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A NOVEL POWER DIVIDER BASED ON THE COMPOSITE RIGHT/LEFT HANDED METAMATERIAL TRANSMISSION LINE, FOR GSM AND UMTS APPLICATIONS

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Acest articol prezintă un nou divizor de putere capabil să opereze în două benzi de frecvență ce acoperă cele mai comune sisteme de comunicații mobile: „Global System for Mobile Communication" (GSM) şi „Universal Mobile Telecommunication System" (UMTS). Principiul de funcționare se bazează pe mecanismul de rezonanță a liniilor de transmisiune de tipul metamaterial „Composite Right/Left Handed" (CRLH). Divizorul prezintă performanțe ridicate, apropiate de cele ale unui divizor ideal.

This paper presents a novel power divider operating in two frequency bands that cover the most common mobile communication systems: the Global System for Mobile Communication (GSM) and the Universal Mobile Telecommunication System (UMTS). The operating principle is based on the resonance mechanism of the metamaterial Composite Right/Left Handed (CRLH) transmission line. The divider achieves high performances, close to the ones of an ideal power divider.

Keywords: metamaterial, power divider

1. Introduction

Left-handed (LH) metamaterials are defined as artificial, effectively homogeneous electromagnetic structures with unusual properties, not readily available in nature as backward wave propagation, simultaneously negative permittivity and permeability, negative refractive index, zero order and negative resonances [1]. An effectively homogeneous structure is a composite structure having a structural average cell size much smaller than the wavelength, this condition also defining the operating frequency band.

A Composite Right/Left Handed (CRLH) metamaterial is a practical implementation of a LH metamaterial, which also includes unavoidable right-handed (RH) effects [1]. CRLH metamaterial transmission lines have been used to build microwave devices with improved performances such as leaky-wave

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antennas [2], [3], resonant antennas [4],[5] directional couplers [6], power dividers and so on. Power dividers are usually used for dividing a RF signal or to feed an array of antennas. Several power dividers based on the CRLH transmission line have been proposed [7],[8], however they are single band and have either high insertion loss or low isolation between output ports.

This paper presents a novel dual band power divider with improved performances: 0.04 dB maximum magnitude unbalance, 0.4° maximum phase unbalance, – 44 dB isolation between output ports and 0.21 dB additional losses.

2. The CRLH structure

The proposed CRLH cell is presented in fig.1.(a). It is designed in microstrip technology, the metallization being cooper of 0.017 mm thickness and the dielectric layer being Rogers RT5880, with $\varepsilon_r = 2.2$ and 1.574 mm thickness. The cell is composed of an interdigital capacitor (12 digits of 0.1 mm width each) which provides the series left-handed capacitance C_L and a custom designed shortcircuited stub which provides the parallel left-handed inductance L_L. When characterizing the cell, the effects of parasitic right-handed elements (L_R and C_R) must also be taken into account. This is shown in fig.1.(b), where the equivalent cell's circuit is presented. By using the T-π method presented in [1], the theoretical values for the cell's parameters were extracted: $C_L = 1.14$ pF, $L_R = 4.33$ nH, $L_L = 9.93$ nH, $C_R = 0.66$ pF.

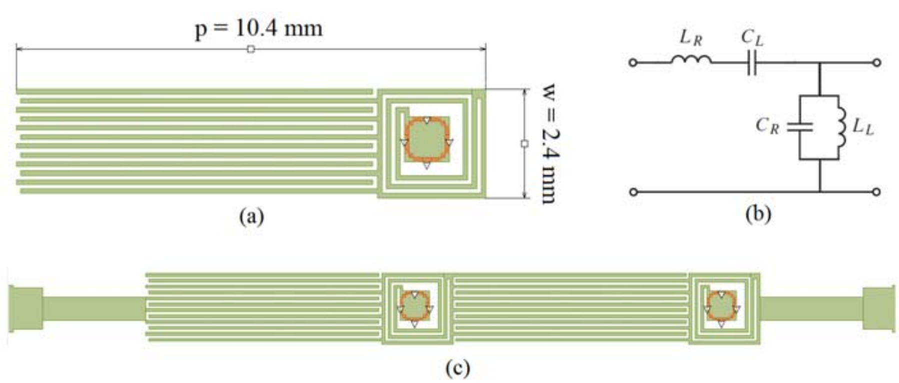

Fig.1. (a) The CRLH cell, (b) equivalent circuit for the cell, (c) the CRLH structure

If two such cells are arranged in the configuration presented in fig.1.(c), results an unbalanced transmission line with a phase constant (β) taking negative values for the LH operating band and positive values for the RH operating band, as shown in fig.2. The phase constant can be expressed using equation (1) [1].

$$\beta = \frac{s(\omega)}{p}\sqrt{\left(\frac{\omega}{\omega_R}\right)^2 + \left(\frac{\omega_L}{\omega}\right)^2 - k\omega_L^2}\ , \tag{1}$$

where:

$$\omega_R = \frac{1}{\sqrt{L_R \cdot C_R}}\ , \tag{2}$$

$$\omega_L = \frac{1}{\sqrt{L_L \cdot C_L}}\ , \tag{3}$$

$$k = L_R \cdot C_L + L_L \cdot C_R\ , \tag{4}$$

$$\omega_{se} = \frac{1}{\sqrt{L_R \cdot C_L}}\ , \tag{5}$$

$$\omega_{sh} = \frac{1}{\sqrt{L_L \cdot C_R}}\ , \tag{6}$$

and $s(\omega) = -1$ if $\omega < \min(\omega_{se}, \omega_{sh})$ or $s(\omega) = +1$ if $\omega > \max(\omega_{se}, \omega_{sh})$.

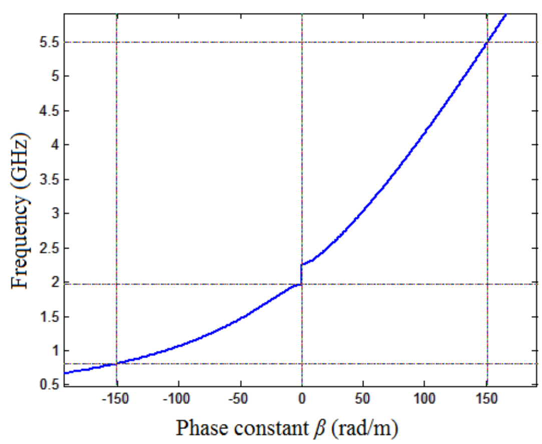

Fig.2 Sampled dispersion diagram for the two-cells CRLH structure

Due to the effective homogeneity, when the CRLH structure is open-ended it behaves like a resonator. The open-ended resonating structure can be coupled to the external ports by very thin microstrip lines.

For regular RH resonators, the resonance frequencies are the frequencies at which the physical length of the structure is a multiple of half a wavelength, or the electrical length is a multiple of π radians. This is expressed in equation (7):

$$\theta_m = \beta_m \cdot l = \left(\frac{2\pi}{\lambda}\right) \cdot \left(\frac{m\lambda}{2}\right) = m\pi \,, \qquad (7)$$

where l is the total length of the structure.

The resonance frequencies can be extracted by sampling the dispersion diagram with a sampling rate of π/l. In the case of RH structures, the phase constant is positive and linear so the resonances will be positive and in harmonic ratios. On the other hand, for CRLH structures the phase constant can also be negative or equal to zero, and therefore, in addition to the conventional positive resonances, negative resonances and a zero-order resonance also exist. The CRLH structure will have a finite number of resonances: N–1 positive resonances, N–1 negative resonances and the zero-order resonance, where N is the number of involved cells.

The proposed CRLH structure (fig.1.(c)) consists of two cells and therefore a total number of 3 resonances can be achieved (one positive, one negative and a zero-order resonance). The zero-order resonance is of great interest due to the fact that it corresponds to the shunt resonance frequency (f_{sh}) and therefore it depends only on the circuit elements L_L and C_R of the unit cell and not on the physical length of the resonator.

The constitutive elements of the cell have been designed to obtain the zero-order resonance frequency in the UMTS operating band and the first negative resonance frequency in the GSM operating band. This is confirmed by fig.2, where by sampling the phase constant we obtain $f_0 = 1.97$ GHz and $f_{-1} = 0.81$ GHz.

3. The power divider

Fig.3 shows the power divider. It is composed of two CRLH structures connected in parallel. Port no.1 is the input port, where the structure is excited using a coaxial feed from bellow and port no.2 and no.3 are output ports.

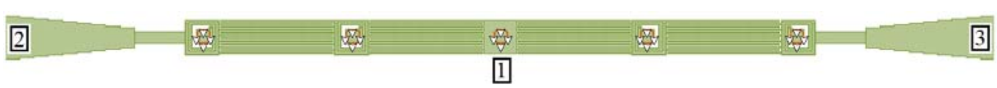

Fig.3 The power divider

This structure was analyzed with an electromagnetic simulation software (Sonnet Professional, v.12 [9]) and the results are shown in fig.4.

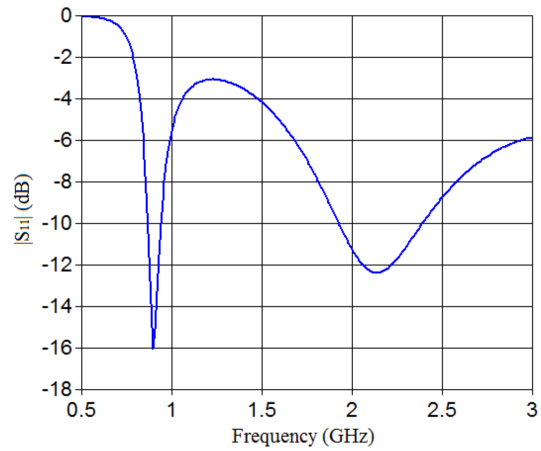

Fig.4 Magnitude of S_{11} for the power divider with two output ports

The magnitude of the reflection coefficient can be improved by optimizing the matching between the characteristic impedance of the port ($Z_0 = 50\ \Omega$) and the input impedance of the power divider. The input impedance of the divider can be modified to a value closer to 50 Ω if the characteristic impedance of the two CRLH structures is modified properly. This is achieved by using the modified structure from fig.5 where at the ends of the divider, two U shaped elements have been added. Fig.6 shows that the real part of the input impedance modifies toward 50 Ω, fig.7 shows that the imaginary part of the input impedance modifies toward zero, and fig.8 shows the improvements achieved for the reflection coefficient when using the optimized structure.

Fig.5 The optimized power divider

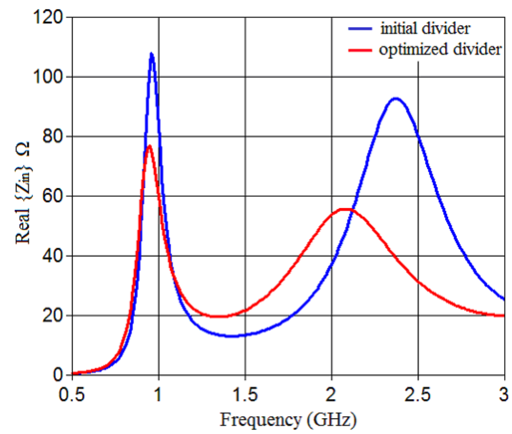

Fig.6 Real part of Z_{in}

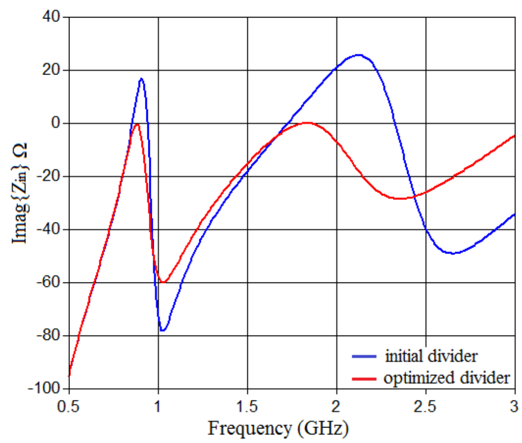

Fig.7 Imaginary part of Z_{in}

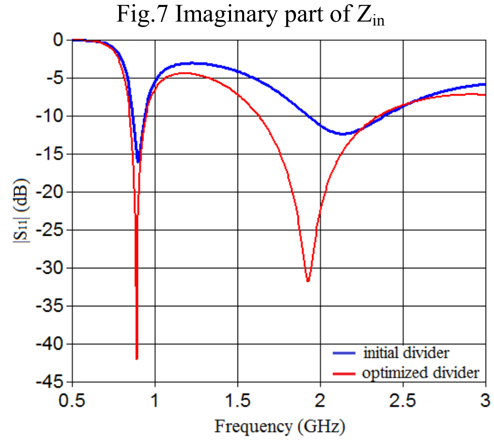

Fig.8 Magnitude of S_{11}

Considering a VSWR lower than 2:1 (or $|S_{11}| < -9.54$dB) the proposed power divider has two operating bands: 0.85 GHz to 0.96 GHz ($BW_1 = 12.1\%$) covering the requirements of the GSM system and 1.62 GHz to 2.4 GHz ($BW_2 = 38.8\%$) covering the requirements of the UMTS system.

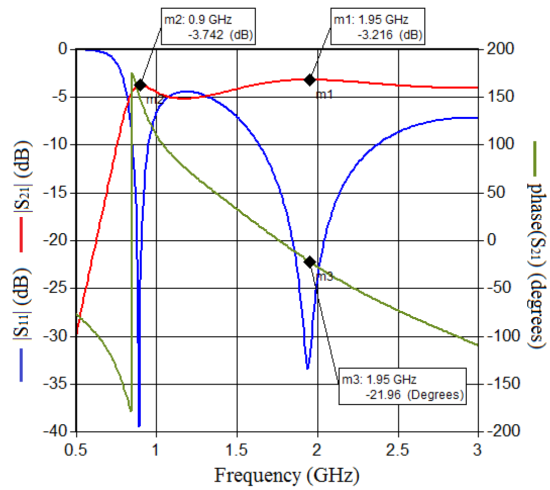

Fig.9 Magnitude of S_{11}, S_{21} and phase of S_{21}

Fig.9 presents the amplitude and phase of the transmission coefficient. At $f_{-1} = 0.9$ GHz, $|S_{21}| = -3.74$ dB and at $f_0 = 1.94$ GHz, $|S_{21}| = -3.21$ dB. Therefore, at these frequencies the additional losses due to the losses in the conductor, in the dielectric layer and by radiation, are very low: 0.74 dB, respectively 0.21 dB.

Fig.10 presents the magnitude and phase differences between the output ports. In the operating bands, the maximum amplitude difference is 0.04 dB and the maximum phase difference is 0.4°.

From fig.11 it can be seen that the matching of the output ports and the isolation between output ports are very poor. These inconveniences can be improved by adding a lumped resistor ($R = 2Z_0 = 100\ \Omega$) and a lumped capacitor ($C = 3$ pF) between the output ports of the structure modified as shown in fig.12. Bending the structure has only a small negative effect on the device's response which shifts in frequency but it can be easily compensated by modifying the U shaped elements. Fig.13 shows the matching of the output ports. In this configuration, the structure is well matched at all its ports. Fig.14 shows that good isolation is achieved between the output ports in the bands of interest: at

$f_{-1} = 0.9$ GHz, $|S_{23}|$ is –31 dB and at $f_0 = 1.94$ GHz, $|S_{23}|$ is –44 dB.

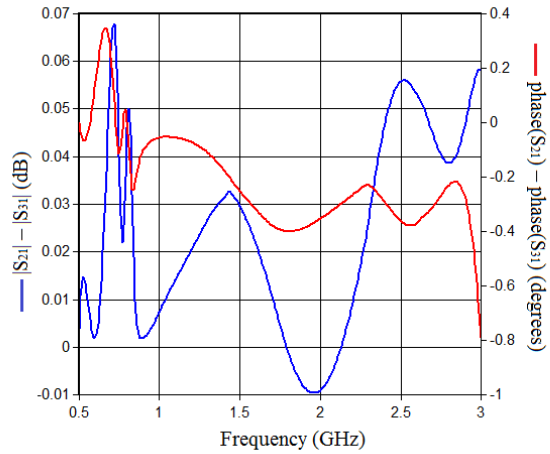

Fig.10 Magnitude and phase difference

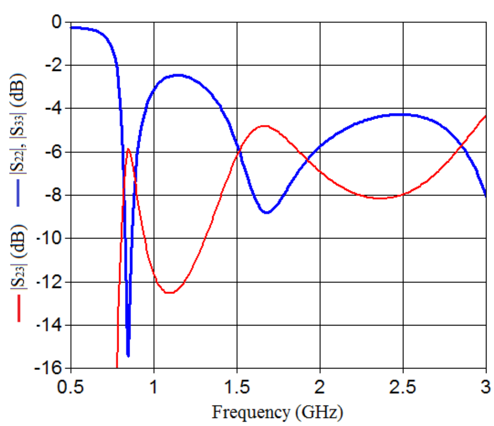

Fig.11. Magnitude of S_{22}, S_{33}, S_{23}

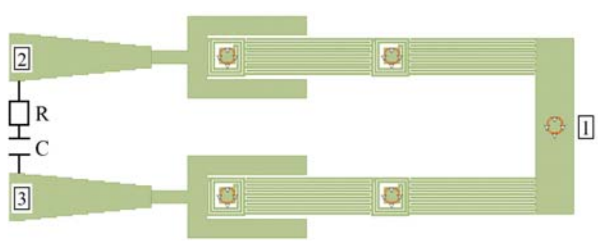

Fig.12. The power divider with lumped elements

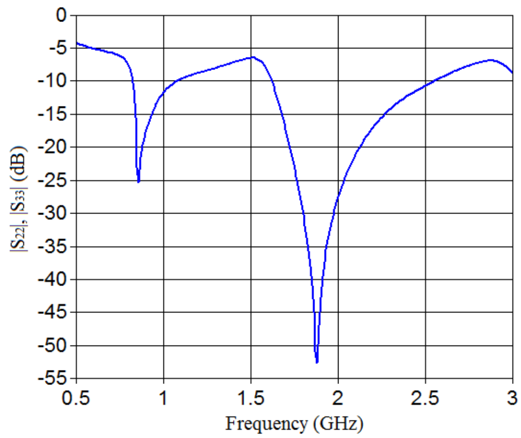

Fig.13. Magnitude of S_{22}, S_{33}

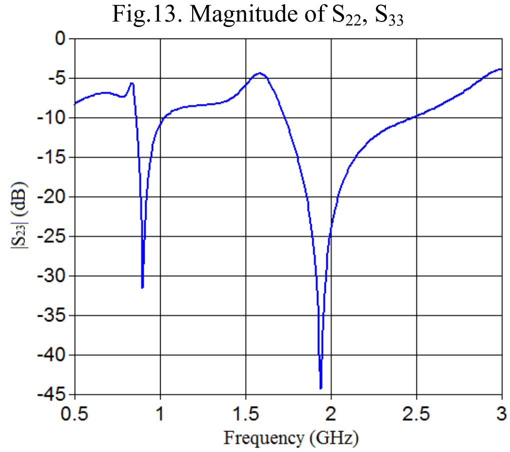

Fig.14. Magnitude of S_{23}

6. Conclusion

In this paper a novel compact power divider with high performances as low losses, high isolation and good balance of amplitude and phase between output ports is presented. The dual-band (GSM and UMTS operating bands) is achieved by taking advantage of the first negative and the zero-order resonance of the proposed CRLH transmission line. The divider can be used in many applications. For example, it can be used to split / add RF signals, or to feed an array of antennas. Future work will focus on designing multi-port power dividers, by solving the problem of inserting lumped elements between output ports, in order to obtain a good isolation.

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