A LOW LOSS, 5.5 GHZ - 20 GHZ MONOLITHIC BALUN*

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ABSTRACT

A low-loss monolithic Marchand Balun has been designed and fabricated using polyimide as the inter-metal dielectric. The measured return loss is less than -10 dB from 5.5 GHz to 20 GHz. The balun loss is less than 0.7 dB over the 6 GHz to 21 GHz operating band. This is the lowest loss ever reported for such a balun. The excellent loss is the result of using a relatively thick polyimide layer (10 μm) as the inter-metal dielectric. This balun has been applied to HBT and pHEMT amplifiers with second harmonic components suppressed > 40 dB, even in compression, demonstrating very good push-pull operation.

INTRODUCTION

Mixers, push-pull amplifiers and multipliers require baluns to derive the balanced signals necessary for their operation. To date, considerable effort has been devoted to the study and development of such components. The well known Marchand Balun [1], which has been realized in both coaxial and planar form, is capable of operating over multi-octave bandwidths. Figure 1 is a schematic representation of this type of balun. Unfortunately, the multi-layer monolithic version of this balun has suffered from loss on the order of 2 dB [2], [3]. This is believed to be due to the very narrow metal lines which must be used. These narrow metal lines are required because the silicon nitride (SiN), which was used as the inter-metal dielectric, is restricted to values less than approximately 3 μm. The purpose of this paper is to describe the design, fabrication and experimental results of a 5.5 GHz to 20 GHz, multilayer, monolithic Marchand balun with <0.7 dB loss. This is the lowest loss reported for this type of balun. Polyimide has been used to replace the SiN inter-metal dielectric and provides the key to the low loss operation.

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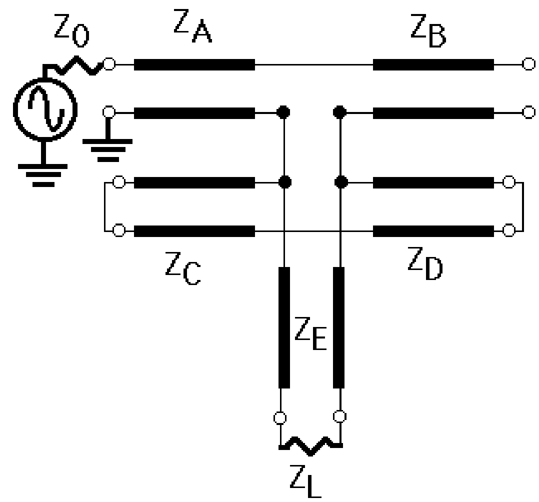

Figure 1: Transmission line representation of the Marchand Balun.

ADVANTAGES of POLYIMIDE

Polyimide has two fundamental advantages over SiN as the inter-metal dielectric for this application. First, polyimide can be easily spun to thicknesses of 25μm, or more. In contrast, high quality SiN is deposited using PECVD which can only deposit SiN at very slow rates. Furthermore, as the SiN thickness is increased, it is more prone to cracking. Consequently, SiN thicknesses are constrained to <10μm and typically never exceed more than 2μm or 3μm. Second, polyimide's relative dielectric constant (ε_r=3) is considerably less than that of SiN (ε_r=6.8). Both of these features enable wider linewidthes, for a given impedance, when using polyimide compared to SiN. This increased linewidth translates directly into reduced loss which is extremely important in all passive elements.

DESIGN PROCEDURE

Several papers, [4]-[6], have been written to analyze the coupled line structures used in planar baluns. The Marchand balun presents several problems to such an analysis. First, this is a

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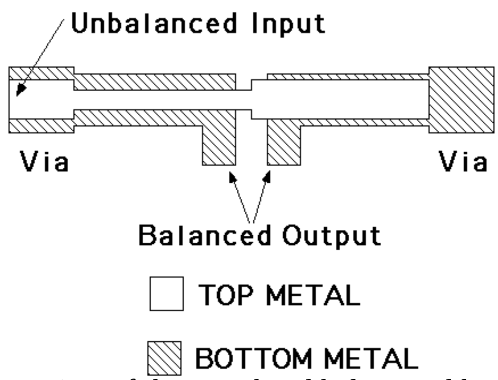
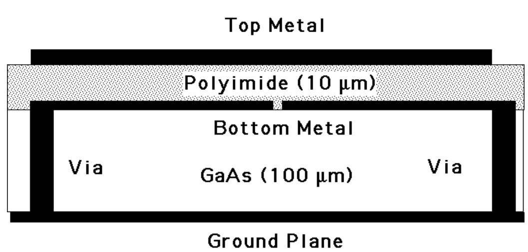
mixed dielectric problem which results in unequal even and odd mode phase velocities. Second, the coupled line segments are asymmetric, with the bottom line wider than the top line. Third, the two coupled line sections are different. The analyses in [4] and [5] assume tight coupling and similar phase velocities in the coupled line segments. This would require using thin polyimide, which in turn would result in increased losses. The work in [6] assumes that the two coupled line sections are identical, which cannot be the case in a Marchand balun. As a result, a multilayer Marchand balun was designed using the commercial electromagnetic magnetic simulator, Sonnet [7].

The unbalanced input impedance is 25Ω and the balanced output impedance is 50Ω. Figure 2 shows the top view and the side view of a stacked Marchand balun. It consists of two layers of metal separated by an inter-metal dielectric. The input is applied to one end of the top metal while the other end is open circuited. The outer ends of the lower metal are shorted to the lower ground plane using vias and the balanced signal is taken from the inner ends of the lower metal. This configuration results in two pairs of broadside coupled lines. The simulations were simplified by assuming ideal vias. Table 1 contains the simulation conditions used, including estimated conductor losses.



Top view of the Marchand balun used here.



Side view of the Marchand balun used here.

Figure 2: Top view and side view of the Marchand balun in this work.

Metal Loss	1.818e-07*sqrt(F)
Dielectric Thick.	10 µm
GaAs Thickness	100 µm

Table 1: Simulation conditions for the balun.

Figures 3 through 5 show the results of the electromagnetic simulation of the balun. The return loss was less than -10 dB over the band from 6 GHz to 23 GHz. Most importantly, the insertion loss was less than 3.4 dB, which indicates that the actual balun loss is less than 0.4 dB. In addition, the amplitude imbalance was less than 0.5 dB across the same band. These results demonstrate the broadband, low loss performance that can be obtained. Finally, the phase difference varied between 178 degrees and 173 degrees. Table 2 summarizes the dimensions of the balun.

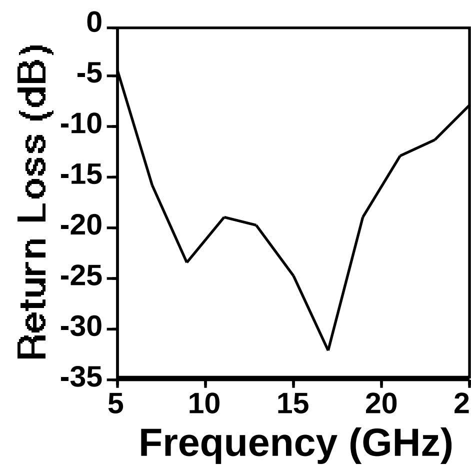


Figure 3: Calculated Return Loss of the balun.

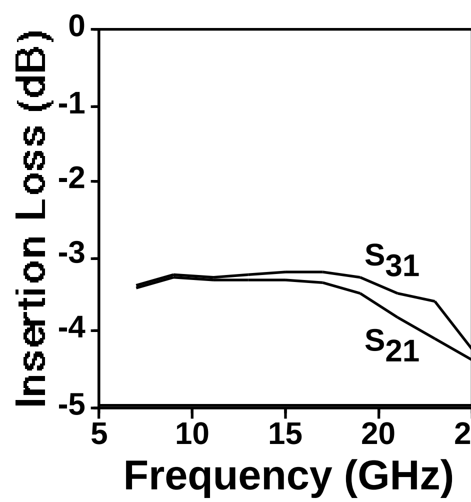


Figure 4: Calculated Insertion Loss.

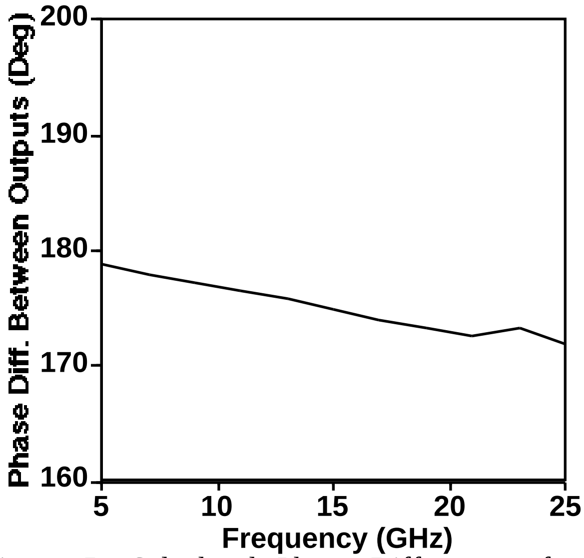


Figure 5: Calculated Phase Difference of the balanced output.

Input line length	1440 µm
Input line width	40 µm
Open line length	1420 µm
Open line width	140 µm
Bottom line length	1427 µm
Bottom line width	120 µm

Table 2: Table of balun dimensions for the circuit simulations shown in figures 3 through 5.

EXPERIMENTAL RESULTS

Figure 6 is a photograph of a fabricated balun measuring 3580 µm x 1302 µm. The S-parameters of the fabricated baluns were measured on-wafer using an ANA. The input return loss, S_{11}, of the balun was determined by measuring a balun terminated into a balanced load fabricated on-wafer. S_{11} measurements demonstrated values less than -10 dB from 5.5 GHz to 20 GHz (Fig. 7). This is a slightly narrower frequency range compared to the simulated results. The loss of two back to back baluns demonstrated a single balun loss of less than 0.7 dB from 6 GHz to 21 GHz (Fig. 5). This is the lowest reported loss for a monolithic multilayer Marchand balun. The measured amplitude balance was within 0.5 dB from 7 GHz to 21 GHz (Fig. 8) with a corresponding phase difference of 178 degrees to 172 degrees. The difference between the measured and simulated results is attributed to the simplified via structures used in the electromagnetic simulations and the differences between the assumed dielectric properties and the actual dielectric properties of the polyimide.

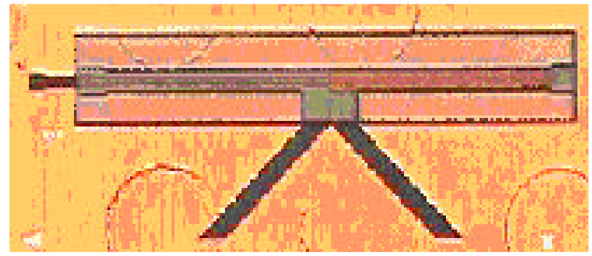


Fig. 6: Photo of the fabricated Marchand balun.

The baluns were applied to heterojunction bipolar transistor (HBT) push-pull amplifiers and pHEMT push-pull amplifiers. The HBT amplifier was built using an existing one-stage HBT MMIC amplifier which used a single 480µm transistor. It achieved an output power of 2W with 6 dB gain and 43% PAE at 8 GHz (the design frequency of the HBT MMIC). Considering that a single MMIC produced 1W of output power with similar gain and efficiency, these results demonstrate the good power splitting and power combining performance of the balun. The pHEMT amplifier was built using two discrete transistors. It demonstrated 1W of output power with 10 dB gain and 50% PAE at 10 GHz (Fig. 9).

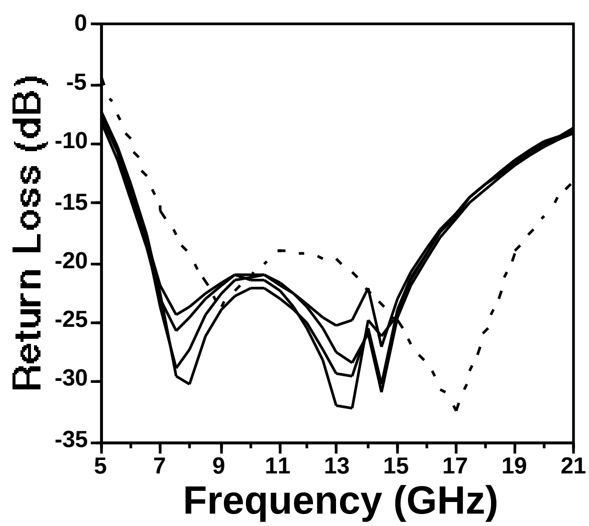


Fig. 7: Measured return loss of four baluns terminated into a balanced 50Ω load (solid curves). The simulated return loss is included for comparison (dashed curve).

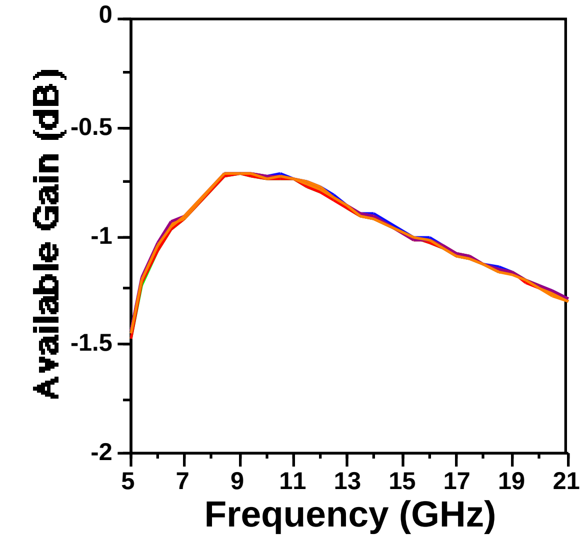


Fig. 8: Measured loss of four pairs of back-to-back baluns.

The second harmonic was monitored during the testing of both amplifiers. In all cases, the second harmonic signals were >40 dBc even at saturation, indicating the correct push-pull operation with second harmonic cancellation.

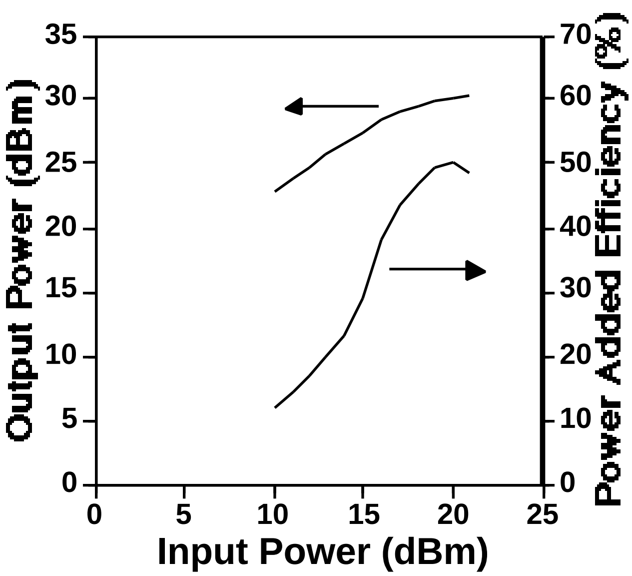


Fig. 9: Measured results of the pHEMT push-pull amplifier built using the balun from this work.

CONCLUSIONS

In conclusion, a 5.5 GHz to 20 GHz, monolithic, multilayer Marchand balun has been designed and fabricated using a GaAs technology which has incorporated polyimide processing. It has demonstrated a loss <0.7dB which is the lowest loss ever reported for this type of balun. These baluns were used in both HBT and pHEMT push-pull amplifiers which displayed >40 dB suppression of the second harmonic thus demonstrating proper push-pull performance.

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