A Microstrip Diplexer from Metamaterial Transmission Lines

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***Abstract* — A planar diplexer using a metamaterial directional coupler is presented. It is composed of a conventional microstrip line and a metamaterial transmission line, which is a dual composite right/left-handed (D-CRLH) transmission line. The metamaterial coupler works in dual modes and leads to alternative coupling coefficients. At the right-handed mode, it is under weak coupling condition. It works under tight coupling at the left-handed mode, while a quasi 0-dB coupling is achieved. Then, the input microwave is delivered to the coupled port and the transmitted port with respect to the operating mode of the diplexer, respectively. The proposed diplexer is compact and owns a deep rejection band between two output bands. An insertion loss less than 1.7 dB and isolation higher than 20 dB are achieved in the demonstrated design. Simulated results agree well with measurements.**

***Index Terms* — Metamaterial, diplexer, planar circuit.**

I. INTRODUCTION

Metamaterial transmission lines, which are known as composite right/left-handed (CRLH) transmission lines and negative refractive index (NRI) transmission lines, own some unique characteristics at frequencies, such as backward wave propagation, simultaneously negative permittivity and permeability, zeroth order resonance, tight coupling and so on. [1]-[6] A widely used microstrip metamaterial transmission line consists of series capacitors from interdigital capacitors and shunt inductors from short-ended microstrip lines Such metamaterial transmission lines are referred to as “Left-Handed” transmission lines as well. At center frequency or transit frequency, there is no phase shift of the transmission line. It works in the right-handed region while frequency is above the transit frequency and in the left-handed while frequency is blow the transit frequency. Metamaterial transmission lines have be applied to antennas, directional couplers, baluns, power dividers, dual/quad-frequency components and so on, since they are compact and with unique dispersion characteristics.

Another kind of metamaterial transmission line is the dual CRLH (D-CRLH) transmission line, which is the counterpart of a CRLH transmission line. [7] It has a stop band between the right-handed and left handed regions. It works in the right-handed mode below the stop band, and in the left-handed mode above the stop band, which is the reverse case of a CRLH transmission line.

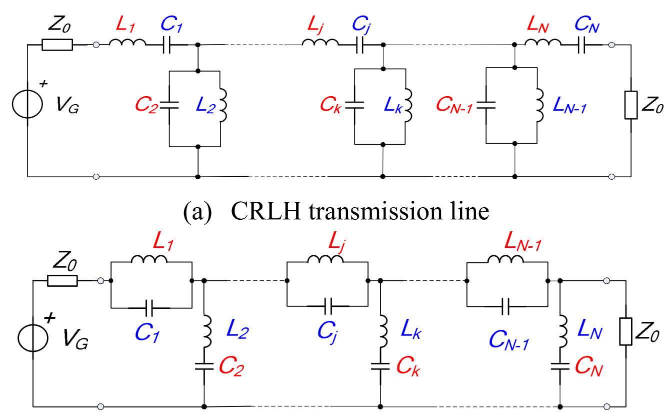
One characteristic of a metamaterial transmission line is the tight coupling between parallel metamaterial transmission lines or between conventional and metamaterial transmission lines. Arbitrary coupling level can be realized in a coupler based on metamaterial transmission line. Quasi 0-dB couplings can be achieved as well.

A diplexer using metamaterial directional coupler is presented in this paper. The metamaterial coupler is composed of a D-CRLH transmission line and a conventional microstrip line. At low frequencies, it works in the right-handed mode and the coupler is under weak coupling. At high frequencies, it works in the left-handed mode and the coupler is under tight coupling (quasi 0-dB coupling). Thus, microwave is delivered to the transmitted and the coupled port, respectively. The proposed diplexer is compact and owns a good rejection band in between. It has potential applications in various microwave systems.

II. PRINCIPLES

A. D-CRLH Transmission Lines

The equivalent circuit of a CRLH transmission line and a D-CRLH transmission line is shown in Fig. 1 (a) and (b), respectively. The D-CRLH transmission line model has parallel LC resonators in series branches and series LC resonators in parallel branches, which is the reverse case of a CRLH transmission line.



(a) CRLH transmission line

(b) D-CRLH transmission line

Fig. 1 Circuit models of CRLH and D-CRLH transmission lines

For the D-CRLH transmission line, LC circuits are

$$\begin{cases} L_j = L_R, \quad C_j = C_L, & \text{for series resonators} \\ L_k = L_L, \quad C_k = C_R, & \text{for shunt resonators} \end{cases} \tag{1}$$

The resonant frequencies of the series and shunt resonators are

$$\omega_{se} = \frac{1}{\sqrt{L_R C_L}} \text{ and } \omega_{sh} = \frac{1}{\sqrt{L_L C_R}} \tag{2}$$

The resonant frequencies of the left/right handed circuits are

$$\omega_L = \frac{1}{\sqrt{L_L C_L}} \text{ and } \omega_R = \frac{1}{\sqrt{L_R C_R}} \tag{3}$$

To minimize the band gap between the left/right handed regions, the following condition should be satisfied

$$\omega_{se} = \omega_{sh} = \omega_0 \text{ or } L_R C_L = L_L C_R \tag{4}$$

which is identical to the balanced case of the CRLH transmission line. From the image impedance analysis, the characteristic impedance Z_C of the D-CRLH transmission line in the balanced case is

$$Z_C = Z_0 \sqrt{1 - \frac{1}{4\varepsilon^2}\frac{\omega_L}{\omega_R}} \tag{5}$$

where $\varepsilon = \frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}$. The characteristic impedances of a D-CRLH transmission line in the balanced and unbalanced cases are shown in Fig. 2.

The stop-band of the D-CRLH transmission line is determined with the condition that Z_C is real. In the balanced case, the cut-off frequencies are then obtained from (5) as

$$\begin{cases} \omega_{cL} = \omega_0 \left(\sqrt{1 + \frac{1}{16}\frac{\omega_L}{\omega_R}} + \frac{1}{4}\sqrt{\frac{\omega_L}{\omega_R}} \right) \\ \omega_{cR} = \omega_0 \left(\sqrt{1 + \frac{1}{16}\frac{\omega_L}{\omega_R}} - \frac{1}{4}\sqrt{\frac{\omega_L}{\omega_R}} \right) \end{cases} \tag{6}$$

The band-gap between right-handed and left-handed regions is desirable with various left/right-handed circuit resonant frequencies.

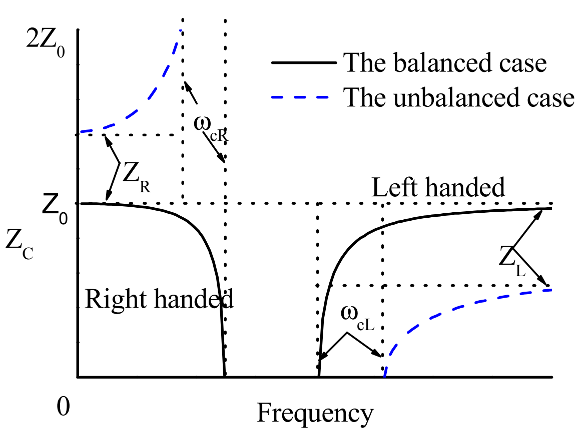


Fig. 2 Characteristic impedance of a D-CRLH transmission line

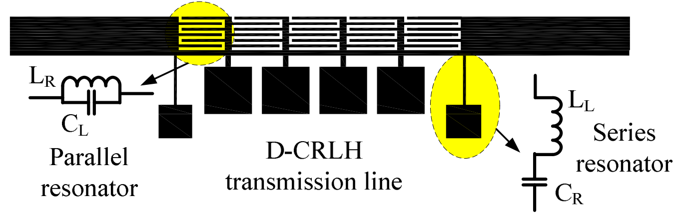
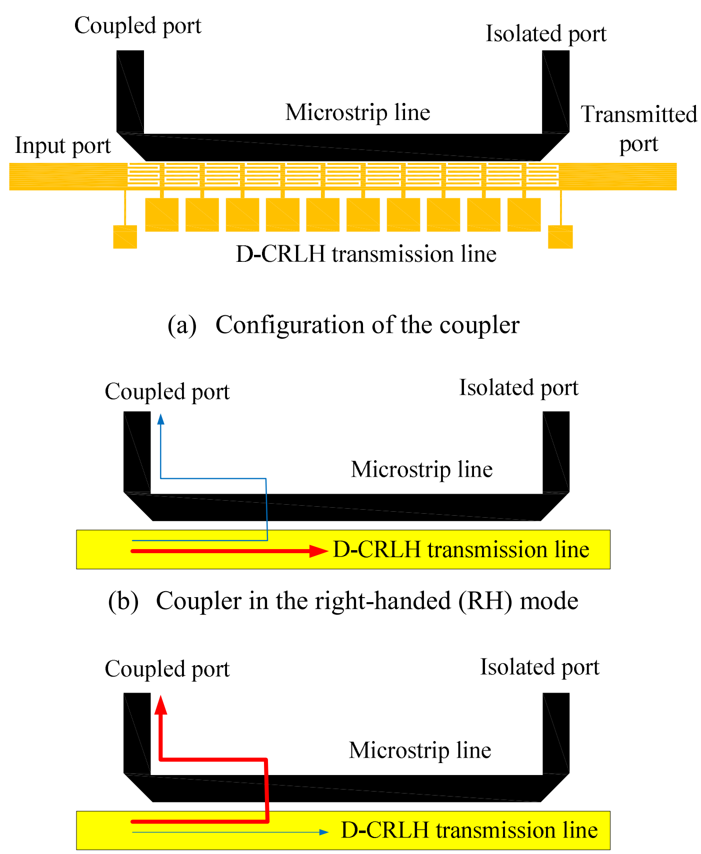


Fig. 3 Configuration of a D-CRLH transmission line

A microstrip realization of D-CRLH transmission line is shown in Fig. 3. The parallel LC resonator is composed of a interdigital capacitor (C_L) and a short narrow microstrip line (L_R). The series LC resonator is composed of a small patch (C_R) and a short narrow microstrip line (L_L). LC components are adjusted at both ends to achieve better impedance match and bandwidth. [8][9]

B. Directional Couplers

A conventional microstrip line and a D-CRLH transmission line parallel to each other to form a directional coupler, as shown in Fig. 4 (a). The demonstrated D-CRLH transmission line contains twelve unit elements.



(a) Configuration of the coupler

(b) Coupler in the right-handed (RH) mode

(c) Coupler in the left-handed (LH) mode

Fig. 4 Directional coupler from D-CRLH transmission lines

It is a dual-band directional coupler, which works at both right-handed and left-handed regions. However, the coupling coefficients are much different from each other. When the frequency is below the band-gap, it works in the right-handed mode and a weak coupling is obtained, as shown in Fig. 4 (b). On the other hand, when the frequency is above the band-gap, it works in the left-handed region and a strong coupling is achieved, as shown in Fig. 4 (c).

The coupling coefficient difference between the left-handed and right-handed modes can be higher than 20 dB in the above design. If the coupling coefficient is nearly 0 dB at the left-handed mode, it may reach 20 dB at the right-handed mode. Thus, microwave at different frequencies are transmitted to different ports dependent on its modes.

III. Diplexer simulation and measurements

The fabricated diplexer is shown in Fig. 5, which contains a D-CRLH transmission line and a conventional microstrip line. There are twelve unit elements in the D-CRLH transmission line to achieve 0 dB coupling in the left-handed mode. The diplexer is fabricated on FB4-2 substrate with dielectric constant of 2.65 and thickness of 1 mm. The thickness of copper foils of both sides is 0.017 mm. The dimension of the diplexer is about 65 mm by 25 mm. All spacings and finger widths of interdigital capacitors are 0.2 mm, and the length of each interdigital capacitor is 3.27 mm. The inductor L_R is formed by short microstrip lines with width 0.4 mm. The capacitor C_R is a rectangle patch with dimension 3.4 mm by 3.4 mm. The inductor L_L is formed by microstrip line with width of 0.4 mm and length of 0.8 mm. The distance between the conventional and the D-CRLH transmission lines is 0.15 mm.

Port 1 to port 4 are the input port, the transmitted port, the coupled port, and the isolated port, respectively. Measurements have been performed by Agilent E8362B vector microwave network analyzer. The measured results are shown in Fig. 6 with solid lines. Simulations have been performed by Zeland IE3D, and are shown in Fig. 6 with dashed lines. Simulated results agree well with measured results.

The transmission characteristic of the diplexer is shown in Fig. 6(a). When the frequency is below 3.7 GHz, microwave is delivered to port 2 with an insertion loss less than 1 dB. Due to the parasitic effects of interdigital capacitors, there is a upper frequency limitation for the D-CRLH transmission line. In the proposed design, it is about 7.6 GHz. Thus, when the frequency is from 6.8 GHz to 7.6 GHz, microwave is transferred to port 3 with an insertion loss less than 1.7 dB.

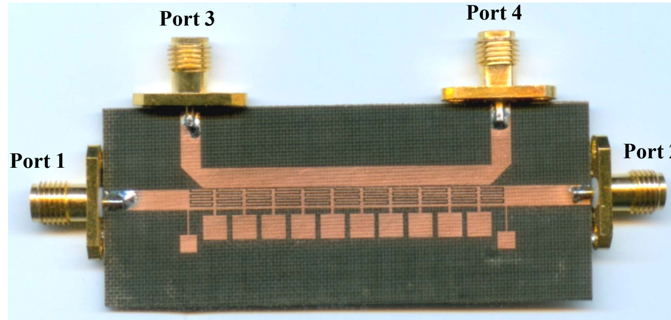
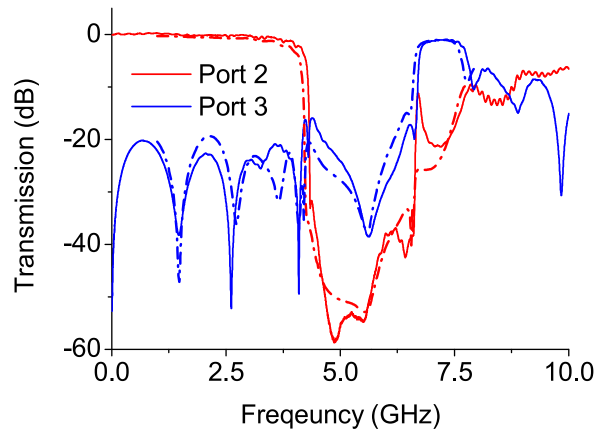
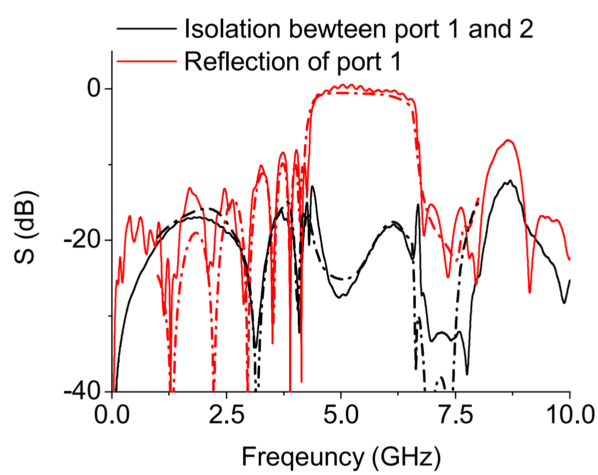


Fig. 5 Fabricated diplexer



(a) Transmission



(b) Isolation and reflection

Fig. 6 Simulated and measured results. Simulated and measured results are in solid lines and dashed lines, respectively.

The rejection band of the diplexer is from about 4.4 GHz to 6.6 GHz as shown in Fig. 6(b). The isolation between port 2 and port 3 is higher than 20 dB in lower frequency band, and greater than 35 dB in higher frequency band. A quite high isolation is achieved over a wide frequency band, e.g. from DC up to 3.7 GHz.

IV. CONCLUSION

A novel diplexer from metamaterial coupler is presented in this paper. The metamaterial coupler works in dual modes: the left-handed and the right-handed modes. The coupling coefficient varies from 0 dB to 20 dB between those two modes. Thus, the input microwave is delivered to the transmitted and the coupled ports with respect to its operating mode.

The proposed diplexer is based on a novel dual modes coupling mechanism. It is compact and with a good rejection band. It has a reasonable insertion loss and high isolation between two output ports.

A metal enclosure may reduce the insertion loss at higher frequency band and improve the diplexer performance. Meanwhile, a narrower rejection band between two operation modes is interesting as well. In future design, these two points will be taken into consideration.

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