4-12 GHz and 25-34 GHz Cryogenic MHEMT MMIC Low Noise Amplifiers for Radio Astronomy

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Abstract — **MMIC Broadband Low Noise Amplifiers (LNA) for radio astronomy applications with 100 nm GaAs metamorphic High Electron Mobility Transistor (mHEMT) process have been developed. Cryogenic performance of a 4-12 GHz and a 25-34 GHz LNAs is presented. The 4-12 GHz LNA cooled at 15 K exhibits an associated gain of 31.5 dB ± 1.8 dB and average noise temperature of 5.3 K with a low power dissipation of 8 mW. Cooled to 15 K the 25-34 GHz amplifier has demonstrated a flat gain of 24.2 dB ± 0.4 dB with 15.2 K average noise temperature, and a very low power dissipation of 2.8 mW on chip. The mHEMT based LNA MMICs have demonstrated excellent noise characteristics at cryogenic temperatures for their use in radio astronomy applications.**

Index Terms — **Cryogenic, Low noise amplifier, MMIC, mHEMT.**

I. Introduction

There is a strong interest in the availability of MMIC Low Noise Amplifiers (LNA) for cryogenic receivers for ultra-low noise radio astronomy applications and Deep-Space Network (DSN) receivers. The cryogenic LNA is a key component in the front-end of those receivers, having a crucial role in their sensitivity. They require the lowest noise as well as wide instantaneous bandwidths to increase the sensitivity in continuum observations. Moreover, the MMICs enable simple, small size, and low cost production of the large number of LNAs needed in the focal plane arrays used to enhance the mapping efficiency of the radio telescopes.

To date, InP pHEMT MMIC LNAs have demonstrated outstanding noise at cryogenic temperatures [1]-[5]. But recently mHEMT based LNAs have been also reported with good performances [6]-[7]. The advantages of mHEMT technology lie in lower costs, better robustness and availability of larger GaAs wafers for production compared to InP substrate materials. The potential of the 100 nm mHEMT technology for MMIC applications at cryogenic temperatures is evaluated here.

II. Technology

The amplifiers were fabricated with use of an InAlAs/InGaAs material system HEMT technology grown by molecular beam epitaxy (MBE) on 4-inch semi-insulated GaAs substrates. The active devices feature T-shaped 100 nm gates with an indium content of 65% in the main channel. The devices typically have a f_T of 220 GHz and a f_{max} of 300 GHz. For a two finger device with 0.06 mm unit gate width, the extrinsic maximum transconductance is 1400 mS/mm with a drain bias of 1V and a peak-gm gate bias of 0.1 V at ambient temperature. At 15 K the same device has an extrinsic maximum transconductance of 1600 mS/mm with a drain bias of 0.6 V and a peak-gm gate bias of 0.2 V. The transmission lines used in the MMICs are grounded coplanar waveguides with two metallization levels and 3 μm Au thickness. The process further includes 50 Ohm/sq NiCr thin-film resistors, 225 pF/mm^2 metal-insulator-metal (MIM) capacitors, via-holes and CVD SiN passivation. The substrate thickness is 50 μm.

III. Amplifiers Design

To demonstrate the potential of the mHEMT technology at cryogenic temperatures, two MMIC LNAs were designed and manufactured. The two single-ended low noise amplifiers cover the frequency range of 4 to 12 GHz (IF for millimeter receivers, VLBI 2010) and 25 to 34 GHz (ESOC K and Ka band DSN, VLBI 2010) respectively. Both MMIC LNAs consist of three stages, each of which has inductive source feedback in the first two stages. The noise parameters of the transistors were modeled following the approach of Pospieszalski [8]. Cryogenic models were improved based on data from previous runs. The first stage is mainly optimized for minimum noise figure, while the second stage is matched partially for noise and the third stage fully for gain. Gain flatness and input and output reflection coefficients were also taken into account during the optimization of the design. Grounded coplanar waveguide lines are used for matching networks and interconnection. Bias is brought into the transistors through resistors and stubs capacitively shorted with RF bypass MIM capacitors, at frequencies in the band and below. The resistors act as damping elements suppressing the excess out-of-band gain and stabilizing the amplifier.

A. LNA 4-12 GHz

The LNA has three stages, each of which includes a 4x30 μm transistor. Fig. 1 shows a picture of the MMIC LNA. The chip size is 2.5 mm x 1 mm.

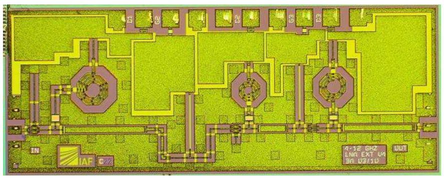

Fig. 1. Picture of the manufactured 4-12 GHz MMIC LNA. The chip size is 2.5 mm x 1 mm.

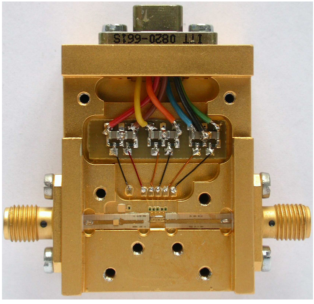

Fig. 2. Packaged module of the 4-12 GHz LNA. The box dimensions are 31.34 mm x 40 mm x 15 mm.

The LNA has an external microstrip input matching network, which is fabricated on 10 mils CLTE-XT Arlon® substrate with lower losses than GaAs. This allows to achieve broadband matching and to reduce the circuit noise figure and to tune the amplifier. In order to characterize its cryogenic performance, the MMIC was assembled in a gold plated brass module with SMA coaxial connectors, shown in Fig. 2.

B. *LNA 25-34 GHz*

The MMIC LNA consists of three stages, each of which employs a 4 x 15 µm transistor. Fig. 3 shows a picture of the chip, which size is 2.5 mm x 1 mm.

The LNA MMIC was also assembled in a gold plated aluminum module, with 2.92 mm coaxial connectors, shown in Fig 4. Gold plated microstrip lines on 5 mils CLTE-XT Arlon® dielectric substrate were used at the input and output of the MMIC.

IV. Experimental Results

S-parameters, noise temperature and gain fluctuations were tested at 300 K and at 15 K temperatures. The chips were first tested on-wafer at room temperature and then the packaged LNAs were measured at 300 K and at 15 K.

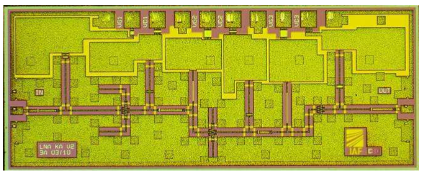

Fig. 3. Picture of the manufactured 25-34 GHz MMIC LNA. The chip size is 2.5 mm x 1 mm.

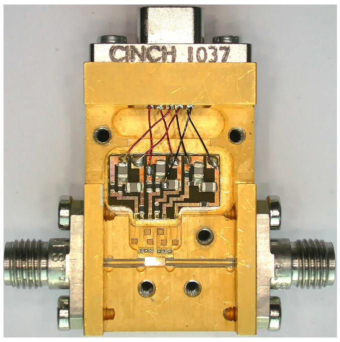

Fig. 4. Packaged module of the 25-34 GHz LNA. The dimensions of the box are 20.6 mm x 32. 5 mm x 12 mm.

At cryogenic temperature (15 K) S-parameters were measured referred to the input and output ports of the packaged amplifier. The cold attenuator method was used to measure the LNA module noise performance, where the incoming noise power is generated by a commercial noise source. A cooled 15 dB attenuator provides a well defined cold temperature noise reference at the input of the LNA and reduces the change of reflection coefficient between the on and off states of the noise source. In this way the measurement uncertainty of the noise temperature is reduced to ±1.4 K.

A. *LNA 4-12 GHz*

The measured and simulated gain and noise temperature at 15 K from 3 GHz to 13 GHz are shown in Fig. 5. The simulation comprises the MMIC LNA as well as the external microstrip network and coaxial connectors. From 4 to 12 GHz, the amplifier achieves 31.5 dB gain with ±1.8 dB flatness. The average noise temperature is 5.3 K from 4 to 12 GHz. Input and output return losses are better than -5 dB and -14 dB in the band respectively (IRL is better than -12 dB from 5 to 12 GHz). The measurement was made at a drain voltage V_D = 0.53 V with a total drain current of 15 mA. The DC power dissipation is 8 mW on chip.

B. *LNA 25-34 GHz*

For cryogenic temperature the measured and simulated gain and noise temperature from 20 to 40 GHz at 15 K are shown in Fig. 6. The simulation includes the amplifier with bonding wires, microstrip lines and coaxial connectors. The average noise temperature in the 25-34 GHz band is around 15.2 K with more than 24 dB gain and the input and output return losses better than -13 dB and -15 dB respectively. The minimum noise temperature of the amplifier is 11.8 K at 29.5 GHz. The total power dissipation on chip is just 2.8 mW, with drain voltage V_D = 0.37 V and total drain current 7.5 mA..

A comparison of the two LNA with other reported wide-band MMIC LNAs, working in the same frequency ranges at cryogenic temperature is given in Table I.

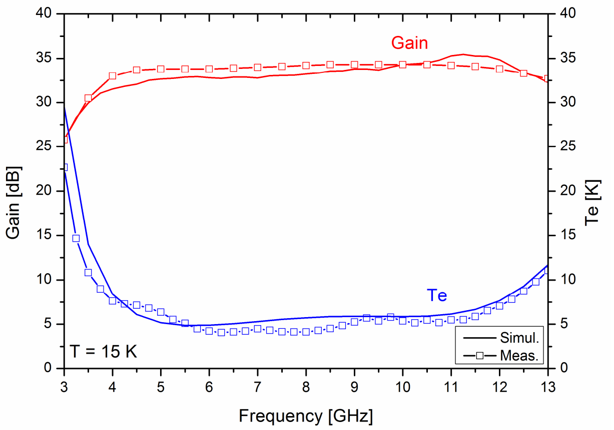

Fig. 5. Measured and simulated gain and noise temperature of the LNA 4-12 GHz at 15 K.

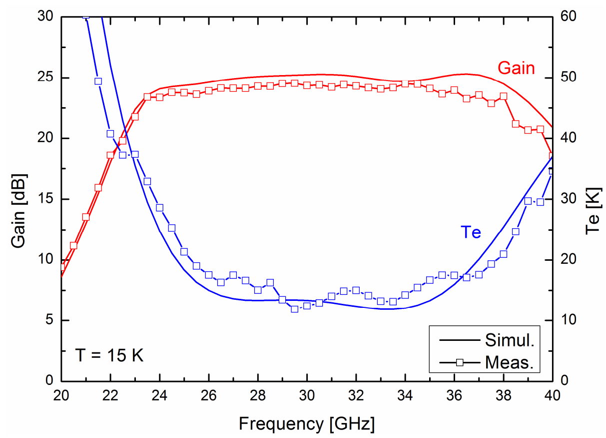

Fig. 6. Measured and simulated gain and noise temperature of the LNA 25-34 GHz at 15 K.

VII. Conclusion

Two very low noise and low power dissipation mHEMT LNAs working at cryogenic temperatures are presented. The low noise amplifiers are MMICs based on 100 nm mHEMT technology. A three-stage LNA demonstrated a small signal gain of 31.5 dB and average noise temperature of 5.3 K from 4 to 12 GHz when cooled at 15 K with only 8.0 mW power consumption. The 25-34 GHz MMIC LNA exhibited a gain of 24.2 dB and average noise temperature of 15.2 K with 2.8 mW power consumption. The presented results demonstrate that mHEMT technology is suitable for cryogenically cooled very sensitive wide-band receivers.

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TABLE I
Comparison of Wide-Bandwidth LNA at Cryogenic Temperature

Ref.	Process	Type	Freq (GHz)	Gain (dB)	Te @ Tamb (K)	Pdis (mW)
[1]	0.1 µm InP HEMT	3-stages MMIC	1-11	33.4±0.3	3.9 @ 4.1	24
[2]	0.1 µm InP HEMT	3-stages MMIC	4-12	37	3.9 @ 12	9.2
[6]	0.1µm mHEMT	3-stages MMIC	4-12	26±1.2	8.1 @ 15	12
This Work	0.1µm mHEMT	3-stages MMIC	4-12	31.5±1.8	5.3 @ 15	8
[3]	0.1µm InP HEMT	3-stages MMIC	26-40	23±1.1	15.5 @ 12	5.95
[4]	InP HEMT	Hybrid	27-37(*)	28±7	14.5 @ 12	--
[5]	InP HEMT	4-stages MMIC	26-36	42	20.0 @ 15	--
This Work	0.1µm mHEMT	3-stages MMIC	25-34	24.2±0.4	15.2 @ 15	2.8

(*) Narrow band design with Te = 9 K and Gain = 30 dB at 32 GHz when cooled at 12 K.

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