A Monolithic HEMT Diode Balanced Mixer for 100-140 GHz

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***Abstract* — We report the design and evaluation of a broadband, balanced mixer for 100-140 GHz using a HEMT MMIC process on a 75 µm InP substrate. The circuit uses the gate Schottky diodes as mixing elements. It demonstrates a conversion loss of 15 ± 2 dB from 100-130 GHz with 5 dBm LO drive at 80 GHz. Measurements indicate a wide IF bandwidth extending beyond 50 GHz. This is the first demonstration of a monolithic HEMT diode balanced mixer in this frequency range.**

I. INTRODUCTION

Broadband mixers are important components for millimeter-wave radiometers. A monolithic approach enables compact receivers to be assembled into a focal plane array for millimeter-wave imaging applications. HEMT diodes have been used in recent MMIC mixers [2]-[4] with encouraging results. This approach has the advantage of being compatible with existing LNA technology, allowing a complete millimeter-wave down-converter to be integrated monolithically [3].

Balanced mixers have the useful property of suppressing LO amplitude noise as well as some high order mixing products [1]. Unfortunately, the bandwidth of monolithic balanced mixers is limited by that of the RF/LO coupler, which must have 3 dB coupling and 180° output phase difference across the band to realize these benefits (90° couplers may also be used, but suffer from poor RF-to-LO isolation). For example, the branch-line or ring hybrids are common choices for microstrip balanced mixers, but the bandwidth is typically only 10% to 20% [6].

This paper presents the design and evaluation of a broadband balanced diode mixer with RF from 100-140 GHz, and IF from 20-60 GHz. The circuit is fabricated on InP using a standard HEMT MMIC process.

II. CIRCUIT DESIGN

The circuit is designed to downconvert an RF band of 100-140 GHz to an IF of 20-60 GHz by mixing with a fixed 80 GHz LO. A photograph of the chip is shown in Figure 1 and a schematic is in Figure 2. As described earlier, the 180° coupler is a key component of this type of mixer, and constrains the bandwidth in many implementations. To overcome this limitation, we incorporate the novel combination of a Lange coupler with 90° coupled-line phase shifters [7]-[8] to synthesize a broadband 180° coupler, as shown in Figure 3. The Lange coupler was fabricated in the First-Level Interconnect (FIC) metal layer, which is thinner and allows tighter spacing between lines than top-metal in this process. Although this approach incurs greater losses, it was necessary to achieve the tight 3 dB coupling that is critical to the operation of the mixer. The coupled-line phase shifters that follow are designed to provide good input match and a differential phase shift of 90° ± 5° from 80-140 GHz. Both the coupler and the phase shifters were simulated using the HP Momentum software. Together they comprise a 180°, 3-dB coupler with approximately 55% bandwidth.

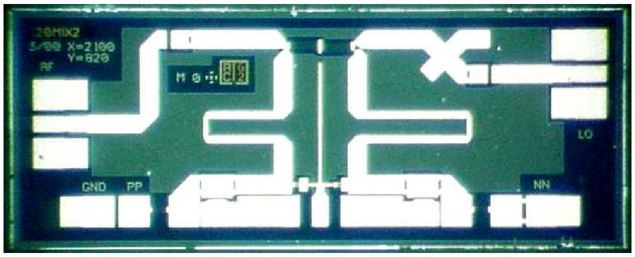

Fig. 1. Photograph of the MMIC mixer. Chip dimensions are 2.0 x 0.74 mm. InP substrate thickness is 75 µm.

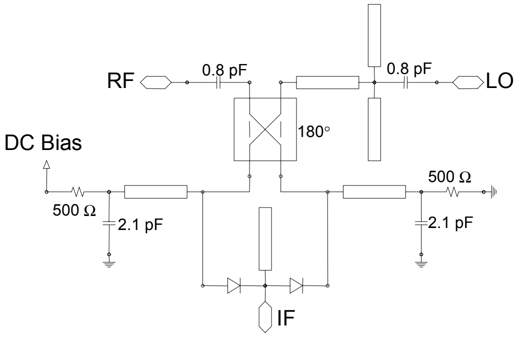

Fig. 2. Schematic of the mixer, showing MIM capacitors, thin-film resistors, and transmission line sections.

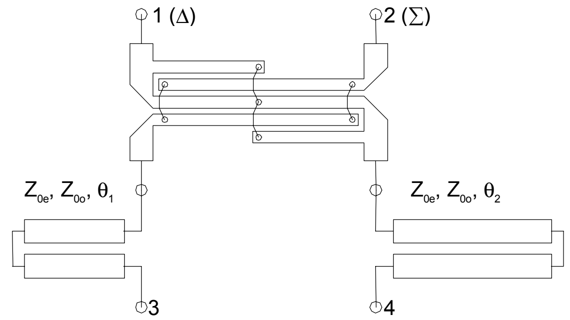

Fig. 3. Schematic of the 180° directional coupler.

Two HEMT-gate Schottky diodes, available in the TRW InP HEMT Process [9], were used as mixing elements. Based on a 2-finger, 40 µm FET model for this process, the gate structure was designed to simultaneously minimize the parasitic resistance and capacitance of the Schottky diode. Specifically, the diode cell consists of two fingers, each 5 µm long. Our conservative estimate is that this structure has $R_s = 33\ \Omega$, and $C_{j0} = 16$ fF. More rigorous testing of this structure leading to a better model of the diode is planned for future wafer runs.

The diodes are biased in series through low-impedance transmission lines along the bottom edge of the chip. The lines are bypassed at a quarter-wavelength from the diode in the center of the RF band. This provides a ground return and isolation for the IF, while allowing RF and LO frequencies to pass.

Directly on the IF port, between the two diodes, is an open-circuited stub which is intended to be a quarter-wavelength long at the LO frequency. This was done to prevent LO power from leaking at this port. The stub was designed to be tunable by including a series of air-bridges near the open end, which could be selectively broken to shorten the stub's length.

A microstrip matching section tuned for 80 GHz was added to the LO side. No matching section was used on the RF port, because this point is too far from the diodes to match the signal over such a wide bandwidth. Nevertheless, simulations indicate that the input return loss should be greater than 6 dB across the band.

III. Measurements

The test setup is shown in Figure 4. A Thomson Components Backward Wave Oscillator (BWO), model RWO 110S, was used to provide the LO signal. The power from the BWO was adjusted with a WR-10 precision attenuator and monitored through a 10 dB coupler with an HP W8486A power meter. The LO power was coupled into the MMIC through a GGB Industries coplanar wafer probe. The precise coupling of the coupler, always close to 10 dB, was recorded and used in the calibration of the measurements. The insertion loss of the wafer probe, about 1.3 dB, was also calibrated out of the measurement.

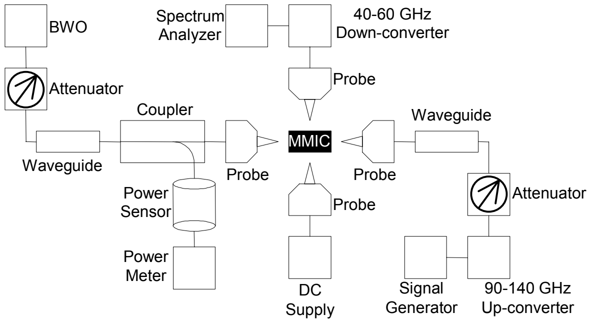

Fig. 4. Block diagram of the test setup. The 40-60 GHz down-converter was omitted for IF < 40 GHz.

The RF signal was supplied by an HP 83650B Signal Generator, feeding a Millitech 90-140 GHz waveguide mixer utilized as an up-converter. A 120 GHz low-pass filter was attached to the 90 GHz second harmonic Gunn on the Millitech module to remove a strong spurious tone at 135 GHz. RF signal power was adjusted with a WR-8 precision attenuator. Finally, the RF signal was coupled into the chip through another GGB Industries wafer probe. The attenuator setting that provided –15 dBm of signal power at the probe tips was measured and recorded for each frequency point. This signal level was strong enough to allow easy measurement of conversion loss without entering compression.

The IF signal was extracted with a 50 GHz wafer probe. For IF below 40 GHz, the output was measured directly with an HP 8564E Spectrum Analyzer. The loss in the coaxial cable, typically on the order of 2-8 dB, was calibrated out. To extend the range of IF measurements, a 40-60 GHz down-converter module was added in front of the Spectrum Analyzer, as shown in Figure 4. The conversion loss of this module is about 14-18 dB, and was calibrated out.

The most significant results are plotted in Figures 5-8. As shown in Figure 5, the conversion loss is about 15 dB overall from 100 GHz to 130 GHz. Although the circuit was designed for an 80 GHz LO, additional data was taken with other LO frequencies in order to get some idea how the conversion loss changes with RF and IF frequencies

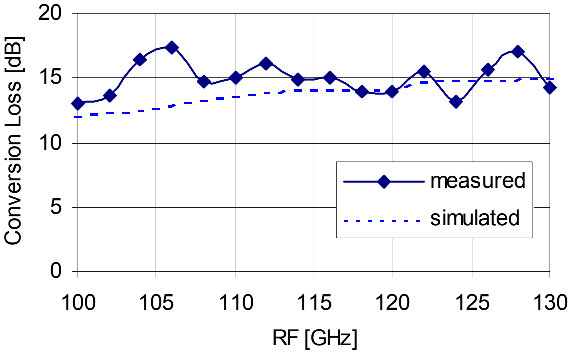

Fig. 5. Measured and simulated conversion loss vs. RF frequency. LO was +5 dBm at 80 GHz. RF power was –15 dBm. The circuit was biased with a constant current of 2.4 mA.

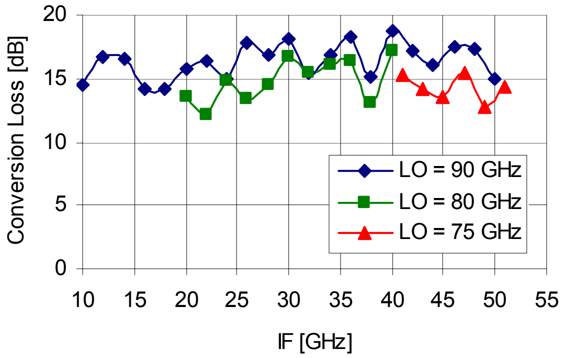

Fig. 6. Measured conversion loss vs. IF frequency for various LO frequencies. LO power was +5 dBm in all cases. RF power was –15 dBm, and the bias was held constant at 3.6 V.

that would otherwise be outside the range of the measurement setup. The results are shown in Figure 6. The conversion loss remains in the vicinity of 15 dB for IF from 10-50 GHz, and RF from 100-135 GHz.

The conversion loss in the center of the band for various LO powers and bias conditions is mapped out in Figure 7. Each curve represents a different LO power, and illustrates a different optimum current level. The curves converge at the low current end, implying that the conversion loss can be made relatively independent of LO power if a sacrifice of a few dB in conversion loss is acceptable.

The amount of LO power the circuit can withstand and how it affects the conversion loss would be of interest in some applications. As shown in Figure 8, the LO power was swept up to 17 dBm, limited by the test equipment, without any detectable damage to the chip. A minimum of 12 dB conversion loss was found with 10 dBm LO power, though one would expect the noise performance of the mixer to suffer at this drive level.

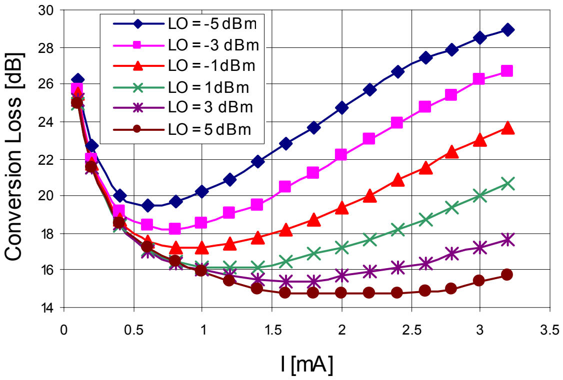

Fig. 7. Conversion loss vs. LO power and bias condition. The LO frequency was 80 GHz, and RF was –15 dBm at 110 GHz.

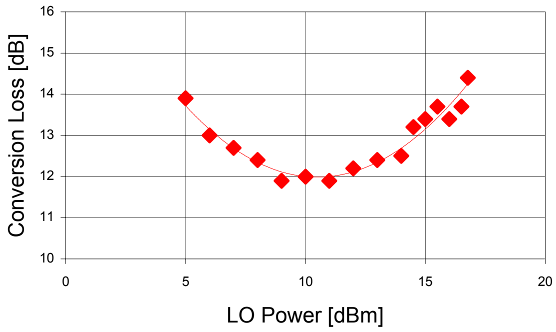

Fig. 8. Conversion loss vs. LO power for high drive level. The LO frequency was 88 GHz, and the RF signal was –15 dBm at 132 GHz. Bias was held constant at 2.4 mA.

IV. CONCLUSION

A broadband, balanced mixer for 100-140 GHz has been demonstrated using a monolithic HEMT process. The chip demonstrates between 13 and 17 dB conversion loss from 100-135 GHz. The design incorporates a novel 180° microstrip coupler with 55% bandwidth, which enables the broadband balanced mixer. This is the first monolithic HEMT diode balanced mixer in this frequency range.

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