A Millimeter-Wave Ultra-Compact Broadband Diode Mixer Using Modified Marchand Balun

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Abstract — **In this paper, a broadband mixer has been developed using 0.15-μm pHEMT technology. This singly balanced mixer was realized by using Schottky diodes. A modified Marchand balun was employed at the LO port and matched to the diodes directly to achieve wideband performance and compact size. This diode mixer achieves conversion loss of better than 10 dB from 46 to 78 GHz with LO power of 12.5 dBm, and the chip size is only 0.57 mm x 0.52 mm. Compared with previously reported MMIC mixers in millimeter-wave frequencies, this circuit has the smallest chip size with competitive performance and wide bandwidth.**

I. INTRODUCTION

Recently, there are more and more commercial applications seeking for millimeter-wave frequency solutions such as 60 GHz wireless LANs. Other applications already exist, for example, commercial automotive collision-avoidance radar system has been developed at 77 GHz millimeter-wave frequency band. Mixers play important rules at the front end of these systems. The conversion loss of the mixer determines the gain and noise requirements of the low noise amplifier of the system.

Passive mixers have been developed for many years, diode mixer are still popular in millimeter-wave regime. There are several diode mixers reported for E-band applications. Trinh et al. has published a singly balanced diode mixer using Lange coupler [1], which has a broadband performance from 75 GHz to 88 GHz with conversion loss from 6.8 dB to 10 dB. Another diode mixer was reported by Verweyen et al. [2]. This mixer was also a singly balanced mixer using a capacitively loaded branch-line coupler, with a conversion loss of 9 dB at 77 GHz.

Marchand baluns have a wide-bandwidth and is widely used in microwave frequency. The design and analysis procedure of conventional Marchand baluns are well-discussed [3]-[4]. However, conventional Marchand baluns do not use the electric field efficiently. Since conventional Marchand baluns are edge coupled, it has leakage electric fields on the outer sides. Consequently, Basu et al. proposed a three edge-coupled-line Marchand balun to improve the bandwidth and designed a 5-13 GHz star mixer [5]. Kamozaki et al. used broadside-coupled Marchand balun to achieve a 50-100 GHz resistive mixer [6]. In this work, we combined these two structures to design an ultra-compact balanced mixer at millimeter-wave frequencies.

II. DEVICE CHARACTERISTICS AND MMIC PROCESS

The device used in this design is WIN's standard 0.15-μm high power InGaAs/AlGaAs/GaAs pHEMT MMIC process. This process employs a hybrid lithographic approach using direct-write electron beam lithography for the sub-micron gate definition and optical lithography for the other steps. The diode is realized by connecting the drain and source pads of a HEMT device to form the cathode. The cut-off frequency of the two-finger 15-μm Schottky diode is about 381 GHz. Other passive components including thin film resistor, MIM capacitors, spiral inductors and air-bridges are all available. The 6" wafer is thinned down to 4-mil for the gold plating of the backside, and slot via holes are used for dc grounding.

III. CIRCUIT DESIGN

This singly balanced mixer is a broadband design and the circuit configuration is shown in Fig. 1(a). The primary components of the circuit are the modified Marchand balun, RF band-pass filter, and IF low-pass filter.

Conventional Marchand balun consists of two quarter-wavelength edge-coupled lines. Because the two edge-coupled-lines have leakage electric field along the outer sides, the conventional Marchand balun is lossy. Several methods were proposed to improve the performance of Marchand baluns. A three edge-coupled-line Marchand balun has been reported to enhance the performance [5]. On the other hand, broadside-coupled Marchand balun can achieve wide bandwidth [6]. To combine these two features, three edge-coupled-lines are used, and a pair of broadside coupled-lines is added. The broadside couple-lines are achieved by stacking two lines fully overlapped; the upper line is implemented using air-bridges to cross over the bottom line. Figure 1(b) shows the cross view of the proposed Marchand balun. In this standard foundry process, the maximum width of the air-bridge is 20 μm, therefore multiple short air-bridges are used instead of one long air-bridge line. By combining three edge-coupled-lines and broadside coupled-line, it will make the Marchand balun have a higher coupling

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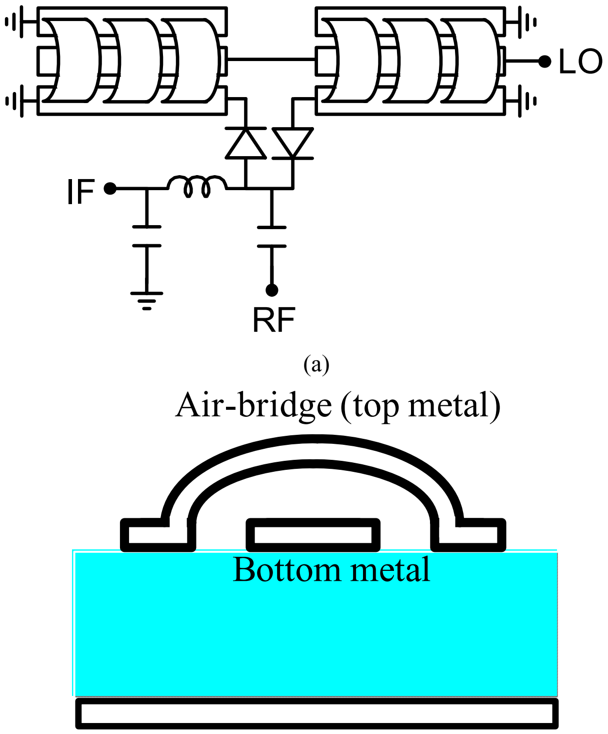
coefficient and increase the operating bandwidth. With a wider operating bandwidth, the Marchand balun can be designed at a higher center frequency, reducing the chip size. Two fingers with total length 15-µm diodes are selected as the mixing device. The proposed Marchand balun is designed to match for the diodes directly to eliminate the matching circuits between the balun and the diodes, and thus results in a compact size. The chip photo of the Marchand balun test circuit is shown in Fig. 2.

At RF port, a small series capacitor is employed as a band-pass filter to provide IF-to-RF isolation. At IF port, a low-pass filter consisting of an inductor and a shunt capacitor is used to increase LO-to-IF and RF-to-IF isolations. LO-to-RF isolation is achieved because the RF port is at virtual ground. The microphotograph of this broadband mixer is shown in Fig. 3.



(a)

(b)

Fig. 1. (a) Circuit configuration of this broadband mixer with the proposed Marchand balun. (b) Cross view of the balun.

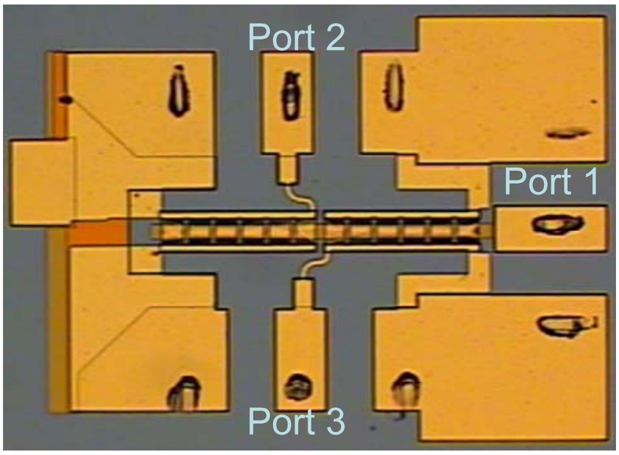


Fig. 2. The chip photo of the Marchand balun test circuit.

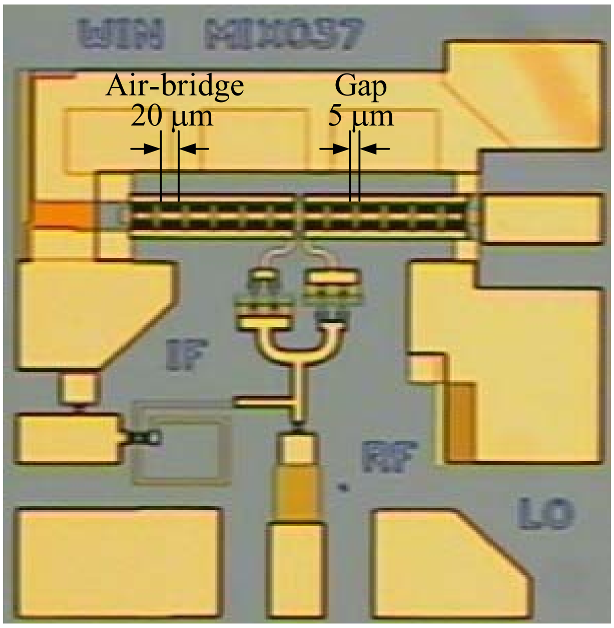


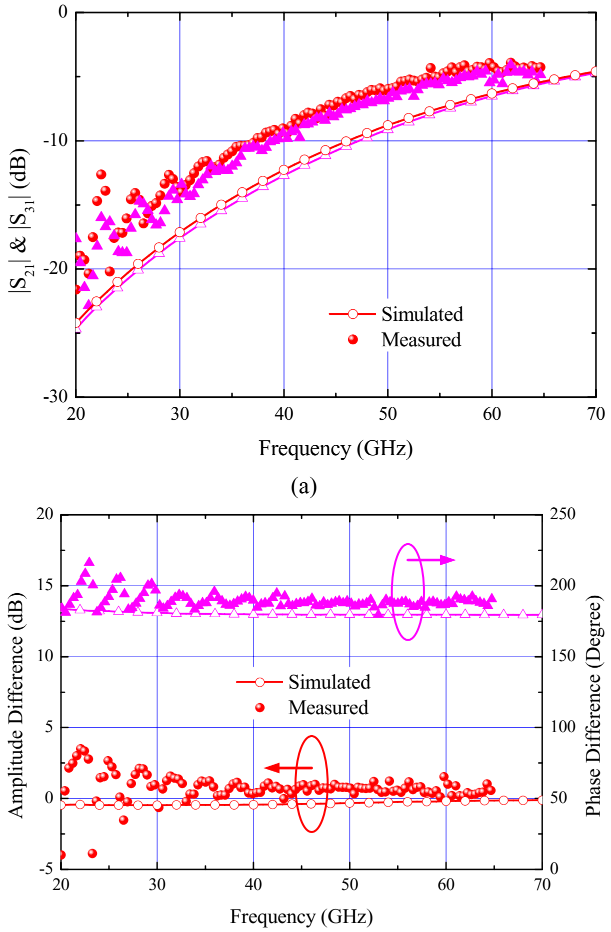
Fig. 3. The chip photograph of this broadband mixer. The chip size is only 0.57 mm x 0.52 mm.

IV. MEASUREMENT RESULTS

The Marchand balun test circuit was tested via on-wafer probing. We used an Anritsu 37397A vector network analyzer to measure the small-signal data up to 65 GHz. The 3-port *S*-parameters are extracted from the 2-port measurements using a port-reduction method [7]-[8]. Figure 4(a) shows the simulated and measured insertions losses. Magnitude and phase difference of the balanced ports are shown in Fig. 4(b). The Marchand balun achieves better than 1 dB and 12° of magnitude and phase imbalance respectively, from 40 to 65 GHz.

This broadband MMIC mixer was measured via on-wafer probing using spectrum analyzer and millimeter-wave power meter. We can only measure from 41 to 78 GHz due to W-band high power source limitation in our measurement setup. The LO power is driven using a signal generator with a power amplifier. The RF signal is provided from an Agilent 8510C network analyzer with millimeter test set. The measured conversion loss swept over LO drive power at 77 GHz is shown in Fig. 5, indicating that an LO power of above 12.5 dBm is adequate to drive this mixer for low conversion loss. The simulated and measured conversion loss versus LO frequency is shown in Fig. 6. This mixer can achieve a conversion loss of 7 to 10 dB from 46 to 78 GHz for down conversion, with LO power of 12.5 dBm and IF fixed at 1 GHz. Figure 7 shows the measured LO-to-RF isolation. The isolation is greater than 20 dB from 50 to 94 GHz.

Table I summarizes reported performances of millimeter-wave passive MMIC mixers. Our circuit has a smallest chip size with competitive performance and wide bandwidth.



(a)

(b)

Fig. 4. Simulated and measured results of (a) insertion losses, (b) amplitude and phase difference of S_{21} and S_{31} of the proposed Marchand balun.

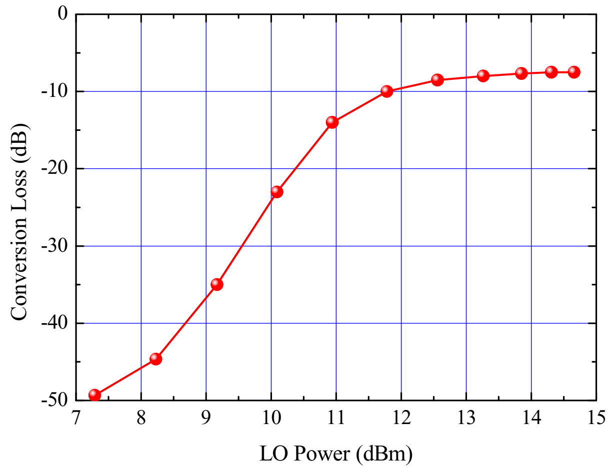


Fig. 5. (a) Simulated and measured results of $|S_{21}|$, $|S_{31}|$, and (b) amplitude and phase difference of balanced ports of the proposed Marchand balun.

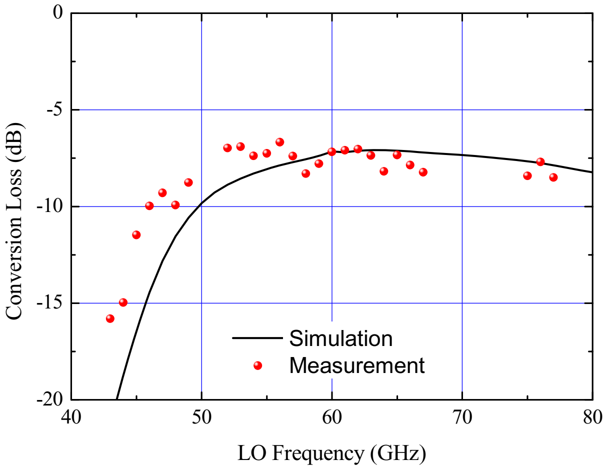


Fig. 6. Simulated and measured conversion loss of this broadband mixer for down conversion, which LO power is 12.5 dBm and IF is fixed at 1 GHz.

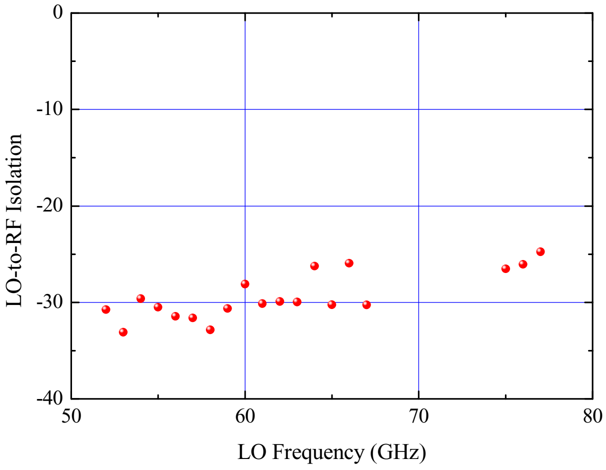


Fig. 7. Measured LO-to-RF isolation of the mixer.

V. CONCLUSION

A miniature broadband singly balanced mixer has been designed, fabricated, and measured. By using the newly proposed Marchand balun, this mixer achieves a wideband performance and an ultra-small chip area. The conversion loss is from 7 to 10 dB from 46 to 78 GHz with LO driven power of 12.5 dBm and IF frequency fixed at 1 GHz. The chip size is only 0.57 x 0.52 mm^2.

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Ref.	Frequency (GHz)	Conversion Loss (dB)	Design Topology	Process	Chip Size (mm^2)
[1]	75-88	6.8-10	Singly balanced diode mixer	GaAs MESFET	1.6 x 2.4
[2]	76.6	9.5	Singly balanced diode mixer	0.15 µm GaAs HEMT	1.2 x 1.4
[6]	50-103.5	11.6±2.8	Singly balanced resistive mixer	0.15 µm GaAs HEMT	1.2 x 1.2
[9]	88-100	8	Single-ended resistive mixer	0.1 µm InP HEMT	1.175 x 1.1
[9]	75-105	10-12	Singly balanced resistive mixer	0.1 µm InP HEMT	1.8 x 1.1
[10]	52-64	12-14	Singly balanced resistive mixer	0.15 µm GaAs HEMT	1.18 x 1.2
[11]	74-76	10	Single-device balanced mixer	0.13 µm GaAs HEMT	0.7 x 0.8
[12]	56-72	10.6	Singly balanced resistive mixer	0.15 µm GaAs HEMT	1.8 x 2
[12]	72-84	10.6	Singly balanced resistive mixer	0.15 µm GaAs HEMT	1.8 x 2.4
This work	**46-78**	**7-10**	**Singly balanced diode mixer**	**0.15 µm GaAs HEMT**	**0.57 x 0.52**

Table I. Reported performances of millimeter-wave passive MMIC mixers.