A Novel Design of Balun using Left-Handed Transmission Line

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1. Introduction

Double Negative (DNG) materials with both negative permittivity and negative permeability have been a topic of high interest in recent years [1, 2]. They are known to exhibit 'Left-Handed' propagation characteristics within a particular frequency range. In other words, the wave vector k in a DNG material is opposite to the Poynting's vector associated with the plane wave propagating in it, and negative refractive indices. For these properties, DNG materials have been utilized to several microwave components.
Composite media that exhibit simultaneous negative permittivity and permeability were originally developed using thin wire strips and large 3-D split-ring resonators [3, 4]. Their size however rendered them impractical for the physical realization of microwave circuits. More recently, a theory and implementation of a compact and practical LH-transmission line was developed by Caloz et al [5]. The LH-transmission line is the electrically dual of the conventional transmission line, in which the inductance and capacitance have been interchanged, and realized by periodical loading a conventional transmission line with lumped element series capacitors (Co) and shunt inductors (Lo). The equivalent model of the LH-transmission line shows that it provides negative phase delay or phase advance. On the other hand, the conventional transmission line has positive phase delay.
When such properties are applied to the circuits, they can improve the performances of the circuit in size and bandwidth [6]. Based on previous analytical studies of the LH-transmission line several practical applications and usages in the design of couplers and antennas have been proposed.
In this paper, we propose a new type of balun by using a LH-transmission line that can overcome the shortcomings of the conventional baluns such as the narrow bandwidth and the large size characteristics.
Basic Guidelines

2. Proposed balun and appling LH-transmission line

Fig. 1(a), (b) shows the unit-cell equivalent circuit models for a RH-transmission line and a LH-transmission line, respectively. The LH-transmission line is electrically dual of the conventional RH-transmission line, in which the inductance and capacitance have been interchanged. In the LH-TL, the wave number, the characteristic impedance the cut-off frequency and the insertion phase-rotation are given by (1)-(4), respectively. The LH-transmission line is characterized by a negative and the positive .

$$\beta \approx \beta_L = -1/\omega\sqrt{L_o C_o} \tag{1}$$

$$Z_{OL} = \sqrt{L_O / C_O} \tag{2}$$

$$\omega_{cL} = 1/(2\sqrt{L_O C_O}) \tag{3}$$

$$\Phi_L = -\arctan\left[\frac{\omega\left(L_o/Z_o + C_L Z_o\right)}{1-2\left(\omega/\omega_{cL}\right)^2}\right] \tag{4}$$

At low frequencies, the transmission line is dominantly Left Handed with the hyperbolic dispersive $\beta \approx \beta_L = -1/\omega\sqrt{L_o C_o}$, while at high frequencies, it is dominantly Right Handed, with the linear non-

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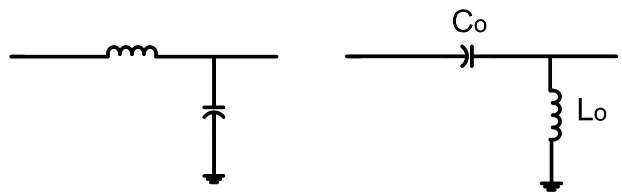


Fig. 1 Unit-cell equivalent circuit models of transmission lines (a) Right-Handed transmission line. (b) Left-Handed transmission line.

dispersive. $\beta \approx \beta_R = +\omega\sqrt{LC}$ The properties of the LH-transmission line derive from those of the RH-transmission line by low-pass to high-pass transformation. The proposed balun structure is shown in Fig. 2.This balun is developed based on Willkinson power divider. By inserting 2λ/4 transmission line between port 1 and port 3 of Willkinson power divider, we can obtain $180°$ phase difference of port2 and port3. The additional 2λ/4 transmission line is attached to the isolation resistor for the separation of output ports and isolation. The proposed Wilkinson balun has 1:1 output power dividing ratio and 180o phase difference at output ports [7].

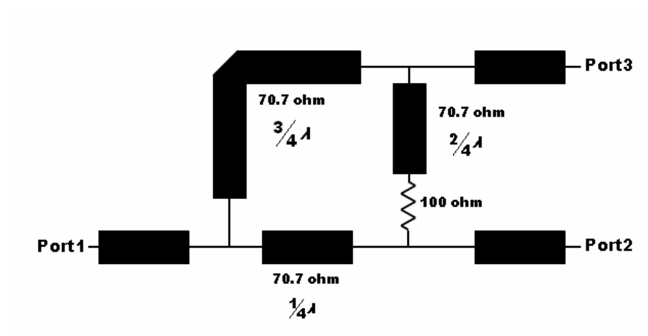


Fig. 2 Structure of the proposed balun with the Wilkinson structure.

Owing to the resistive component, this balun have good matching at all ports and isolation characteristics compared to conventional baluns [8, 9]. However, the size of the circuit become large and the bandwidth also become narrow because of using the 3/4λ transmission line at design frequency. So we, using LH-transmission line, replaced the 3/4λ transmission line with the –1/4λ LH-transmission line. The proposed –1/4λ LH-transmission line is implemented as a host transmission line periodically loaded with discrete lumped element components, L and C as Shown in Fig. 3.

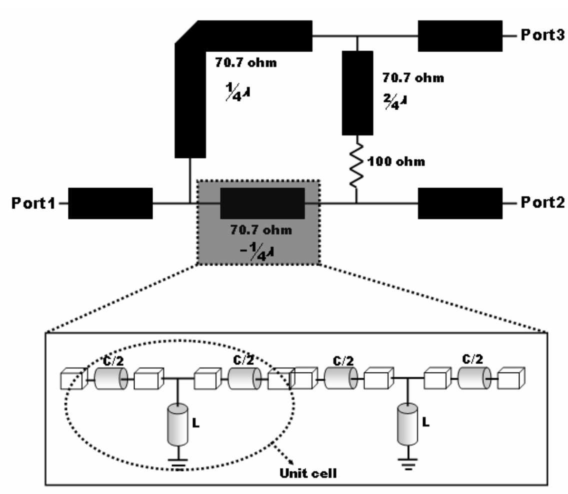


Fig. 3 Proposed balun with a LH-transmission line.

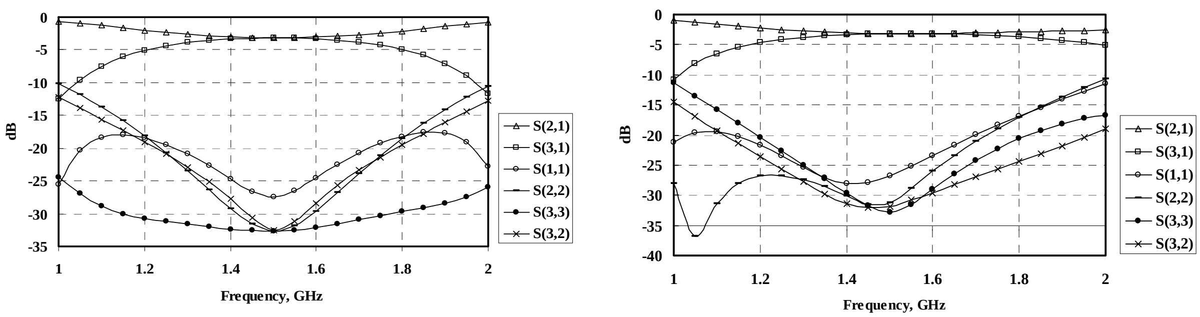
In this paper, we implement –1/8λ LH-transmission line unit cell and made total –1/4λ phase delay with two-unit cells. As shown in Fig. 3, this LH-transmission line was utilized to the proposed balun.

3. Simulation and Measurement

To verify the effects of LH-transmission line in the proposed balun and to compare to the balun without LH- transmission, the proposed balun are designed and measured at 1.5GHz. The substrate with 0.504mm of thickness, 2.52 of dielectric constant, and 18 μm of metal thickness is adopted. Fig. 4 shows the simulated insertion-loss, matching and isolation characteristic of the proposed balun. Fig. 5 and Fig. 6 show the measured results of the fabricated balun.

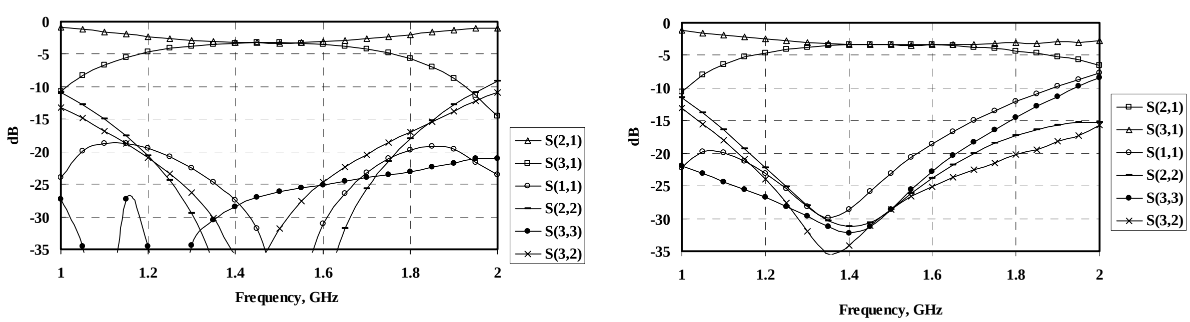
The bandwidths of the baluns with LH-transmission and without LH-transmission line are 24 % (-3 ± 0.5 dB), 57.3% (180 ± 10 deg.), respectively and 28 % (-3 ± 0.5 dB), 63.3% (180 ± 10 deg.), respectively. The bandwidth of the balun with LH-transmission was enhanced by 16.7% compared to that of the balun without LH-transmission line, while the average magnitude was reduced by only 0.1 dB.

The size of the balun with LH-transmission was reduced by 75 % compared to that of the balun without LH-transmission line. All measured characteristics of the baluns are listed in Table I.Although the measured results are slightly different from the simulated results because of the parasitic components of Chip capacitor and chip inductor, we were able to confirm size-reduction and bandwidth-enhancement effects through LH-transmission line.



(a) (b)

Fig. 4 Simulated characteristics of the balun. (a) with LH-transmission line (b) without LH-transmission line



(a) (b)

Fig. 5 Measured characteristics of the balun. (a) with LH-transmission line (b) without LH-transmission line

4. Conclusion

A novel structure of balun has been introduced. Using the LH-transmission line to the conventional balun, we reduced the size and enhance the bandwidth. By replacing the 3/4λ transmission line with the –1/4λ LH-transmission line, the size of balun was reduced by 75 %. Also due to the loading elements of LH-transmission line we obtained 16.7% bandwidth enhancement. Namely, this paper showed the opportunity of implementing a compact, enhanced bandwidth microwave component with the LH-transmission line. If the parasitic effect of the lumped components can be reduced, we will be able to obtain the better result.

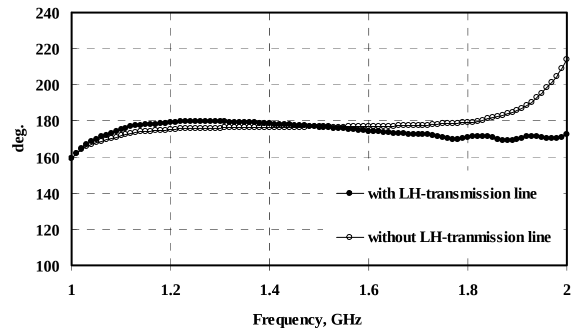


Fig. 6 Measured phase balances of the baluns.

	Without LH-transmission line	With LH-transmission line	Comparison
Bandwidth	24 % (-3 ± 0.5 dB)	28 % (-3 ± 0.5 dB)	16.7 % enhancement
Phase difference	57.3% (180 ± 10 deg.)	63.3% (180 ± 10 deg.),	10.5% enhancement
Size	70mm * 36mm	59mm *11mm	75 % reduction

Table I. Measured characteristics of the baluns

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