied to coupled-line configuration successfully, where symmetric and asymmetric CRLH coupled-line directional couplers were demonstrated [2] [3].

This paper presents a novel coupled-line coupler, which consists of a planar artificial transmission line edge-coupled with a CRLH−TL. The novel planar artificial transmission line, which was used to implement the miniaturization and broadband response in microwave circuits, was proposed in [4]. This coupler exhibits the backward and tight coupling characteristics. Three couplers with 6dB, 10dB, and 20dB coupling coefficients are practically implemented with microstrip transmission lines. These couplers working from 1.3GHz to 1.8GHz are fabricated and measured.

II. PRINCIPLE AND DESIGN

A. CRLH−TL

The layout and the equivalent circuit of a CRLH−TL cell are given in Figure 1. Figure 1(a) depicts a unit cell of the structure constituted by interdigital capacitor and stub inductors shorted to the ground plane by vias [5]. In Figure 1(b), C_S^{int} and L_S^{int} are the equivalent series capacitance and inductance of the interdigital capacitor, C_p^{int} is the equivalent capacitance of the interdigital capacitor due to ground plane,

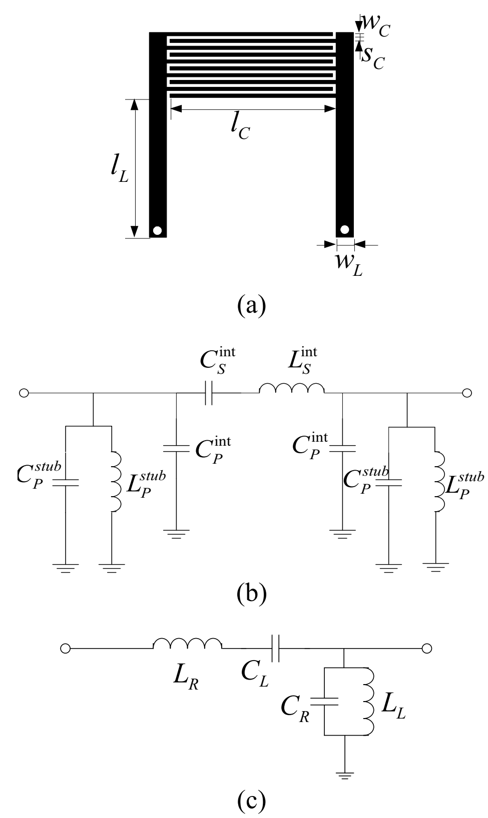

Figure 1. Unit cell of a CRLH−TL (a) Layout (b) Equivalent circuit (c) Simplified equivalent circuit

C_p^{stub} and L_p^{stub} are equivalent parallel capacitance and inductance of the shorted stub inductor.

Figure 1(c) shows the simplified circuit of Figure 1(b). C_L and L_L are capacitance and inductance of the left-handed (LH), C_R and L_R are capacitance and inductance of the right-handed (RH). The CRLH of Figure 1(c) is equivalent to a band-pass filter [6], of which the LH high-pass cutoff f_{CL} and the RH low-pass cutoff f_{CR} are determined by:

$$f_{CL} = \frac{1}{2\pi}\left(\sqrt{\frac{1}{L_R C_R} + \frac{1}{\sqrt{L_L C_L L_R C_R}}} - \frac{1}{\sqrt{L_R C_R}}\right) \qquad (1)$$

$$f_{CL}=\frac{1}{2\pi}\left(\sqrt{\frac{1}{L_RC_R}+\frac{1}{\sqrt{L_LC_LL_RC_R}}+\frac{1}{\sqrt{L_RC_R}}}\right) \qquad (2)$$

Under the balanced condition ($L_RC_L= L_LC_R$), the characteristic impedance of CRLH-TL is:

$$Z_0=\sqrt{L_L/C_L}=\sqrt{L_R/C_R}\ . \qquad (3)$$

The propagation constant β_s of CRLH-TL is given by:

$$\beta_s=\beta_R+\beta_L=\omega\sqrt{L_RC_R}-\frac{1}{\omega\sqrt{L_LC_L}}\ . \qquad (4)$$

This expression points out the LH behaviors at low frequencies and the RH behaviors at high frequencies. The transition frequency f_0 between the LH and RH is given by (5), when β_s =0 with the balanced condition.

$$f_0=\frac{1}{2\pi\sqrt{L_RC_L}}=\frac{1}{2\pi\sqrt{L_LC_R}}\ . \qquad (5)$$

B. Artificial Transmission Line

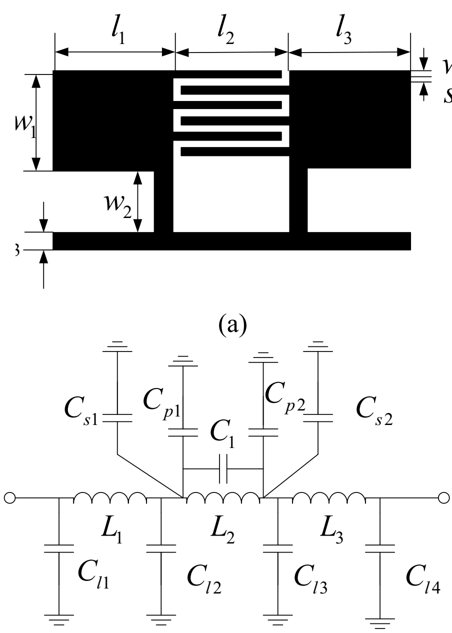

Figure 2. Unit cell of a artificial transmission line
(a) Layout (b) Equivalent circuit

The layout and the equivalent circuit for a unit cell of an artificial transmission line are given in Figure 2. According to the equivalent circuit in Figure 2(a), the inductor L_1, L_2, L_3 are realized by high-impedance microstrip line. C_{l1}, C_{l2}, C_{l3}, and C_{l4} represent the parasitic capacitance of inductors L_1 and L_3. The capacitance C_1, C_{s1}, and C_{s2} are realized by interdigital capacitor and low-impedance microstrip line, while the capacitance C_{p1} and C_{p2} represent the parasitic capacitors of inductor L_2 and interdigital capacitor C_1.

Referring to transmission line theory, the characteristic impedance Z_c , the propagation constant β and cutoff frequency f_0 of the artificial transmission line are given by:

$$Z_c=\sqrt{\frac{L_{tot}}{C_{tot}}} \qquad (6)$$

$$\beta=\omega\sqrt{L_{tot}C_{tot}} \qquad (7)$$

$$f_c=\frac{1}{\pi\sqrt{L_{tot}C_{tot}}}\ . \qquad (8)$$

Where $L_{tot}= L_1+ L_2+ L_3$, $C_{tot}= C_{l1}+C_{l2}+ C_{l3}+C_{l4} + C_{p1}+ C_{p2}+ C_1+C_{s1}+ C_{s2}$. These expressions show that the changes of L_{tot} and C_{tot} can adjust characteristic impedance and propagation constant of the artificial transmission line.

C. A Novel Coupled–Line Coupler

Figure 3 shows layout of the novel microstrip coupled-line coupler. It is constituted of a CRLH–TL and an artificial transmission line. In order to realize this coupler, three CRLH cells and two artificial transmission cells are used. The distance between the two transmission lines affects the coupling coefficient. The substrate used in this design is F4B-2 (ε_r =2.65, h=1.5mm). As shown in Figure 1(a), the dimensions of CRLH-TL are given by $w_C= s_C$=0.2 mm, l_C=10 mm, w_L=1 mm, the first and the last short-ended microstrip lines have the lengths equal to 13.8 mm (l_L), while the others have the length of 6.7 mm. The tapered transmission lines are used to realize the impedance match to 50 Ω. As shown in Figure 2(a), the parameters of artificial line: l_1=5.3mm, l_2=4.6mm, l_3 =5.3mm, w_1=3.9, w_2=2.4mm, w_1=0.8mm, w_1=0.3mm, s_1 =0.3mm. 6 dB, 10 dB, and 20 dB coupled-line couplers were designed with gaps s=0.4 mm, 1.1 mm. 3.8 mm, respectively. The coupling increases as the gap decreases.

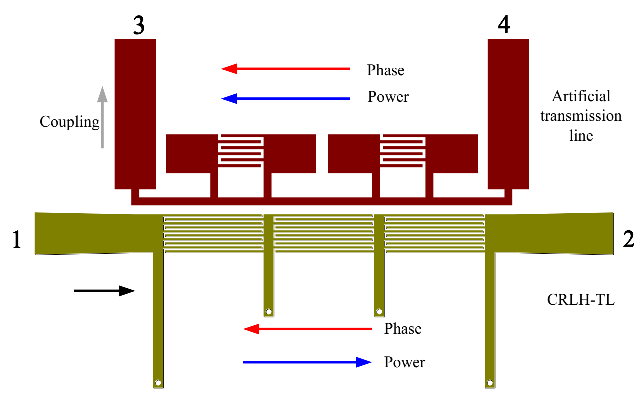

Figure 3. Structure of the proposed coupler.

When a signal input from port 1, power propagates toward port 2, but phase propagates backward port 1 at LH range of CRLH–TL. Artificial transmission line is RH line. Therefore, the signal is coupled to the artificial transmission line. Phase and power propagate are in the same direction toward port 3 [7]. Backward coupling is achieved. Generally, the electrical length of the transmission line of is not $\lambda_g/4$, but depends on reactive LC of the line.

The coupler simulated performances versus the gap s are summarized in Table 1, for coupling, C (dB), isolation, I (dB), input return-loss, RL (dB) and frequency bandwidth from 1.3GHz to 1.8GHz.

Table 1. Coupler parameters versus the gap s, for frequencies from 1.3GHz to 1.8GHz. X_Z^Y, where X is the maximum coupling, X+Y is the coupling at 1.3GHz and X+Z is the coupling at 1.8GHz.

s (mm)	C (dB)	I (dB)	RL (dB)
0.1	$3.9^{+0.7}_{+0.8}$	>20	>26
0.2	$4.6^{+0.9}_{+0.9}$	>21	>24
0.4	$5.9^{+1.3}_{+0.9}$	>22	>22
0.6	$7.1^{+1.4}_{+0.9}$	>23	>20
0.8	$8.1^{+1.4}_{+0.9}$	>24	>18
1.1	$9.6^{+1.5}_{+0.9}$	>25	>17
2.0	$13.5^{+1.7}_{+0.9}$	>27	>16
3.0	$17.8^{+1.8}_{+0.9}$	>29	>16
3.8	$19.8^{+2.0}_{+0.9}$	>32	>15
4.0	$20.4^{+2.1}_{+0.9}$	>32	>15
5.0	$23.1^{+2.3}_{+0.9}$	>34	>15
6.0	$25.5^{+2.5}_{+0.9}$	>35	>15

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III. EXPERMENTAL RESULTS

In this section, 6 dB, 10 dB, and 20 dB coupled-line couplers were measured using a vector network analyzer (Aglient N5230A), respectively. Figure 4, 5, and 6 show the photographs of the proposed couplers. The experimental results show that 6 dB, 10 dB, 20 dB coupling are achieved over the rage from 1.3 GHz to 1.8 GHz, which represent the fractional bandwidth of 32%. Coupling flatness is less than 2 dB over the bandwidth. Isolation of the couplers with 6 dB, 10 dB, and 20 dB coupling are greater than 23 dB, 25 dB, and 34 dB, respectively. The simulated and measured S-parameters of the design are plotted from Figure 7 to 9. The simulations show good agreements with the measured results.

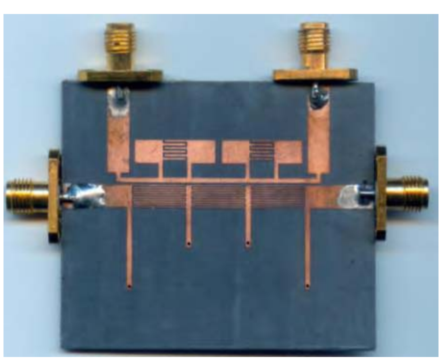


Figure 4. Photo of the fabricated 6 dB coupler.

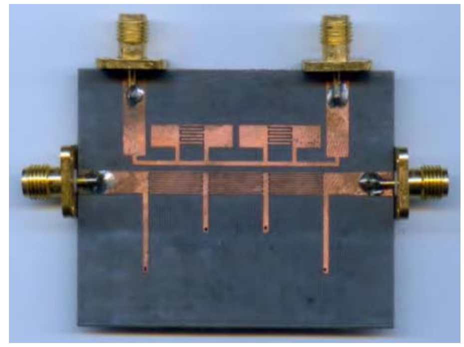


Figure 5. Photo of the fabricated 10 dB coupler.

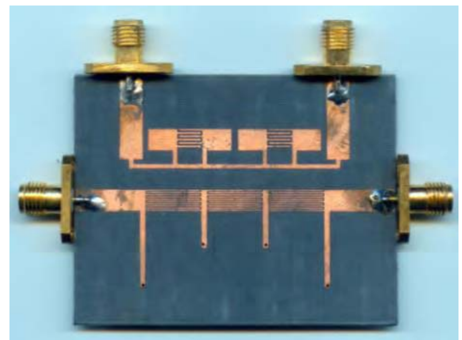
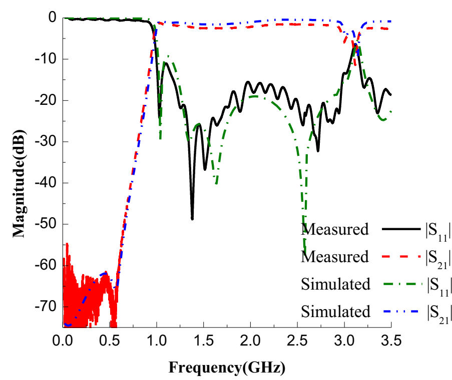
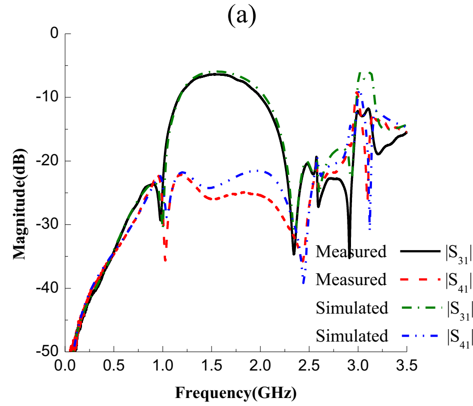


Figure 6. Photo of the fabricated 20 dB coupler.

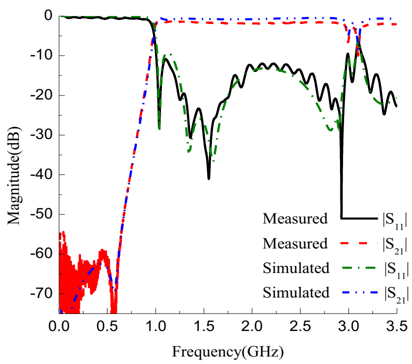


(a)



(b)

Figure 7. Simulated and measured S parameter of 6dB coupler. (a) Magnitude of S_{11} and S_{21}. (b) Magnitude of S_{31} and S_{41}.



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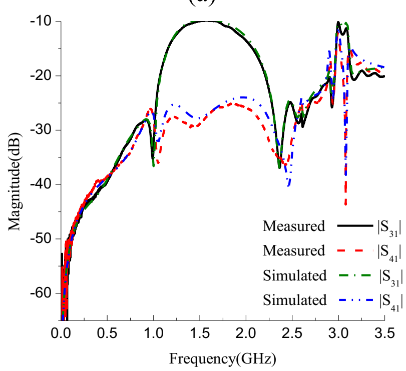
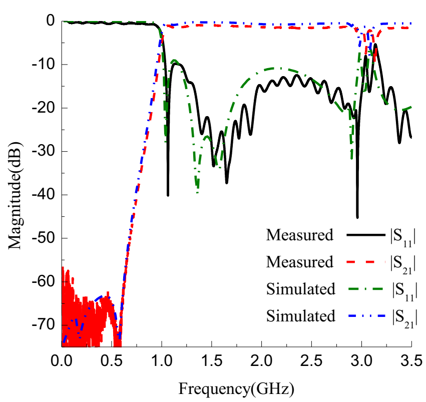


(b)

Figure 8. Simulated and measured S parameter of 10dB coupler. (a) Magnitude of S_{11} and S_{21}. (b) Magnitude of S_{31} and S_{41}.



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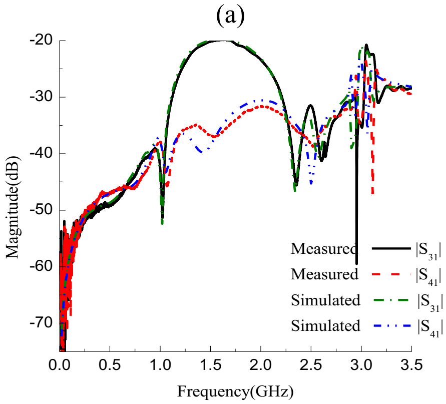

(b)

Figure 8. Simulated and measured S parameter of 20dB coupler. (a) Magnitude of S_{11} and S_{21}. (b) Magnitude of S_{31} and S_{41}

IV. Conclusion

In this paper, a novel microstrip coupled-line coupler has been designed based on CRLH-TL and artificial transmission lines. This design can be achieved with coupling factors from 6 dB to 30 dB according to the distance between the two parallel coupled lines. It can be applied to microwave power monitoring, distribution and synthesis, antenna transceiver switches and so on.

V. Acknowledge

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