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SYMMETRIC COUPLED COMPOSITE RIGHT-/LEFT-HANDED TRANSMISSION LINE IN COMMON-/DIFFERENTIAL-MODE OPERATION

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Abstract—In this paper, a novel four-port symmetric coupled composite right-/left-handed (CRLH) transmission line in common-/differential-mode operation is introduced. The symmetric metamaterial structure is based on a unit-cell which under a differential-mode excitation behaves like a CRLH metamaterial with bandpass filter characteristics. In contrast, the CRLH metamaterial is below the cut-off frequency under a common-mode excitation. To validate these features, a five-cell four-port symmetric CRLH-TL is simulated, fabricated, and measured, and the obtained results verify the bandpass filter features of the structure under differential-mode excitation.

1. INTRODUCTION

In modern wireless communication systems, a filter is a very important element in RF/microwave circuits to eliminate undesired signals. Because the desired signal is extracted by mixing, amplifying, and demodulation, these processes add noise and consequently degrade the system performance. This noise consists of environmental noise and electronic device noise. The noise limits the minimum received signal level that a circuit can process with acceptable quality. The most important advantage of balanced circuits with differential-mode operation is higher immunity to environmental noise compared to unbalanced circuits with single-ended signaling [1–3].

In this paper, we research the application of CRLH-TL metamaterial for receiver front-ends for further common-mode noise suppression. Recently, the coupled CRLH-TL has been used as a broadband balun [4], and an integrated antenna front-end based on

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a balanced mixer with differential-mode excitation [5]. In particular, a symmetric metamaterial structure applicable to common-/differential-mode excitation is proposed. Under differential-mode excitation, the symmetric metamaterial unit-cell behaves like a balanced CRLH unit-cell; it is supported by the series resonance frequency (f_{se}) of the unit-cell for passband characteristics. However, the symmetric metamaterial unit-cell has a cut-off frequency of f_{se} for stopband characteristics under common-mode excitation. As a result, the proposed metamaterial can be used as a bandpass filter that covers a left-handed frequency region under differential-mode excitation. Five unit-cells of the proposed metamaterial are cascaded to form a bandpass filter. This bandpass filter has intrinsic common-mode filtering below f_{se} and can be directly applied to a balanced filter, eliminating the environmental noise and signals from other bands. The block diagram of a receiver system based on the proposed metamaterial structure in common-/differential-mode is illustrated in Fig. 1.

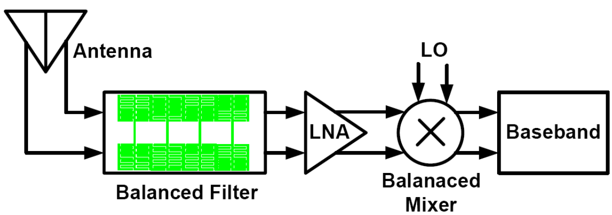

Figure 1. Block diagram of a receiver using the proposed CRLH-TL metamaterial under differential-mode operation.

2. THEORY AND DESIGN

In this section, the analysis and design of the common-/differential-mode metamaterial unit-cell is presented. Using a CRLH unit-cell as a basis [4–10], the proposed metamaterial unit cell is realized as a symmetric coupled unit-cell applicable to differential-mode excitation. The equivalent circuit of the proposed metamaterial unit-cell is shown in Fig. 2(a). From the circuit viewpoint, the symmetry plane is a virtual ground under differential-mode excitation, and the resulting circuit is a normal CRLH unit-cell. However, the inductance (L_L) does not contribute to the CRLH model under common-mode excitation, because the symmetry plane is a virtual open ground.

To implement the equivalent circuit model, microstrip technology was chosen. The series capacitance (C_L) is physically realized by an interdigital capacitor, and the shunt inductance (L_L) is physically realized by a high impedance line connecting both interdigital capacitors together, as illustrated in Fig. 2(b). In addition, the proposed unit-cell does not require a via to introduce the shunt inductance because of the virtual short at the center line under differential-mode excitation. Additionally, the Bloch impedance of the CRLH unit-cell is frequency independent because the unit cell is designed to meet the balanced CRLH condition. Microwave Office from the AWR Corporation was used to analyze and design the CRLH unit-cell. The four-port S-parameters were obtained and then common-/differential-mode excitation was applied to obtain the two-port S-parameters.

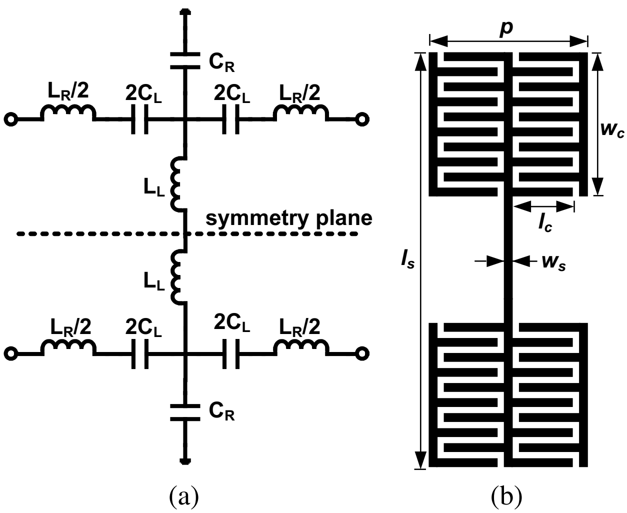

Figure 2. The proposed CRLH metamaterial unit-cell. (a) Equivalent circuit model. (b) Microstrip realization.

The resulting common-/differential-mode dispersion diagram and Bloch impedance for the unit-cell is shown in Fig. 3. In Fig. 3(a), the proposed structure supports passband characteristics below 1.3 GHz in the LH region and above 1.3 GHz in the RH region under differential-mode excitation. However, a cut-off region occurs below 1.3 GHz under common-mode excitation, and a passband above 1.3 GHz is supported, but this band is not of interest. Additionally, in Fig. 3(b), the Bloch impedance under differential mode represents a 50 ohm resistance at 1.3 GHz, but has high impedance values under common-mode.

The optimized parameters for the proposed CRLH metamaterial unit-cell are: $p = 24.54$ mm, $l_s = 57.3$ mm, $w_s = 4.22$ mm, $l_c = 10.16$ mm, $w_c = 4.8$ mm and the five pairs of interdigital fingers have

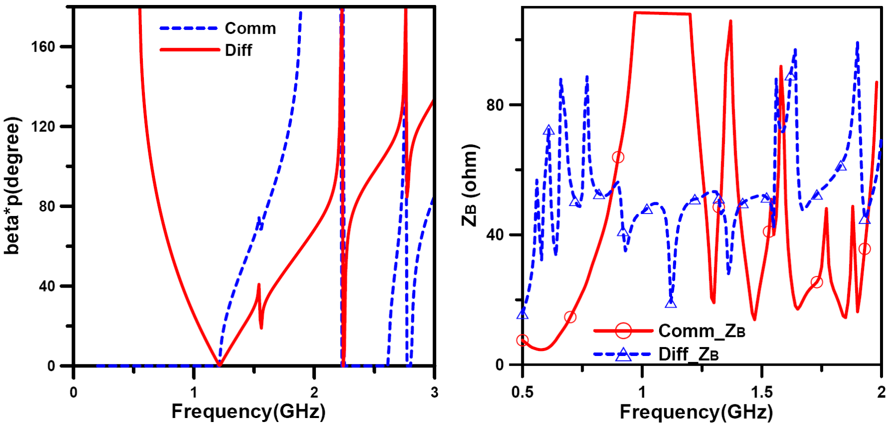

Figure 3. Characteristics of symmetric coupled CRLH-TL unit-cell under common-/differential-mode excitation. (a) Dispersion diagram. (b) Bloch impedance.

spacings of 0.3 and 0.25 mm spacing. Because the equivalent circuit of CRLH unit cell constituted by the series connection of the interdigital capacitor and the shorted stub inductor, the S-parameters of the interdigital capacitor and of the stub inductor are determined by EM simulation. The extracted element values of the equivalent circuit with S-parameters [10] are: $C_L = 2.48\,\text{pF}$, $L_R = 6.11\,\text{nH}$, $C_R = 2.82\,\text{pF}$, and $L_L = 0.16\,\text{nH}$. Fig. 3 shows that the proposed CRLH metamaterial unit-cell can be used as a bandpass filter in the LH frequency region, 0.56 GHz to 1.3 GHz, under differential-mode excitation with intrinsic common-mode suppression.

3. SIMULATION AND EXPERIMENTAL RESULTS

A well-designed bandpass filter should possess the capability of reducing the level of common-mode noise in addition to providing the desired bandpass frequency response in differential-mode excitation. A photograph of a symmetric coupled CRLH bandpass filter is shown in Fig. 4. It shows that the five cascade unit-cells proposed with the metamaterial bandpass filter are realized on the basis of the symmetric CRLH unit-cell. The symmetric CRLH bandpass filter was fabricated on Rogers RT/Duroid 5880 with a dielectric constant of 2.2 and a thickness $h = 62\,\text{mil}$.

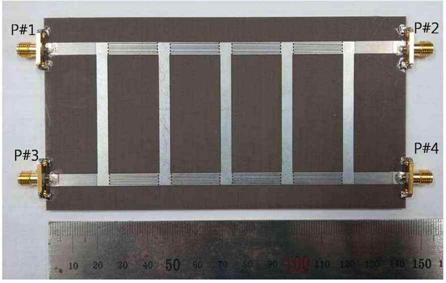

Figure 4. Photograph of the symmetric coupled CRLH bandpass filter.

3.1. Differential-mode Response

For the balanced filter using CRLH unit-cells, the corresponding differential-mode equivalent circuit is composed of two bandpass normal CRLH unit-cells, owing to the virtual short in the center line. L_L is realized by the short-ended stub structure. This filter is simulated using the full-wave simulator AWR Microwave Office, and is measured using a wideband balun for differential-mode operating condition. The wideband balun is designed by the coplanar wave guided structure and depicted the S-parameters and phase characteristics in Fig. 5(a). The measurement configuration under differential-mode is represented in Fig. 6(a) and the measured and simulated differential-mode responses

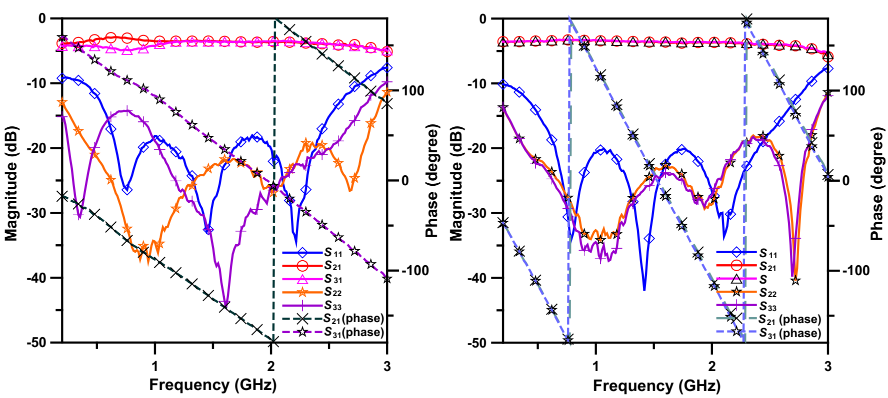

Figure 5. Measured S-parameters and phase characteristics. (a) Balun. (b) Divider.

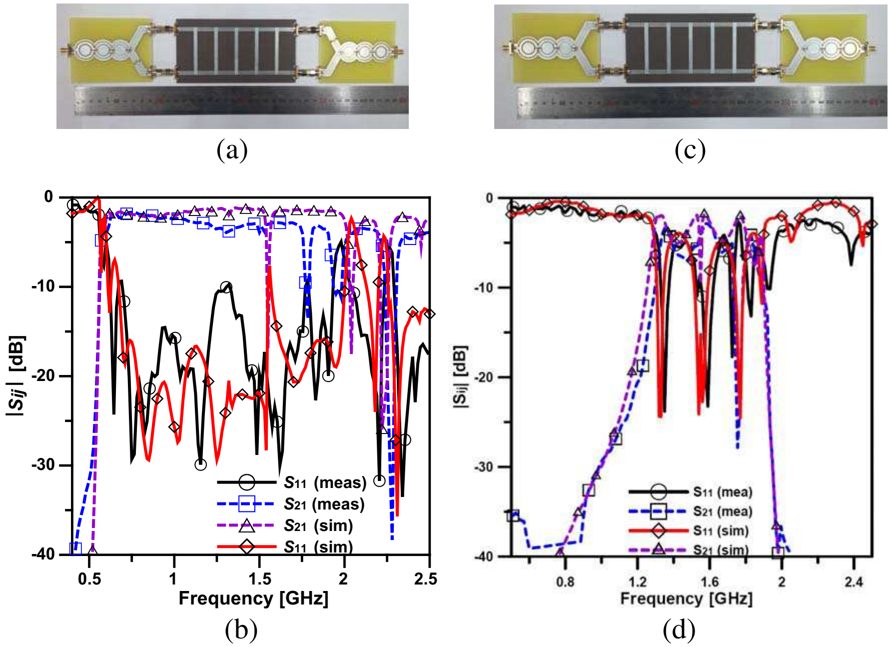

Figure 6. Bandpass filter with five-symmetric CRLH unit-cells. (a) Measurement configuration for differential-mode. (b) Measured S-parameters under differential-mode excitation. (c) Measurement configuration for common-mode. (d) Measured S-parameters under common-mode excitation.

are shown in Fig. 6(b). Good agreement between the measured and simulated results is observed. In Fig. 6(b), the self-resonance of the interdigital capacitor is seen to occur around 1.5 GHz and above 2.0 GHz, but this effect can be eliminated by the technique outlined in [11]. The measured LH operation frequencies are 0.56 GHz to 1.3 GHz, with a maximum differential-mode insertion loss of 2.7 dB and a group delay of 1.7 ns.

3.2. Common-mode Response

For the symmetric CRLH-TL filter using CRLH unit-cells, the corresponding common-mode equivalent circuit is composed of two series LC resonators and shunt capacitors, owing to the virtual open in the center line. In Fig. 3(a), the LH frequency range dispersion diagram of the CRLH unit-cell is neglected, owing to abnormal operation of the CRLH-TL filter. Because L_L does not contribute to the LH frequency range, the symmetric CRLH-TL filter is cut-off. This filter is measured using a wideband divider for common-mode operating condition. The wideband divider is designed by the coplanar wave guided structure and depicted the S-parameters and phase characteristics in Fig. 5(b). The measurement configuration under common-mode is depicted in Fig. 6(c), and the measured and simulated common-mode responses are shown in Fig. 6(d). Good agreement between the measured and simulated results is observed. The measured LH operation frequencies are 0.56 GHz to 1.3 GHz, with a minimum common-mode suppression of $20 \sim 40$ dB.

4. CONCLUSION

A novel four-port symmetric coupled CRLH transmission line in common-/differential-mode operation has been proposed and measured. A symmetric CRLH unit-cell was designed to operate as a bandpass filter under differential-mode excitation, while operating in the cut-off region under common-mode excitation. This fabricated filter has a high CMRR, low insertion loss, and high suppression of common-mode noise. This concept can be proposed for other integrated circuits such as a differential receiver system.

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