On-wafer Testing of a W-band HEMT Image-rejection Downconverter MMIC

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ABSTRACT

This paper describes the first successful on-wafer conversion gain and noise figure measurements taken on a downconverter MMIC at W-band. On-wafer and in-fixture measured results are consistent for a 0.1 μm AlGaAs-InGaAs-GaAs HEMT-based W-band image-rejection downconverter MMIC which has attained good RF yield. With an LO drive of 5 dBm at 94 GHz, the downconverter chip has achieved an USB conversion gain of 7.5–8.5 dB and noise figure of 6.5–7.5 dB for an IF signal in the range of 40 to 400 MHz.

INTRODUCTION

For the first time, an automated on-wafer test set has been constructed to allow for the rapid characterization of MMIC downconverter noise figure at W-band. In this paper, the test set configuration is described, and both conversion gain and noise figure data are presented for several hundred downconverter MMICs tested using the automated on-wafer setup. The on-wafer results correllate well with measured in-fixture data. The downconverter MMIC, developed using 0.1 μm AlGaAs-InGaAs-GaAs HEMT technology, utilizes an image-rejection topology, and improves on a proven W-band design [1] by incorporating an LO buffer amplifer to reduce the input LO drive required to achieve significant conversion gain. The current chip requires over 3 dB less LO power to attain a comparable level of conversion gain as described previously [1].

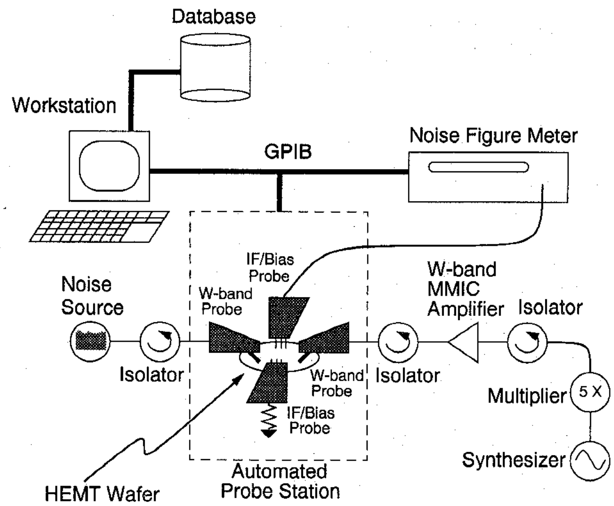

Figure 1: **Block diagram of on-wafer test set configuration.**

W-BAND ON-WAFER TEST SET

The configuration for the automated on-wafer noise figure measurement system is shown in Fig. 1. The test set requires one set of low loss, high-frequency (W-band) probes [2], with an additional set of probes required to monitor the IF outputs of the downconverter. In the test set, the W-band noise source and LO signal are injected through the W-band probes, while the separate set of probes apply bias to the chip and extract the IF output. To avoid the effects of unwanted radio frequency interference, particularly at low IF frequencies (up to several hundred MHz), shielded coaxial ca-

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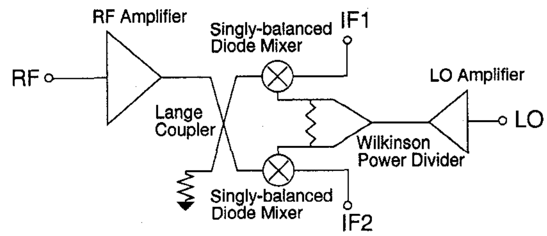
ble is used for the IF probe leads. In addition, the system uses a high ENR noise source to provide sufficient excess noise to the DUT, and includes an in-house designed W-band MMIC amplifier after the multiplier output to provide adequate LO drive. The entire test set is controlled with computer-aided test software.

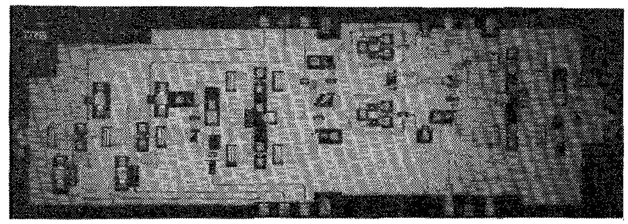
MMIC DESIGN

The monolithic downconverter circuit was fabricated using GaAs-based, MBE-grown double-heterojunction $0.1 \times 40\ \mu m^2$ AlGaAs-InGaAs-GaAs pseudomorphic HEMT devices. The active devices possess typical unity current gain cutoff frequencies in excess of 100 GHz, while the passive HEMT gate-diodes exhibit cutoff frequencies greater than 450 GHz.

The topology of the downconverter is shown in Fig. 2(a). The entire image-reject downconverter consists of a three-stage LNA serving as the RF front end, an image-reject HEMT Schottky-diode mixer, and an LO buffer amplifier. The three-stage RF preamplier design uses a single-ended two-stage amplifier cascaded with a balanced single-stage output amplifier similar to the one reported in [3]. The image-reject mixer is based on the design reported in [4] and utilizes two singly-balanced ratrace diode mixers, a Lange coupler, and a Wilkinson power divider. The RF preamplifier output is applied to one port of the Lange coupler, while the Wilkinson is driven from the output of the balanced LO buffer amplifier stage. The mixer circuit was fabricated using TRW's baseline MMIC process which has been described previously [5]. A photograph of the completed monolithic chip, which possesses dimensions of 6.0×2.0 mm^2, is shown in Fig. 2(b).



(a)

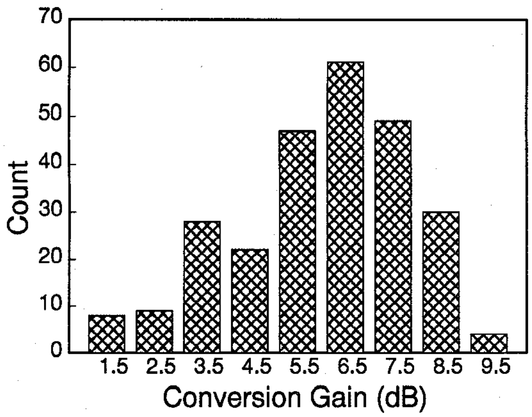


(b)

Figure 2: **(a) Downconverter topology and (b) monolithic chip photo.**

ON-WAFER and IN-FIXTURE MEASUREMENT RESULTS

During testing, the downconverter MMIC was biased with 2 V on the drains of the HEMTs, and the total power consumption of this chip is less than 125 mW. A total of 360 MMIC chips on 10 wafers (2 wafer lots, 36 chips per wafer) were on-wafer probed for both conversion gain and noise figure. Histogram plots of both the conversion gain and noise figure data derived from the on-wafer measurements are shown in Fig. 3, and indicate that the conversion gain for the downconverter varied from 5.5 to 9.5 dB while the noise figure varied between 5.5 to 8.5 dB. RF yields of 51% and 53% have been calculated for the chip using a noise figure of 7.5 dB and a conversion gain of 5.5 dB, respectively, as the screening criteria. These yield percentages do not account for DC prescreening.



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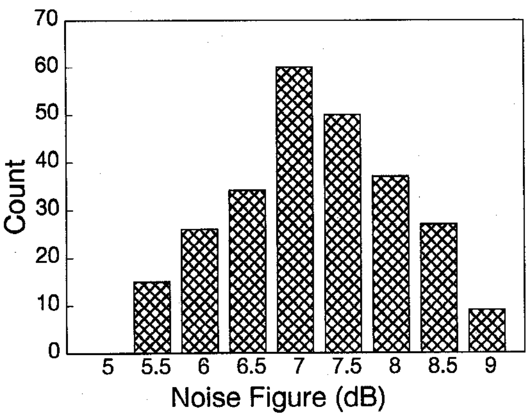
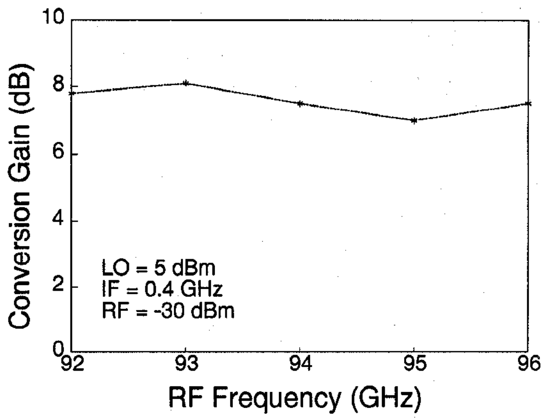
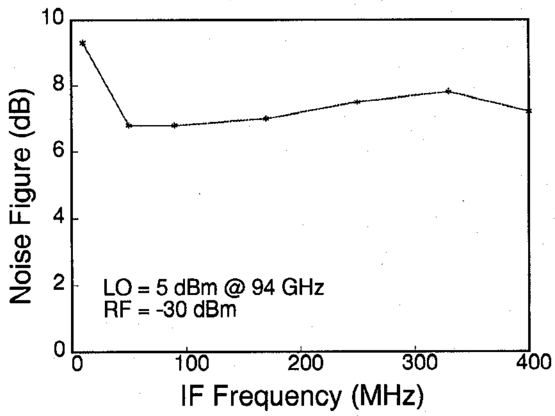


(b)

Figure 3: **Histogram plots of on-wafer probed (a) conversion gain and (b) noise figure.**



(a)



(b)

Figure 4: **In-fixture measured (a) conversion gain and (b) noise figure for the downconverter MMIC.**

The entire downconverter MMIC was mounted in a waveguide fixture and tested with the two IF outputs connected with a 3 dB 90° hybrid coupler. The in-fixture measurement results for conversion gain across the RF frequency band from 92 to 96 GHz and noise figure across the IF frequency band from 10 to 400 MHz at an LO drive of 5 dBm are shown in Fig. 4, and agree admirably with the on-wafer data. The typical measured USB conversion gain and and image rejection at an RF of 94.1 GHz and an LO at 94 GHz were 7.5 dB and 15 dB, respectively, while the SSB noise figure was measured to be 6.5 dB.

CONCLUSION

We have successfully demonstrated the capability for on-wafer characterization of both conversion gain and noise figure at W-band for an image-reject downconverter MMIC. The downconverter has achieved a conversion gain of 7.5–8.5 dB and a noise figure of 6.5–7.5 dB under a moderate LO drive of 5 dBm at 94 GHz. Based on on-wafer conversion gain and noise figure data taken on several hundred test sites over ten wafers, the chip has achieved high RF yield greater than 50%, attesting to the maturity of pseudomorphic InGaAs HEMT technology for increasingly complex MMIC designs at W-band.

ACKNOWLEDGMENTS

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