A W-Band Monolithic, Singly Balanced Resistive Mixer With Low Conversion Loss

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Abstract—**We report the design, measured and simulated performance of a novel W-band monolithic, singly balanced resistive FET mixer utilizing 0.1–μm pseudomorphic AlGaAs/InGaAs on GaAs HEMT technology. At an LO drive of +8 dBm, this mixer has exhibited a minimum measured conversion loss of 12.8 dB, nearly a 10 dB improvement over previously reported data in this frequency range. Furthermore, the mixer figure of merit, defined as $P_{1\text{-dB},in} - P_{LO}$, is at least +2 dBm, which is nominally 6 dBm better than that of comparable diode mixers at W-band. These results indicate the excellent potential of this mixer for integration with other circuit components in fully monolithic subsystems.**

I. Introduction

Recently, there has been an emphasis on the development of wide dynamic range mixers at millimeter-wave frequencies [1]–[3]. Resistive FET mixers have been shown to possess better intermodulation and compression performance compared to their diode-based mixer counterparts, with similar LO power requirements, conversion loss, and noise performance. GaAs-based resistive FET mixers utilizing hybrid circuit technology have demonstrated low intermodulation distortion as well as good conversion loss and noise performance at microwave and millimeter-wave frequencies [4]. We present the design, fabrication, and measured and simulated performance of a monolithic, singly balanced resistive mixer based on 0.1-μm pseudomorphic GaAs HEMT technology that has achieved a near-10-dB improvement in conversion loss over previously reported resistive FET mixer data at W-band [1].

II. Mixer Design and Fabrication

The mixer's singly balanced topology, originally proposed by Kruger [5], is shown in Fig. 1 and is well-suited for monolithic implementation. Such a mixer configuration provides good VSWR at the RF and LO ports and has demonstrated good even-order spurious response rejection as well as good LO to RF isolation [6].

The monolithic mixer circuit was fabricated using GaAs-based, MBE-grown $0.1 \times 40 \mu m^2$ AlGaAs/InGaAs pseudomorphic HEMT devices. The details of the device structure have been reported elsewhere [7]. In the design, the sources of the HEMT devices were grounded through via holes while the gates were reverse biased. The matching circuits for the LO and RF inputs at the gates and drains of the HEMT's, respectively, were constructed from MIM capacitors and cascaded high-low impedance microstrip lines. The IF signals were extracted through low-pass filters at the drains of both devices. The mixer circuit was fabricated using TRW's baseline MMIC process, which has been described previously [7]. A photograph of the completed monolithic chip is shown in Fig. 2.

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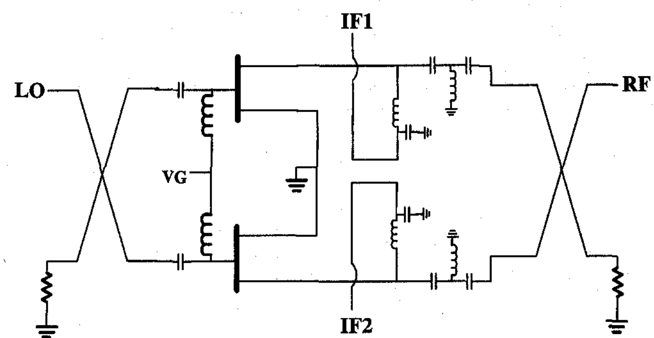

Fig. 1. Schematic of singly balanced resistive FET mixer topology using two quadrature couplers.

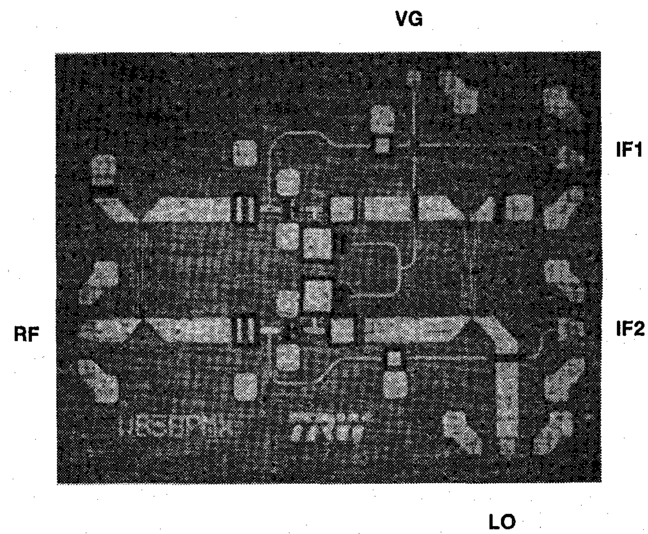

Fig. 2. Photograph of monolithic singly balanced resistive HEMT mixer chip.

III. Measured and Simulated Mixer Performance

During testing, the monolithic mixer chip was mounted in a brass fixture incorporating finlines for the waveguide to microstrip transistion at both the RF and LO ports. The transition losses were estimated to be 1.0 dB at each port with the feedline at the LO port contributing an additional 1.0 dB of loss. The LO and RF frequencies were set at 93.0 GHz and 93.2 GHz, respectively. The source powers at the LO and RF

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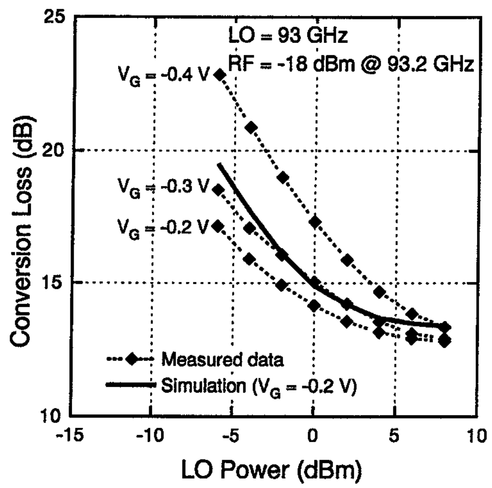

Fig. 3. Plot of measured and simulated conversion loss versus LO power for different values of gate bias.

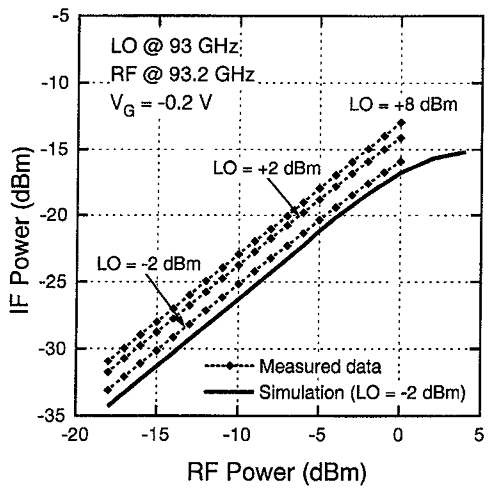

Fig. 4. Plot of measured and simulated output IF power versus input RF power for different levels of LO drive.

ports were calibrated and then applied to the mixer chip, and the two separate, in-phase IF output signals extracted from the chip were combined using an external hybrid coupler.

First, the dependence of conversion loss on both gate bias and LO power was determined. The RF power was set to -18 dBm. Fig. 3 shows the conversion loss versus LO power for different values of gate bias. At a smaller reverse gate bias, the conversion loss begins to saturate at a lower LO power. This correlates well with the physical picture of device operation where the saturation of the conversion loss occurs due to the saturation of the HEMT's channel electron density, and hence the channel conductivity, in the heterojunction potential well under a forward-applied gate voltage. For the mixer, the lowest conversion loss of 12.8 dB is achieved at a gate bias of $V_G = -0.2$ V and with an LO drive of +8 dBm, although the conversion loss saturates near its minimum at an LO power of +4 dBm.

Fig. 4 is a plot of measured IF power versus RF power for different LO powers. This figure shows that the input 1-dB compression point, $P_{1\text{-dB},in}$, is greater than 0 dBm for an LO power of -2 dBm. Unfortunately, the RF source generator could not output more than +4 dBm power so that compression at the higher LO powers was not be observed. The figure of merit, $P_{1\text{-dB},in} - P_{LO}$, is estimated to be at least +2 dBm for our resistive mixer, which is nominally 6 dBm better than that of comparable diode mixers at this frequency.

An extended large-signal model, which is based on analytic equations proposed by Plà and Struble for GaAs MESFET RF switches [8], has been developed to simulate the operation of the HEMT at zero drain bias. The extended model includes nonlinear current sources to model the gate-to-drain and gate-to-source Schottky diode junction currents and treats the total gate capacitance as an asymmetric distribution between the gate-drain and gate-source capacitances. Using this model, the performance of the mixer was simulated using EEsof's harmonic balance simulator, *Libra*, and the simulation results are plotted as the solid line in Figs. 3 and 4. The figures clearly show that the model is capable of accurately predicting the trends in both the saturation of the conversion loss versus LO power and the compression of the output IF power versus input RF power.

IV. Conclusion

The operation of a monolithic, GaAs-based pseudomorphic InGaAs HEMT singly balanced resistive FET mixer has been demonstrated at W-band. The mixer has achieved a minimum conversion loss of 12.8 dB at an LO drive of +8 dBm and has also exhibited superior compression characteristics. The topology of the mixer is well-suited for monolithic implementation and its conversion-loss performance demonstrates its excellent potential for use in wide dynamic range mixing applications at W-band frequencies.

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