Compact Broadband Wilkinson Balun Using Metamaterial Transmission Lines

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1. Introduction

Recently, various structures such as zeroth order antennas, dual band branch line couplers, compact ring hybrids, broadband baluns, and so on, have been introduced by using metamaterial transmission lines (MTM TLs) of the composite right/left handed (CRLH) or the LC loaded (LCL) lines [1-2]. In general, most of passive circuits in RF/microwave systems are designed by using -90° or -180° phase shifting lines. The phase shifter using MTM TLs introduced in Ref. [3] is applicable for these circuits to achieve the size reduction and/or the bandwidth extension [4-5]. A broadband balun was introduced in Ref. [4]. The balun is comprised a Wilkinson divider, followed by a +90° and -90° MTM phase shifting lines along two output ports, respectively. Although the designed balun has broadband differential output phase bandwidth of 77 %, the size of the balun is increased when the operating frequency is lower than the designed frequency due to two quarter wavelength lines. In this letter, we propose a compact broadband Wilkinson balun using three MTM TLs. The size of the proposed balun is 70 mm × 15 mm excluding the port areas and has no effect on the operating frequency.

2. Balun Design

Fig. 1 shows the structure of the proposed compact broadband Wilkinson balun using MTM phase shifting lines. The quarter wavelength lines of a general Wilkinson divider are replaced by +90° and -90° MTM phase shifting lines with the characteristic impedance of $\sqrt{2}Z_0 = 70.7\Omega$ to achieve differential output phase performance in output ports of the designed balun. The isolation between two output ports is improved by adding a +180° MTM phase shifting line with two series resistances of $Z_0 = 50\Omega$ between two output ports. Three MTM phase shifting lines are designed by using MTM phase shifter unit cell shown in Fig. 2 and Eq. (1) [3-4].

$$\Phi_{MM} = n\left(\omega\sqrt{LC}d_0 + \frac{-1}{\omega\sqrt{L_0 C_0}}\right) \qquad (1)$$

Here, L and C are the distributed inductance and capacitance of the host TL with propagation constant $\beta = \omega\sqrt{LC}$ and d_0 is its length, while L_0 and C_0 are the loading element values. In addition, n is the number of unit cell and ω is the operating frequency. Eq. (1) must satisfy the following impedance matching condition: $Z_0 = \sqrt{L_0 / C_0} = \sqrt{L / C}$. The various parameters of each phase shifting MTM TL are summarized in Table I.

3. Experimental Results

Fig. 3 shows the photograph of the fabricated compact broadband balun. The balun is implemented on FR-4 substrate with $\varepsilon_r = 4.4$ and height h = 0.8 mm. Fig. 4 shows the measured s-parameters of the balun. The -10 dB return loss bandwidth of the balun is 425 – 700 MHz at port #1, 390 – 760 MHz at port #2, and 370 – 785 MHz at port #3 as shown in Fig. 4(a). Fig. 4(b) shows the insertion losses S_{21} and S_{31}, and isolation S_{32}. The measured S_{21} and S_{31} have the maximum values of S_{21} = -3.817 dB and S_{31} = -3.171 dB. 1 dB bandwidth at each port is 470 – 695 MHz at port #2 and 465 – 650 MHz at port #3. The isolation remains below -10 dB from 380 – 905 MHz with the minimum value of S_{32} = -40.28 dB at 580 MHz. Fig. 5 shows the measured phase responses of two outputs and the differential output phase of the designed balun. It can be observed that the phases of S_{21} and S_{31} are equal to +90° and -90° at 500 MHz, respectively, and the phase characteristics of the two signal paths are very similar. The differential output phase remains flat over the wide frequency band. The balun has the measured differential output phase bandwidth (180° ± 10°) of 340 MHz (55%) from 445 to 785 MHz.

4. Conclusions

In this paper, we proposed a compact and broadband Wilkinson balun using three MTM TLs. Two quarter wavelength lines in a general Wilkinson divider are replaced by -90° and +90° MTM phase shifting lines with the characteristic impedance of 70.7 Ω. To improve the isolation characteristic between output ports, +180° MTM phase shifting line with the characteristic impedance of 50 Ω is connected in series with two 50 Ω resistors between the two output ports. The designed balun has the measured differential output phase bandwidth (180° ± 10°) of 340 MHz (55%) from 445 to 785 MHz. The size of the designed balun is 70 mm × 15 mm excluding the port areas and has no effect on the operating frequency. Although the insertion loss of the designed balun is greater than that of a general balun, the size of the proposed balun does not depend upon the operating frequency and the broadband differential output phase bandwidth. Therefore, the proposed balun structure can be used for various planar devices that require a broadband differential input signal, for example a broadband dipole antenna, a spiral antenna, and so on.

Acknowledgments

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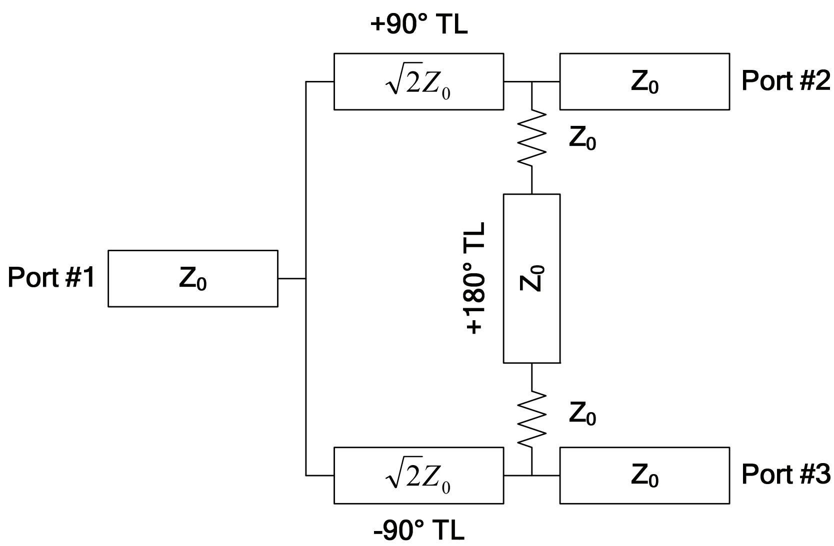


Figure 1: Basic structure of the proposed Wilkinson balun

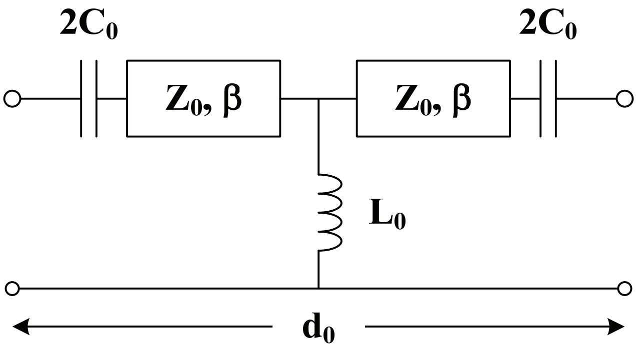


Figure 2: Unit cell of a MTM TL phase shifter

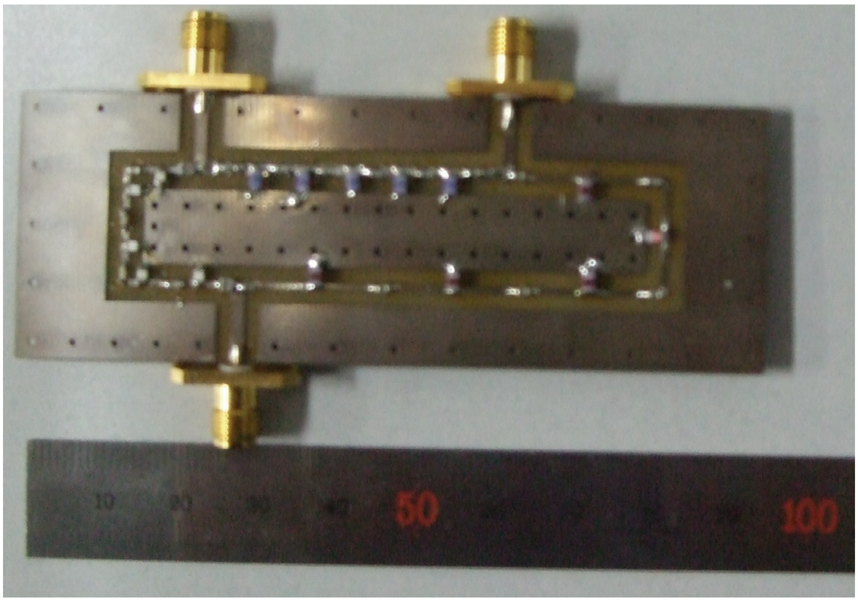
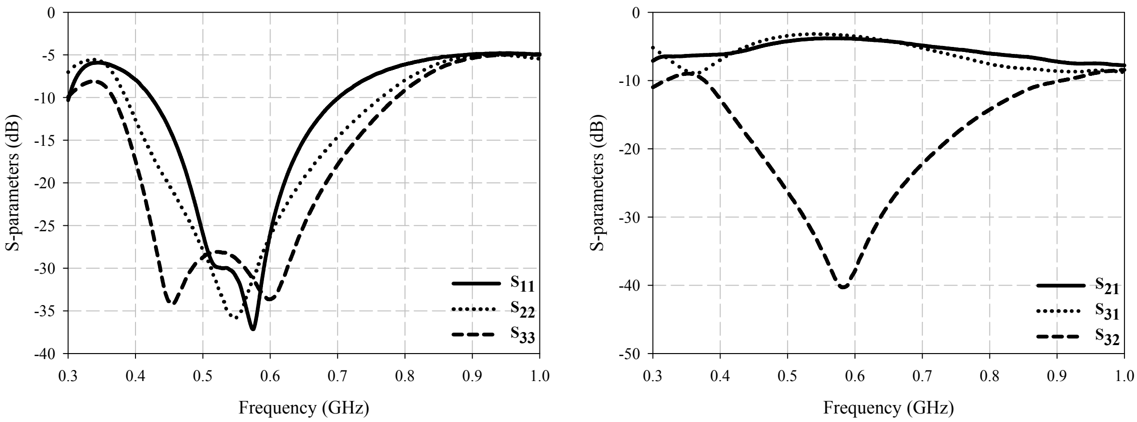


Figure 3: Fabricated compact broadband balun



(a) Return losses (b) Insertion losses and isolation

Figure 4: Measured S-parameters of the designed balun

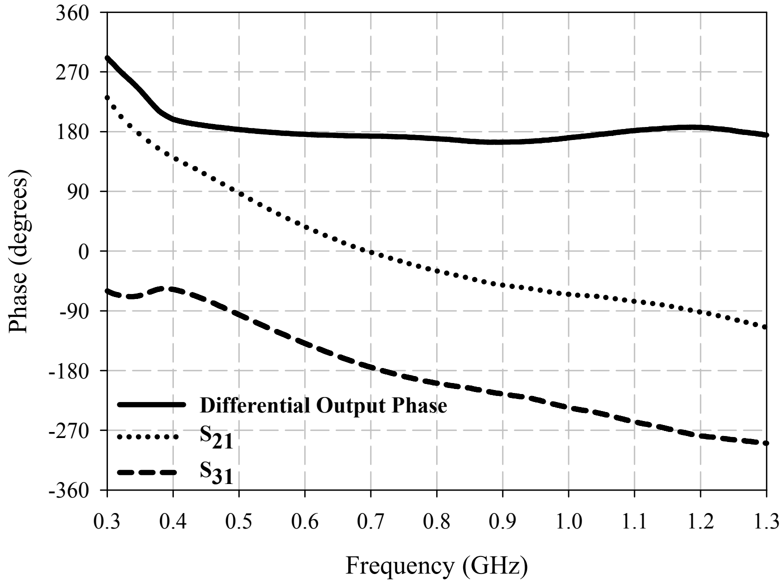


Figure 5: Measured phase responses of the designed balun

Table 1: The various parameters of each phase shifting MTM TL

	+90°	-90°	+180°
L_0	42 nH	470 nH	18 nH
C_0	8.4 pF	94 pF	7.2 pF
d_0	6 mm	16 mm	5 mm
n	5	5	5

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