On Miniaturization Isolation Network of an All-Ports Matched Impedance-Transforming Marchand Balun

Mitchai Chongcheawchamnan, Choon Yong Ng, Kamorn Bandudej, Apisak Worapishet, and Ian D. Robertson

***Abstract*—A technique for reducing the isolation network's size in a Marchand balun needed for perfect all-ports matching and isolation is proposed in this letter. The proposed isolation circuit is realized using a coupled-line phase-inverter in place of the bulky 180° line section that has been previously proposed. Analysis of the proposed circuit yields the required relationship between the coupling coefficient and the electrical length of the coupler. Based on the design equations, the circuit is experimentally demonstrated at 1.8 GHz and has shown excellent results.**

***Index Terms*—All-ports matching, coupled-line phase-inverter, impedance transforming, Marchand balun.**

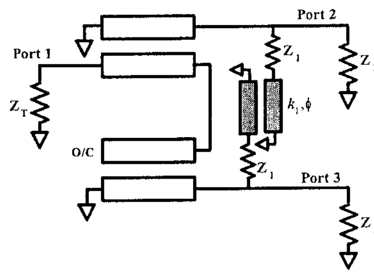

Fig. 1. Schematic of the proposed all-ports matched Marchand balun.

I. Introduction

DUE TO THEIR simplicity and wideband performance [1], Marchand baluns have been extensively applied in balanced mixers and push-pull amplifiers [2], [3]. The balun consists of two coupled-line sections, which may be realized using parallel-coupled microstrip lines, Lange couplers, multi-layer coupled structures or spiral transformers. The Marchand balun can achieve a perfect matching at the unbalanced port but its poor balanced port matching and isolation limits its applications. For example, an extra output impedance-transforming matching network is needed for a push-pull amplifier design if a Marchand balun is applied at the power amplifiers' output.

Perfect balanced port matching and isolation can be achieved by employing an isolation network that consists of two resistors and a half-wavelength transmission line between the balun's balanced ports [4]. This bulky isolation network consumes a large circuit area, hence, a new technique using a physically short phase-inverter network is proposed. The circuit with the proposed isolation network is more compact.

The design equations, based on the ideal transmission line model, are also provided.

II. Proposed Isolation Network for the All-Ports Matched Impedance-Transforming Balun

It is shown that an all-ports matched impedance transforming Marchand balun can be achieved by inserting the ideal isolation network (composing of an ideal phase inverter and two series resistors) at the balanced ports of the impedance-transforming Marchand balun. The transmission matrix (ABCD matrix) of the ideal isolation network [4] can be obtained as in (1), which can be simplified as a series impedance [5]

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_R = -\begin{bmatrix} 1 & 2Z_1 \\ 0 & 1 \end{bmatrix} \tag{1}$$

where Z_1 is the terminated impedance at the balanced ports.

A phase inverter realized using a $\lambda_g/2$ transmission line was proposed in [4], but this is not an ideal solution as it consumes a large circuit area. Here, an alternative technique, which miniaturizes the isolation network, is proposed: a coupled line section grounded at each end (the coupled and direct ports) acts as a phase inverter in the all-ports matched impedance-transforming Marchand balun (APMB) as shown in Fig. 1. This phase-inverter has previously been used in a miniaturized rat-race coupler [6]. The proposed phase inverter section (k_I coupling coefficient, ϕ electrical length and its characteristic impedance Z_o) is described using 4-port S-parameters, from which the two-port section's S-parameters are calculated [7] and then converted to the ABCD matrix. Multiplying the ABCD matrices of the reduced-ports coupler and the two series impedances, the final ABCD matrix of the proposed isolation network is found from (2), as shown at the bottom of the next page.

These two networks (the ideal and the proposed isolation networks) are electrically equivalent and hence the proposed network can be simplified to a single series impedance with the condition that $k_I = \cos\phi$. Then, the ABCD matrix of the proposed isolation network is

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{k_I=\cos\phi} = -\begin{bmatrix} 1 & Z_x \\ 0 & 1 \end{bmatrix} \tag{3}$$

where

$$Z_x = 2Z_1 + jZ_0 \sin\phi \tan\phi. \tag{4}$$

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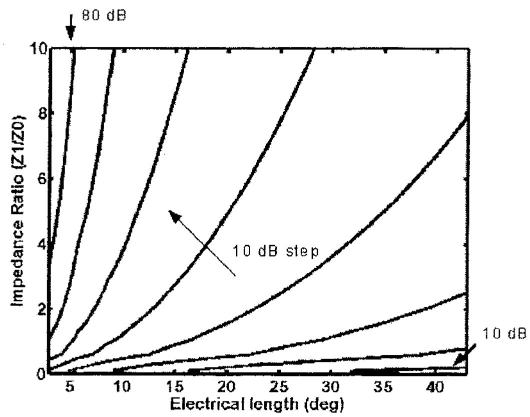

Fig. 2. Contour plot of return and isolation losses versus the center coupler's electrical length and the impedance ratio.

After shunting this isolation network across the impedance-transforming Marchand balun's balanced ports, the S-parameters of the balun with the proposed isolation network are obtained as shown

$$[S]_{balunI} = \begin{bmatrix} 0 & \frac{j}{\sqrt{2}} & \frac{-j}{\sqrt{2}} \\ \frac{j}{\sqrt{2}} & r & r \\ \frac{-j}{\sqrt{2}} & r & r \end{bmatrix} \tag{5}$$

where

$$r = \frac{1}{2\left(1 - j\,\frac{4Z_1}{Z_o}\,\cot\phi\csc\phi\right)}. \tag{6}$$

The S-parameters shown in (5) can be made very close to the ideal APMB one if the phase inverter coupler parameters are selected so that r is close to zero. This r determines the circuit's balanced port return and the isolation losses with the proposed isolation network. Fig. 2 shows a contour plot of r (in dB) obtained from (6). The center coupler's electrical length should be made small and Z_1/Z_0 should be large to obtain a nearly perfect impedance-transforming balun.

III. Experimental Results

The proposed circuit is realized in microstrip form, fabricated on a low-cost FR4 board with a dielectric constant of 4.55 and thickness of 1.6 mm. Lange couplers are employed to achieve the required tight coupling. The phase-inverter coupler with 2.8 dB coupling factor is designed with 50 Ω characteristic impedance and is in series with two SMT resistors of 25 Ω each.

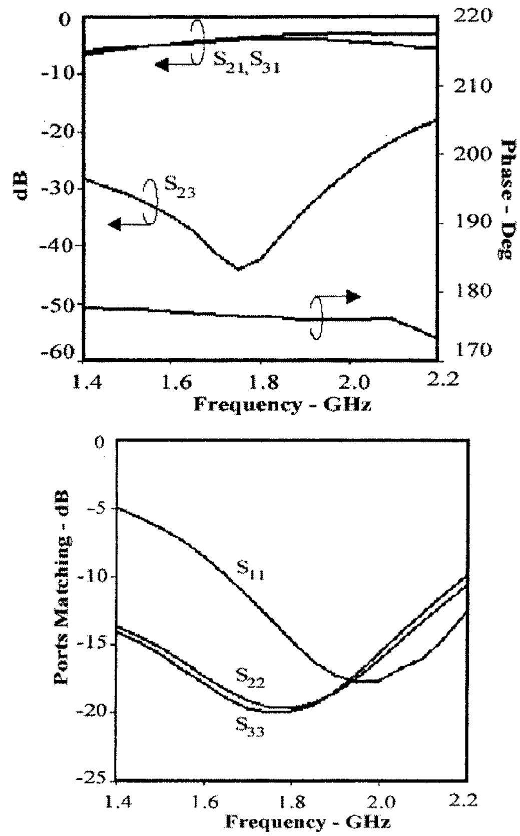

Fig. 3. Measured performances of the all-ports matched Marchand balun.

The coupler length was initially designed using $k_I = \cos\phi$, which results in less than $\lambda_g/8$, and was further optimized using *Momentum* by HPADS. The fabricated circuit was then measured using an HP8510 vector network analyzer with an SOLT calibration.

Fig. 3 shows the experimental results of the 50–25 Ω APMB. The balun at the center operating frequency of 1.8 GHz, presents good matching of more than −15 dB at all ports, with isolation of more than −40 dB between the two balanced output ports, and a minimum insertion loss of 4 dB. The increasing amplitude imbalance at the high frequency end of the passband is attributed to the poor directivity of the microstrip coupled lines. As the transformation ratio is smaller, the available operating bandwidth is thus larger in this case at 600 MHz. The balun exhibits a nominal phase difference of 176° between the two output ports.

IV. Conclusions

The technique for miniaturizing the isolation network required in the all-ports matched impedance-transforming

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_I = \frac{1}{k_I}\begin{bmatrix} -\cos\phi - j\,\dfrac{Z_1\left(k_I^2-\cos^2\phi\right)}{Z_0\sin\phi\sqrt{1-k_I^2}} & -\left(2Z_1\cos\phi + j\left\{Z_0\sin\phi\sqrt{1-k_I^2} + \dfrac{Z_1^2\left(k_I^2-\cos^2\phi\right)}{Z_0\sin\phi\sqrt{1-k_I^2}}\right\}\right) \\ -j\,\dfrac{\left(k_I^2-\cos^2\phi\right)}{Z_0\sin\phi\sqrt{1-k_I^2}} & -\cos\phi - j\,\dfrac{Z_1\left(k_I^2-\cos^2\phi\right)}{Z_0\sin\phi\sqrt{1-k_I^2}} \end{bmatrix} \tag{2}$$

Marchand balun is analyzed and demonstrated in this paper. The proposed isolation network is composed of a shorted coupled-line, with a length significantly shorter than the 180° transmission line previously reported. The perfectly matched balun can offer excellent all-ports matching with good isolation characteristics. These improved Marchand baluns are applicable to many circuits and systems.

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REFERENCES

[1] N. Marchand, "Transmission-line conversion transformers," *Electronics*, pp. 142–145, Dec. 1994.
[2] S. A. Maas, F. M. Yamada, A. K. Oki, N. Matovelle, and C. Hochuli, "An 18-40 GHz monolithic ring mixer," in *IEEE MTT RFIC Symp. Dig.*, 1998, pp. 1–4.
[3] M. Chongcheawchamnan, K. S. Ang, J. N. H. Wong, and I. D. Robertson, "A push-pull power amplifier using novel impedance transforming baluns," in *30th Eur. Microwave Conf. Proc.*, October 2000.
[4] K. S. Ang and I. D. Robertson, "Analysis and design of impedance-transforming Marchand balun," *IEEE Trans. Microwave Theory Tech.*, vol. 49, pp. 402–405, Feb. 2001.
[5] D. M. Pozar, *Microwave Engineering*, 2nd ed. New York: Wiley, 1998.
[6] S. P. Marsh, "A wide-band stripline hybrid ring," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, p. 361, June 1968.
[7] T. Y. Otoshi, "On the scattering parameters of a reduced multiport," *Trans. Microwave Theory Tech.*, vol. MTT-17, pp. 722–724, Sept. 1969.