A Monolithically Integrated F-Band Resistive InAlAs/InGaAs/InP HFET Mixer

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***Abstract*—A monolithically inte grated F-band resistive HFET mixer has been designed, simulated, fabricated, and characterized. The mixer is based on an InAlAs/InGaAs/InP HFET with 0.15 μm gate length. The measured minimum conversion loss is 9 dB at 112.5 GHz and an LO power of 4 dBm, which is the lowest conversion loss reported for resistive HFET mixers in this frequency range.**

I. Introduction

The resistive FET mixer has previously demonstrated good performance at microwave and millimeterwave frequencies [1]–[4]. Compared to other FET mixers, it has the advantage of zero dc-power consumption, better intermodulation properties, and unconditional electric stability. Furthermore, due to the topology of the mixer, the LO port and the RF/IF ports are separated, introducing an intrinsic LO to RF/IF isolation. This mixer is therefore very suitable for integrated receivers based on FET devices. Due to the low LO-power requirement, it is an interesting alternative for receiving arrays, and different antenna-integrated resistive HFET-mixers have already been demonstrated [5], [6].

We present simulations and measurements of a resistive HFET mixer working in the F-band (90–140 GHz), based on a 0.15-μm gate length InAlAs/InGaAs/InP HFET. It is to our knowledge the first monolithically integrated resistive HFET mixer in this frequency range, and it demonstrated a 3-dB improvement over previously reported results with a GaAs pseudomorphic HFET in hybrid technology [4].

A. Circuit Design and Fabrication

The mixer circuit was fabricated using our in-house MMIC process. The circuit consists of the HFET, via-holes, mesa-resistors, and microstrip transmission line components. Fig. 1 shows a photograph of the mixer. The LO-signal is applied to the left and matched to the gate of the device through an impedance transformer. Bias is applied from the top of the circuit through a radial stub filter. The sources of the device are grounded with via-holes. The RF-signal is connected from the right and a finger coupler serves as a combined dc-block and high-pass filter. The IF is extracted from the drain through a radial stub filter to the IF-output port, and a 5 kΩ mesa resistor sets the drain potential to 0 V. The mixer was simulated and optimized by using a harmonic balance simulator (MDS from HP) with the device model used in [5]. The simulated and measured conversion losses versus LO power are shown in Fig. 2. The device width was optimized to give low reflection loss at the RF-port without any output matching circuit. The simulated isolation between the LO-port and the RF-port is 12 dB at the gate voltage for minimum conversion loss.

The mixer is fabricated on a lattice-matched InAlAs/InGaAs/InP MBE-grown material. The material consists of a 50 Å $In_{0.53}Ga_{0.47}As$ cap layer, a 200 Å $In_{0.52}Al_{0.48}As$ Schottky layer, a Si δ-doping layer ($4 \cdot 10^{12}\,cm^{-2}$), a 40 Å $In_{0.52}Al_{0.48}As$ spacer layer, a 300 Å

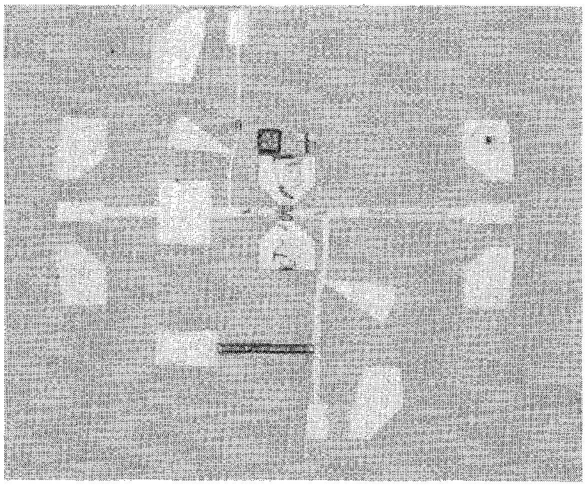

Fig. 1. Photograph of the monolithically integrated resistive HFET mixer circuit.

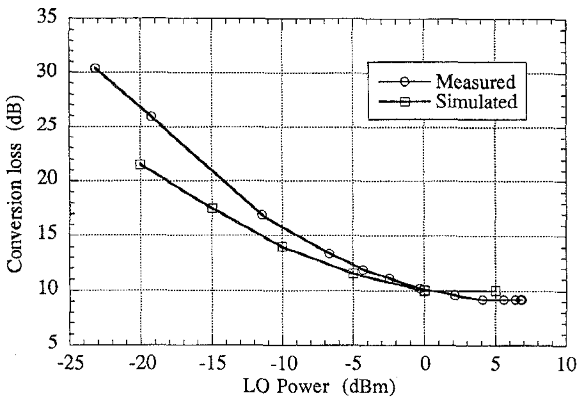

Fig. 2. Measured and simulated conversion loss versus LO power ($V_g = -0.4$ V).

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$In_{0.53}Ga_{0.47}As$ channel layer, and a 5000 Å $In_{0.52}Al_{0.48}As$ buffer layer on semi-insulating InP. Hall measurement shows a room temperature mobility of 8200 cm^2/Vs and a carrier concentration of $1.5 \cdot 10^{12}\,cm^{-2}$. The HFET's were fabricated using standard photolithography techniques for isolation and ohmic contact patterning, and electron beam lithography for the $0.15 \times 50\,\mu m^2$ T-gates. The maximum dc transconductance is 400 mS/mm and the saturated drain to source current is 260 mA/mm. S-parameters were measured up to 62.5 GHz, and an $f_{\max}$ of 260 GHz and an extrinsic f_T of 110 GHz were extrapolated.

This material and fabrication process are well suited for MMIC's. Amplifiers have been fabricated using the same material and process, and 5–6 dB gain has been measured on-wafer for a one-stage amplifier, showing the possibility of making a complete integrated receiver.

B. Measurements

The mixer was measured on-wafer using coplanar W-band probes for the RF and LO ports, and a coplanar V-band probe for the IF port. The losses in the probes have been accounted for. The LO frequency was set to 110 GHz and the RF to 112.5 GHz. The power from the LO and RF sources (Gunn oscillators) were calibrated using an Anritsu power meter (ML4803A) and varied using precision rotary attenuators. The IF signal was measured with a spectrum analyzer (HP8565E) and calibrated with a power meter.

A minimum conversion loss of 9 dB was measured with a saturated LO power of 4 dBm and an RF power of −14 dBm. We define the conversion loss as the available power at the RF-port of the MMIC divided by the output power at the IF-port of the MMIC. The measured conversion loss versus LO power is plotted in Fig. 2. The gate-voltage for minimum conversion loss coincides well with simulations at LO-powers larger than −10 dBm. The measured and simulated optimum gate voltage (for minimum conversion loss) coincides within 0.05 V. At the optimum gate voltage, an LO power of 4 dBm is sufficient to saturate the mixer, i.e. the conversion loss is not decreasing further if the LO-power is increased. The conversion loss versus gate voltage is plotted in Fig. 3. The LO-RF isolation was measured to be 11 dB. Due to the lack of RF-power, we were unable to observe the 1 dB compression point, even at very low LO power levels.

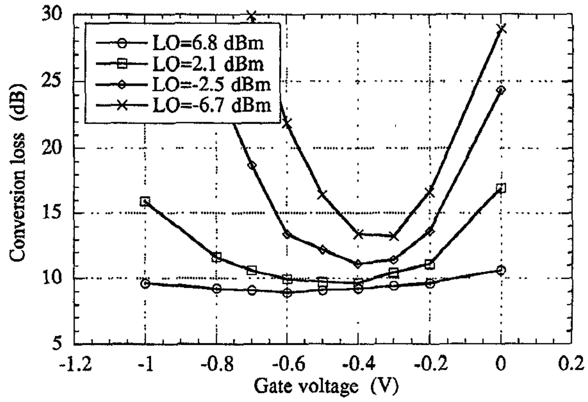

Fig. 3. Measured conversion loss versus gate voltage.

II. Conclusion

The operation of a monolithically integrated resistive InP-based HFET mixer has been demonstrated in the F-band. A minimum conversion loss of 9 dB was measured at an LO power of 4 dBm. This is to our knowledge the lowest reported conversion loss in this frequency range.

Acknowledgment

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