A NEW DESIGN PROCEDURE FOR SINGLE-LAYER AND TWO-LAYER 3-LINE BALUNS

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Abstract

This paper describes a design procedure for a class of 3-line baluns. It is shown that the balun can be considered as a combination of two identical couplers. Thus the method developed uses the design of couplers with an appropriate coupling factor for designing this class of baluns. This procedure has been implemented for 2-layer configurations and verified by comparison with results from a full-wave electromagnetic simulation.

I. INTRODUCTION

Many microwave applications need the balun which transforms a balanced transmission signal to an unbalanced transmission signal and vice versa. These include double balanced mixers, push-pull amplifiers, antenna feed networks, frequency doublers and etc. A large number of balun configurations have been reported in literature. For use in monolithic and hybrid microwave/millimeter-wave circuits, wide bandwidth and compactness of baluns are of high interest. A compact configuration reported recently in literature [1] is shown in Figure 1. However, a design procedure for implementing this configuration in single layer or two-layer geometry has not been available.

In this paper, we describe a generic approach suitable for designing this 3-line balun configuration. It can be shown that this 3-line balun configuration can be considered as a combination of two identical couplers. This representation is the key step in the design procedure developed. The procedure has been used for designing two-layer baluns. The approach is verified by comparing the results with full-wave simulation results.

II. DESIGN PROCEDURE

A. Representation of 3-line balun by 2-line couplers

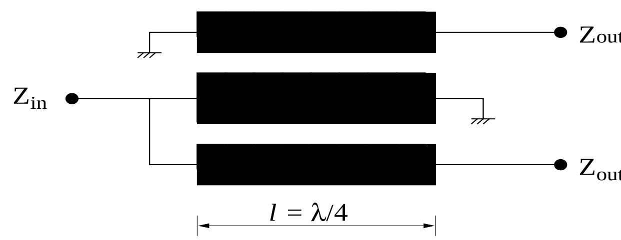

Figure 1: The general configuration of a 3-line balun

Considering the central strip of 3-line configuration shown in Figure 1 to be bifurcated in two strips which are isolated, one can derive an equivalent configuration shown in Figure 2. The configuration of Figure 2 can behave like a balun when:

$$[S]_{circuitA} = \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}, [S]_{circuitB} = \begin{bmatrix} 0 & -j \\ -j & 0 \end{bmatrix}.$$

The combination of these two 2-line coupler circuits yields the following S-parameters and functions as a balun:

$$[S]_{balun} = \begin{bmatrix} 0 & j/\sqrt{2} & -j/\sqrt{2} \\ j/\sqrt{2} & 1/2 & 1/2 \\ -j/\sqrt{2} & 1/2 & 1/2 \end{bmatrix}.$$

These conditions can be satisfied when (i) the two couplers have a coupling factor which is related to the port impedances (Z_{01}, Z_{02}) of the two couplers as:

$$\beta = \frac{1}{2}\sqrt{\frac{Z_{02}}{Z_{01}}} \tag{1}$$

and (ii) the coupler port impedances and balun input/output impedances (Z_{in}, Z_{out}) are related as:

$$Z_{02} = 4Z_{01} - \frac{2Z_{in}Z_{out}}{Z_{01}} \tag{2}$$

$Z_{01}(\Omega)$	$Z_{02}(\Omega)$	β(Coupling factor)
38	20.42	0.367
40.825	40.825	0.5
50	100	0.707

Table 1: Some choices of Z_{01}, Z_{02} and for balun input/output impedances $Z_{in} = Z_{out} = 50\Omega$

We note that for a given set of Z_{in} and Z_{out}, the values of Z_{01} and Z_{02} are not unique. For example when $Z_{in} = Z_{out} = 50\Omega$, any of the combinations shown in Table 1 will satisfy equations (1) and (2). However, if we constrain $Z_{01} = Z_{02} = Z_0$, then $\beta = 0.5$ and $Z_0 = \sqrt{2Z_{in}Z_{out}/3}$.

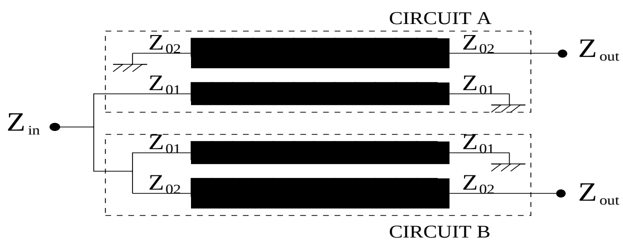

Figure 2: A 3-line balun composed of two 2-line couplers

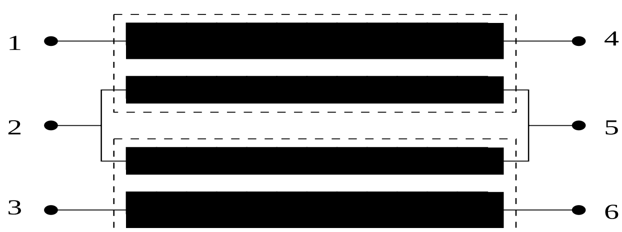

Figure 3: 6-port network combination of two couplers

B. Normal mode parameters for 3-coupled lines

The normal mode parameters of the 3-coupled lines used in the balun of Figure 1 can be found by equating 6-port [Y] matrix of these 3-coupled lines to the [Y] matrix of the 6-port circuit shown in Figure 3. This leads to:

$$Y_{m1} = \frac{R_\pi Y_{c1} - R_c Y_{\pi 1}}{R_\pi - R_c} \tag{3}$$

$$\frac{Y_{p1} - Y_{n1}}{R_{V1} - R_{V2}} = \frac{Y_{c1} - Y_{\pi 1}}{R_\pi - R_c} \tag{4}$$

$$\frac{R_{V2}Y_{p1} - R_{V1}Y_{n1}}{R_{V1}R_{V2}(Y_{p1} - Y_{n1})} = \frac{R_c Y_{c1} - R_\pi Y_{\pi 1}}{R_c R_\pi (Y_{c1} - Y_{\pi 1})} \tag{5}$$

$$\frac{R_{V1}Y_{p1} - R_{V2}Y_{n1}}{Y_{p1} - Y_{n1}} = \frac{R_\pi Y_{c1} - R_c Y_{\pi 1}}{Y_{c1} - Y_{\pi 1}} \tag{6}$$

where R_{V1}, R_{V2} are the voltage ratios and Y_{m1}, Y_{n1}, Y_{p1} are the admittances of 3 normal modes (m, n, p modes) for 3-coupled lines [2], and $R_c, R_\pi, Y_{c1}, Y_{\pi 1}$ are $c-$ and π-mode voltage ratios and admittances for 2-line couplers [3, 4, 5]. It is noted that we have only 4 equations (3-6) for 5 independent values ($R_{V1}, R_{V2}, Y_{m1}, Y_{n1}$ and Y_{p1}) of NMP(Normal Mode Parameters) of 3-coupled lines. Thus one of these parameters needs to be selected independently and this choice will lead to different designs for the balun.

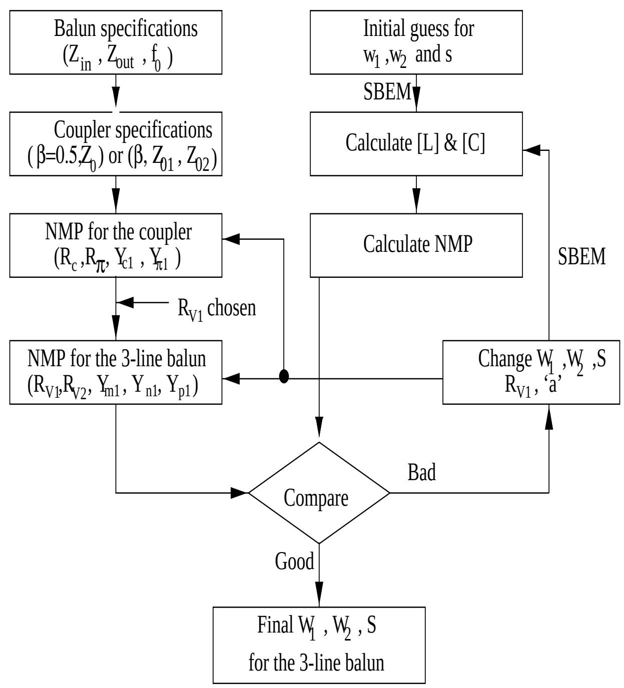

Figure 4: A design procedure for 3-line baluns

C. Physical geometry for the 3-line balun

Physical geometry is determined by an optimization process. This process repeatedly compares the desired NMP for 3-coupled lines evaluated in Section II.B with NMP calculated from a selected geometry for 3-coupled lines. A quasi-static field analysis program *SBEM* (Segmentation and Boundary Element

Method) [4] has been used to calculate inductance and capacitance matrices for specific geometries.

The design procedure discussed in this section is summarized in the flow diagram of Figure 4. The electrical part in the left hand column produces NMP for 3-coupled lines, and the physical part in the right hand column finds the physical geometry appropriate for NMP calculated in the electrical part.

The design is verified by simulating the optimized geometry on a full-wave electromagnetic simulator.

III. DESIGN EXAMPLE

We illustrate the procedure developed by two examples for the design of two-layer 3-line baluns shown in Figure 5 and Figure 6. Input parameters and optimized output parameters for these design examples are shown in Table 2 and Table 3. For the $\lambda/4$ length of the balun, the wavelength is taken as the arithmetic mean of phase velocities of 3 normal modes divided by the design frequency.

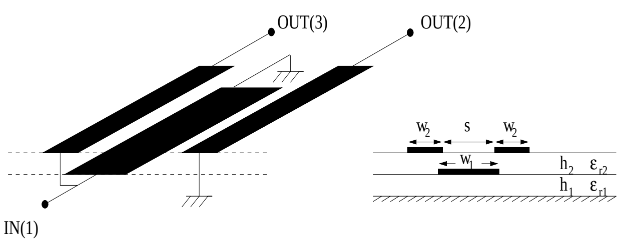

Figure 5: The physical layout of a two-layer 3-line balun (Topology A)

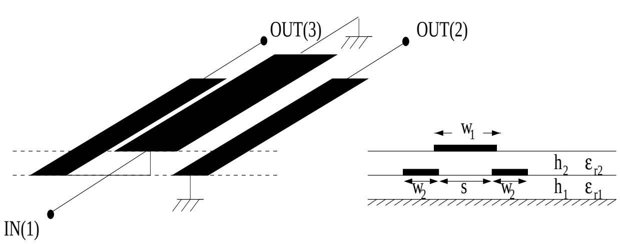

Figure 6: The physical layout of a two-layer 3-line balun (Topology B)

Using the physical geometry obtained above, the 3-line balun structure has been simulated on a full-wave EM simulator (*HP Momentum*). S-parameters obtained from Momentum are compared with the design specification as shown in Figure 7 and Figure 8. The phase balance ($\angle S_{21} - \angle S_{31}$) is also plotted in Figure 9. We note that for topology A, the center frequency is shifted to 2.86 GHz, the amplitude balance at the balanced output ports is within 0.35 dB and

Inputs		Outputs	
h_1	20 mil	Z_{01}	40 Ω
h_2	20 mil	Z_{02}	35 Ω
ϵ_{r1}	2.2	Coupling factor(β)	-6.6 dB
ϵ_{r2}	2.2	W_1	4.280 mm
Z_{in}	50 Ω	W_2	3.643 mm
Z_{out}	50 Ω	S	1.710 mm
		Length(at 3 GHz)	17.749 mm

Table 2: Parameters for the design example of a 3-line balun (Topology A)

Inputs		Outputs	
h_1	20 mil	Z_{01}	43 Ω
h_2	20 mil	Z_{02}	55.7 Ω
ϵ_{r1}	2.2	Coupling factor(β)	-4.9 dB
ϵ_{r2}	2.2	W_1	1.343 mm
Z_{in}	50 Ω	W_2	5.771 mm
Z_{out}	50 Ω	S	0.506 mm
		Length(at 3 GHz)	17.243 mm

Table 3: Parameters for the design example of a 3-line balun (Topology B)

the phase error is less than 9.8° over 2.65 – 3.07 GHz. For topology B, the center frequency is shifted to 2.98 GHz, the amplitude balance at the balanced output ports is within 0.44 dB and phase error is only 0.2° over 2.56 – 3.34 GHz. It may be noted that, as in other synthesis procedures at microwave frequencies, procedure developed here does not take into account via inductances, discontinuity reactances, difference in the phase velocities of 3 normal modes, and dispersion in coupled lines. One needs to compensate for these effects by an optimization of the initial design

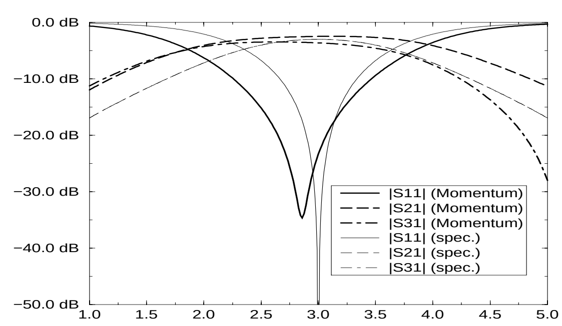

Figure 7: The performance of two-layer 3-line balun (Topology A) designed by the procedure developed and comparison with an 'ideal' balun

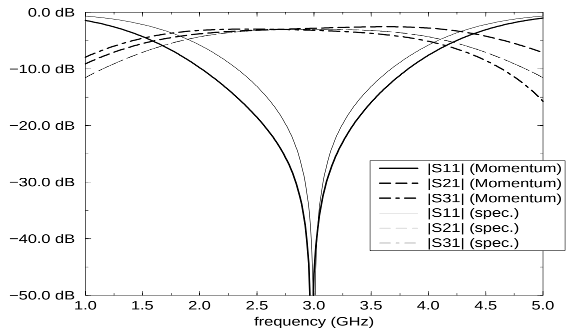

Figure 8: The performance of two-layer 3-line balun (Topology B) designed by the procedure developed and comparison with an 'ideal' balun

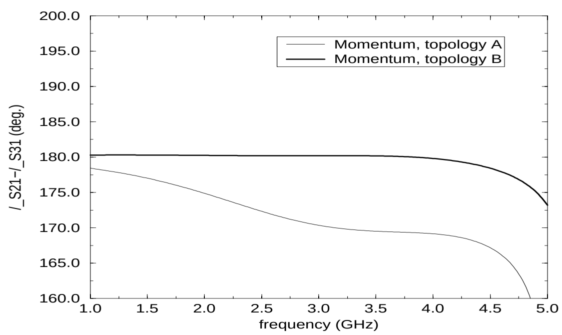

Figure 9: The phase balances of two-layer 3-line baluns designed by the procedure developed

obtained. However, the method developed provides an efficient tool for initial design.

IV. CONCLUDING REMARKS

A design procedure for the three-line balun using the design of a coupler has been presented. The analytical procedure yields normal mode parameters for the coupled lines. Physical geometry is obtained by optimization using a quasi-static analysis program. Alternatively an EM-ANN (Electromagnetic Artificial Neural Network) model could be used for this procedure.

This method was verified by designing two-layer 3-line baluns. Single-layer 3-line baluns can also be designed by this method.

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