A 6 TO 20 GHz PLANAR BALUN USING A WILKINSON DIVIDER AND LANGE COUPLERS

J. Rogers, R. Bhatia

Teledyne Monolithic Microwave
1274 Terra Bella Ave.
Mountain View, CA 94043

ABSTRACT

A simple broadband microstrip balun has been developed using a Wilkinson divider for power splitting followed by Lange couplers for phase shifting. This planar balun structure can be easily fabricated on alumina substrate using conventional MIC process without the need for multi-layer or suspended substrate techniques. The inherent wideband characteristics of the Wilkinson divider and Lange couplers and symmetry of the structure has resulted in good broadband amplitude and phase balance performance . The balun fabricated on 10 mil alumina measures an amplitude imbalance of +/- 0.6 dB, average phase imbalance of 7 degrees and total insertion loss of 1.2 dB max. from 6 to 20 GHz.

INTRODUCTION

Baluns perform the function of transforming an unbalanced line like a coaxial cable or microstrip to a balanced line with equal magnitude and 180 degrees out-of-phase outputs. This component is essential in circuits like balanced mixers, multipliers or push-pull amplifiers that rely on balanced signals to achieve broadband inter-port isolation and undesired or spurious signal cancellation. Baluns have been designed using transformer hybrids at low frequencies and transmission line structures at microwave frequencies. The transmission-line balun structures are semi-planar in the sense that they require either suspended substrate technique [1] that makes it difficult to integrate with planar components, or multi-layer structure that require additional processing steps [2,5]. The balun described here is a planar microstrip structure that can be easily fabricated with conventional MIC process and be easily incorporated in MIC components like balanced mixers, multipliers, push-pull amplifiers and antenna feeds. Measured performance is also better than the balun reported in [5] in terms of broadband amplitude and phase balance.

DESIGN

The balun described here was required for a 6 to 18 GHz double balanced mixer and had to be designed in a short time with very low risk. Hence it was decided to use a circuit topology using components with proven broadband performance.The chip size was not very critical in this application.

The balun consists of a 3-section Wilkinson divider that provides two well-balanced equal amplitude in-phase signals with a good input/output match and isolation between output ports over a 3 : 1 bandwidth. Each of these signals is then phase shifted by +90 degrees and -90 degrees respectively resulting in 180 degrees differential phase, equal amplitude outputs.

The circuit schematic of the balun is shown in Figure 1. The 3-section wilkinson divider is designed using theory described in [3]. In order to keep transmission line-widths of the divider reasonable for small chip size, 10 mil alumina substrate thickness was chosen. The + and - 90 degrees phase shifting is achieved using 3-dB quadrature coupler with short and open termination respectively on through and coupled ports and using isolated port as the output. This phase shift can be explained in terms of s-parameters as follows by referring to the 4-port, 3 dB quadrature coupler schematic shown in Figure 2.

The s-parameter matrix of an ideal 3-db quadrature hybrid at center frequency is given by:

$$[S] = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 0 & -j & 1 \\ 0 & 0 & 1 & -j \\ -j & 1 & 0 & 0 \\ 1 & -j & 0 & 0 \end{bmatrix}$$

If ports 3 and 4 are terminated in short-circuit, then

$$a_3 = -b_3 \quad \text{and} \quad a_4 = -b_4$$

The result is a 2-port network with s-matrix given by

$$[S] = \begin{bmatrix} 0 & j \\ j & 0 \end{bmatrix}$$

So, the shorted coupler gives + 90 degrees phase shift.

Z

Similarly, if ports 3 and 4 are terminated in open-circuit, the resulting 2-port has s-matrix given by

$$[S] = \begin{bmatrix} 0 & -j \\ -j & 0 \end{bmatrix}$$

Hence, an open coupler gives - 90 degrees phase shift. The ideal characteristics will only be obtained over a very narrow bandwidth. Because of circuit losses, imperfect terminations and deviation from 1/4 wavelength, each of the phase shift networks will exhibit some insertion loss, amplitude and phase imbalance over a certain bandwidth. The complementary nature of the two couplers will actually result in broadband relative phase of 180 degrees which is the main requirement rather than the absolute phase shift in each path.

In order to achieve the required tight coupling over 3:1 bandwidth interdigitated Lange couplers were employed as phase shifting elements. Due to the inherent symmetry and broadband characteristics of the components, good amplitude and phase balance performance is achievable. The structure symmetry has to be maintained in layout to minimize imbalance. Lange couplers are realized in an unfolded configuration to minimize bond wire connections and have input/output ports on opposite sides as desired. The simulation of the balun circuit was done on Supercompact with complete distributed and discontinuity models. Each section of the Wilkinson divider is laid out as U-shaped line to minimize chip size . The coupling in each U-section is fully modeled. Predicted amplitude and phase performance of the balun is shown in Figure 3. Insertion loss of each path is about 3.8 dB with +/- 0.4 dB of imbalance; relative phase is 180 +/- 7 degrees from 6 to 19 GHz. The predicted input return loss and output port isolation were less than -17 dB and -24 dB respectively.

FABRICATION

The planar balun was fabricated on 10 mil alumina. The Lange coupler was realized with 1 mil line-width and 0.5 mil gaps. Since it is difficult to realize 0.5 mil gaps uniformly with wet chemical etching, fabrication was done using ion-beam milling which involves dry etching techniques. The main advantage being that the photo resist image is precisely duplicated with zero undercut [4]. Lange couplers realized with this technique are extremely uniform and well defined. Hence fabricated structure has close agreement with the modeled parameters. Via-holes were used to provide low-inductance ground to the shorted Lange coupler. The photograph of the fabricated chip is shown in Figure 4.

MEASURED RESULTS

Although 3-port measurements are required to fully characterize the balun, the measurement was done as 2-port on HP8510 with the undesired port terminated in a good compensated thin-film 50 ohm termination. The return loss of this 50 ohm termination was a minimum of 14 dB upto 19 GHz. The fixture effects were calibrated out using TRL technique. Measured amplitude and phase response of balun are shown in Figure 5. Amplitude balance is about +/- 0.6 dB with relative average phase imbalance of 7 degrees from 6 to 20 GHz. Worst-case phase imbalance is 11 degrees. This performance is better than that of the multi-layer balun structure reported in [5]. The total insertion loss is 1.2 dB max. The VSWRs at all three ports are better than 2 : 1. The measured data agrees very well with the modeled performance. The isolation between the two output ports was measured to be 20 dB min. from 6 to 18 GHz but degrades to 16 dB at 20 GHz. The measured isolation was lower than modeled mainly because of the non-ideal 50 ohm termination on the input port. The reverse simulation of the balun with the imperfect termination model agreed well with the measured isolation data.

CONCLUSION

A planar microstrip balun has been designed using Wilkinson and Lange Couplers with good amplitude and phase balance performance over a broad band of 6 to 20 GHz. The above balun does not require multi-layer or suspended substrate techniques . This makes it easy to fabricate and incorporate in MIC components like balanced mixers, multipliers and push-pull amplifiers. This distributed planar balun can also be implemented in MMIC form, although with slightly higher insertion loss and cost.

ACKNOWLEDGEMENT

The authors wish to thank V. Steel and D. Scott for useful discussions related to this project. They also appreciate the support given by D. Brubaker.

REFERENCES

[1] R. M. Narayan, "Multioctave,Double-Balanced Mixers Designed Using MIC Technology," MSN & CT, Jan. 1987, pp. 108-115.

[2] A. M. Pavio and A. Kikel, " A Monolithic or Hybrid Broadband Compensated Balun," 1990 IEEE MTT-S International Symposium Digest, pp. 483-486.

[3] S. B. Cohn, " A Class of Broadband Three-Port TEM-Mode Hybrids," IEEE Trans. Microwave Theory & Techniques, vol. MTT-16, no 2, February 1968. pp 110-116.

[4] B. Quagan and P. Lostomolo ,"Ion Milling Cures Wet-etching Woes," Microwaves & RF , January 1985.

[5] A. M. Pavio and S. K. Sutton, " A Microstrip Re-entrant Mode Quadrature Coupler For Hybrid and Monolithic Circuit Applications," 1990 IEEE MTT-S International Symposium Digest, pp.573-575.

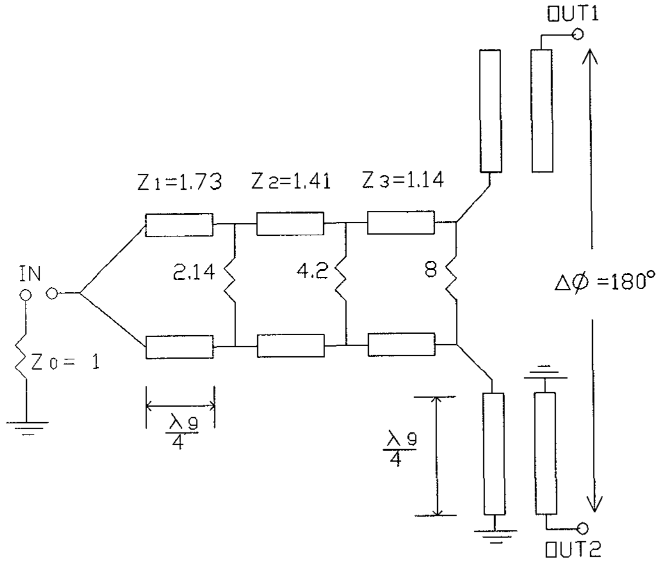


Figure 1. Ciruit Schematic of Planar Balun

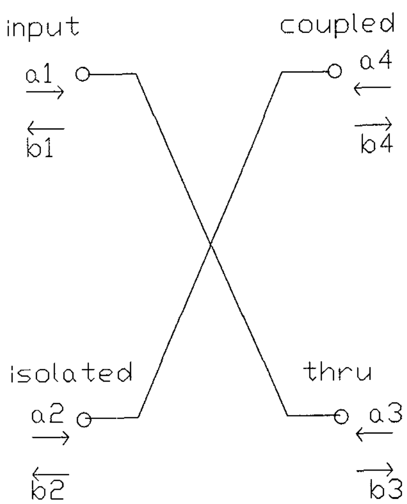


Figure 2. 4-Port Representation of Coupler

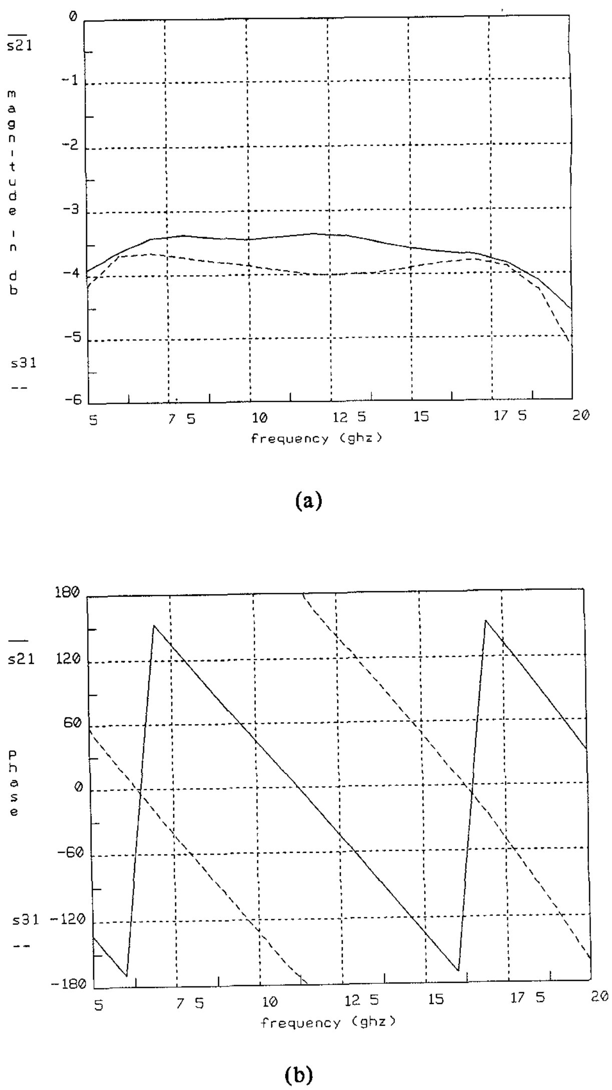


Figure 3. Modeled Amplitude (a) and Phase (b) Performance of Planar Balun

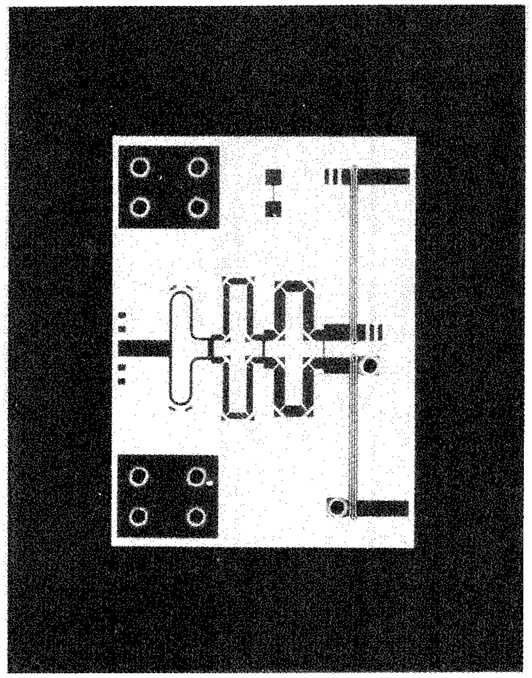
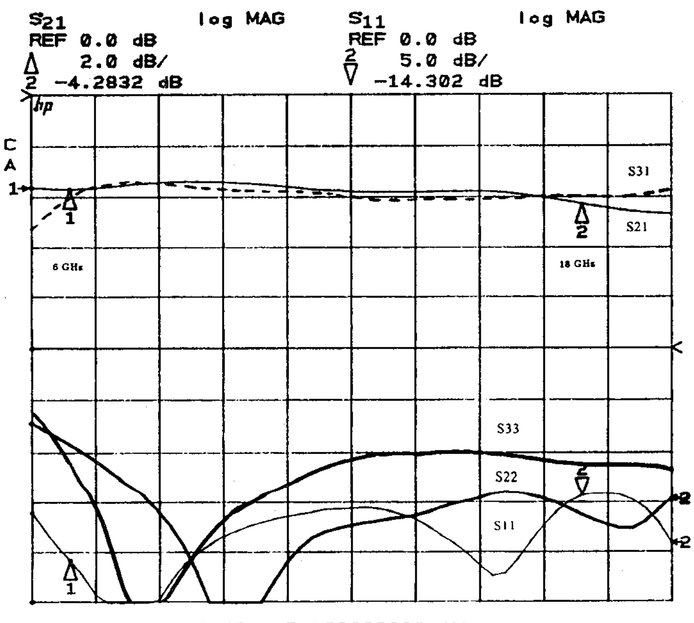
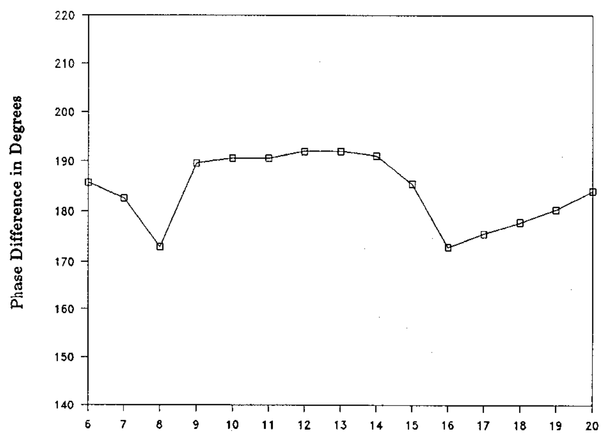


Figure 4. Photo of Fabricated Balun Chip



(a)



(b)

Figure 5. Measured Amplitude, Return Loss (a) and Phase Balance (b) of Planar Balun