A Q-BAND MONOLITHIC BALANCED DIODE MIXER USING AlGaAs/GaAs HEMT AND CPW HYBRID

T.H. Chen, T.N. Ton, G.S. Dow, K. Nakano, L.C.T. Liu, and J. Berenz

TRW / ESG, Electronics and Technology Division,
One Space Park, Redondo Beach, CA 90278

ABSTRACT

A Q-band balanced diode mixer has been developed using AlGaAs/GaAs HEMTs, a CPW ratrace hybrid, and a lumped-element low-pass filter. The mixer can be easily intergrated with the RF, LO, and IF HEMT amplifiers on one chip because it uses HEMT as a mixer diode. Furthermore, the mixer does not require backside and via-hole process and has small size, 1.4 X 1.5 mm. Therefore, it has good RF circuit yield. The mixer downconverts the 41 - 48 GHz RF to a 0.5 - 3.5 GHz IF. Without DC bias, it shows 9.4 dB conversion loss for RF at 42 GHz, with a LO drive of 11 dBm at 44.45 GHz. The presented mixer is the first monolithic CPW mixer for operation at Q-band frequencies.

INTRODUCTION

High level integration of millimeter-wave MMICs achieves not only space and weight conservation but also higher reliability and better performance due to fewer number of bonding wires and other parasitics. Therefore, the feasibility of millimeter-wave systems in large quantities depends on the availability of millimeter-wave MMICs, such as monolithic millimeter-wave receiver. The high electron mobility transistor (HEMT) is superior to the GaAs MESFET when used in millimeter-wave low-noise and power amplifiers [1,2]. On the other hand, GaAs Schottky barrier diodes have shown very good mixing performance for millimeter-wave frequencies [3]. Although diode mixers which is compatible with MESFET processing technologies have been reported [4,5], the easiest way to integrate diode mixer and HEMT amplifiers on one chip is to use the gate Schottky contact of the HEMT as a diode. This paper describes a broadband single balanced mixer using HEMTs as mixer diodes for operation at Q-band frequencies. Broadband performance is realized by utilizing a monolithic CPW ratrace hybrid. This further relaxes the requirement for the process technology and increases circuit yield because CPW circuit elements do not require backside and via-hole process. A conversion loss of less than 12 dB has been measured for RF frequency range from 41 to 47 GHz, with a LO drive of 11 dBm at 44.45 GHz. The mixer performance can be further improved by reducing the series source and drain resistances of the HEMT device to increase the cutoff frequency. This will also improve the gain and the noise performances of the HEMT used as an active three terminal device in a amplifier.

BALANCED MIXER DESIGN

A single balanced mixer configuration was used in the design of the Q-band monolithic mixer. Figure 1 shows the circuit schematic. The circuit consists of a CPW ratrace hybrid, a pair of HEMT gate diodes, and a lumped-element low-pass filter. Two 30 micron AlGaAs/GaAs HEMTs with 0.25 micron gate length are used as diodes in the mixer design. A nonlinear model of the 30 micron HEMT as a diode is constructed from measured S-parameter and DC I-V curves. Figure 2 shows the diode model. The cutoff frequency of the HEMT gate diode is 250 GHz at zero bias. LO and RF signals, as shown in Figure 1, are fed at the two input ports of the CPW ratrace hybrid. The other two ports of the CPW ratrace hybrid are connected to the anode of one diode and the cathode of the other diode, respectively, through an MIM capacitor. These two MIM capacitors are used to block IF signal from leaking to RF and LO ports as well as to couple RF and LO signals to the diodes. Two high impedance CPW lines are used to provide IF ground and DC returns for the diodes. The IF signal is extracted from the common node of two diodes and coupled to the external IF port through a low-pass filter. This filter provides RF and LO ground as well as the RF-to-IF isolation. It also improves the LO-to-IF isolation. No DC bias is required for this mixer circuit.

CIRCUIT FABRICATION

The circuit was fabricated on an AlGaAs/GaAs heterostructure HEMT wafer grown with MBE. Figure 3 shows the device structure. The process begins with oxygen ion implantation to obtain device isolation. This implantation process is critical for uniform EBL gate processing. Ohmic contacts are deposited using gold-germanium metalization. A contact resistance of less than 0.08 ohm-mm is achieved by using rapid thermal alloying. A thin layer of metal (Ti-Au) is deposited to form the first level metal, this layer is used to form the matching networks and bottom plate of the MIM capacitors. Electron beam lithography is used to define the 0.2 to 0.25 micron gate length resist patterns. Gate recess etching is performed followed by gate metal deposition. A thin dielectric film (silicon-dioxide) is deposited to form the MIM capacitors. The top metal is defined using an air-bridge process. This form of interconnection reduces cross-over parasitics and improves circuit yield. Lift- off techniques are used in both dielectric and top metal process steps. Figure 4 shows a photograph of the fabricated mixer chip. The chip measures 1.4 X 1.5 mm. Figure 5 illustrates the DC I-V curve of two diodes connected in parallel with opposite polarity on the mixer chip.

RF PERFORMANCE

The Q-band monolithic balanced mixer was tested on-wafer with cascade RF probes. A conversion loss of less than 12 dB for RF frequencies from 41 to 47 GHz was measured with a LO drive of 11 dBm at 44.45 GHz. It showed a minimum conversion loss of 9.4 dB at 43 GHz RF frequency. For comparison, Figure 6 shows the measured and the simulated conversion loss of the mixer as a function of RF frequency. The IF output power of the mixer was also measured with various RF input power levels. The IF output power did not show any noticeable compression up to 0 dBm of RF input power.

In Figure 7, the measured and simulated mixer conversion loss are compared as a function of LO power at LO frequency of 44.45 GHz and RF frequency of 42.0 GHz. The measured mixer conversion loss shows a minimum at LO drive between 11 and 13 dBm while the simulated conversion loss does not decrease with increasing LO power up to 15 dBm. The discrepancy between the measured and the simulated results may be due to the simplified diode model where the series resistance is assumed to be bias-independent however, in reality, it increases with the DC bias or the LO drive. In addition, it is worth mentioning that this mixer shows very good RF yield. Seven out of ten mixer chips across the wafer that we have tested show simular performance. This is mainly due to the simple circuit topology and less critical process requirement.

CONCLUSION

A Q-band single balanced mixer was designed, fabricated, and tested. It demonstrates low conversion loss, broadband performance, small chip size and high RF yield. The mixer uses a CPW ratrace hybrid, a lumped-element low-pass filter, and quarter micron AlGaAs/GaAs HEMTs as mixing diodes. The mixer performance can be further improved by reducing the series source and drain resistances of the HEMT device. This will also improve the gain and the noise performances of the HEMT used as an active three terminal device in a amplifier. The most important feature of this mixer is that it can be easily integrated with the RF, LO, and IF HEMT CPW amplifiers into a single chip downconverter/upconverter. This type of downconverter/upconverter chip uses only one type of device, the AlGaAs/GaAs HEMT, and does not require backside and via-hole process. It is very suitable for the future high level integration of millimeter-wave MMICs.

ACKNOWLEDGEMENT

The authors would like to thank Dr. D. Yang, Dr. H. Wang, and S. Back for their help in testing the mixers. Also, the authors would like to thank J. Coakley for the layout.

REFERENCES

[1] P.M Smith, U.K. Mishra, P.C. Chao, S.C. Palmateer, and J.C.M. Hwang, "Power Performance of microwave high electron mobility transistor," IEEE Electron Device Lett., Vol. EDL-6, pp. 86-87, Feb. 1985.

[2] K. Hikosaka, Y. Hirachi, T. Mimura, and M. Abe, "A Microwave Power Double- heterojunction High Electron Mobility Transistor," IEEE Electron Device Lett., Vol. EDL-6, pp. 341-343, July 1985.

[3] P. Bauhahn, T. Contolatis, J. Abrokwah, C. Chao and C. Seashore, "94 GHz Planar GaAs Monolithic Balanced Mixer," IEEE 1984 Microwave and Millimeter-Wave Monolithic Circuit Symposium, pp. 70-73.

[4] T.N. Trinh, W.S. Wong, D. Li and J.R. Kessler, "Ion Implanted W-Band Monolithic Balanced Mixers for Broadband Applications," IEEE 1987 Microwave and Millimeter-Wave Monolithic Circuit Symposium.

[5] B. Adelseck, A. Colquhoun, J.M. Dieudonne, G. Ebert, J. Selders, K.E. Schmegner, and W. Schwab, "A Monolithic 60 GHz Diode Mixer in FET Compatible Technology," IEEE 1989 Microwave and Millimeter-Wave Monolithic Circuits Symposium.

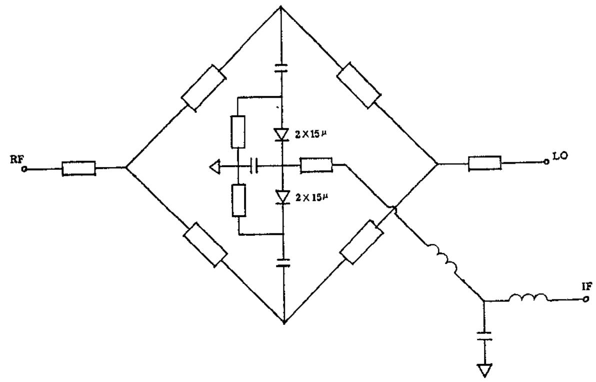
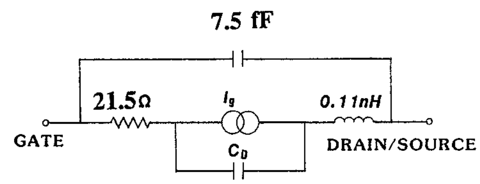


Figure 1 Circuit schematic of the Q-band single balanced diode mixer



Ideality Factor = 1.328
Leakage Current = 22.7 fA
C_D (@ zero Volt) = 22.1 fF

Figure 2 AlGaAs/GaAs diode nonlinear model

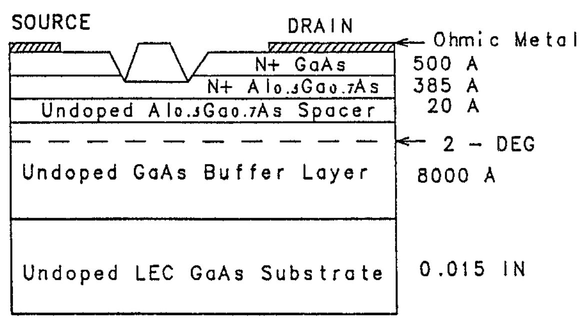


Figure 3 AlGaAs/GaAs HEMT device structure

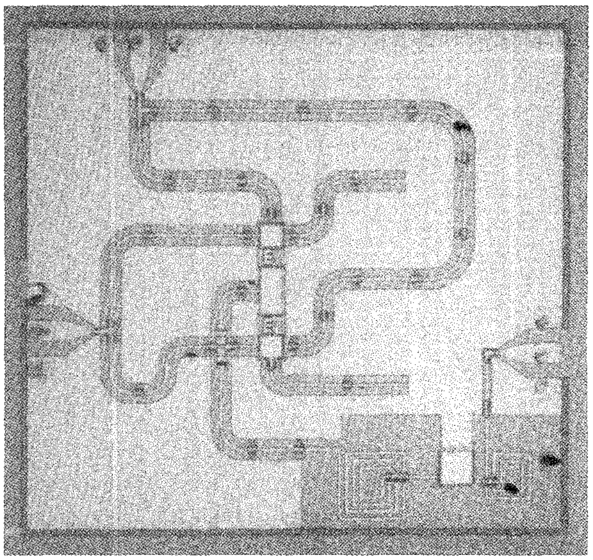


Figure 4 Photograph of the Q-band balanced mixer chip

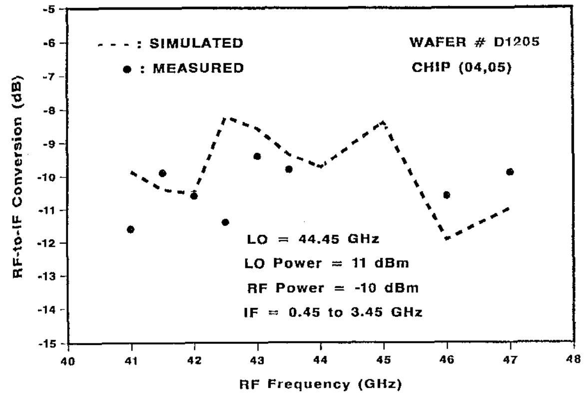


Figure 6 Measured and simulated conversion loss vs. RF frequency

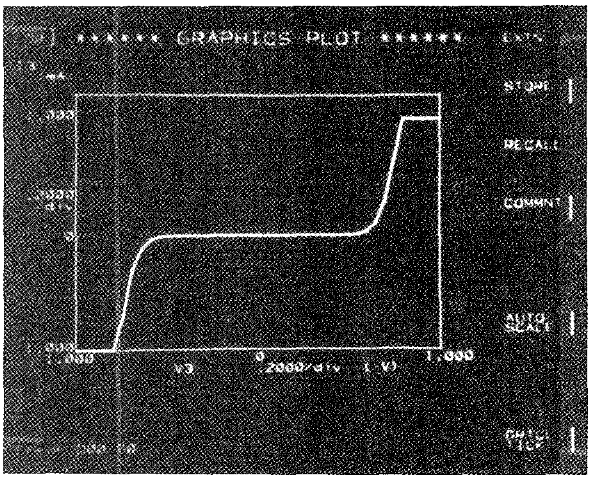


Figure 5 DC I-V curve of 2 diodes connected in parallel with opposite polarity on the mixer chip

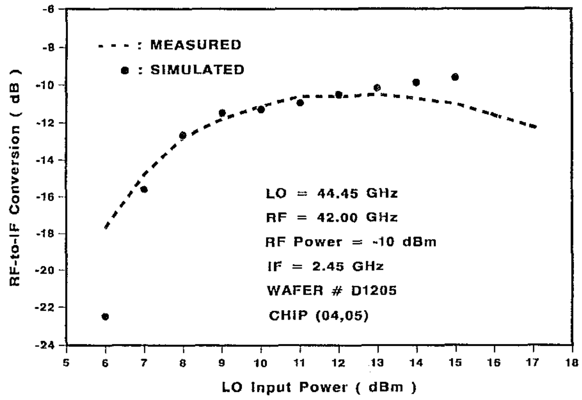


Figure 7 Measured and simulated conversion loss vs. LO power