An Unequal Power Divider Using Composite Right/Left-Handed Transmission Line Couplers

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***Abstract*-A novel microwave power divider based on composite right/left-handed transmission line (CRLH TL) is presented. The power divider is composed of a segment of CRLH TL and several microstrip lines coupled with it. This design is based on the zeroth order resonance of CRLH TL. A prototype power divider at 2.4 GHz is presented. Unequal power division can be easily achieved. It is very compact along the longitudinal direction. The total insertion loss of the proposed CRLH power divider is less than 1.2 dB. Good phase balance and isolation among output ports are obtained.**

I. INTRODUCTION

Metamaterial transmission lines, composite right/left-handed transmission lines (CRLH TLs), and negative refractive index transmission lines (NRI-TLs) show some unique characteristics at frequencies, such as backward wave propagation, simultaneously negative permittivity and permeability, negative refractive index, zeroth order resonance and so on [1,2]. A widely used metamaterial transmission line consists of interdigital capacitors and short-ended transmission lines, which result in series capacitance and shunt inductance required by left-handed transmission line. Such metamaterial transmission lines are referred to as "Left-Handed" transmission lines as well.

Metatarsal transmission lines can be applied to build some new microwave components, especially with compact structures or superior performance. They have been successfully applied to leaky-wave antennas, compact and broadband phase-shifters, tight coupling directional couplers, power dividers, and so on [3~6]. The special dispersion characteristic of metamaterial transmission lines are usually utilized in those microwave components. Several kinds of microwave power dividers based on metamaterial transmission lines have been built and studied.

The microwave power divider based on the zeroth order resonance of metamaterial transmission lines is compact and broadband. However they either suffer low isolation between output ports, or are difficult to extend to multi-output ports due to the limitation of high impedance of output ports.

The microwave power divider based on directional couplers with a cascading topology is compact in the longitudinal direction and can be extended multi-output ports with high isolation between output ports. Metamaterial transmission lines and phase shift techniques are used in that microwave power divider.

The proposed power divider in this paper consists of a CRLH TL with limited length, which works around the transition frequency (between the left-handed and right-handed pass-band), and several conventional microstrip lines coupled with the CRLH TL for output ports. At the transition frequency, the CRLH TL unit cells are in phase. Therefore, no phase adjustments are required among those outputs.

II. PRINCIPLE OF THE POWER DIVIDER

A. Basic Structure of a CRLH TL

A conventional CRLH TL is used in the proposed power divider. The CRLH TL consists of series interdigital capacitors and shunt stubs shorted to ground. Fig. 1 shows the geometric structure of the CRLH TL. It is designed on an F4B-2 substrate with ε_r =2.65 and thickness of 1.0 mm. All finger widths of interdigital capacitors are 0.2 mm.

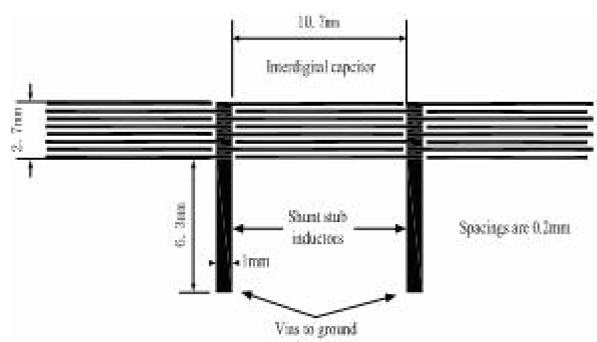


Fig. 1. Layout of the unit cells with dimensions of the CRLH TL of microstrip implementation

The characteristic impedance of the CRLH TL is designed to 50 Ohm, and the width of the interdigital capacitor is 2.7 mm, which is equal to the width of a conventional microstrip line on the same substrate. The zeroth order resonant frequency of the CRLH TL is f_0=2.5 GHz. The phases of unit cells of the CRLH TL can be achieved from simulations. We have compared the phase differences between the ends of shunt stub inductors and the input port. It shows that all unit cells are in phase at the zeroth order resonant frequency f_0.

B. CRLH Couplers

Two CRLH TLs or a CRLH TL and a conventional microstrip transmission lines can form a directional coupler, namely a CRLH coupler, as shown in Fig. 2. A CRLH TL coupler shows a unique characteristic of tight coupling [7]. It has arbitrary coupling level and broad bandwidth (over 30%). The coupling level may reach quis-0-dB, which cannot be achieved by conventional directional couplers.

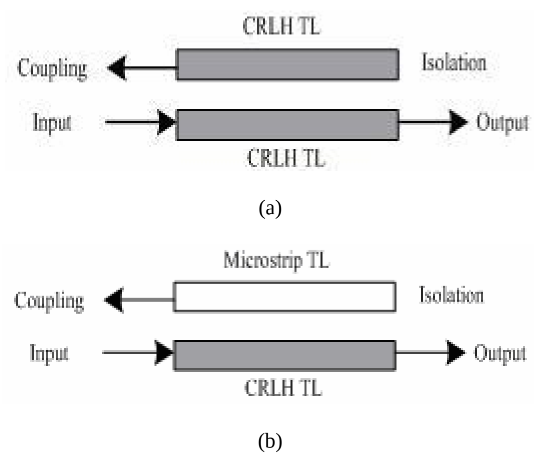


Fig. 2. CRLH couplers from (a) two CRLH TLs, and (b) a CRLH TL and a microstrip line

The coupling level can be easily adjusted with the number of coupling unite cells and the distance between two coupled transmission lines. When the isolated port is connected to a match load, a directivity of about 20 dB can usually be obtained with microstrip implementation. In this paper, we use configure (b) in Fig. 2 to build a power divider, which is easier to realize compared with configure (a) in Fig. 2.

C. Schematic Design

3 dB CRLH directional couplers are used to build power dividers, e.g. a 1:4 power divider was built by three 3 dB CRLH directional couplers with corporation scheme [7]. It works at left-handed region. Due to the dispersion of CRLH TLs, phase adjustments have to be involved in the power divider to make all output ports in phase.

Another scheme of power divider is to use the zeroth order resonance of a CRLH TL. All output ports are in phase at the transition frequency. Due to the intrinsic parallel connection (the wavelength is infinite at the resonant frequency) in the power divider, the number of output ports is limited.

We propose a power divider based on a segment of CRLH TL and three conventional microstrip lines, as shown in Fig. 3. Each unused conventional microstrip line end is connected with one match load. We assume that the coupling coefficients of those ideal couplers are C_1, C_2 and C_3, respectively. The feeding power at port 1 is P_1, and the output powers are P_2, P_3, P_4, and P_5 at the respective ports. When the reflection at port 1 and the insertion loss of the CRLH TL are neglected, the output powers are obtained as

$$\begin{cases} P_2 = P_1 - P_3 - P_4 - P \\ P_3 = C_1 P_1 \\ P_4 = C_2 (P_1 - P_3) \\ P_5 = C_3 (P_1 - P_3 - P_4) \end{cases} \tag{1}$$

With careful design (choosing right coupler coefficients C_1 to C_3), the desired power division among port 2 to port 3 can be satisfied.

At the transition frequency of CRLH TLs, there is no phase difference among their unit cells. Then, the outputs of a CRLH Coupler are in phase as well, since they have the same phase shift to the feeding port. Therefore, no phase adjusting is required in a CRLH coupler based on the zeroth order resonance.

III. Simulations and Experiments

We have designed a 1:4 unequal power divider at 2.4 GHz based on the proposed scheme in Section II. Several unit cells at both ending of the CRLH TL are modified to obtain between impedance matching according to our previous discussion on CRLH TL designs. [7] The distance between the CRLH TL and the coupling conventional microstrip TL is 0.15 mm. The layout of the proposed power divider based on CRLH couplers is shown in Fig. 4. The substrate is F4B-2 with ε_r=2.65 and thickness of 1 mm.

The unequal power division between port 2, port 3, port 4, and port 5 is designed to 4:2:1:1, in which the transmission from port 1 to those corresponding ports are -3 dB, -6 B, -9 dB and -9 dB, respectively. The lengths of the coupling conventional microstrip TLs are adjusted to realize the desired unequal power division.

The simulated amplitude response is shown in Fig. 5(a). At the transition frequency f_0=2.4 GHz, those transmitted amplitudes among output ports are -4.2 dB, -6.9 dB, -9.8 dB and -9.8 dB. The reflection of port 1 at f_0 is -28 dB. The insertion loss is about 1.2 dB. For amplitude consideration, the reasonable bandwidth is about 500 MHz around the transition frequency. The problem is the coupled power at port 3 drops obviously when frequency is away from the transition frequency. A better bandwidth can be obtained with extra efforts to optimize the first coupler.

The phase shifts between output ports are shown in Fig. 5(b). At transition frequency f_0, all output ports share the same phase. Due to the dispersion characteristic of a CRLH TL, the bandwidth of ±10° is much narrower than the amplitude bandwidth. There is a phase difference of about 90° caused by the coupler. The microstrip TLs at port 3, port 4 and port 5 are extended to compensate the phase shift.

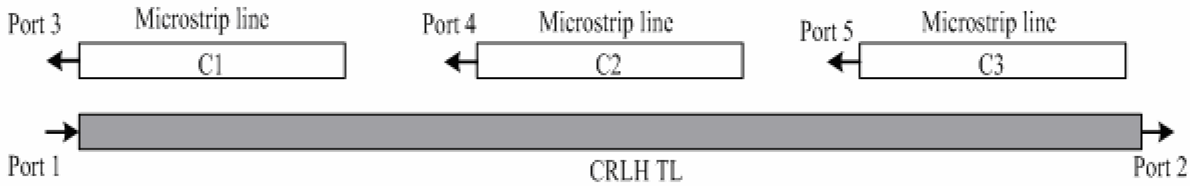


Fig. 3. Scheme of the proposed CRLH coupler. It is a 1:4 power divider, which contains one CRLH TL and three conventional microstrip lines. Port 1 is input ports.

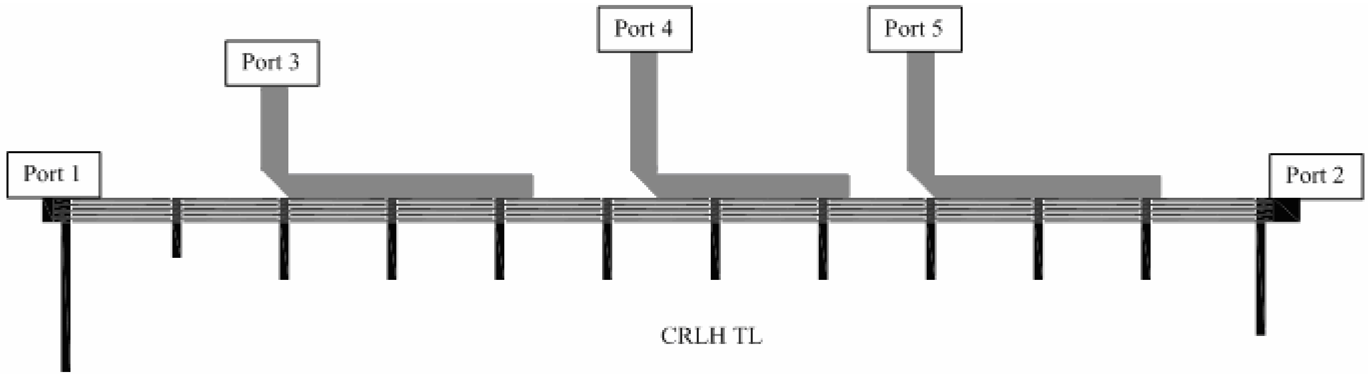
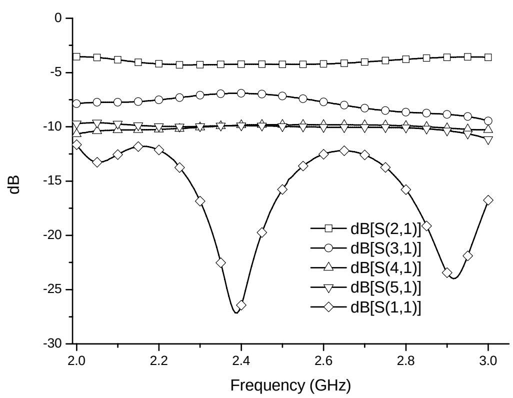
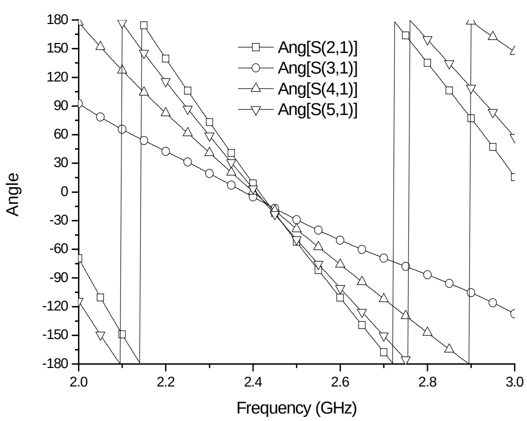


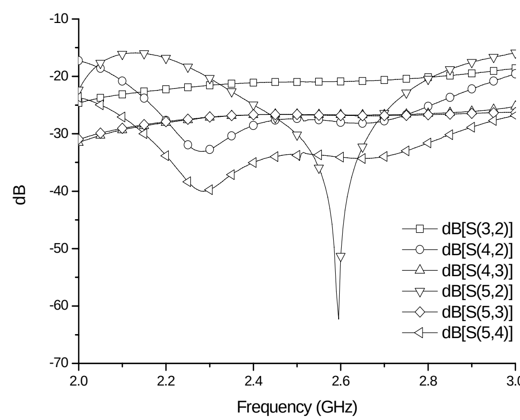
Fig. 4. Layout of the proposed power divider based on CRLH couplers



(a) Amplitude



(b) Phase



(c) Isolation

Fig. 5. Simulation results of the proposed CRLH coupler

Transmissions between output ports are shown in Fig. 5(c). The isolations between output ports are higher than 20 dB, as shown in Fig. 5(c). We hope that in next design the isolation can be further improved.

Experimental results will be presented and discussed in details in the coming conference.

IV. DISCUSSIONS

A novel unequal power divider based on the zeroth order resonance of a CRLH TL is presented in this paper. It is a miniaturized design along the longitudinal direction. The power divider can be easily extended to an arbitrary number of output ports. Not only even numbers but also odd numbers of output ports are suitable for the proposed power divider. Thus, the proposed power divider is a practical design.

Both equal and unequal power division are possible for the power divider. In further study, equal power divider will be considered and designed. Since the power divider is very compact along the longitudinal direction, it is suitable to realize an antenna feeding network. With desired unequal power division, an antenna array with very low side lobs can be fed with the power divider.

The insertion loss of the CRLH TL at zeroth order resonance frequency is a little high. In future, we will try to reduce the insertion loss and make the proposed power divider more reliable.

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