InP HEMT MMICs FOR RADIOMETER APPLICATIONS

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ABSTRACT

We present results of developments of low noise millimeter wave receivers for space applications utilizing InP HEMT monolithic microwave integrated circuits (MMICs). Wafers have been produced resulting in state-of-the-art performance for a variety of radiometer applications. We have developed two MMIC downconverter chipsets for earth remote sensing applications. All chips have been fabricated entirely on InP with a 0.1 micron gate length. The first of these is a 54 GHz receiver with 8 GHz IF bandwidth and a low noise amplifier front end with a measured noise figure of 3.8 dB. A second chip set has been fabricated for operation at 118 GHz also with an IF bandwidth of 8 GHz and an LNA noise figure of 5.2 dB. As part of this program the capability of measuring on-wafer S-parameters from 140-220 GHz has been developed and demonstrated on amplifiers with measured gain of 20 dB from 150-180 GHz, from a 6-stage design and greater than 4 dB from 165-190 GHz on a 2 stage balanced design

In support of ESA's Planck Surveyor, we are working on the development of cryogenic low noise amplifiers at 100 GHz. Two designs have been fabricated and tested with results presented. After fixturing, a 3-stage MMIC microstrip design obtained 20 dB of gain and 59 K noise figure at 95 GHz at 25 K ambient temperature. A 4-stage coplanar waveguide design performs with 18 dB gain from 75-110 GHz and less than 50 K noise from 95-105 GHz.

1.0 INTRODUCTION

Millimeter wave radiometer systems typically benefit by having the lowest possible receiver noise. Jet Propulsion Laboratory, TRW and the University of Massachusetts, have teamed to develop low noise receivers for radio astronomy and atmospheric remote sensing. The goal of the effort is to use InP HEMT MMIC technology to develop low noise receivers and receiver components operating with low power and mass. The effort is broken into two parts; InP heterodyne receivers for earth atmospheric sensing; and ultra-low noise cryogenic InP MMIC amplifiers for radio astronomy applications.

Heterodyne receivers are being developed for the Integrated Multi-spectral Atmospheric Sounder (IMAS), a combined infrared and millimeter wave, satellite based atmospheric nadir sounder. The millimeter wave instrument meets most of the science requirements of AMSU-A and B in a small, low power package. Receivers are required at 54., 118 and 183 GHz. The technology development effort seeks to produce heterodyne receivers at 54 and 118 GHz and the world's first functional low noise amplifier at 183 GHz.

At frequencies above 60 GHz, InP MMIC technology may provide the lowest noise practical solution for cryogenic radio astronomy receiver front ends. This is particularly true if a large number of receivers are required, as in the ESA's Planck LFI and the proposed Millimeter Array. We have designed, fabricated and cryogenically tested, 75-115 GHz InP MMIC amplifiers intended for ultra-low noise operation. These amplifiers have demonstrated the lowest noise performance to date for an amplifier covering this frequency range.

This paper serves to outline the development efforts, highlighting technology breakthroughs and performance benchmarks. Details of the individual circuits and measurements will be left to other papers cited throughout.

2.0 IMAS HETERODYNE RECEIVERS

The IMAS millimeter wave instrument is designed to provide temperature, pressure and humidity data by radiometric measurements of atmospheric spectral lines. The spectral range of the measurement must be broad enough to cover the tails of the spectral emission lines as well as approaching the peak. An amplifier front end is capable of broad bandwidth and low noise. In order to obtain resolution bandwidths narrow enough to sample the emission curves (0.2%), heterodyne operation of the receivers is required.

Receivers covering the O_2 lines at 60 GHz and 118 GHz have been fabricated. Amplifiers for a receiver front end for H_2O monitoring at 183 GHz have also been developed.

2.1 54 GHz Receiver

A complete downconverter chipset has been developed for the IMAS 54 GHz receiver. The technology employed is 0.1 μm InGaAs/InAlAs/InP HEMT MMIC (Lai et al 1997). The chipset consists of a 3-stage balanced low noise amplifier, second harmonic mixer, LO amplifier and IF amplifier. All chips were fabricated on a common wafer, enabling future integration into a MMIC downconverter chip, although the chips developed here are used in integrated hybrid assemblies

The amplifier has a measured gain of 19 dB and a noise of 3.8 dB from 51-60 GHz. The second harmonic mixer utilizes a balanced pair of HEMT gate Schottky diodes. The conversion loss of the mixer has been measured to be 12 dB at 53 GHz with 20 mW of LO power. In the module, the LO source is a 23 GHz DRO acquired from another vendor. The IF amplifier has 3.2 dB noise figure from 4-12 GHz and a 1 dB compression point of +10 dBm. The noise figure of the receiver is 4 dB across the IMAS band. The total power required to operate the receiver is 3 watts, including the DRO.

2.2 118 GHz Receiver

A similar approach was taken to fabricate the 118 GHz receiver. All designs were fabricated on the same wafer as the 54 GHz receiver. The chipset includes a low noise single-ended 3-stage amplifier from 105-130 GHz, a balanced buffer amplifier, second harmonic downconverter, LO active multiplier and IF amplifier (same as above).

Both RF amplifiers were measured on-wafer with a test set and wafer probes covering 85-140 GHz. Typical data from these chips are shown in Figure 2. Additional tests were performed in order to measure the RF gain fluctuations of the low noise chips, critical to radiometer performance for slow signal modulation. A "1/f" power spectrum was obtained with an amplitude of $\Delta G/G = 4\times10^{-5}$ $/\sqrt{Hz}$ at 1 Hz. The chips were then packaged in order to measure noise figure. The single ended design obtained 5.2 dB noise figure at the input waveguide flange while the balanced design has 7 dB noise figure.

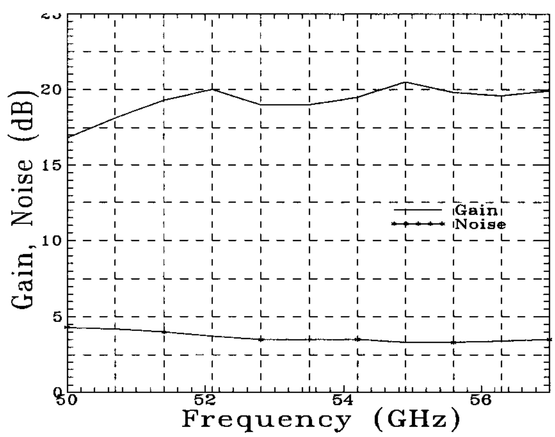

Figure 1. Gain and noise figure of fixtured 3-stage balanced amplifier.

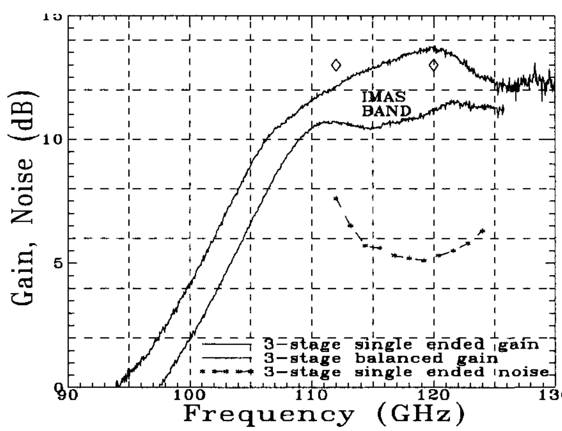

Figure 2. On-wafer gain of 3-stage single ended and balanced amplifiers. The noise figure of a fixtured amplifier is also shown.

The mixers were measured on wafer and achieve a conversion loss of 15 dB with LO power 4 mW. The IF bandwidth was confirmed to extend to 15 GHz (Kok et al 1998). The LO multiplier converts a 15.25 GHz, +10 dBm signal to a 61 GHz, +4 dBm signal, meeting the mixer power requirement.

2.3 183 GHz Amplifiers

Prior to this development, the highest frequency measured for a functional amplifier was 155 GHz (Wang et al, 1998) . The fabrication approach towards this amplifier was to use a 0.08 μm InGaAs/InAlAs/InP HEMT MMIC on 50 μm thick InP substrate (Lai et. al. 1998). Several design approaches were taken in order to maximize the probability of obtaining a functional amplifier at 190 GHz.

The primary design for IMAS was a 2-stage fully balanced amplifier utilizing 2 finger 30 μm devices. Input, interstage and output coupling is achieved with Lange couplers. The amplifier was modeled to have 7 dB gain at 185 GHz (figure 3). Two wafers fabricated achieved a device DC g_m> 1000 mS/mm, while the other two in the lot were closer to g_m= 800 mS/mm. One of the wafers with high g_m was probed using a WR-5 wafer probe and pseudo-scalar network analyzer (Gaier et al, 1998). The 2-stage chip exhibits >4 dB of gain from 165-193 GHz, with a peak gain of 7.2 dB at 190 GHz (figure 3). The balanced input will provide a good impedance match for cascading of several chips together in order to achieve the goal of 20 dB gain from a module.

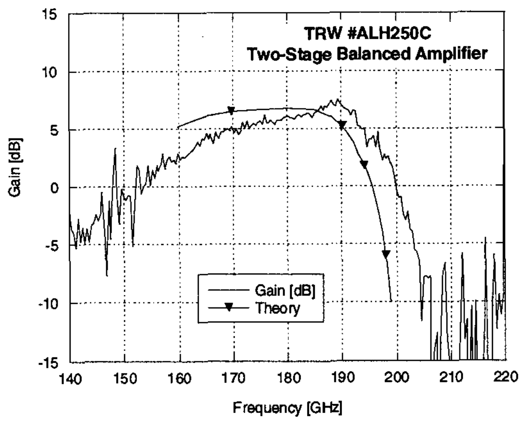

Figure 3. On-wafer measurement and model data of 2-stage balanced amplifier on a wafer with g_m=1000 mS/mm.

A second design on the wafer was a 6-stage single ended, grounded coplanar waveguide (CPW) design using 2 finger 20µm devices. The design has waveguide coupling probes integrated on the chip for fixture mounting (Weinreb et al, 1998).The chip was wafer probed at a pad at the waveguide probe-chip interface in order to approximately determine the performance on a high g_m (1000 mS/mm) wafer.

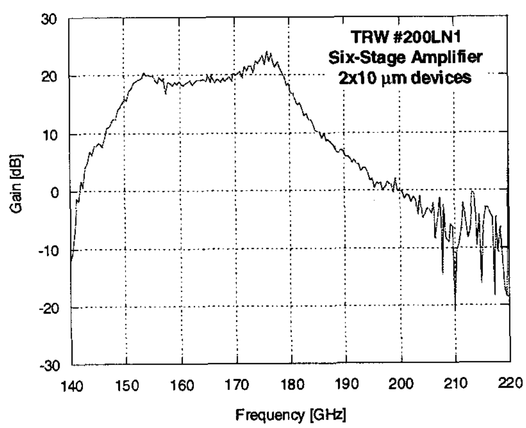

Figure 4. Figure 4. On-wafergain measurement of 6-stage CPW amplifier with waveguide probes intact with typical g_m of 1000 mS/mm.

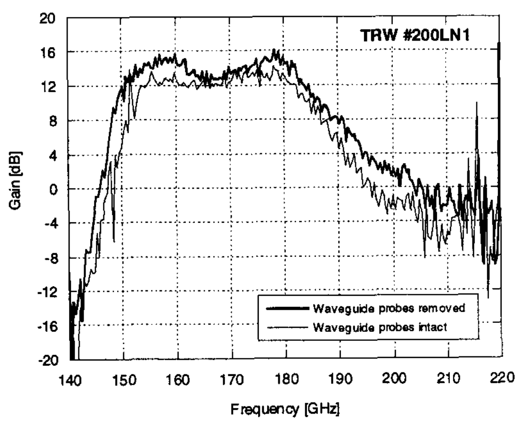

Figure 5. Wafer-probe measurement of 6-stageCPW amplifier showing the effects of waveguide probe removal. The wafer has a typical g_m of 800 mS/mm.

The amplifier demonstrated > 17 dB gain from 150-180 GHz, with a peak gain of 24 dB at 176 GHz (figure 4). Microsurgery to remove the waveguide probe was performed on a chip on a lower g_m wafer. The before and after gain curves are shown in figure 5, demonstrating the effect of waveguide probe removal

3.0 MMIC W-BAND AMPLIFIERS FOR CRYOGENIC ULTRA-LOW NOISE APPLICATIONS

To support future NASA astrophysics missions, including NASA's involvement with ESA's Planck Surveyor, a development effort has begun to produce ultra-low noise amplifiers at frequencies as high as 100 GHz. Two amplifiers have been designed, fabricated and cryogenically tested, demonstrating state-of-the-art performance at 100 GHz.

3.1 94 GHz 3-Stage MMIC LNA

A three stage amplifier has been developed for low noise applications at 94 GHz. This design is a modification of previous designs (H. Wang et al, 1996) and fabricated on the same InP process described above utilizing 4 finger 40 μm devices. The amplifier was packaged in a waveguide housing with longitudinal E-plane probes providing microstrip transitions.

Cryogenic measurements were performed at 25 K, for noise and gain. The amplifier exhibited 19 dB of gain at 95 GHz with a noise temperature of 59 K. The swept characteristics are shown in figure 6.

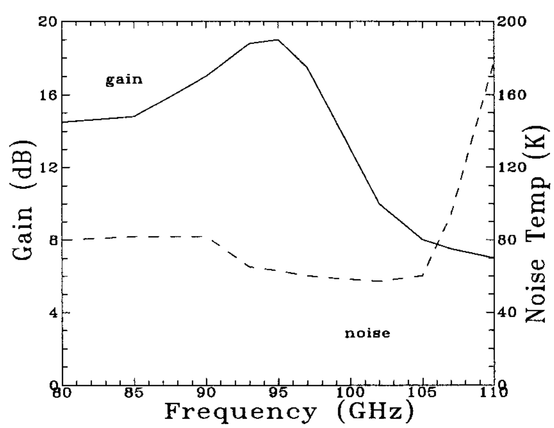

Figure 6. Cryogenic gain and noise of 3-stage microstrip amplifier.

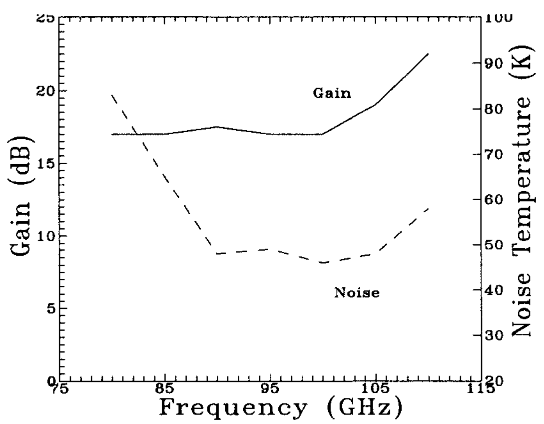

Figure 7. Cryogenic gain and noise of 4 stage CPW amplifier.

3.2 75-115 GHz 4-Stage CPW LNA

A 4-stage single ended low noise amplifier has been designed and fabricated on the same process described in 2.1. Chips have been packaged in a housing similar to the one described in 3.1. The packaged amplifier demonstrates a typical gain of 18 dB from 75-115 GHz with a 3.8 dB noise figure at room temperature.

Cryogenic measurements show that the amplifier gain is maintained and a record low noise temperature of 45 K at 100 GHz (9 times the quantum limit at this frequency) is observed (figure 7). The noise is less than 50 K from 95-105 GHz and less than 55 K from 85-110 GHz. Four of these amplifiers are currently operating on the Sequoia Array at FCRAO at the University of Massachusetts.

4.0 CONCLUSION

We have demonstrated that InP HEMT MMIC technology is capable of providing state-of-the-art performance for a variety of low noise radiometer applications. Amplifiers and components at record high frequencies have been produced, including a 105-130 GHz amplifier with 5 dB noise figure, two functional 180 GHz amplifiers useful gain, and two exceptionally low noise cryogenic amplifiers at W-band.

5.0 ACKNOWLEGEMENTS

The authors would like to thank B. Allen for his constant guidance as well as J. Wielgus and B. Osgood for their technical assistance during this project as well as. This work was supported under NASA Code Y technology development funds for the IMAS project. The cryogenic work was supported by NASA under grant UPN 632 for the Center for Space Microelectronics Technology. Some of the MMIC devices were designed and fabricated under TRW IR&D funds. Portions of this work were carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA.

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