CRYOGENIC 1.5-4.5 GHz ULTRA LOW NOISE AMPLIFIER

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Abstract - **This paper describes cryogenic broadband amplifier with very low noise for the frequency band 1.5-4.5 GHz. At 15 K the two-stage InP-based amplifier has a gain of 28+/-2 dB dB and a noise temperature below 5 K. For a narrower band of 2-4 GHz at 15 K the measured gain is 30.0+/-0.8 dB and noise temperature is 1.5 K. The total DC power consumption of the amplifier is 6.8 mW.**

Index Terms – **cryogenic low noise amplifier, HEMT, InP, noise temperature, LNA.**

I. INTRODUCTION

InP based High Electron Mobility Transistors (HEMTs) have extremely good low-noise performance and superior high frequency performance [1-4]. The drain to source voltage can be kept at a very low level due to the high carrier mobility and velocity in the InGaAs-layer. The HEMT technology does not suffer from freeze-out at cryogenic temperatures. The ionization energy of dopants in InGaAs is very low and the electrons reside in a quantum well of energy below the donor levels in the high bandgap material. Thus a sufficient carrier density for high gain microwave operation can be achieved even at cryogenic temperatures. In this study we have designed and measured amplifiers with ultra-low noise and very low DC power dissipation. Amplifiers with ultra-low noise and low DC power dissipation are of interest for space applications, where cooling and DC power budgets are crucial.

II. HEMT FABRICATION AND CHARACTERISTICS

A lattice matched structure on InP grown by molecular beam epitaxy was used in the fabrication of the Chalmers HEMT. The structure has a 40Å AlInAs space layer, whose purpose is to separate the 300Å thick $In_{0.53}Ga_{0.47}As$ channel from the planar silicon doping. We use a 200Å thick AlInAs Schottky barrier and a cap layer consisting of 50Å undoped InGaAs. The measured transconductance at room temperature is around 550mS/mm, which gives ≈ 110 mS/200μm device.

The Chalmers transistors were fabricated according to the Chalmers standard InP HEMT process. A combination of optical and electron beam lithography techniques was used [6]. Mesa isolation was obtained by means of wet chemical etching. The channel layer was selectively etched at the mesa sidewall. This procedure prevented the gate electrode from contacting the channel at the mesa edge and thereby decreased the gate leakage current.

We use nickel germanium and gold (Ni/Ge/Au) to form the ohmic contacts with a source-drain spacing of 2 μm. Rapid Thermal Annealer (RTA) is used for annealing. The measured contact resistance was 0.2 Ωmm

We used electron beam lithography to define the 0.1 μm T-shaped gates. A special development patterns were added to control the developing time of the bottom layer. A wet etching process was used to obtain the gate recess. Evaporated titanium, platinum and gold (Ti/Pt/Au) formed the gate electrodes. A lift-off process with Ti/Au defined the terminals.

The devices were passivated by reactive sputtering of silicon nitride (Si_3N_4). An optimized process has been developed which leaves the Schottky barriers unaffected. The introduction of interface states is negligible.

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Plating was then used for air-bridge formation, connecting the source electrodes. In this step additional metal was grown on the pads to ensure good wire bonding ability.

Fig. 1 shows a photograph of a complete four gate finger device with a total gate width of 200 µm.

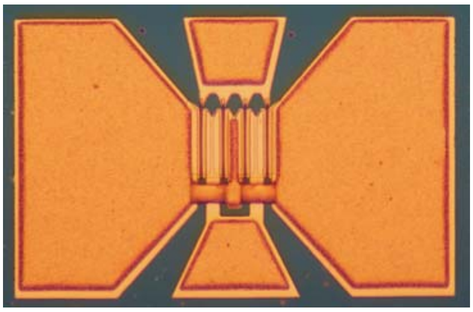

Fig. 1. Complete four - finger 0.1 x 200 µm Chalmers InP HEMT.

III. MODELING

The S-parameters of the transistors were measured in a cryogenic probe station at ambient temperature of 20 K. A small signal model is shown in Fig. 2. This model was used for extraction of model parameters from the measured data, Table 1 [7]. Noise measurement was performed in a special pre-match circuit described in [8]. This noise data was used to extract the noise model parameter T_d. All other resistors were set to ambient temperature. The extracted small signal model together with T_d and the amplifier circuit were then used to calculate the expected noise and gain.

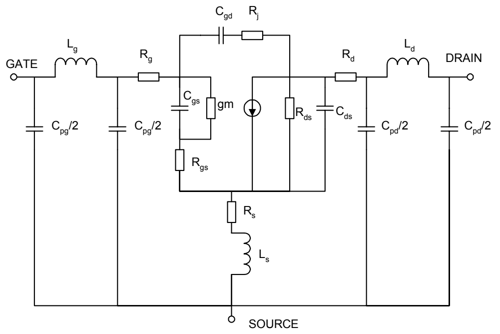

Fig. 2. Small signal circuit used to model the transistors.

TABLE I

Extracted values for the small signal model for a device with a 200 µm gate periphery.

		Chalmers InP 28
Intrinsic	C_{gs}, fF	120.9
	C_{ds}, fF	65.6
	C_{gd}, fF	40.0
	g_m, mS	110.0
	R_{gs}, Ω	1.5
	R_j, Ω	0.3
	R_{ds}, Ω	102.0
Parasitics	C_{pg}, C_{pd}	6.0
	L_g, mS	28.5
	L_s, mS	1.7
	L_d, mS	28.5
	R_g, Ω	1.0
	R_s, Ω	2.7
	R_d, Ω	3.2
Noise	$T_{d,}$, K	500

IV. AMPLIFIER DESIGN

A two-stage, 2-4 GHz, single ended amplifier with specified gain of 29 dB was designed. The design was optimized for low noise at 15 K ambient temperature with constraints on the power dissipation.

The input match was improved by using an inductive feedback consisting of four bonding wires between the source of the transistor and the ground. The feedback technique increases the resistive part of z_{11} leaving Γ_{opt} almost unaffected. A proper choice of the inductance gives $S_{11}^* \approx \Gamma_{opt}$. The devices have R_N in the range of a few ohms, which makes the noise match less critical. The ground is obtained through vertical metallic posts machined in the bottom of the box.

The inductive source feedback reduces high frequency stability and gain. Stability problems were avoided by using resistive loading of the drains together with careful design of bias and interstage circuits.

The amplifier was built in hybrid technology using microstrip transmission lines on Rogers RT/duroid 6002 substrate with a dielectric constant of ε_r =2.94 (2.93) at 300 K (15 K). Fig. 3 shows a photograph of the amplifier and a close-up view of the input transistor with the inductive source feedback bond wires and the long input matching wire.

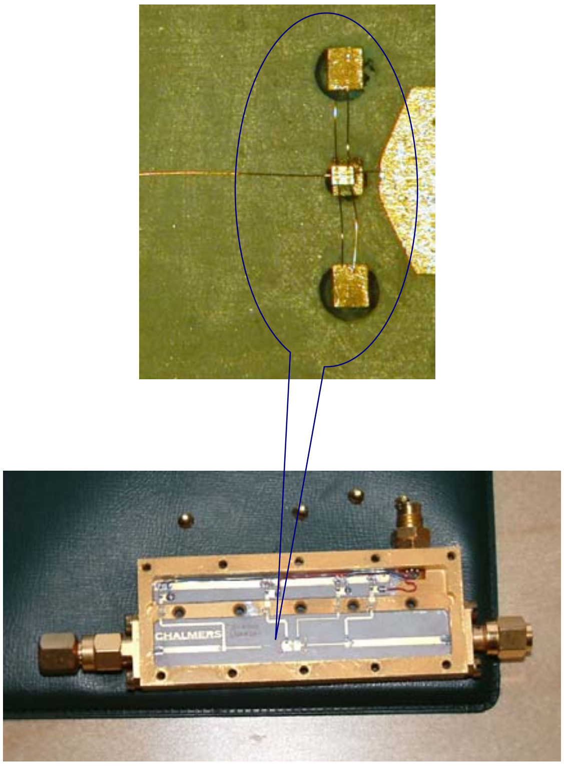

Fig. 3. A photograph of the assembled amplifier and a magnified detail of the input transistor.

V. MEASUREMENTS

A. *Measurement Setup*

The LNA was tested at 15 K using a cold attenuator (CAT).

The noise source in the cold attenuator system consists of a room temperature 13.5 dB ENR noise diode together with a 23 dB attenuator cooled to 15 K. This gives a $T_{cold} \approx 16.5$ K and a $T_{hot} \approx 50$ K and a measured Y-factor of about 4.5 dB.

The measured results are shown in Figs. 4 and 5.

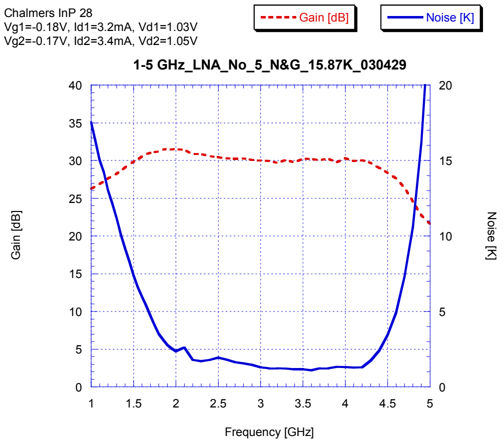

Fig. 4. Measured noise and gain of the LNA at 15 K.

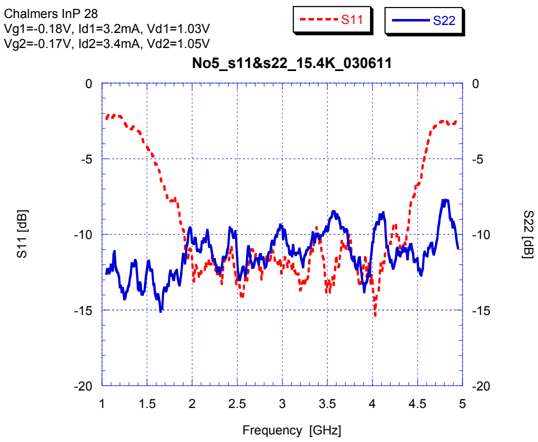

Fig. 5. Measured s_{11} and s_{22} of LNA at 15 K.

VI. SUMMARY AND CONCLUSION

Recent work on cryogenically cooled HEMT-based amplifiers has been presented. A best minimum noise temperature of 1.5 K has been achieved with an InP-based amplifier over the 2-4 GHz band with an associated gain of 30.0+/-0.8 dB. The power dissipation was 6.8 mW for the entire amplifier. The input and output match was better than 10 dB for the same frequency range.

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