High Performance Resistive EHF Mixers Using InGaAs HEMTs

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ABSTRACT

This paper presents the design, fabrication, and testing of a hybrid and a monolithic single-balanced EHF mixers. Very low mixer intermodulation distortion was achieved using 0.2x160 μm^2 pseudomorphic InGaAs high electron mobility transistor biased in the resistive mode. Both mixers show similar excellent measured performance. Mixer conversion loss over the 26-29 GHz RF frequency band is about 7~9 dB for DC to 2 GHz IF frequencies. With an LO power of +13 dBm, the measured input two-tone third-order intercept point is higher than +24 dBm.

INTRODUCTION

The mixer is a key component for a receiver and the current trend of the mixer development effort is emphasized on wide dynamic range applications, which are limited by the mixer conversion loss, noise figure, and intermodulation distortion (IMD) characteristics. Resistive mixer development has drawn a great deal of attention [1]-[6] since its initial demonstration [1] of a very low IMD microwave mixer using the GaAs MESFET in a resistive mode, i. e., no drain bias is applied to the FET device. Most of the mixers reported in [1]-[6] are based on GaAs MESFETs and have demonstrated low IMD performance at microwave frequencies. Key performance parameters of the published mixers are summarized in Table I, where the mixer figure-of-merit (FOM) is defined as the difference between the mixer input two-tone third-order intercept (IP_3) and the required LO power. The FOM of the published resistive mixers ranges from +17 dB of a narrow band single-ended (SE) circuit [1] to +7 dB of a broad band double-balanced (DB) circuit [3] whereas the typical FOM for a diode mixer is below +5 dB for microwave applications [7]. From the tabulated data in Table I and reference [7], it appears that the resistive FET mixer usually has a higher IP_3, a comparable conversion loss, and noise figure when compared to its diode counterpart at the same LO drive.

At the EHF and millimeter-wave frequencies, similar conversion loss was obtained for both diode mixers and resistive mixers using high electron mobility transistors (HEMTs) [8,9]. However, the diode mixer is more popular for system applications and the low IMD advantage of a resistive mixer has not been successfully demonstrated. The motivation of this work was, therefore, to investigate the potential of superior performance of a resistive mixer at EHF frequencies.

Table I
Summary of the published resistive mixers

Freq. (GHz)	C.L. (dB)	IP3 @ LO (dBm)	FOM	Reference
10.0 - 10.5	-6.5	+27 @ +10	+17	SE, Maas [1]
10.0 - 11.0	-7.0	+28 @ +17	+11	SB, Maas [2]
2.0 - 8.0	-8.0	+30 @ +23	+7	DB, Weiner et al [3]
10.3 - 11.8	-7.0	+33 @ +23	+10	SE, Chang et al [4]
9.5 - 14.5	-10.0	+19 @ +10	+9	SB, Kruger [6]

NOTES:
FOM = mixer input IP3 - LO power
SE = single-ended, SB = single-balanced, and DB = double-balanced

MM

MIXER DESIGN

In order to reject the even order spurious signals, the single-balanced (SB) circuit configuration shown in Figure 1 was chosen for the present work. The mixer circuit consists of two Lange couplers for the RF and LO ports, two 0.2x160 μm^2 pseudomorphic InGaAs HEMTs for mixing elements, and a single-ended IF output. The SB mixer configuration using two 90^o hybrids instead of the 180^o baluns were used because the dual 90° hybrids provide good return loss for the RF and LO ports, isolation between the RF and LO ports, and allow the IF frequency to decrease to DC [6]. Moreover, the circuit topology is well-suited for monolithic implementation allowing easy integration with other circuits in a fully integrated monolithic subsystem. Table II compares the frequency conversion products and spurious rejection characteristics of the present design and other SB FET/HEMT mixers using 180° baluns. A simple switch model was used for the FET/HEMT device to derive the results shown in Table II.

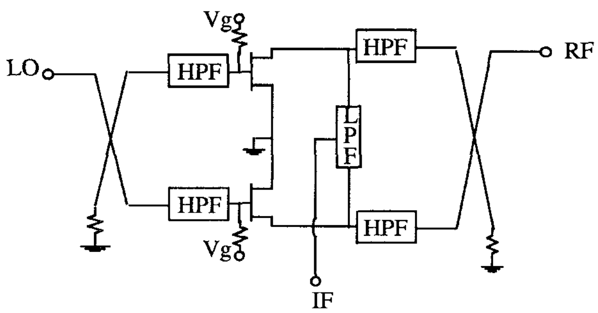


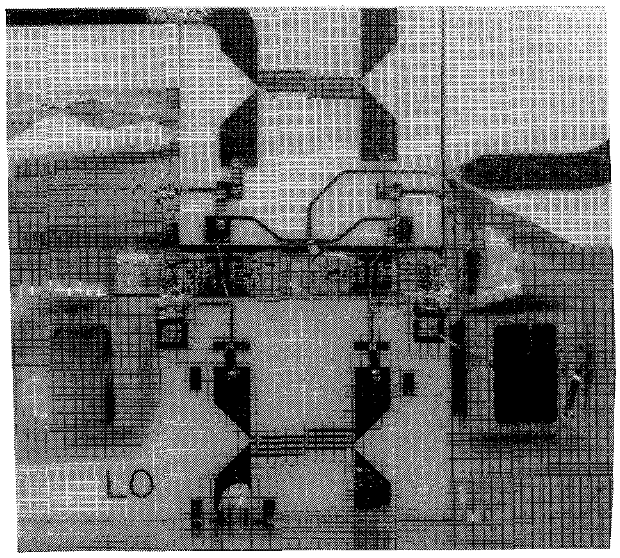
Figure 1. Simplified circuit schematic of the SB resistive HEMT mixer.

Table II
Output characteristics of the SB resistive FET mixer

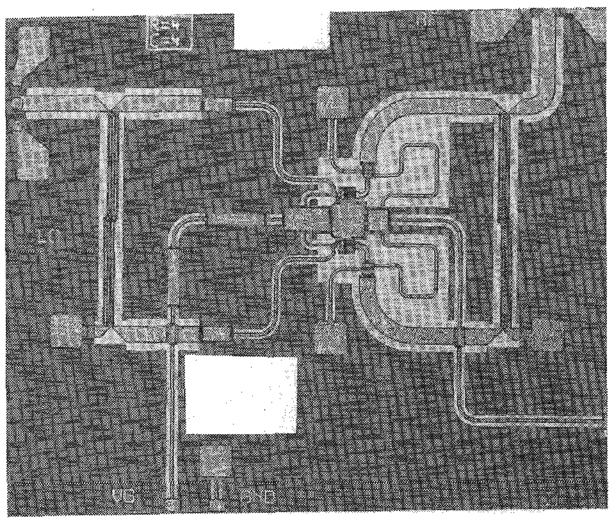
RF	LO	RF-in phase LO&IF-180° hybrid	IF-in phase LO&RF-180° hybrid	IF-in phase LO&RF-90° hybrid
1	0	x	x	√
0	1	√	x	x
1	-1	√	√	√
1	1	√	√	x
2	0	x	√	x
0	2	x	√	x
2	±1	√	x	x
±1	2	x	x	√
2	2	x	x	x
3	0	x	x	√
0	3	√	x	x

NOTES:
√ - exist x - non-exist

To realize a resistive mixer, the HEMT device is gate-biased near pinch-off and requires no drain bias. The LO and RF signals are applied to the gate and drain, respectively, and the IF output is filtered out from the drain. The source terminals of both HEMT devices are grounded. The hybrid circuit was realized on 15-mil alumina substrates and both microstrip transmission lines and beam lead capacitors were used to design the matching circuits for the LO and RF ports, At the IF port two low pass filters were combined to form the single-ended output. The monolithic circuit was designed directly from the hybrid one and realized on a 4-mil thick GaAs substrate. Figures 2(a) and (b) illustrate the hybrid and monolithic mixer circuits, respectively.



(a)



(b)

Figure 2. Photographs of the (a) hybrid and (b) monolithic resistive HEMT mixers.

CIRCUIT FABRICATION

The HEMT device was fabricated on an MBE-grown wafer with an AlGaAs/InGaAs heterostructure. Figure 3 illustrates the device structure. The InGaAs channel layer grown on top of the superlattice buffer is 150 Å thick. A 300 Å AlGaAs donor layer and a 400 Å of 6×10^{18} cm^{-2} GaAs contact layer are then followed in sequence. The device current handling capability is increased by inserting a silicon planar doping of 1×10^{12} cm^{-2} in the center of the InGaAs channel in addition to the AlGaAs donor layer doping of 4×10^{12} cm^{-2}.

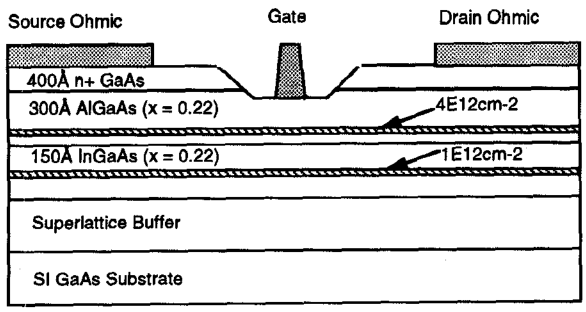


Figure 3. Cross section of AlGaAs/InGaAs HEMT.

The monolithic mixer circuit process begins with a multiple oxygen-ion implantation to obtain device isolation and is followed by an ohmic contact deposition. A low contact resistance is achieved by using Ni/AuGe/Ag/Au metal with rapid thermal alloying at 540 °C. The 0.2 µm gate is delineated by electron-beam lithography. After the gate recess etching, the Ti/Pt/Au gate metal is evaporated and lifted off. The first-level metal consisting of Ti/Au is used to provide low-resistance interconnections and the bottom plate of MIM capacitors. A silicon nitride layer is used to form the MIM capacitor and the air-bridge process is used to define the second level interconnections. After the wafer is thinned down to 4-mil thick, reactive ion etching (RIE) via hole and backside metalization are added for signal grounding. The monolithic mixer chip measures 2.4 x 2.8 mm^2.

MEASURED PERFORMANCES

Figure 4 shows the measured conversion loss and input IP_3 of the hybrid mixer as a function of the RF frequency. A fixed gate bias of -2 V and an LO input power of +13 dBm were used for the measurement. The conversion loss is about 7~9 dB for a 26-29 GHz RF frequency and DC to 2 GHz IF frequency. No external tuning was required in the measurement and the 7 dB minimum conversion loss is in good agreement with the simulated result of 8 dB. The measured input IP_3 over the same RF frequency range is higher than +24 dBm. The calculated FOM of this mixer is +11 dB and at least 5 dB higher than the diode mixer at the same frequency range and bandwidth. This result is believed to be the best reported IP_3 performance for a EHF mixer. The measured spurious signal rejection characteristic is close to the predicted result in Table II. The LO to RF isolation is dependent on the C_{gd} ratio between the "ON" and "OFF" states of the device and the imbalance between the two Lange couplers. It is greater than 16 dB. The VSWR is better than 2.5:1 for all three mixer ports. A salient feature of the presented mixer is that the circuit performance is relatively insensitive to the device characteristics. Similar results have also been achieved for the monolithic mixer circuit.

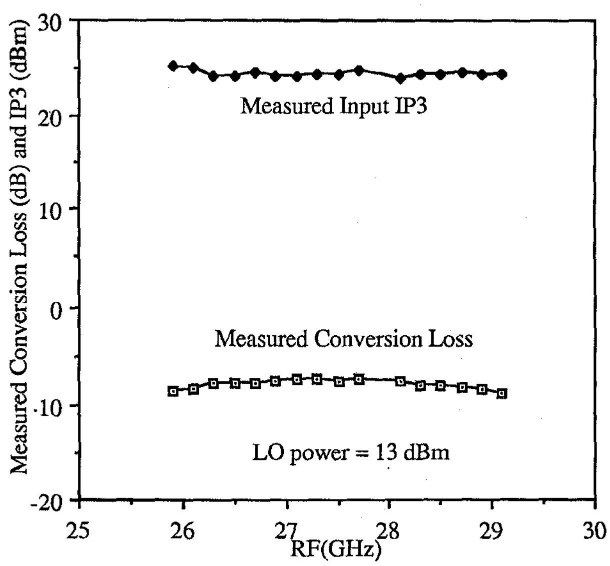


Figure 4. Measured conversion loss and input IP_3 of the hybrid EHF resistive mixer.

CONCLUSION

We have designed, fabricated and tested a hybrid and a monolithic SB EHF resistive mixers. The SB mixer was designed with two Lange couplers and two 0.2x160 μm^2 pseudomorphic InGaAs HEMTs. Both mixers have demonstrated similar excellent measured performance. Mixer conversion loss over the 26-29 GHz RF frequency band is about 7~9 dB for DC to 2 GHz IF frequencies. With an LO power of +13 dBm, the measured input two-tone third-order intercept point is higher than +24 dBm.

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