BROADBAND MONOLITHIC PASSIVE BALUNS AND MONOLITHIC DOUBLE-BALANCED MIXER

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ABSTRACT

This paper presents the design and fabrication of four broadband monolithic passive baluns including CPW Marchand, multilayer MS Marchand, planar-transformer, and broadside-coupled line baluns. Operational frequencies range from 1.5 GHz to 24 GHz. Maximum relative bandwidths in excess of 3:1 are achieved. Simulated performances using full wave electromagnetic (EM) analysis are in good agreement with the measured results. The design of a monolithic double-balanced diode mixer using two planar-transformer baluns are also presented. Without dc bias, the mixer shows a minimum conversion loss of 6 dB with the RF at 5 GHz.and a LO drive of 15 dBm at 4 GHz. The measured input IP_3 of this mixer is better than 15 dBm over the 4 to 5.75 GHz frequency band.

INTRODUCTION

Baluns are required in a variety of important microwave components such as balanced mixers, push-pull amplifiers, multipliers, and phase shifters. As monolithic microwave integrated circuit technology advances, the need for broadband monolithic baluns that can be fabricated with the same technology becomes evident. Although multi-octave distributed active baluns [1] have been reported, they not only consume dc power but suffer from high noise figure, high spurious responses, low power handling capability, and low 3rd order intermodulation intercept point. Therefore a broadband monolithic passive balun is an indispensable element in realizing high performance and low risk MMICs. This paper reports four different monolithic passive baluns designed with a full-wave EM analysis [2]. We also report a monolithic double-balanced diode mixer which incorporates two of the planar-transformer baluns.

BALUN DESIGNS

Marchand compensated baluns The Marchand compensated balun is a bandpass network consisting of an unbalanced, balanced, compensation open-circuited, and two compensation short-circuited transmission lines. Each transmission line is a quarter wavelength at the center frequency of the operating band. Figure 1 shows the Marchand balun's equivalent circuit. The two short-circuited transmission lines are shunted across the balanced load and thus their characteristic impedances are made as large as possible. The remaining transmission lines' impedances determine the bandwidth and the impedance transformation between the unbalanced and the balanced ports. In this design, the marchand baluns are realized in two different structures: the multilayer MS [3] and the uniplanar CPW/Slot-line Marchand balun structures. A three-layer conductor structure is utilized to realize four distinct transmission lines in the multilayer MS Marchand balun shown in Figure 2. The structure consists of a backside, first interconnection, and air-bridge metallizations with the first interconnection and the the air-bridge metallizations seperated by 3 μm thick SiO_2. Because of the limitation of the realizable line width, the multilayer MS marchand balun is designed to transform a 30 ohm unbalanced impedance to a 90 ohm balanced impedance.

The uniplanar CPW Marchand balun shown in Figure 3 utilizes CPWs as unbalanced and open-circuited lines and slot-lines as balanced and short-circuited lines. The uniplanar CPW marchand balun transforms a 50 ohm unbalanced impedance to a 100 ohm balanced impedance.

Planar-transformer baluns The planar-transformer balun consists of two oppositely wrapped twin-coil transformers connected in series with one of its four outer nodes and one of its two inner common nodes grounded. Figure 4 shows the simplified circuit diagram and a photograph of a rectangular spiral transformer. The resonant frequency of the spiral coil divides the operating frequencies of the transformer balun into two regions: the magnetic coupling domain (frequencies below the resonant frequency) and the magnetic/electric coupling domain (frequencies above the resonant frequency) [4]. The former region is usually more useful because of its wider relative bandwidth. In this region, the inductance and the resonant frequency of the spiral coil are the two bandwidth-limiting factors. The coil inductance sets the lower limit of the frequency band while the resonant frequency sets the upper limit. Therefore, the bandwidth can be increased either by reducing the electrical length of the spiral coil at high frequencies while maintaining the same inductance or by increasing the inductance of the coil while

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maintaining the same spiral length. In the present design, the electrical length of the spiral coil is reduced by using thicker substrate and air-bridged metallizations to lower line capacitances and the coil inductance is increased by maximizing the spiral area-to-length ratio. The transformer baluns are constructed with both landed and air-bridged lines and are surrounded by ground metal so that they can be on-wafer tested for both the thick and thin substrates without and with backside metallization, respectively.

Broadside-coupled line balun The broadside-coupled line (BCL) balun shown in Figure 5 is a monolithic version of the hybrid double-sided microstrip/strip-line balun. It comprises a dielectric sheet with metallizations of equal width on both sides. This sandwiched structure realized with the first interconnection and air-bridge metallizations and a 3 μm thick SiO_2 sits on top of a 25 mil thick GaAs substrate. Because of the large thickness ratio of the GaAs substrate to the SiO_2 layer, the BCL structure has a large even-mode impedance which is essential for good balun performance. The BCL balun is designed using two cascaded BCL sections with different impedances to improve the performance at higher frequencies in addition to a 1:1 impedance transformation between the unbalanced and balanced ports.

MIXER DESIGN

A double-balanced diode mixer configuration is used in the design of the 4 - 6 GHz monolithic mixer. Figure 6 shows a photograph of the mixer chip which measures 2.25 x 1.75 mm^2. The mixer circuit consists of a diode quad, two planar-transformer baluns, and several MIM capacitors and spiral inductors for impedance matching. The Schottky diode is a two finger 0.5 x 60 μm^2 MESFET with its drain and source connected together. The cutoff frequency of the diode is near 130 GHz at zero bias. Two transformer baluns are used for the LO and RF ports with RF balun's center tap serving as the IF output. The center tap of LO balun is grounded. No dc bias is required for the mixer circuit.

RF PERFORMANCES

Figure 7 shows the measured performances of the uniplanar CPW Marchand balun. The amplitude and phase unbalances between the two balanced ports are less than 1.5 dB and 15°, respectively, over the 2 to 16 GHz frequency band. Figure 8 shows the measured performances of a planar-transformer balun constructed with air-bridged lines. The amplitude and phase unbalances between the two balanced ports are less than 1.5dB and 10°, respectively, over the 1.5 to 6.5 GHz and 13 to 24 GHz frequency bands. Figure 9 compares simulated results using EM analysis with measured data for a transformer balun constructed with landed lines. The agreement is reasonably good. In addition, measured results show that a 30% banwidth improvement is obtained by using air-bridged lines instead of landed lines.

Figure 10 compares the measured and simulated performances of a multilayer MS Marchand balun. The EM simulated results are in good agreement with the measured data. The amplitude and phase trackings between two balanced ports are excellent and the insertion loss is between 2 and 4 dB over the 2 to 16 GHz frequency band. Figure 11 compares the simulated and measured performances of a BCL balun. The agreement is generally good, however the bandwidth is relatively narrow compared to other types of baluns. The measured conversion loss of a double-balanced diode mixer as a function of the RF frequency is shown in Figure 12. A fixed IF frequency of 1 GHz and LO drive of 15 dBm were used. The best conversion loss is about 6 dB at RF of 5GHz while the average loss varies from 7.5 to 8.5 dB and the input IP_3 is better than 15 dBm over the 4 to 5.75 GHz frequency band.

CONCLUSION

Four different monolithic passive baluns have been designed and fabricated. The uniplanar CPW Marchand balun, the planar-transformer baluns, and the BCL balun have been tested on the 25 mil thick GaAs substrate, while the multilayer MS Marchand balun has been tested on the 4 mil thick substrate. Both the Marchand compensated and transformer baluns achieve maximum relative bandwidths in excess of 3:1. Although the multilayer MS Marchand balun requires one additional thick SiO_2 layer, it is the most promising passive balun due to its compact size and high performance. Additionally, good agreements between the measured and EM simulated results have also been achieved. Finally, the planar-transformer baluns have been utilized in a double-balanced diode mixer design and good measured performance has been achieved.

ACKNOWLEDGEMENT

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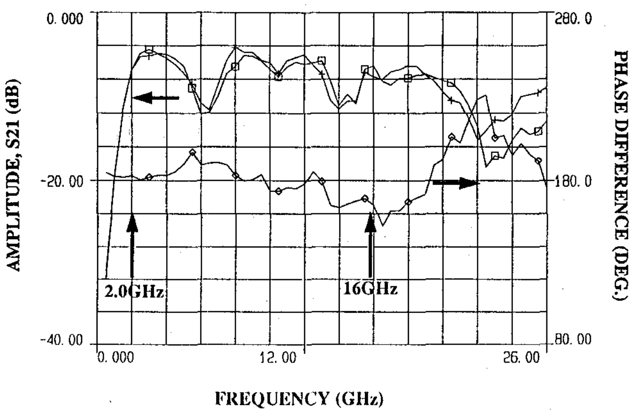

Figure 7 Measured performances of an uniplanar CPW Marchand balun

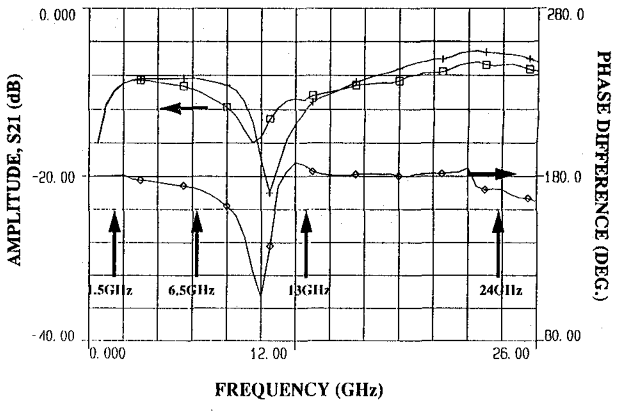

Figure 8 Measured performances of a planar-transformer (air-bridged lines)

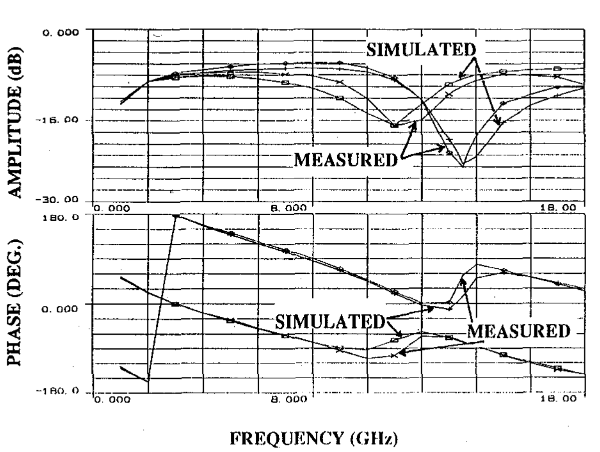

Figure 9 Comparison between simulated and measured performances of a transformer balun

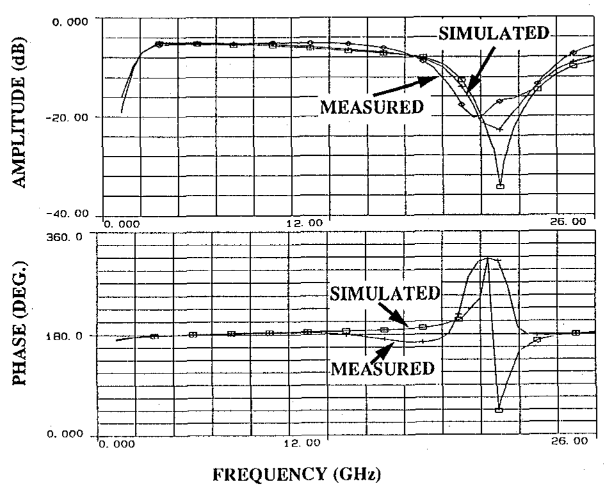

Figure 10 Comparison between simulated and measured performances of a multilayer MS Marchand balun

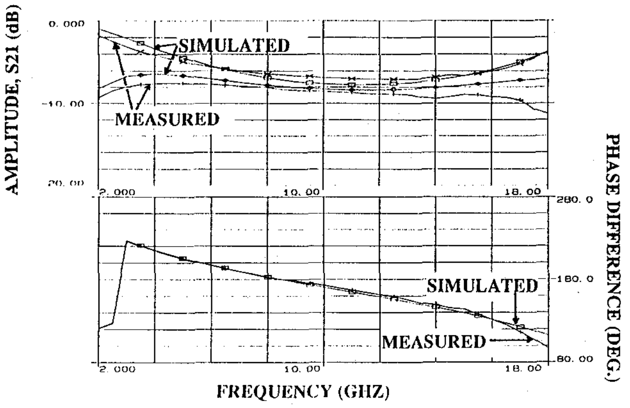

Figure 11 Comparison between simulated and measured performances of a BCL balun

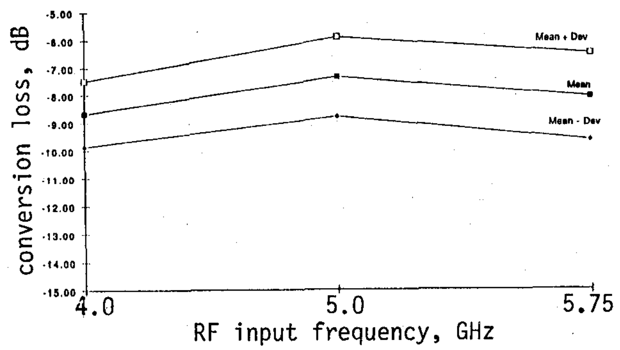

Figure 12 Measured conversion loss od a double-balanced diode mixer

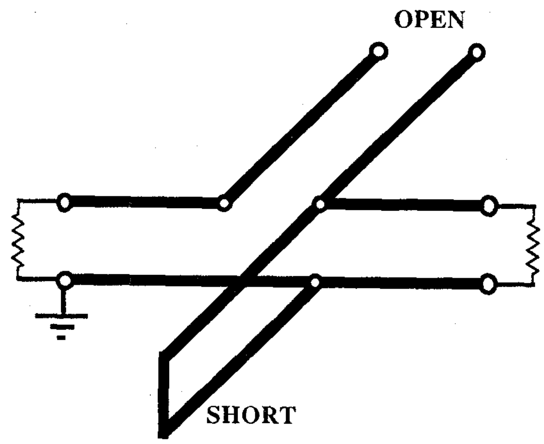

Figure 1 Marchand balun's equivalent circuit

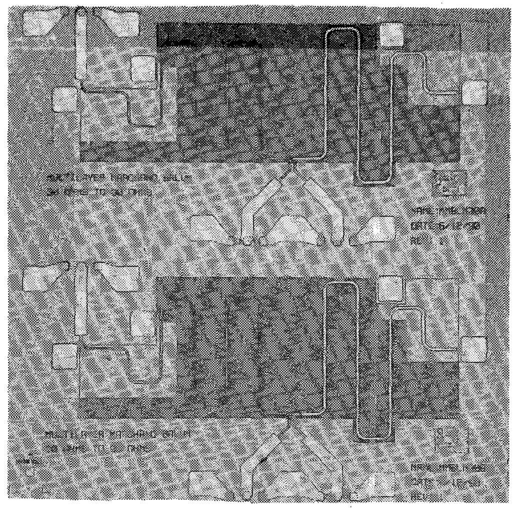

Figure 2 Photo of a multilayer MS Marchand balun

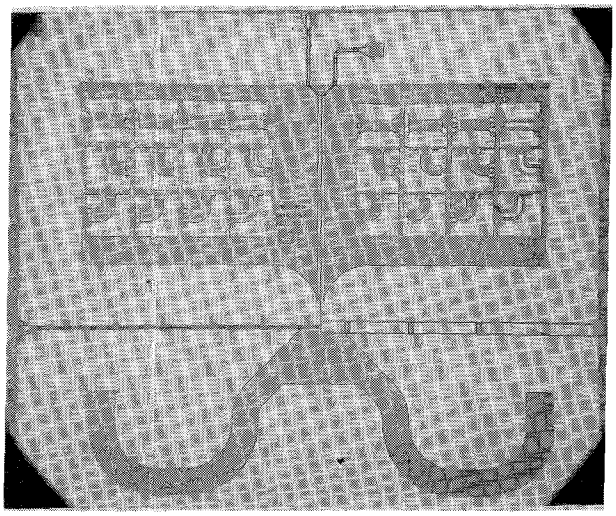

Figure 3 Photo of a CPW Marchand balun

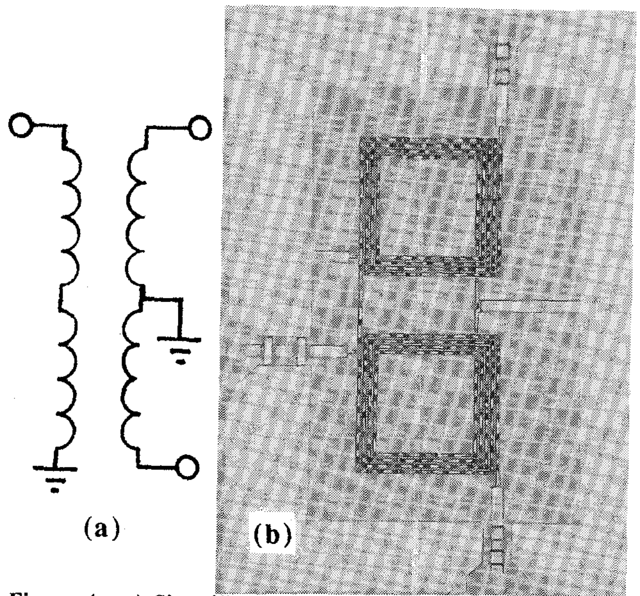

Figure 4 a) Simplified circuit diagram and b) photo of a rectangular spiral transformer balun

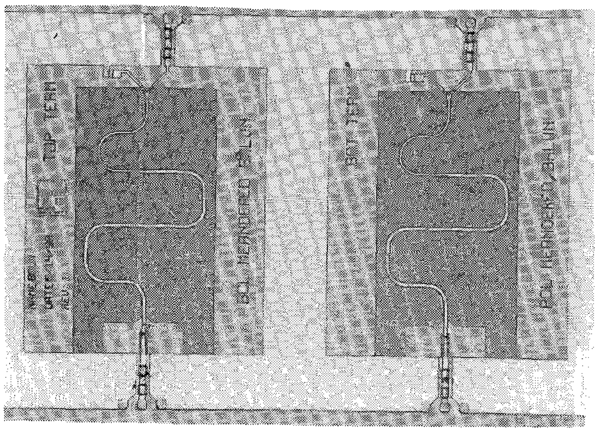

Figure 5 Photo of a broadside-coupled line balun

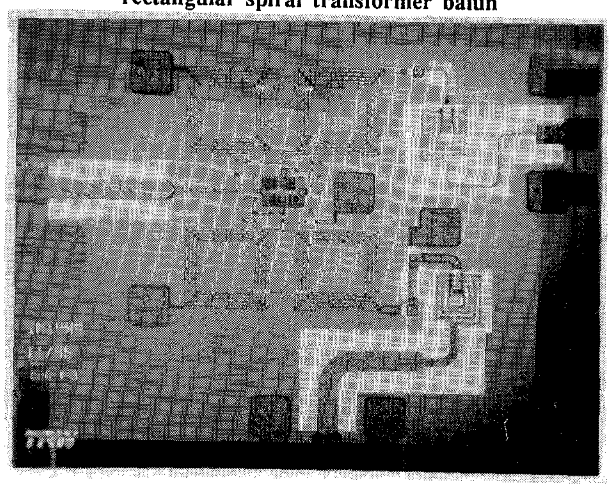

Figure 6 Photo of a double-balanced diode mixer