A 183 GHz LOW NOISE AMPLIFIER MODULE WITH 5.5 dB NOISE FIGURE FOR THE CONICAL-SCANNING MICROWAVE IMAGER SOUNDER (CMIS) PROGRAM

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Abstract **We present the development of a low noise amplifier (LNA) module which demonstrates gain > 24 dB and noise figure (NF) < 5.5 dB at 183 GHz. Our previous results reported NF < 8.3 dB [1]. This improvement was achieved by inserting a single-ended microwave monolithic integrated circuit (MMIC) LNA utilizing TRW's 0.08 μm gate InP MMIC technology. This paper discusses the development of the new MMIC LNA, reviews the previous results and presents the new data that was obtained.**

I. INTRODUCTION

The development of radiometers at 183 GHz arises because an atmospheric absorption due to H_2O occurs at 183.31 GHz, and there is also a presence of an O_3 line at 184.3 GHz. The knowledge of the concentrations of H_2O, O_2, and O_3 are important parameters for models of the weather and for global warming.

The best-reported receivers to date have employed subharmonically pumped waveguide mixers using a pair of anti-parallel planar air-bridge-type GaAs Schottky-barrier diodes. This diode pair configuration has the advantages of subharmonic pumping and local oscillator noise suppression [2]. However, there are constraints on the obtainable mixer performance due to the practical realization of the diode circuitry. The PUCCI receiver front-end (RFE) developed by Aerojet has demonstrated an average double side-band (DSB) receiver NF ~ 7.7 dB [3].

An alternative approach is to employ front-end low noise MMIC amplifiers in front of a MMIC-based subharmonically pumped mixer integrated into a single module. This approach was not feasible in the past to the lack of low noise amplifier technology at these frequencies. Recently however, TRW has developed and demonstrated advanced InP HEMT technology that has resulted in the first ever MMIC LNA demonstrations at these frequencies. These include a 7.2 dB gain 2-stage balanced amplifier at 190 GHz and a 15 dB gain 6-stage amplifier at 215 GHz, the highest frequency gain amplifier ever demonstrated [4]-[7]. The advent of this technology has made a low noise front-end approach feasible above 100 GHz, with the benefits of superior performance and lower weight and size. In this paper, we present a low noise amplifier module that has demonstrated a NF of 5.5 dB at 183 GHz using a new MMIC LNA design.

II. AMPLIFIER BLOCK DIAGRAM

A block diagram of the amplifier module demonstrated in this paper is shown in Figure 1.

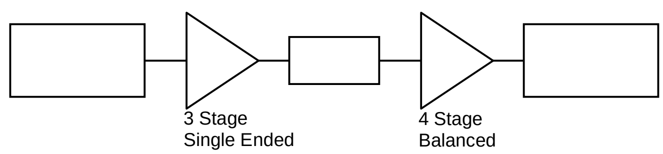

Fig. 1 Block Diagram of the LNA module

To achieve the lowest NF, the 3-stage single-ended design was used at the front of the module. This topology offers a lower NF compared to the balanced topology since there is no loss due to the coupler. However, the benefit of the low NF comes at the expense of input return loss.

The 4-stage balanced design was used to eliminate the back-end noise contributions, and provide gain for the module. The balanced topology was chosen for the 4-Stage amplifier to improve the return loss since the NF is set by the front-end LNA. The microstrip line provides some isolation between the two MMICs.

It was imperative that the losses at the input be kept to a minimum to meet the noise temperature requirements. Thus, special care was taken to minimize losses associated with the waveguide transition and the ribbon bond.

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III. INP HEMT TECHNOLOGY

The device performance necessary to achieve usable gain and NF for low noise amplifiers operating at frequencies between 100 to 200 GHz requires very high device transconductance above 1000 mS/mm, cutoff frequencies above 200 GHz and maximum oscillation frequencies above 400 GHz. To achieve usable gain and sufficient MMIC design margin, the device must exhibit a maximum available gain of 7-8 dB per stage up to 200 GHz. InGaAs/InAlAs/InP HEMTs are the only three terminal devices that have demonstrated performance at these levels [8]-[11].

In developing a MMIC process for this frequency range, several significant process enhancements were implemented to develop the final baseline 0.08 μm InP HEMT process [4], [6], [7], and [12]. Good MMIC yield and repeatability for this process has already been demonstrated on several wafer lots. The development of a robust InP MMIC process has been a critical key to the first-pass design success of the variety of MMIC amplifier designs referenced in this paper.

IV. MMIC AMPLIFIER DESIGN

To achieve the requirements of the low noise temperature, we had to design new MMIC low noise amplifiers. The choices of the front-end and back-end amplifiers have been addressed in Section 2. Each of the stages on the amplifiers utilizes 2 finger HEMT with 30-μm gate periphery per device. The process utilizes TRW's dry-etch via process for InP substrates and is described in detail in reference [6].

The passive matching networks were simulated using Sonnet EM software. The amplifier designs employed simple transmission lines to transform the device optimum load and avoided any complex matching structures. Radial stubs were employed as RF shorts to provide the bias for the amplifiers. Many different trade-offs were done for the optimum gain and the optimum NF for the each of the amplifiers.

Figure 3 illustrates the 3-Stage single-ended amplifier. The overall chip dimension is 1.9 x 1.1 mm. This chip was designed to have gain > 14.0 dB and NF < 5.0 dB. The amp was measured on-wafer at JPL (NASA Jet Propulsion Lab in Pasadena, CA) for gain and return loss. The s-parameter data was obtained using wafer probes that operate up to 220 GHz. The amplifier demonstrated measured gain > 12dB from 175 – 200 GHz. The measured gain of the MMIC LNA, shown in Figure 4, shows excellent agreement with the circuit simulations.

V. MEASURED RESULTS

The measured gain of the overall amplifier is shown in Figure 5. The gain is greater than 20 dB from 165 - 195 GHz, with a peak gain of ~ 26 dB at 180 GHz. The data was taken using a WR-05 Vector Network Analyzer purchased from Olsen Microwave Laboratories (OML).

The NF data was taken by employing the Y-Factor method, using a sub-harmonic MMIC mixer that was designed and developed at TRW. The IF frequency was set to 500 MHz and the LO frequency was adjusted to obtain the RF frequency. A piece of ecosorb at room temperature was used as the hot load, and another piece of ecosorb dipped in liquid nitrogen was used as the cold load. A power meter was used to detect the power levels and the Y-Factor calculations were obtained in that manner. The data is shown in Figure 6. The NF variation is less than ± 0.5 dB, with a minimum NF of 5.5 dB at 183 GHz measured at the waveguide flange. The results imply that the NF of the 3-stage single-ended LNA is less than 4.5 dB.

We built a number of these amplifier modules over the course of the program. Our results, shown in Figure 8, show that the NF variation across the modules is ± 0.4 dB. These results demonstrate the repeatability of the module assembly as well as the MMIC amplifiers.

VI. DISCUSSION OF RESULTS

This results discussed above have shown a tremendous improvement in the MMIC technology for high frequency applications. This is a rapidly maturing technology that can push the frontier in future remote sensing and communication applications.

A MMIC based front-end module can potentially offer a true single side-band NF of ~ 6.0 dB at the waveguide flange. This is comparable to the results that have been achieved with waveguide RFEs. Further potential advantages compared to waveguide mixer front-ends include reduction in size and weight. The amplifier modules exhibit remarkable consistency that may result in lower production costs since less manual tuning is required for these modules.

VII. CONCLUSION

We have presented data on a low noise amplifier module that has exhibited gain > 24 dB and NF < 5.5 dB at 183 GHz. We have shown consistent results with multiple builds of the modules, which demonstrates the repeatability of the assembly and the process. This low-noise broadband amplifier is suitable for remote sensing and radiometer applications to improve performance and simultaneously decrease size, weight and cost.

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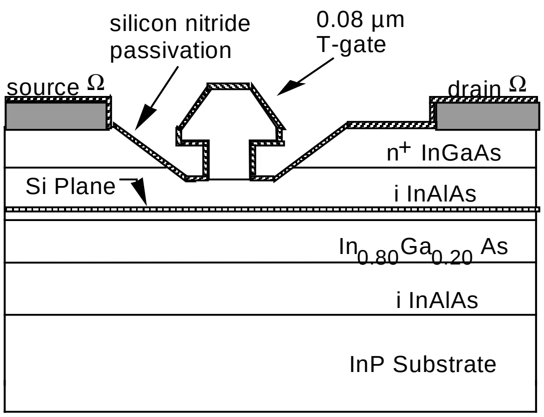

Fig. 2 Layer cross section of MBE grown 0.08-µm device

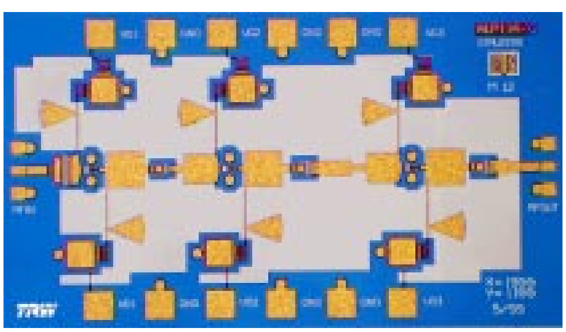

Fig. 3 Picture of the 3-Stage MMIC LNA

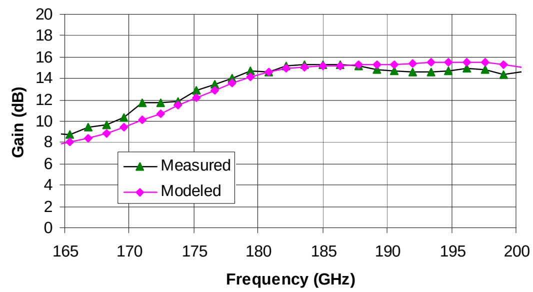

Fig. 4 Comparison of the Measured v. Modeled Gain of the 3-Stage MMIC LNA

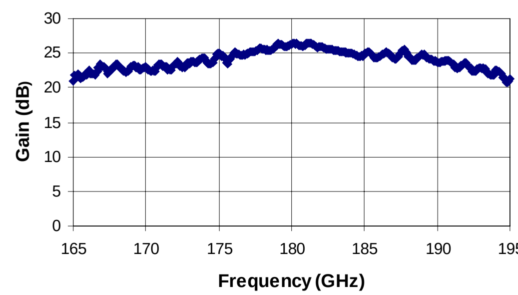

Fig. 5 Measured Gain of the LNA module

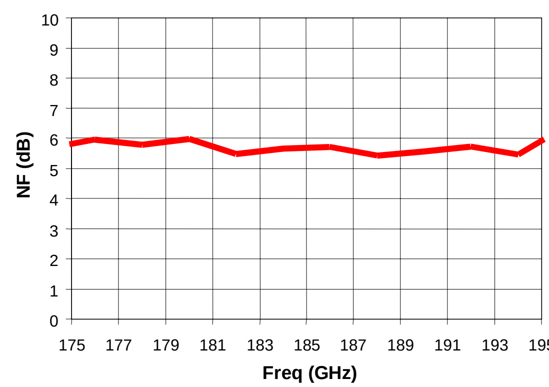

Fig. 6 Measured Y-Factor NF of the LNA module

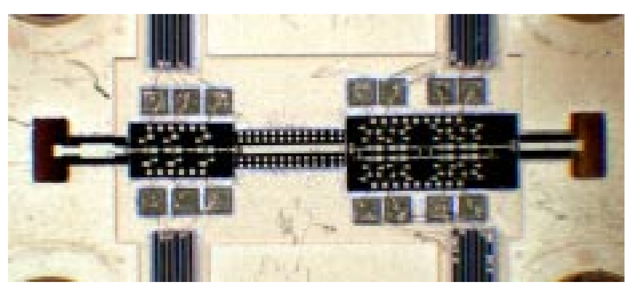

Fig. 7 Top View of the RF cavity of the module

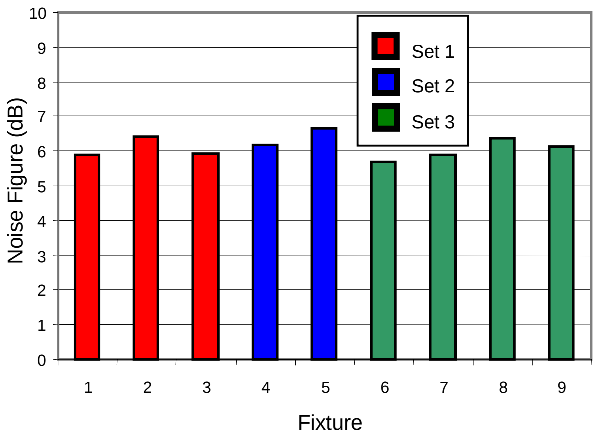

Fig. 8 Repeatability of the LNA Modules

Freq (GHz)	LNA Description	NF (dB)	Gain (dB)
100-110	4-stage LNA (cooled to 20K)	0.5	20-22
112-120	3-stage single ended LNA	3.9	16-18
139-142	2-stage single ended LNA	5.8	8-10
150-157	3-stage single ended LNA	5.1	9-12
165-190	3-stage single ended LNA	7.0	13-15
160-215	6-stage single ended LNA	8.0	15-27

Table 1. TRW's state-of-art InP HEMT MMIC low noise amplifiers >100 GHz

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