

A BROADSIDE-EDGE-COUPLED VIALESS BALUN

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Abstract — This paper presents the design procedure for a new two-level vialess balun configuration. Simple design equations are reported for designing the impedance transforming balun in broadside-edge-coupled configuration. The balun is realized in a six-conductor line two-layer topology with no ground connections and interconnecting vias. The simulated results are validated by full-wave electromagnetic simulation and found to be in good agreement.

I. INTRODUCTION

Baluns are passive components which transform the unbalanced input to balanced outputs having equal magnitude and 180° phase shift. This component is essential in several circuits including balanced mixers, antenna feed networks, multipliers or push-pull amplifiers, which rely on balanced signals to achieve broadband isolation and spurious signal cancellation. A large number of balun configurations have been reported by several researchers over the years. Among them, the planar version of Marchand balun [1] is the most popular one because of its ease of implementation and wide bandwidth. Several variations of Marchand-type baluns have been extensively studied in the past which include implementations using coupled microstrip lines [2], Lange couplers [3] and spiral coils [4, 5]. With the recent advances in three-dimensional MMIC technology and multilayer ceramic (MLC) technology, multilayer-multiconductor topologies have become popular due to their compact footprint. Accordingly, several multilayer realizations of balun configurations have been recently reported [6-9]. However, multilayer realizations often require interconnecting vias and ground connections that could lead to complex layouts resulting in tighter fabrication tolerances.

In this paper, the analysis and design procedure for a compact, impedance-transforming, broadside-edge-coupled balun consisting of folded coupled lines in a two-layer medium is presented. Simple closed-form design equations are derived for the new configuration in terms of the modal admittances. The paper also presents the layout implementation in a two-layered medium with no connecting vias between conductors

or to the ground without compromising the performance of the balun over the desired bandwidth. The simulation results are validated by the full-wave electromagnetic simulation using Agilent Momentum.

II. THEORY

Fig.1a shows the conventional planar version of Marchand balun consisting of two coupled line sections connected together to function as a balun transformer. In Fig. 1b, we propose a more compact version in a two-level environment using broadside-edge-coupled configuration. All four conductors have a common width w with an edge-coupled spacing of s and broadside coupled spacing of d to facilitate the development of simple design equations.

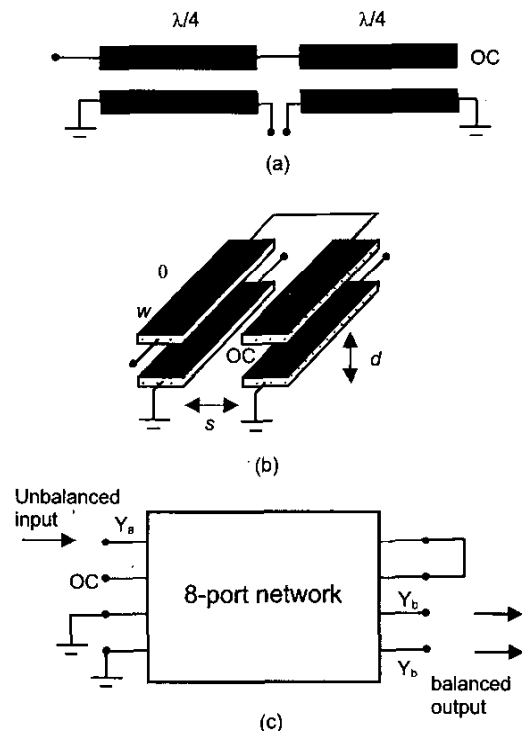


Fig.1 (a) Conventional printed Marchand balun (b) Proposed broadside-edge-coupled configuration (c) network representation of the new configuration

Considering the planes of symmetry as magnetic and electric walls, respectively, this structure supports four modes of propagation viz. even-even, even-odd, odd-even, and odd-odd whose transmission-line characteristics are reported in [10].

The equivalent network representation of the proposed configuration is given in Fig. 1c. Here, the broadside-edge-coupled stripline is represented as an eight-port network, whose admittance matrix can be written as

$$Y = \begin{bmatrix} -j[Y_m]\cot\theta & j[Y_m]\operatorname{cosec}\theta \\ j[Y_m]\operatorname{cosec}\theta & -j[Y_m]\cot\theta \end{bmatrix} \quad (1)$$

where θ is the electrical length of the line and $[Y_m]$ is the 4×4 characteristic admittance matrix expressed in terms of the even-even, even-odd, odd-even and odd-odd modal admittances Y_{ee} , Y_{eo} , Y_{oe} and Y_{oo} respectively. For a quarter-wave length at the center frequency, the three-port scattering matrix of the balun can be written as

$$S = \frac{1}{2Y_o^2 + (Y_{oo} - Y_{oe})^2} \begin{bmatrix} 2Y_o^2 - (Y_{oo} - Y_{oe})^2 & 2jY_o(Y_{oo} - Y_{oe}) & -2jY_o(Y_{oo} - Y_{oe}) \\ 2jY_o(Y_{oo} - Y_{oe}) & 2Y_o^2 & (Y_{oo} - Y_{oe})^2 \\ -2jY_o(Y_{oo} - Y_{oe}) & (Y_{oo} - Y_{oe})^2 & 2Y_o^2 \end{bmatrix} \quad (2)$$

where

$$Y_o = \sqrt{Y_a Y_b} \quad (3)$$

and Y_a and Y_b are the terminating admittances for the unbalanced and balanced ports respectively. We can obtain the desired design equation for the balun by setting S_{11} in (2) to be equal to zero as

$$Y_{oo} - Y_{oe} = \sqrt{2Y_a Y_b} \quad (4)$$

It may be noted that substitution of (4) in (2) gives the three-port S-parameters of an ideal balun. From (4), it is interesting to note that the functionality of the balun is essentially decided by only two modal admittances viz. Y_{oe} and Y_{oo} . For any given set of conductor spacings, s and d , (4) can be satisfied by tuning the conductor width w . This gives the designer a wide choice of physical parameters to choose from, for a given dielectric constant of the medium. Based on the variational technique and unified approach described in [10], a software program is developed to synthesize the

physical configuration of the broadside-edge-coupled line for a given set of four modal admittances.

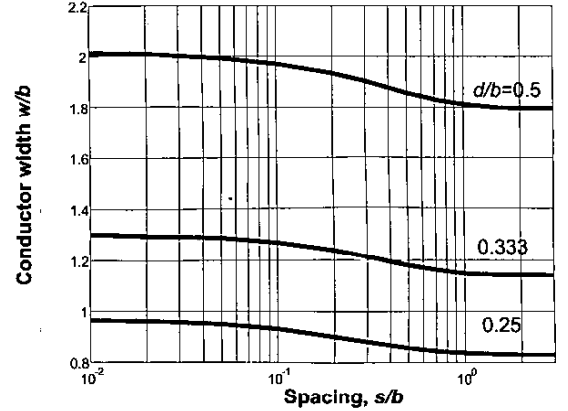


Fig.2 Variation of conductor width, w/b as a function of edge-coupled spacing s/b for different values of broadside-coupled spacing, d/b for $S_{11}=0$ for the balun (homogeneous medium with $\epsilon_r=2.2$).

Fig.2 presents the design graph for the new balun configuration in a homogeneous medium with a dielectric constant of $\epsilon_r=2.2$. The termination impedances for the input and output are considered to be $Z_a = Z_b = 50\Omega$. For a given set of normalized edge-coupled and broadside-coupled spacings, s/b and d/b respectively (where b is the ground plane spacing), normalized conductor width w/b , which satisfies (4) to give a zero input reflection coefficient at the center frequency, is plotted.

To illustrate the simplicity of the design procedure, the balun topology shown in Fig. 1b is designed at a center frequency of 1.8 GHz. The frequency response of the balun in terms of the S-parameters is plotted in Figs.3a and 3b. The response is computed for a d/b ratio of 0.333 and for three different values of $s/b = 0.1, 0.5$ and 1. From the design graph shown in Fig.2, the values of w/b were readily found as 1.27, 1.181 and 1.15 respectively. For a very tight edge-coupling ($s/b = 0.1$), the bandwidth of the balun is observed to be marginally reduced. Due to the ideal nature of the interconnections and ground connections, the amplitude and phase balance are computed to be nearly equal to zero at all computed frequencies.

III. VIALESS IMPLEMENTATION

Fig. 4 shows the proposed vialess implementation of the broadside-edge-coupled balun. Here, the two ground connections on the bottom layer are eliminated by extending the line length and folding it on either

side to form a six-coupled line configuration. As the balun is quarter-wave length long at the center frequency, the foldings can be easily implemented as the extended line lengths are also of quarter-wavelength. The conductor width is maintained to be the same for both layers. Small lengths of interconnecting transmission lines are introduced on both the layers for connecting the coupled line sections.

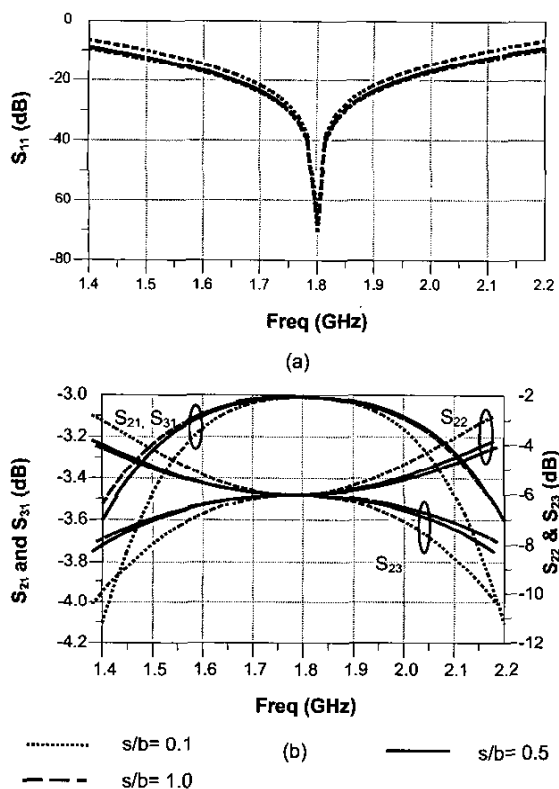


Fig.3 Frequency response of the balun topology shown in Fig1b for different edge-coupled spacings, s/b

As a design example, the balun is designed at 1.8 GHz in a homogeneous stripline medium with a dielectric constant of $\epsilon_r=2.2$ and a ground-plane spacing, $b=60$ mil. The thickness of the middle dielectric layer is considered to be 20mil ($d/b=0.333$). The input and output terminating impedances are assumed to be 50Ω . An initial design is carried out using the design equation (4), and the physical dimensions w and s_1 are found to be 1.8 mm and 1.524 mm respectively. The second spacing, s_2 is arbitrarily chosen to be 2 mm. The ideal length of balun is calculated to be $\lambda/4=28.1$ mm at the center frequency. The length of the balun is adjusted to compensate for the additional phase delay that has been introduced due to the 90° bends and small

lengths of transmission lines connecting the coupled lines. The tuned length of the six-coupled-line section is found to be 25.1 mm.

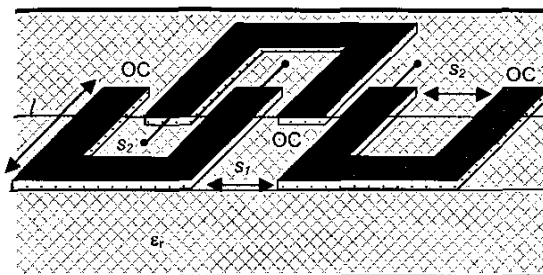
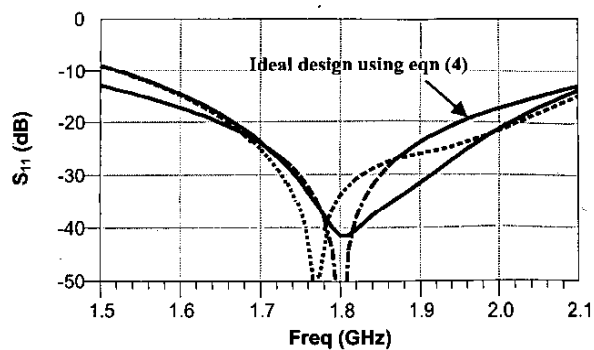


Fig.4 Implementation of vialess balun configuration

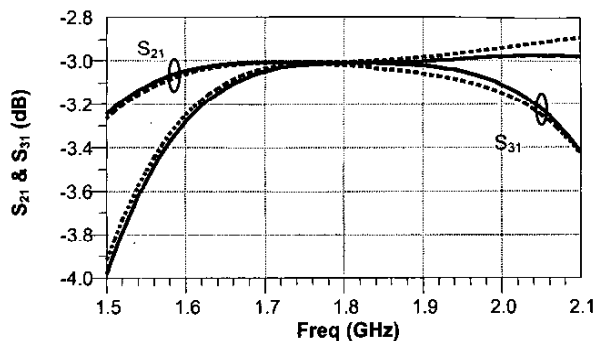
Fig. 5 shows the simulated theoretical response of the balun and a comparison with the full-wave electromagnetic simulation using Agilent-Momentum. The results show very good agreement. The input return loss, S_{11} for the ideal design in Fig. 1b, theoretical and EM simulated response for the structure in Fig. 4 are plotted in Fig. 5a. It may be observed that S_{11} is better than -20 dB over the frequency band 1.6-2.0 GHz. The slight shift in the center frequency is attributed to broadside-coupling between the 90° bends, which is not taken into account in the theoretical calculations. The return loss at 1.77 GHz is found to be around -50 dB. The transmission losses, S_{21} and S_{31} are plotted in Fig. 5b. The amplitude balance and phase balance of the balun are shown in Figs. 5c and 5d. It may be observed that the balun has an amplitude balance of < 0.2 dB over 1.6 - 2.0 GHz and a phase balance of $\pm 4.8^\circ$ from 1.6- 2.0 GHz. The Agilent-Momentum layout of the designed balun is shown in Fig.6. The balun has a footprint of 12.7mm x 26.6 mm.

IV. CONCLUSION

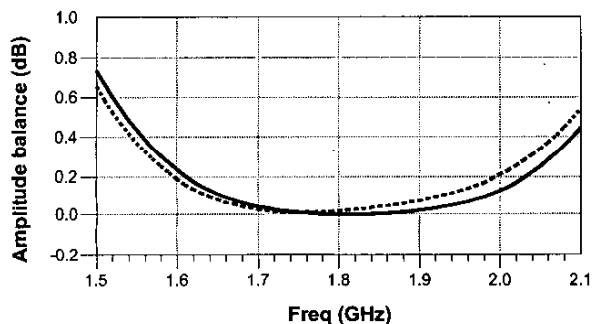
A simple design procedure, which did not require any optimization for a two-level broadside-edge-coupled impedance transforming balun has been presented. Closed-form expressions and a design graph have been reported to design the new balun configuration. The new topology has been implemented with no interconnecting or ground vias in two-layer homogeneous stripline geometry and the theoretical results have been validated by the full-wave simulation. The balun reported compact footprint, good input return loss, amplitude and phase balances at the output ports. The new topology should prove useful for easier implementation in LTCC and MMIC technologies for a variety of applications.



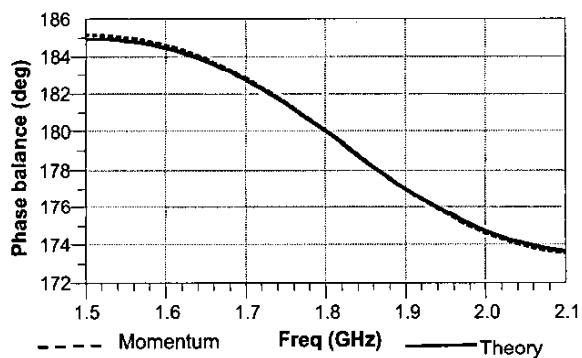
(a)



(b)



(c)



(d)

Fig.5 Frequency response of the vialess balun

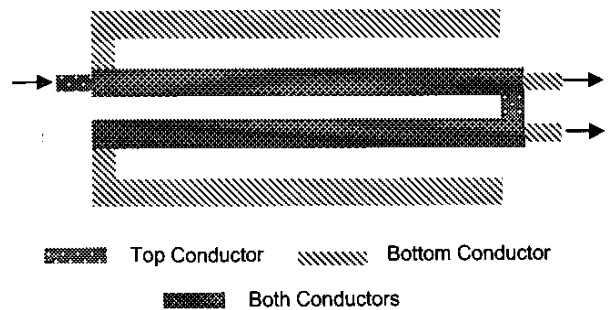


Fig.6 Agilent-Momentum layout for the new balun

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