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A novel two section branch line coupler employing different transmission line techniques

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ABSTRACT

In this paper, a 3 dB wideband branch line coupler with reduced size and harmonic suppression is presented. New multiple asymmetric π-shaped, cross and T-shaped transmission line techniques are used to reduce the physical size of the coupler. At the operating frequency of $f_0 = 0.9$ GHz, the fabricated coupler achieves 15 dB return loss bandwidth of 44.4% with a size reduction of 76.3%. The designed coupler has insertion loss better than 3.6 dB with a magnitude balance of 0 ± 1 dB over the frequency band 0.67–1.05 GHz. In addition to compact design, the unwanted harmonics are well suppressed up to $4f_0$ with a level better than 20 dB by maintaining good agreement between the measured results and theoretical predictions.

1. Introduction

Branch line coupler is one of the basic circuit components in microwave and millimeter wave communication systems and widely used in many applications such as power dividers, power combiners, balanced mixers, image rejection mixers and balanced amplifiers. Modern communication systems require compact, broadband and cost-efficient components. Therefore, size reduction, bandwidth enhancement, cost reduction and high performance are the essential requirements for the design of branch line couplers (BLCs). The bandwidth of single section branch line coupler comprises of four quarter wavelength transmission line sections is very less. In order to improve the bandwidth, several sections have been cascaded [1,2]. But the cascaded sections occupy larger area at lower microwave frequencies. To design a compact BLC, several size reduction techniques have been proposed, such as high impedance transmission lines and interdigitated shunt capacitors [3], partially meandered lines and dual transmission lines [4], recursively loaded stubs [5], meander T- shaped lines [6], folding technique and surrogate-based optimization (SBO) [7], etc. A compact broad band branch line coupler using parallel capacitance and stepped impedance transmission line is reported in [8]. Quarter wavelength open circuited coupled lines are used to realize a wideband 3 dB branch line coupler with a fractional bandwidth of 49% [9]. In [10], a wideband BLC is proposed using nonuniform lines governed by a truncated Fourier series, but the reported design is occupying a large area of $0.25\lambda_g \times 0.75\lambda_g$. Mixed type branch line couplers utilizing T-shaped and Pi-shaped structures with shunt capacitors and open stubs are reported in [11]. The 15 dB return loss bandwidth of the demonstrated mixed type three-branch coupler is 26.3% only and the 3 dB power division is also very poor. A three-branch hybrid designed using lumped distributed elements obtained a fractional bandwidth of 45% [12]. By combining various size reduction techniques like meander line, cross and two step stubs, a compact BLC with fractional bandwidth of 50% is proposed in [13]. A transmission line consisting of single stepped impedance and multiple stepped impedance structures is utilized to design a two section branch line coupler with a fractional bandwidth of 31% and offers size reduction above 60% [14]. Recently, a three section branch line coupler is realized using triple open complementary split ring resonator and open stubs [15]. The proposed coupler occupied an area of 17.46% of the conventional one and the fractional bandwidth obtained is 53%.

In this work, a new multiple asymmetric π-shaped structure is proposed to reduce the size and improve the performance of microwave devices like power dividers and couplers. To validate the size reduction capability of the proposed unit, the horizontal quarter wavelength transmission lines of the conventional two section BLC are replaced using multiple asymmetric π-shaped structure. The designed BLC obtained a size reduction of 72.2%. Furthermore, to reduce the size of the coupler, T-shaped and cross-shaped equivalent lines are used to replace the side vertical branches and the center vertical branch respectively. A wideband branch line coupler operating at 0.9 GHz is simulated, fabricated

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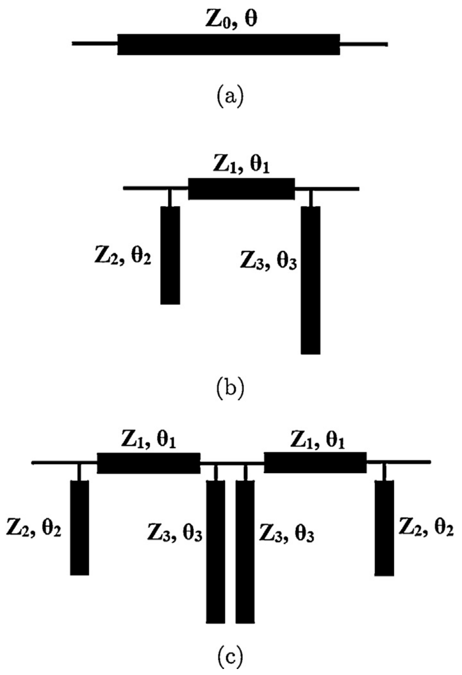

Fig. 1. Layout of (a) conventional transmission line, (b) asymmetric π-shaped transmission line and (c) multiple asymmetric π-shaped transmission line.

and tested. The measured results shows that the 2nd, 3rd and 4th harmonics are suppressed with a level better than 20 dB and the prototype occupies only 23.7% area of the conventional one.

2. Proposed multiple asymmetric π-shaped structure analysis and design of BLC

2.1. Multiple asymmetric π-shaped transmission line

Fig. 1(b) shows the layout of a asymmetric π-shaped transmission line. It consists of two shunt open stubs (Z_2, θ_2) and (Z_3, θ_3) separated by a series transmission line (Z_1, θ_1). The multiple asymmetric π-shaped transmission line is obtained by back to back connection of two asymmetric π-shaped transmission lines as shown in Fig. 1(c). To replace the conventional quarter wavelength transmission line with the proposed unit, the ABCD matrices of the conventional and the proposed transmission lines must be equated to obtain the equivalent impedance relations.

The ABCD matrix of the structure in Fig. 1(c) can be represented as

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = T_1T_2T_3T_3T_2T_1 \tag{1}$$

where

$$T_1 = \begin{bmatrix} 1 & 0 \\ \dfrac{j\tan\theta_2}{Z_2} & 1 \end{bmatrix} \tag{2}$$

$$T_2 = \begin{bmatrix} \cos\theta_1 & jZ_1\sin\theta_1 \\ \dfrac{j\sin\theta_1}{Z_1} & \cos\theta_1 \end{bmatrix} \tag{3}$$

$$T_3 = \begin{bmatrix} 1 & 0 \\ \dfrac{j\tan\theta_3}{Z_3} & 1 \end{bmatrix} \tag{4}$$

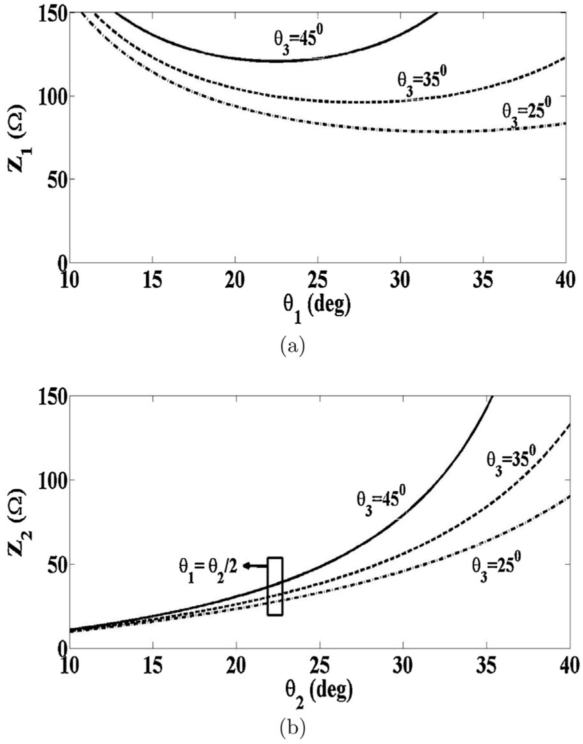

Fig. 2. Design curves for (a) Z_1 versus θ_1 and (b) Z_2 versus θ_2 ($Z_0 = 50\,\Omega$ and $\theta = 90^\circ$).

Now the ABCD matrix of the quarter wavelength transmission line can be written as

$$\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} 0 & jZ_0 \\ \dfrac{j}{Z_0} & 0 \end{bmatrix} \tag{5}$$

Then by equating (1) and (5), Z_1 and Z_2 can be solved as

$$Z_1 = \frac{Z_0}{\sin 2\theta_1 - 2K\sin^2\theta_1\tan\theta_3} \tag{6}$$

$$Z_2 = \frac{Z_0\tan\theta_2}{\cos 2\theta_1 - K\sin 2\theta_1\tan\theta_3} \tag{7}$$

where K=Z_1/Z_3

The transcendental Eqs. (6) and (7) are solved graphically. These provide the design curves for the impedances and electrical lengths of the equivalent multiple asymmetric π-shaped structure. For a 90° transmission line with impedance 50 Ω, Fig. 2(a) represents Z_1 plotted against electrical length θ_1 for three different values of θ_3 and likewise Fig. 2(b) shows Z_2 versus θ_2 for a ratio of θ_2/θ_1 and three different values of θ_3. From (6), considering $K = 1$ and $\theta_3 = 45^\circ$, the equivalent impedances of the multiple asymmetric π shaped structure for $Z_0 = 50\,\Omega$ are obtained as $Z_1 = Z_3 = 141.9\,\Omega$ for $\theta_1 = 14^\circ$ and $Z_2 = 64.3\,\Omega$ is obtained from (7) by choosing $\theta_1 = 14^\circ$ and $\theta_2 = 28^\circ$. The proposed unit electrical length is 28° and is 68.89% smaller than the conventional 50 Ω quarter wavelength transmission line.

2.2. Design of wideband BLC

Fig. 3 shows the schematic diagram of the traditional two section wideband branch line coupler. The optimized impedance values are $Z_A = 38\,\Omega$, $Z_B = 106\,\Omega$ and $Z_C = 50\,\Omega$ [2]. All transmission lines are quarter-wavelength long at the operating frequency.

To make this circuit compact, the conventional quarter wavelength transmission lines are replaced by their equivalent