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Broadband Via-Free Microstrip Balun Using Metamaterial Transmission Lines

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***Abstract*—A novel metamaterial broadband microstrip balun design is proposed. The broadband balun consists of a pair of identical metamaterial transmission lines. In the odd mode, a virtual ground is formed between the symmetric plane. The odd mode is allowed while the even mode is rejected. No vias are required to realize the shunt inductors of the metamaterial lines, and no power divider is used. Baluns with good performance can be achieved. In this letter, two baluns are fabricated and measured. For the balun with seven units, the output amplitude difference is less than 0.7 dB, and the differential phase is 181° ± 3° from 1.6 to 3.6 GHz, while the input return loss is greater than 10 dB.**

***Index Terms*—Balun, composite right/left-handed (CRLH) transmission line, metamaterial, microstrip, negative refractive index.**

I. INTRODUCTION

METAMATERIAL is an artificial electromagnetic material, which does not exist in nature and shows some unique properties. Metamaterial transmission lines, as 1-D metamaterials, have been proposed and studied in the microwave region. Both negative refractive index transmission lines and composite right/left-handed (CRLH) transmission lines are metamaterial transmission lines [1], [2]. They own simultaneous negative effective permittivity and permeability in a limited frequency range, and find successful applications in antennas and dual/quad-band circuits [2], [3].

Baluns are important microwave components to convert unbalanced single input signals into balanced differential signals. Baluns are widely applied to balanced antennas, push-pull amplifiers, balanced mixers, microstrip leaky-wave antennas [4], and so on. Bandwidth and output balance are main performance parameters of a balun.

Recently there have been some reports on metamaterial Wilkinson baluns [5], [6]. Metamaterial transmission lines and classical Wilkinson power dividers are successfully combined together to demonstrate good performance baluns. Two sections of metamaterial transmission lines, which produce +90° and −90° phase shifts, respectively, are added to the two output lines of a Wilkinson power divider [5]. Then, a 180° out-of-phase angle is produced between the two outputs. In [6] an alternative realization is presented. A Wilkinson power divider generates the even mode. When metamaterial transmission lines are applied, the outputs are adjusted to the opposite phases, which is equivalent to switching to the odd mode.

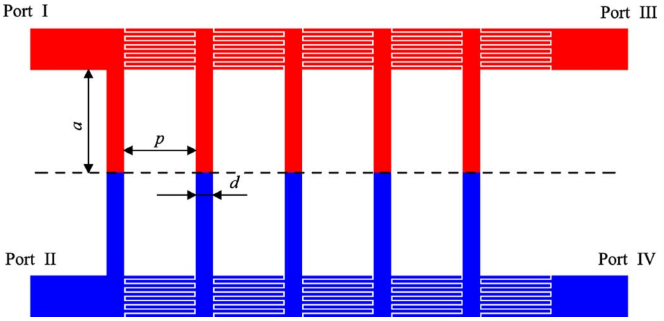

Fig. 1. Structure of the metamaterial balun based on CRLH transmission lines. The gap between fingers of an interdigital capacitor is 0.10 mm, and the width of fingers is 0.15 mm. Other dimensions are: $a = 6.05$ mm, $p = 4.2$ mm, and $d = 1$ mm.

In this letter, we propose a novel metamaterial balun which directly suppresses the even mode and passes through the odd mode. It contains a pair of identical microstrip metamaterial transmission lines, which are based on a CRLH transmission line. No Wilkinson power divider is employed in our design. With a virtual ground formed in the symmetry plane for the odd mode, no vias are required to realize shunt inductors. Open circuits are formed in the symmetry plane for the even mode, which results in a stop-band. Two broadband via-free microstrip metamaterial baluns are fabricated and measured to verify the design.

II. PRINCIPLE OF THE BALUN

The principle structure of the proposed balun is shown in Fig. 1, in which the dimensions of one unit are presented. Each unit contains a series interdigital capacitor and a narrow shunt microstrip branch. At the dashed line in Fig. 1, the balun may be divided into two identical symmetric parts, namely the upper part and the lower part. In the example of Fig. 1, there are five units in either part.

When port I and II are fed with opposite phase and identical amplitude, and port III and IV are connected to matched loads, the odd mode will be excited in the symmetric structure. An electric wall is formed in the symmetry plane along the dashed line, forming a virtual ground. A similar CRLH transmission line structure has been reported in antenna applications [7]. Then, the vertical microstrip branches of length a are equivalent to shunt inductors. The upper part and the lower part become a pair of coupled CRLH microstrip transmission lines [2]. The pass-band of the balun is determined by the CRLH

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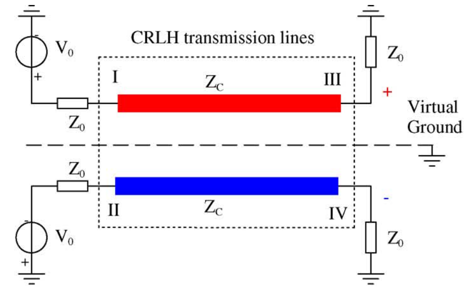
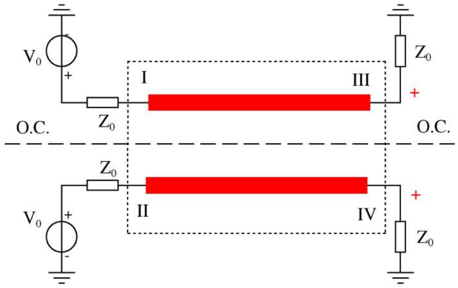
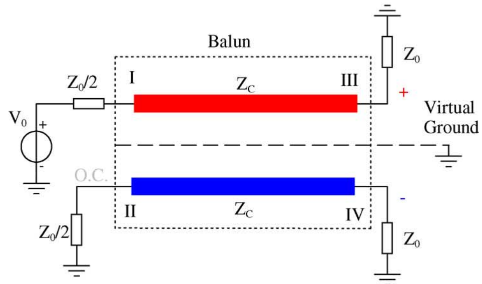


(a) Odd mode

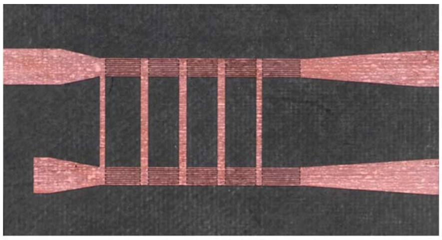


(b) Even mode

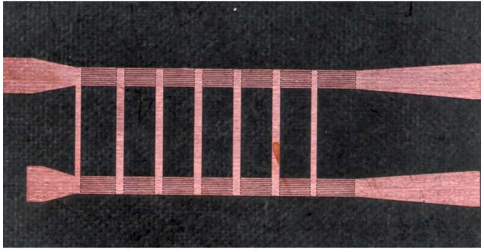


(c) Combination of the odd and even mode

Fig. 2. Odd and even mode equivalent circuits and their combination.

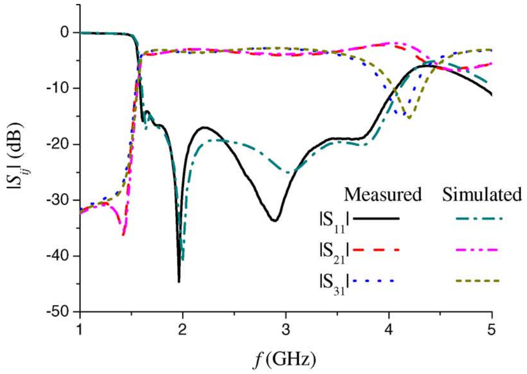


(a) Balun A with five units

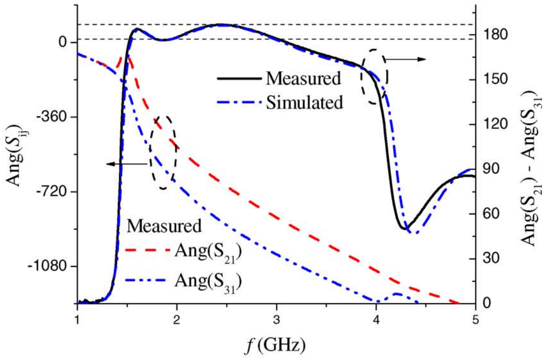


(b) Balun B with seven units

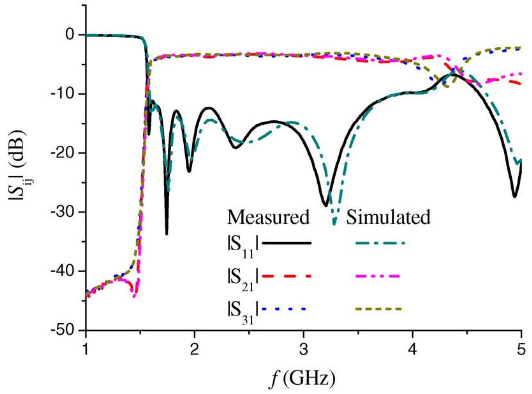
Fig. 3. Photos of two baluns based on metamaterial transmission lines. The two baluns are of sizes of about 60 mm × 35 mm and 65 mm × 35 mm, respectively.



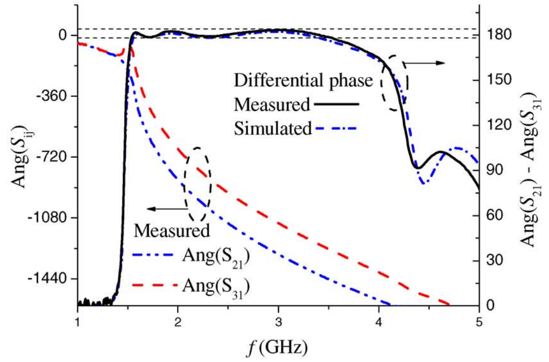
(a) Return loss and transmission performance of balun A



(b) Measured differential phase of balun A



(c) Return loss and transmission performance of balun B



(d) Measured differential phase of balun B

Fig. 4. Simulated and measured results of baluns A and B.

transmission lines, which is between the cut-off frequencies of the left-handed and right-handed modes. The characteristic impedance of the CRLH transmission line is equal to Z_C.

When port I and II are fed with identical amplitude and phase, the even mode will be excited in the balun. A magnetic wall, equivalent to open circuits, is formed in the symmetry plane. In this case, however, the vertical microstrip branches turn from short-ended to open-ended. The previous pass-band for the odd mode becomes a stop-band.

Odd and even mode equivalent circuits and their combination are shown in Fig. 2(a)–(c), respectively. In the combined case, port I is the unique input port. Port III and IV are output ports. The odd mode is supported in the pass-band of the CRLH transmission line, while the even mode sees a stop-band and is suppressed. There is only the odd-mode left in the output resulting in identical amplitude and opposite phase at ports III and IV. Thus, the proposed design works well as a balun, with the unbalanced input at port I and the balanced outputs between ports III and IV.

III. BALUN DESIGN AND MEASUREMENTS

In the proposed balun, the source impedance is required to be half of the load impedance. In applications and measurements, input/output impedances are usually Z_0. Therefore, the characteristic impedance Z_C of the CRLH transmission line should be either $2Z_0$ (source match) or Z_0 (load match), and impedance matching circuits have to be involved in either output or input port. A trade-off is to choose the impedance Z_C between $2Z_0$ and Z_0, and apply short transition microstrip lines for impedance matching at both input and output ports.

When port III and IV are matched, port I and II are isolated against each other. When port I is the input port, port II may be an open circuit. The matching load at port II can be omitted. To keep the structure symmetric, a section of openended microstrip line is kept at port II. In the case of mismatched loads applied at the output ports, a matched load at port II should be used. Moreover, based on the relation between Chebyshev band-pass filters and CRLH transmission lines [8], the first and last units of the CRLH lines are adjusted to achieve better impedance match and wider bandwidth.

Following the above steps, we have designed and optimized two baluns from metamaterial transmission lines with five and seven units, shown in Fig. 3(a) and (b), namely balun A and B, respectively. The substrate material is RT Duroid 5880 of thickness of 1.57 mm and a relative dielectric constant of $\varepsilon_r = 2.2$. All input and output ports are matched to $Z_0 = 50\ \Omega$.

The baluns were measured using a HP 8510C vector network analyzer. Simulated and measured results have good agreements for both amplitudes and phases, as shown in Fig. 4.

For balun A, the output amplitude difference is less than 1.0 dB, and either output insertion loss is less than 4 dB from 1.6 to 3.6 GHz, where the return loss is greater than 15 dB. The phase difference between the two output ports is between 177° and 187° (182° ± 5°) within the frequency range from 1.5 to 3.0 GHz.

For balun B, the output amplitude difference is less than 0.7 dB, and either insertion loss is smaller than 5 dB from 1.6 to 4.0 GHz. Return loss is greater than 10 dB. The phase difference between the two output ports is between 178° and 184° (181° ± 3°) within the frequency range from 1.5 to 3.6 GHz. The performance of balun B is better than balun A due to the extra two more units.

IV. CONCLUSION

A novel broadband metamaterial balun design has been demonstrated. No vias and power dividers are used. Two baluns with five and seven units, respectively, have been fabricated, measured, and compared. Simulations show a good agreement with measured results. The bandwidth of the second balun is from about 1.6 to 3.6 GHz, while the output balance is better than 0.7 dB, and the differential phase is 181° ± 3°.

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