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A power divider based on a new kind of composite right/left-handed transmission line (CRLH TL) unit*

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Abstract: A new power divider, composed of a novel composite right/left-handed (CRLH) transmission line (TL) unit, is proposed. The properties of the power divider based on four CRLH TL unit cells are investigated theoretically. By adjusting the parameters of the capacitors and the inductors, the power divider shows perfectly symmetric power division at 5.13 GHz, return loss up to −24 dB, with the transmitted power being close to −3.1 dB. The phenomena are demonstrated by simulation results. Being compact in size and low-cost, the proposed power divider is very suitable for microwave and millimeter wave integrated circuits.

Key words: Composite right/left-handed (CRLH), Power divider, Metamaterials, Transmission line (TL)
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INTRODUCTION

Wave propagation in a material with negative magnetic permeability and negative electric permittivity was first theoretically analyzed by Veselago (1968). In such a left-handed material (LHM), the electric field $\boldsymbol{E}$, the magnetic field $\boldsymbol{H}$ and the wave vector $\boldsymbol{k}$ of electromagnetic wave propagation obey the left-hand rule (instead of the right-hand rule for usual materials). After Smith *et al*.(2000) demonstrated simultaneously negative permeability and permittivity, using copper split-ring resonators and thin copper wires in microwave region (Shelby *et al*., 2001), LHMs attracted significant attention in the microwave community and their applications were investigated in (Engheta, 2002; Pendry, 2000; Simovski *et al*., 2003). A planar LH structure formed by loading a host microstrip transmission line (TL) with series capacitors and shunt inductors has also been studied theoretically and experimentally (Eleftheriades *et al*., 2002; 2003; Islam and Eleftheriades, 2003). A composite right/left-handed (CRLH) TL, which is the combination of an LH TL and an RH TL, was introduced recently and several applications were studied (Lim *et al*., 2004; Lin *et al*., 2004; Lai *et al*., 2004; Caloz and Ttoh, 2004; Sanada *et al*., 2004).

A power divider is an indispensable component commonly used to split an input signal into two output signals in e.g. satellite communication, RF or microwave communications, and microwave antenna distribution circuits, where size, weight, simplicity, low insertion loss, and symmetric power division are critical design factors (Vassilev *et al*., 2001; Izumi and Arai, 2000). Conventional power dividers such as Wilkinson type or T-junction power dividers have quite large dimension, and complexity (Scardelletti *et*

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al., 2002; Arndt *et al*., 1987). In this work, we present a power divider utilizing a novel CRLH TL unit. The power divider is characterized by simplicity, low insertion loss and perfectly symmetric power division.

NEW CRLH TL UNIT

In this work, we propose a novel CRLH TL, whose unit cell is shown in Fig.1. The propagation constant normalized of the proposed CRLH TL is given by

$$\gamma=\alpha+\mathrm{j}\beta=\sqrt{ZY}, \quad (1)$$

where per-unit length impedance Z and per-unit length admittance Y are defined by

$$Z(\omega)=\mathrm{j}(\omega L_\mathrm{R}-1/(\omega C_\mathrm{L})), \quad (2)$$

$$Y(\omega)=\mathrm{j}(\omega C_\mathrm{R}-1/(\omega L_\mathrm{L}))+1/R. \quad (3)$$

From Eqs.(1)~(3), γ can be written as

$$\gamma=\sqrt{\left(\frac{L_\mathrm{R}}{L_\mathrm{L}}+\frac{C_\mathrm{R}}{C_\mathrm{L}}\right)-\omega^2 L_\mathrm{R}C_\mathrm{R}-\frac{1}{\omega^2 C_\mathrm{L}L_\mathrm{L}}+\mathrm{j}\frac{1}{R}\left(\omega L_\mathrm{R}-\frac{1}{\omega C_\mathrm{L}}\right)}. \quad (4)$$

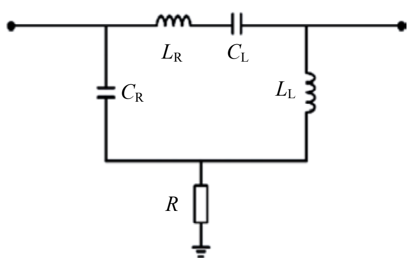

Fig.1 The proposed CRLH TL unit

Under this condition, it can be shown that the dispersion relation for a homogenous CRLH TL is

$$\beta(\omega)=\frac{\sqrt{2}}{2}s(\omega)\sqrt{\omega^2 L_\mathrm{R}C_\mathrm{R}+\frac{1}{\omega^2 C_\mathrm{L}L_\mathrm{L}}-\left(\frac{L_\mathrm{R}}{L_\mathrm{L}}+\frac{C_\mathrm{R}}{C_\mathrm{L}}\right)+W} \quad (5)$$

where

$$s(\omega)=\begin{cases}-1, & \omega<\omega_1=\min\left(1/\sqrt{L_\mathrm{R}C_\mathrm{L}},1/\sqrt{L_\mathrm{L}C_\mathrm{R}}\right),\\ 1, & \omega>\omega_2=\max\left(1/\sqrt{L_\mathrm{R}C_\mathrm{L}},1/\sqrt{L_\mathrm{L}C_\mathrm{R}}\right),\end{cases} \quad (6)$$

$$W=\frac{(\omega^2 L_\mathrm{R}C_\mathrm{L}-1)}{\omega C_\mathrm{L}R}\sqrt{R^2\left(\omega^2 C_\mathrm{R}^2+\frac{1}{\omega^2 L_\mathrm{L}^2}-\frac{2C_\mathrm{R}}{L_\mathrm{L}}\right)+1}.$$

The dispersion curve of the proposed CRLH TL is given in Fig.2, showing that the dispersion β equals 0 at frequency of 5.13 GHz.

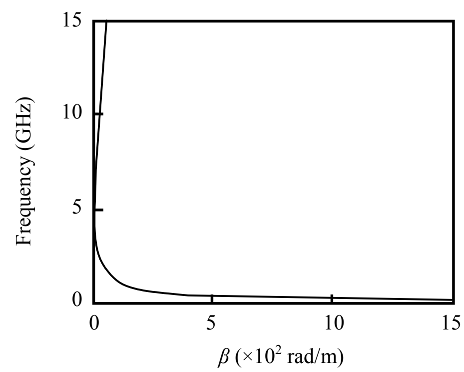

Fig.2 Dispersion curve for the proposed CRLH TL

STRUCTURE FOR THE NOVEL POWER DIVIDER

Here, we develop a 1×2 power divider with the novel CRLH TL. The device is shown in Fig.3.

The S_{21} parameter for the homogenous CRLH TL can be calculated with

$$S_{21}=-2Y_{12}Z_0/[(1+Z_0Y_{11})(1+Z_0Y_{22}-(Z_0Y_{12})^2)], \quad (7)$$

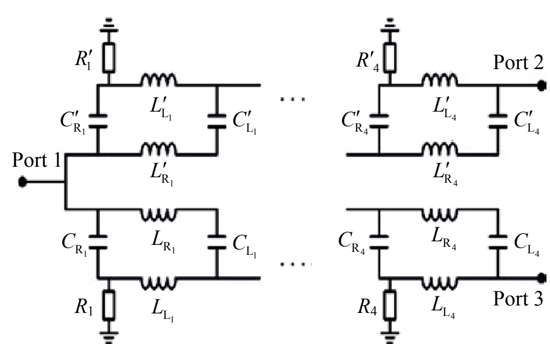

Fig.3 The proposed powder divider

where Z_0 is the impedance of the source and load and the admittance matrix

$$\boldsymbol{Y}=\begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix}, \tag{8}$$

where $Y_{11}=-\mathrm{j}(\omega L_R-1/(\omega C_L))^{-1}$, $Y_{12}=\mathrm{j}(\omega L_R-1/(\omega C_L))^{-1}$, $Y_{21}=-\mathrm{j}(\omega L_R-1/(\omega C_L))^{-1}$, and $Y_{22}=-[-\mathrm{j}(\omega L_R-1/(\omega C_L))^{-1}+\mathrm{j}(\omega C_R-1/(\omega L_L))+1/R]$.

Similarly, S_{31} parameter can be calculated by Eq.(7). Then, Eq.(7) will be used later in choosing (L'_{R_1} ... L'_{R_4}, L'_{L_1} ... L'_{L_4}, C'_{L_1} ... C'_{L_4}, C'_{R_1} ... C'_{R_4}, L_{R_1} ... L_{R_4}, L_{L_1} ... L_{L_4}, C_{L_1} ... C_{L_4}, C_{R_1} ... C_{R_4}, R_1 ... R_4, R'_1 ... R'_4).

SIMULATION RESULTS FOR A NOVEL POWER DIVIDER

In this paper, we set the power division ratio S_{21}/S_{31}=1:1. Fig.2 shows that at frequency of 5.13 GHz, since the dispersion β equals 0, α=0 can be obtained from Eqs.(2) and (3). All the parameters (L'_{R_1} ... L'_{R_4}, L'_{L_1} ... L'_{L_4}, C'_{L_1} ... C'_{L_4}, C'_{R_1} ... C'_{R_4}, L_{R_1} ... L_{R_4}, L_{L_1} ... L_{L_4}, C_{L_1} ... C_{L_4}, C_{R_1} ... C_{R_4}, R_1 ... R_4, R'_1 ... R'_4) for the novel power divider can be calculated according to Eqs.(2), (3), (7) and (8). Then we obtain $L'_{R_1}=L_{R_1}=...=L'_{R_4}=L_{R_4}$=1 nH, $L'_{L_1}=L_{L_1}=...=L'_{L_4}=L_{L_4}$=0.5 nH, $C'_{L_1}=C_{L_1}=...=C'_{L_4}=C_{L_4}$=1 pF, $C'_{R_1}=C_{R_1}=...=C'_{R_4}=C_{R_4}$=1.8 pF, and $R'_1=R_1=...=R'_4=R_4$=100 Ω. Here we use Advanced Design System (ADS), a commercial software for calculating *S* parameter (S_{11}, S_{21}, and S_{31}) for our power divider with 1, or 4 unit cells, and the results are shown in Fig.4 (in dB). Figs.4a and 4b show that the transmitted power is very close to −3 dB (from −3.3 dB to −3.1 dB), and that the return loss decreases (from −11 dB to −24 dB). In this case, the novel CRLH TL unit cell is resonant [$P_1=UI_{in}$, $P_2=P_3=U(I_{in}/2)$], *U* remains the same due to resonance. Since α is minimal, for many cells, α approaches 0, so that the transmission loss is 0. Therefore, the transmission loss of the TL is very minimal. The figures show that the power divider has perfectly symmetric

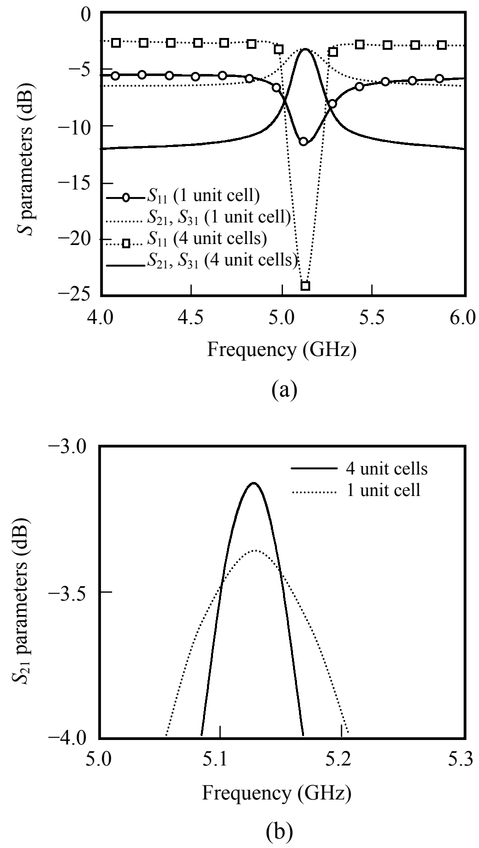

Fig.4 Characteristics of the powder divider

power division at 5.13 GHz. However, the conventional CRLH [see Fig.5 in (Vassilev *et al*., 2001)] cannot be used to achieve a power division.

CONCLUSION

In this work, we presented a novel CRLH TL unit and developed a new power divider using the metamaterial unit cell. Utilizing 4 metamaterial unit cells, the power divider with perfectly symmetric power division at 5.13 GHz and transmitted power of −3.1 dB can be obtained. Simulation results showed that the novel power divider has many advantages over a conventional power divider (Arndt *et al*., 1987) in e.g. the size, weight, simplicity, low insertion loss, cost, and symmetric power division. The novel power divider is a promising device for microwave communication systems.

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