Design of Compact Branchline Balun

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Abstract. This paper presents the compact branch line balun to operate at the frequency range of 2.4GHz. The compact branchline balun is designed using the substrate material with the dielectric constant of FR4 material. The proposed balun is designed using different transmission lines. Thus the balun should achieve -3dB power division and 180° phase differences between the outputs. The main objective of this design focuses on size reduction. To reduce the size, a balun is realized using the equivalent T-shape structure. After the reduction techniques the implemented size of the balun is 29.41x44.32 mm² achieves 35% of size reduction. Thus the measured S11 are -23 dB and the S21, S31 remains -3dB and provide 179° phase difference between the outputs at the frequency of 2.4GHz.

Keywords. Branchline balun, Transmission lines, Size reduction, T-shaped structure.

1. Introduction

A balun is a device used to balance the unbalanced one. A branch line balun is an important feature for designing microwave circuits. The baluns are used in various applications such as mixers, amplifiers, frequency multipliers, couplers and so-on. They are widely used in antennas to balance the circuit design. The microstrip balun are also used in many microwave applications. There are many types of baluns-the designs structures are generally depending on the bandwidth, operating frequency, physical architecture of the network. The branchline balun provide equal amplitude and phase difference between the circuit design. The branchline balun increases the complexity and also achieves better return loss and isolation loss. The branchline balun provide wider bandwidth.

This paper focus on size reduction of the balun with 180° of phase differences. The proposed balun is designed using different transmission lines composed of two λ/4 transmission lines on horizontal branches and two λ/2 transmission lines on vertical branches. The characteristic impedances of the balun are √2Z₀ = 70.7Ω. When the transmission lengths are reduced, characteristics impedances are increased. The size reduction depends on higher impedance transmission lines. By decreasing the length of transmission lines, the entire size of the structure can became compact. In this paper, the reduced size of the balun is presented.

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2. Related works

M. Y. Algumaeiet. al [1] has proposed single balanced mixers for ultra wide band applications. This balun operates at the frequency of 100MHz. Thus the design obtain the phase difference of 180° with the conversion loss of 19dB from 3.1 -10 GHz. Mi Zhou et.al [2] has designed a novel planar branch line balun with the symmetrical network with the transparent port impedance. The balun achieves 180° phase difference with the better return loss of -30dB operates at the frequency of 1GHz. Li Chang et.al [3] has demonstrated dual band branch line balun at two different frequencies of 1.5 & 2.5 GHz. The simulated return loss are 16.5dB and also attains 180° phase difference between the output ports. Chih-Jung Chen et.al [4] has implemented derivation of T-shaped structures for quarter wave transmission lines at the frequency of 2.4 GHz and achieves 180° phase difference. He-XiuXuet. al [5] has proposed a compact balun with enhanced bandwidth with the operating frequency of 1.5 GHz and attains a return loss of 10dB and good amplitude and phase imbalance. Myun-Joo Park [6] has used stubs for reducing the branch length in order to reduce the area of the balun at the centre frequency of 1GHz. Hee-Ran Ahn [7-8] has designed miniturized balun at the centre frequency of 900 MHz with short coupled lines to obtain 180° phase difference. Ming-Guang Chen [9-10] has implemented miniatuirzed balun design with 2.4GHz for dual band transmission line with 60% size reduction.

3. Structure Description and Analysis

A balun is a three port network with port 1 as a input and port 2 and port 3 as a outputs. Thus each port act as a transmitter and receiver. The structured branch line balun (Fig.1) where \( Z_A \) and \( Z_B \) represents the characteristic impedance \( \sqrt{2} Z_0 = 70.7 \Omega \) whereas the wavelength of \( Z_A \) and \( Z_B \) represent the quarter wavelength transmission line (\( \lambda/4 \)) and the half wavelength transmission line (\( \lambda/2 \)). The length and width of both the transmission lines are calculated and are mentioned in Table1. The input signal should split equally between the output ports. Thus the balun should provide -3dB power division and 180° phase difference between the two output ports.

| Parameter | Length(mm) | Width(mm) |
|-----------|------------|-----------|
| \( Z_0 \) | 17.2       | 3.058     |
| \( Z_A \) | 17.54 (\( \lambda/4 \)) | 1.623     |
| \( Z_B \) | 35.08 (\( \lambda/2 \)) | 1.623     |

Table 1. Dimensions of Balun

Figure 1. Structure of Branch line Balun
The balun is optimized and simulated using ADS software with dielectric constant $\varepsilon_r = 4.4$ (FR4 substrate) and at the thickness of $h$ is 1.6mm. The scattering parameter of this balun is simulated by the Electromagnetic (EM) simulation tool over the frequency of 2.4GHz. Thus the simulated $S_{21}$, $S_{31}$ are -3.453 and -3.340 dB. The obtained $S_{11}$ are -31 dB over the same frequency. The implemented size of the branch line balun are 38.32 x 51.78 mm$^2$. Therefore the balun obtains 178° phase differences between the output $S_{21}$, $S_{31}$ over 2.4 GHz. The main focus of the balun focus on size reduction technique.

4. Size Reduction Technique

The size reduction technique or miniaturization of the balun can be implemented using various design procedures such as T-shaped structure, stepped impedance of the balun, by adding stubs along its branches, by using different transmission lines. In this proposed design size reduction is done by the equivalent T-shaped structure. The Proposed balun of $\lambda/4$, $\lambda/2$ transmission lines are replaced by the equivalent T-shaped structure is shown in Fig 5.a. The compact T-shaped structure can be obtained from the
following cases, Where
\[ M = \frac{Z_1}{Z_0} \]  
\[ K = \frac{Z_1}{Z_2} \]  
Thus the total electrical length \( \Theta_T = 2\Theta_1 + \Theta_2 \). In order to avoid the overlapping between the stubs length \( \Theta_2 \) should be lesser than \( \Theta_1 (\Theta_1 < \Theta_2) \) and the stub length of \( \Theta_2 \) should be plotted against \( M \) or \( \Theta_1 \) can be plotted for the different values of \( K \). The total electrical length \( \Theta_T \) decreases when \( K \) increases, where the \( \Theta_T \) depends only on \( M \).

Therefore, \( \tan \Theta_1 = \frac{1}{M} \)  
\( \tan \Theta_2 = \frac{1}{K} (\cot \Theta_1 - \tan \Theta_1) \)  
First select the parameter for the T-shaped structure whose characteristics impedance \( Z_0 = 70.7\Omega \), where, \( Z_1 = MZ_0 = 155.54\Omega \) for \( M = 2.2 \) of \( \Theta_1 = 24.5^\circ \) such that \( Z_2 = Z_1/K = 38.85\Omega \) for \( K = 4 \) of \( \Theta_2 = 23.5^\circ \). Thus the total electrical length \( \Theta_T = 73^\circ \). Thus the calculated length and width for \( Z_1 \) and \( Z_2 \) are shown in Table 2.

Table 2. Dimensions of conventional Balun

| Parameter | Length(mm) | Width(mm) |
|-----------|------------|-----------|
| \( Z_1 \) | 5.046      | 0.143     |
| \( Z_2 \) | 4.359      | 5.568     |

Thus the Proposed branchlinebalun can be realized by the vertical and horizontal branches of T-shaped structure such that the total electrical length will be \( \Theta_T = 73^\circ \) for both the branches.

5. Results And Discussion

Thus the Proposed T-shaped balun is designed and simulated using the ADS software are shown in Fig.6 with its dimensions. The balun operates at the frequency of 2.4GHz. Thus the structural balun achieves 38 x 51mm\(^2\) of size while the proposed balun achieves 29 x 44mm\(^2\) of size. Therefore the balun achieves 35% size reduction.
The simulated $S_{21}$, $S_{31}$ are -3.510/-3.066 and simulated $S_{11}$ are -23dB. Therefore the balun obtains 179° phase differences between the output $S_{21}, S_{31}$ of the same frequency of 2.4 GHz. The bandwidth is about 200MHz for $S_{11}$. Also the output of $S_{21}$ lies at constant -3dB from frequency of 2.2 to 2.9GHz and the bandwidth of $S_{21}$ is 700MHz while the output of $S_{31}$ remains at constant -3dB from the frequency of 2.3to2.9 GHz and the obtained bandwidth is 600MHz. The phase imbalance of compact branch line balun is shown in Fig.8. Thus the total phase difference between $S_{21} & S_{31}$ is 179°. The proposed balun obtains 35% of size reduction. Thus the balun achieves better return loss and insertion loss and also results in good amplitude and phase imbalance[11-13].

Thus the performance of the proposed balun parameters are compared with the structural branch line balun is shown in Table3. Thus the proposed design obtain better results and provide good amplitude and phase imbalance and also obtain 179° phase difference between the two output. Therefore 35% size reduction is achieved. Thus the performance of the proposed balun parameters are compared with the structural branch line balun.

| Parameters                        | Structural Balun | Proposed Balun |
|-----------------------------------|------------------|----------------|
| Frequency                         | 2.4 GHz          |                |
| Size (mm²)                        | 38 x 51          | 29 x 44        |
| $S_{11}$(dB)                      | -31.369          | -23.071        |
| $S_{21},S_{31}$ (dB)              | -3.453, -3.340   | -3.510, -3.066 |
| Phase difference between $S_{21},S_{31}$ (°) | 1780             | 1790           |
6. Conclusion

This paper demonstrates the compact branch line balun with reduced size. To reduce the size, a balun is realized using the equivalent T-shape structure. The T-shaped structures presents the closed form of line equations of both quarterwave and halfwave length transmission lines. After the reduction techniques the balun achieves 35% size reduction. Thus the Branch line balun achieves better return loss and provides good amplitude and phase difference. It provides enhanced bandwidth with low loss and low cost.

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