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A tunable dual-broad-band branch-line coupler utilizing composite right/left-handed transmission lines

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Abstract: A tunable dual-broad-band branch-line coupler (BLC) utilizing composite right/left-handed (CRLH) transmission lines is presented. Two $\lambda/4$ segments consisting of CRLH transmission lines are added to each port to broaden the dual bands of the branch-line coupler. Numerical simulation and optimal design of the novel coupler are presented. The dual bands of the novel coupler are tunable and broad. The 1-dB bandwidth of each passband is more than 16% of the central frequency.

Keywords: Branch-line coupler (BLC), Broad band, Dual-band, Composite right/left-handed (CRLH), Left-handed, Tunable
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INTRODUCTION

Veselago (1968) theoretically analyzed the wave propagation in a left-handed (LH) material which has simultaneously a negative magnetic permeability and a negative electric permittivity. The electric field, the magnetic field, and the wave vector of an electromagnetic wave propagating in such a material obey the left-hand rule (instead of the right-hand rule for usual materials). Such an LH material was first realized in 2001 in microwave region with an array of metallic split ring resonators (Shelby *et al*., 2001). Iyer and Eleftheriades (2002) presented theoretically and experimentally a planar LH structure by loading a host microstrip transmission line with serial capacitors and shunt inductors. A range of new novel devices have then been fabricated utilizing new LH structure, such as a leaky backward-wave antenna (Liu *et al*., 2000), a dual-frequency branch-line coupler (Lin *et al*., 2004) and a highly directive coupled-line couplers (Islam and Eleftheriades, 2003).

In this paper, we present a tunable dual-broad-band branch-line coupler (BLC) using a composite right/left-handed (CRLH) structure. Besides the usual power splitting characteristics, the coupler allows two broad bands centering at arbitrary frequencies (i.e., tunable).

STRUCTURE OF THE NOVEL COUPLER

Fig.1 shows three different kinds of transmission line (TL) unit (lossless): right-handed TL (RHTL) unit (Fig.1a), left-handed TL (LHTL) unit (Fig.1b) and composite right/left-handed TL (CRLH TL) unit (Fig.1c). These three kinds of TL units can form three TLs of different characteristics (Lin *et al*., 2004). In this paper, we present a tunable dual-broad-band coupler utilizing CRLH TL.

Fig.2 shows a conventional 3 dB BLC which consists of $\lambda/4$ RHTLs (with phase response of $\pi/2$). It can operate only at a fundamental frequency f_0 and its odd harmonics due to its phase characteristics (Lin *et*

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al., 2004; Collin, 1966). In other words, the next operating frequencies are $3f_0$, $5f_0$, … The phase responses of a $\lambda/4$ TL are $\pi/2$ and $3\pi/2$ (i.e., $-\pi/2$) for operating frequencies f_0 and $3f_0$, respectively. Thus, RHTLs are not suitable for tunable dual-band application. This limitation can be removed by utilizing CRLH TLs (Lin *et al.*, 2004). The dual-band coupler presented in this paper can operate at a fundamental frequency f_0 and a variable second frequency, which is not necessarily $3f_0$ or other odd harmonics. On the other hand, the BLC (regardless of RH, LH, or CRLH TL) has its intrinsic characteristic in that the bandwidth is very small, usually less than 10%. This reduces very much their application. In this paper, an impedance matching network utilizing CRLH TLs is added to each input/output port, which makes both bands broad (more than 15% of the central frequency).

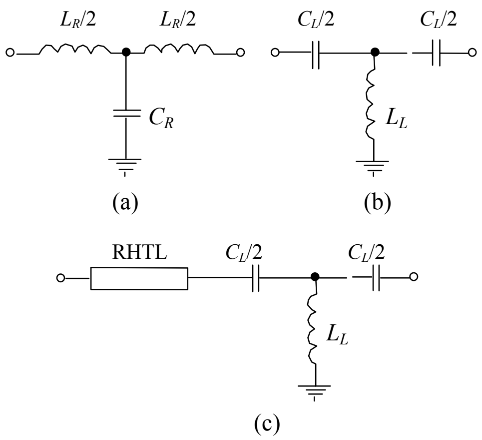

Fig.1 Various kinds of TL unit
(a) RHTL; (b) LHTL; (c) CRLH TL

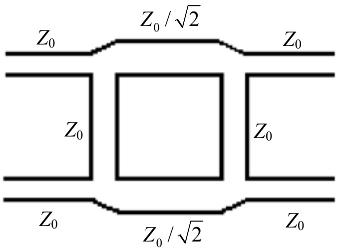

Fig.2 Conventional 3 dB branch-line coupler

Fig.3 shows the structure of this kind of BLC, in which A is the input port, B and C are two output ports and D is the isolation port. Two $\lambda/4$ segments (with characteristic impedances Z_1 and Z_2) consisting of CRLH TLs (the enlarged views for these two segments and segment Z_3 are also shown in the three dashed boxes of Fig.3) are added to each port to broaden the dual bands.

Theoretically speaking, different numbers of $\lambda/4$ segments or $\lambda/2$ segments can be used to achieve different orders of impedance matching network (Ashforsh, 1988). However, it is not practical to construct a high-order coupler due to its complexity and larger size. Here we use the impedance match theory (Collin, 1966) to design tunable dual-broadband BLC. Advanced Design System (ADS), a commercial software developed by Agilent Corp., is used in this paper to simulate the coupler.

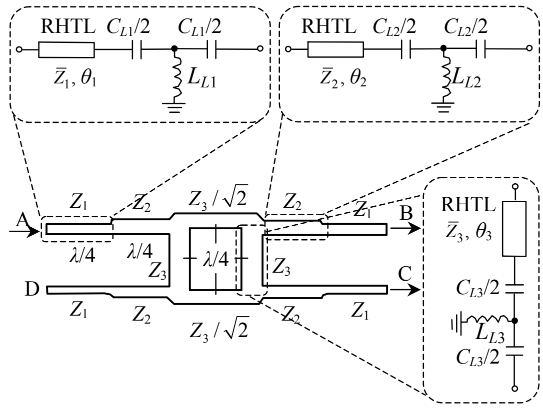

Fig.3 Broadband 3 dB branch-line coupler utilizing CRLH TLs

DESIGN AND SIMULATION

Here we show the design and simulation results for our broadband 3 dB branch-line coupler. In the first design, dual frequencies are set to 1 GHz and 2 GHz (not an odd harmonic), and the characteristic impedances are chosen to be $Z_1=Z_2=91.6\ \Omega$ and $Z_3=70\ \Omega$. Then all the other parameters ($\overline{Z},\theta,C_L$ and L_L) for each CRLH TL can be calculated accordingly (Lin *et al.*, 2004). Port A is excited and all the other ports are terminated with 50 Ω loads. The simulation results for the scattering and phase parameters are shown in Figs.4~6. Fig.5 gives an enlarged view of Fig.4 near the first passband. The performances in both passbands are summarized in Table 1. The 1-dB bandwidths at 1 GHz and 2 GHz are 190 MHz (19%) and 315 MHz (16%), respectively. S_{21} and S_{31} are close to

−3 dB (as a 3 dB coupler), and the isolation/return loss is larger than 14 dB. The phase responses of S_{21} at 1 GHz and 2 GHz are 86.8° and 90.9°, respectively, and the phase responses of S_{31} at 1 GHz and 2 GHz are 3.2° and 1.0°, respectively. In the second design, the two frequency bands are centered at 1 GHz and 2.5 GHz (tuned from 2 GHz to 2.5 GHz). The simulation results are shown in Fig.7. The performances are summarized in Table 2. The broad 1-dB bandwidths at 1 GHz and 2.5 GHz are 275 MHz (27.5%) and 440 MHz (17.5%), respectively.

CONCLUSION

In the present paper we have introduced a 3 dB

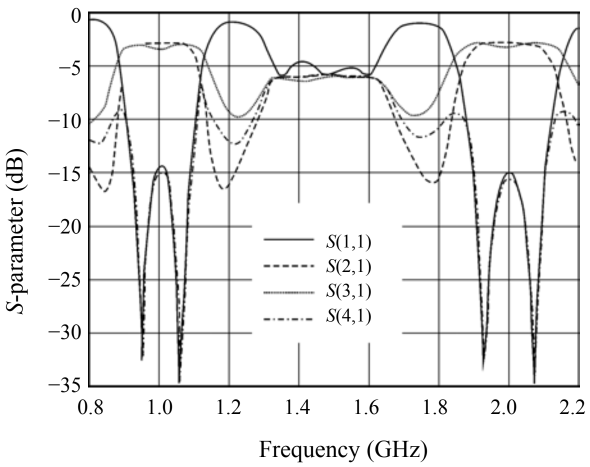

Fig.4 Simulated *S*-parameters (1 GHz and 2 GHz)

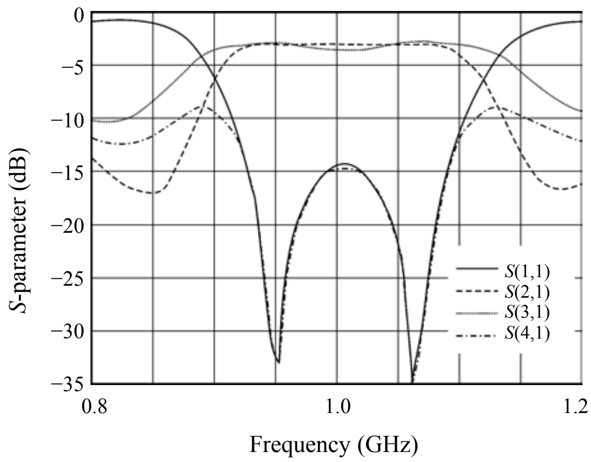

Fig.5 Simulated *S*-parameters (near 1 GHz)

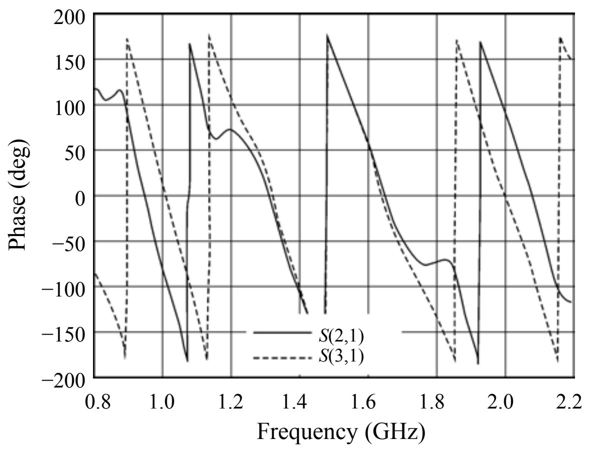

Fig.6 Simulated phase-parameters (1 GHz and 2 GHz)

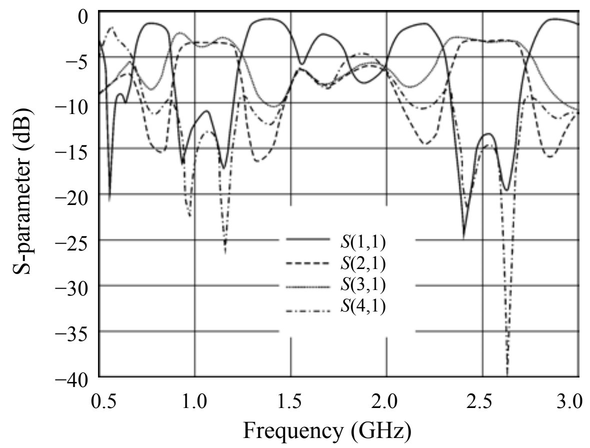

Fig.7 Simulated *S*-parameters (1 GHz and 2.5 GHz)

Table 1 Performances in two passbands (1 GHz and 2 GHz)

Performances	Passband	
	1 GHz	2 GHz
Return loss (S_{11})	−14.23 dB	−15.08 dB
Isolation (S_{41})	−14.71 dB	−15.42 dB
Output 1 (S_{21})	−3.10 dB	−3.11 dB
Output 2 (S_{31})	−3.58 dB	−3.45 dB
Amp. imbalance	0.24 dB	0.52 dB
$BW_{1\ dB}$	190 MHz (19%)	315 MHz (16%)

Table 2 Performances in two passbands (1 GHz and 2.5 GHz)

Performances	Passband	
	1 GHz	2.5 GHz
Return loss (S_{11})	−13.02 dB	−14.72 dB
Isolation (S_{41})	−19.51 dB	−16.05 dB
Output 1 (S_{21})	−3.36 dB	−3.17 dB
Output 2 (S_{31})	−3.20 dB	−3.38 dB
Amp. imbalance	0.37 dB	0.46 dB
$BW_{1\ dB}$	275 MHz (27.5%)	440 MHz (17.5%)

branch-line coupler (using CRLH TLs) which has the properties of tunability and dual broad bands. The 1-dB bandwidth of each passband is more than 16% of the corresponding central frequency. Several applications could be envisaged, for example, dual-mode cell phones and broadband mixers.

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