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A novel fully planar quad band Wilkinson power divider

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ABSTRACT

In this paper, by using extended composite right and left handed transmission line (E-CRLH-TL), the fully planar quad band Wilkinson power divider (WPD) proposed exhibits the benefits of bandwidth enlargement, excellent isolation and equal power split between output ports in the four pass-bands. The proposed divider is designed and fabricated on a low cost substrate with dielectric constant of 4.4 and a thickness of 0.8 mm as work at four arbitrary frequency bands of 2.4 GHz (ISM), 3.5 GHz (WiMax), 5.2 GHz (WiFi) and 5.8 GHz (WiFi). The results of the measured and simulated designs are in good agreement with each other which verifies the proposed design methodology. The design concept of this paper can be easily extended to various multi-band microwave devices.

1. Introduction

During the last decades, due to requirement of multi-band wireless communication systems, a large body of research on multi-band devices have become very popular [1–3]. Nowadays, various techniques have been used to design various multi-band microwave components [4–10]. One of these components is power dividers [11–13]. In [11] a dual-band power divider was designed. While a lot of attention has been paid to the dual-band power dividers, not much work has been done on multi-band power divider even though it is a key passive circuit especially for feeding multi-band antenna arrays. In [14], based on coupled line a triple-band Wilkinson power divider was designed. Also, in [15], composite right and left handed transmission lines (CRLH-TLs) have been used in order to design dual-band Gysel power divider. But, the operation of this divider is limited in dual frequency band. In addition, in [16] metamaterial unit cells were applied in order to design a dual-band and triple-band Wilkinson power divider. But, the designed divider of [16] uses many lumped element components to provide multi-band operation.

However, Extended Composite Right-Left Handed (E-CRLH) structures are one of the main developments in the field of metamaterials. The concept of E-CRLH was first introduced in [17]. In addition to miniaturization, the characteristic non-linear phase response of the E-CRLH-TLs allows the design of many dual-band and multi-band microwave devices. In [18] a quad-band Wilkinson power divider is presented based on the Generalized Negative Refractive Index Transmission Lines (G-NRI-TLs). But this divider is not fully planar and consisted of lumped element components and also provided equal power division in four bands that limited the application of this divider.

In this paper, a novel approach based on E-CRLH-TLs is presented to design fully planar equal quad band power divider. The proposed divider is designed and fabricated on an inexpensive FR4 substrate with dielectric constant of 4.4 and thicknesses of $h = 0.8$ mm. In addition the arbitrary operating frequencies for the proposed Wilkinson power divider (WPD) are chosen as $f_1 = 2.4$ GHz (ISM), $f_2 = 3.5$ GHz (WiMax), $f_3 = 5.2$ GHz (WiFi), $f_4 = 5.8$ GHz (WiFi). It should be noted that, the design concept of this paper can be extended to various multi-band microwave devices. The organization of this article is as follows: Section 2 presents the design methodology leading to multi-band E-CRLH-TL structures. Section 3 introduces an approach to design fully planar E-CRLH-TLs. Finally, to validate the proposed structures, a novel quad band WPD has been designed in Section 4 while conclusions are made in Section 5.

2. Theory

Fig. 1 depicts the circuit model of the unit cell of the E-CRLH structure. As seen in this figure, the unit cell consists of four inductors $L_L^d, L_L^c, L_R^d, L_R^c$ and four capacitors $C_L^d, C_L^c, C_R^d, C_R^c$. In this figure, inductors and capacitors related to convenient CRLH (C-CRLH) structure and dual CRLH (D-CRLH) structure are denoted with superscript "c" and "d", respectively.

As we know, the propagation constant β, and the characteristic impedance Z_0, of a transmission line are given by [19]

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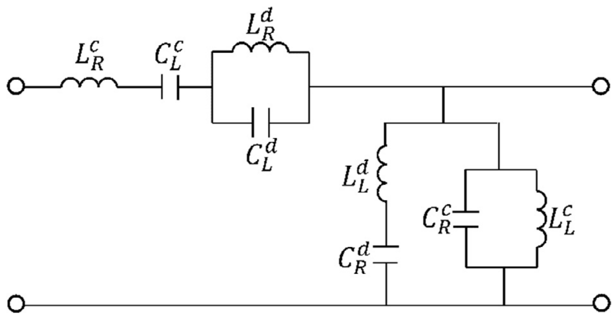

Fig. 1. Circuit model of the unit cell of the E-CRLH structure [17].

$$\beta = -j\sqrt{Z_e Y_e} \tag{1a}$$

$$Z_0 = \sqrt{\frac{Z_e}{Y_e}} \tag{1b}$$

where $Z_e = Z_c + Z_d$ and $Y_e = Y_c + Y_d$ are the series impedance and parallel admittance of the unit cell of the transmission line, respectively. Also, as discussed in [17] for E-CRLH unit cells, Z_c, Z_d, Y_c and Y_d are given by

$$Z_c = j\omega L_R^c\left(1-\left(\frac{\omega_{se}^c}{\omega}\right)^2\right), \quad \omega_{se}^c = \frac{1}{\sqrt{L_R^c C_L^c}} \tag{2a}$$

$$Z_d = \frac{j\omega L_R^d}{1-\left(\frac{\omega}{\omega_{se}^d}\right)^2}, \ \omega_{se}^d = \frac{1}{\sqrt{L_R^d C_L^d}} \tag{2b}$$

$$Y_c = j\omega C_R^c\left(1-\left(\frac{\omega_{sh}^c}{\omega}\right)^2\right), \ \omega_{sh}^c = \frac{1}{\sqrt{L_L^c C_R^c}} \tag{2c}$$

$$Y_d = \frac{j\omega C_R^d}{1-\left(\frac{\omega}{\omega_{sh}^d}\right)^2}, \ \omega_{sh}^d = \frac{1}{\sqrt{L_L^d C_R^d}} \tag{2d}$$

Hence, for the unit cell of Fig. 1, using Eq. 1(a) we obtain the propagation constant of the E-CRLH structure as

$$\beta_{E-CRLH} = \frac{\sqrt{L_R^c C_R^c}}{\omega} \times \sqrt{\frac{(\omega^2-\omega_{se}^{c2})(\omega^2-\omega_{se}^{d\,2})-\frac{1}{L_R^c C_L^d}\omega^2}{(\omega^2-\omega_{se}^{d\,2})} \frac{(\omega^2-\omega_{sh}^{c2})(\omega^2-\omega_{sh}^{d\,2})-\frac{1}{L_L^d C_R^c}\omega^2}{(\omega^2-\omega_{sh}^{d\,2})}} \tag{3}$$

Likewise, we obtain the characteristic impedance Z_0, as

$$Z_{oE-CRLH} = \sqrt{\frac{L_R^c}{C_R^c}}\sqrt{\frac{1-\left(\frac{\omega_{se}^c}{\omega}\right)^2+\frac{L_R^d/L_R^c}{1-\left(\frac{\omega}{\omega_{se}^d}\right)^2}}{1-\left(\frac{\omega_{sh}^c}{\omega}\right)^2+\frac{C_R^d/C_R^c}{1-\left(\frac{\omega}{\omega_{sh}^d}\right)^2}}} \tag{4}$$

Fig. 2 depicts the dispersion and the characteristic impedance of an E-CRLH structure. As can be seen in this figure, the wave cannot propagate in three frequency bands. These frequency bands are called the cut-off frequency bands of the E-CRLH structure. Besides, two parts of the dispersion curve lie in the RH region, whereas the two others in the LH region.

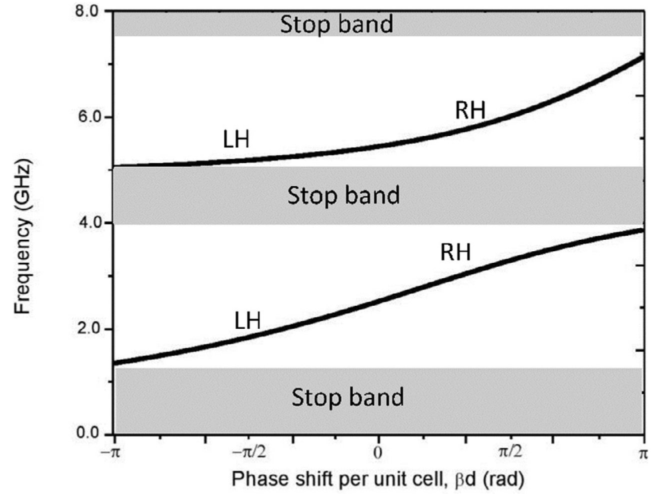

Fig. 2. The dispersion diagram of an E-CRLH structure with $Z_0 = 50\Omega$. $L_R^c = 7.58nH$, $C_L^d = 0.62pF$, $L_R^d = 1.86nH$, $C_L^c = 0.39pF$, $L_L^c = 1.92nH$, $C_R^c = 1.55pF$, $L_L^d = 3.03nH$, $C_R^d = 0.34pF$ to exhibit phase shifts $\varphi_1 = -\pi/2$, $\varphi_2 = +\pi/2$, $\varphi_3 = -3\pi/2$, $\varphi_4 = +3\pi/2$, at four arbitrary frequencies f_1 = 1.83 GHz, f_2 = 3.3 GHz, f_3 = 5.18 GHz, f_4 = 6.02 GHz, respectively.

According to the proposed methodology of designing an E-CRLH structure with zero phase shift at four arbitrary frequencies f_1, f_2, f_3 and f_4, the values of the lumped elements are given as

$$L_R^c = \frac{Z'_{oE-CRLH}}{\omega_R^c} \tag{5a}$$

$$L_R^d = \frac{K_1 Z'_{oE-CRLH}}{\omega_R^c \omega_{se}^{d\,2}} \tag{5b}$$

$$L_L^c = \frac{Z'_{oE-CRLH}\omega_R^c}{\omega_{sh}^{c\,2}} \tag{5c}$$

$$L_L^d = \frac{Z'_{oE-CRLH}\omega_R^c}{K_2} \tag{5d}$$

$$C_R^c = \frac{1}{Z'_{oE-CRLH}\omega_R^c} \tag{5e}$$

$$C_R^d = \frac{K_2}{Z'_{oE-CRLH}\omega_R^c \omega_{sh}^{d\,2}} \tag{5f}$$

$$C_L^c = \frac{\omega_R^c}{Z'_{oE-CRLH}\omega_{se}^{c\,2}} \tag{5g}$$

$$C_R^c = \frac{\omega_R^c}{K_1 Z'_{oE-CRLH}} \tag{5h}$$

where $\omega_{se}^c, \omega_{sh}^c, K_1, K_2, \omega_R^c$ and $Z'_{oE-CRLH}$ are defined accordingly as

$$\omega_{se}^c = \frac{\omega_1 \omega_3}{\omega_{se}^d} \tag{6a}$$

$$\omega_{sh}^c = \frac{\omega_2 \omega_4}{\omega_{sh}^d} \tag{6b}$$

$$K_1 = \frac{1}{L_R^c C_L^d} = \omega_1^2 + \omega_3^2 - \omega_{se}^{c2} - \omega_{se}^{d2} = \omega_{se}^{d2}\left(\left(\frac{\omega_{se}^c}{\omega_1\omega_3}\right)^2(\omega_1^2+\omega_3^2-\omega_{se}^{c2}) - 1\right) \tag{6c}$$