An Ultra-Low Noise Cryogenic Ka-Band InGaAs/InAlAs/InP HEMT Front-End Receiver

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***Abstract*— We present here the design and performance of a 4-stage Ka-band cryogenic amplifier using a front-end 0.1-μm gate length InP HEMT. The amplifier demonstrated 20–25 K uncorrected noise temperature (~0.3-dB noise figure) from 31–33 GHz with 30–33 dB associated gain at 12 K ambient temperature. To date, this is the best reported HEMT cryogenic amplifier performance at this frequency band and is a factor of two improvement in noise temperature compared to previous designs.**

I. Introduction

THERE IS a need for extremely low noise, front-end amplifiers for ultra-sensitive receivers applications such as satallite receiving systems, radiometry, and remote sensing. Most current systems use cooled MASER's, which have provided the best noise performance at microwave- and millimeter-wave frequencies. An attractive alternative is InGaAs/InAlAs/InP High Electron Mobility Transistors (InP HEMT's), which have demonstrated the lowest noise figures and highest gains of any three-terminal device operating at room temperature and at millimeter-wave frequencies [1]–[4]. In addition, cryogenically operated InP HEMT receivers would have the potential benefits of wider bandwidth, lower weight and cost, and improved reliability compared to MASER's. InP HEMTs are coolable down to low physical temperatures and do not exhibit the current collapse phenomenon observed in GaAs-based HEMT's [5], [6]. The noise temperature of the InP HEMT's decreases linearly with physical temperature with no observed "humps" as observed in GaAs-based HEMT's [5]. InP HEMT's are also operated with very low DC power dissipation, which is crucial to minimize the channel temperature of the device at cryogenic temperatures. In this paper, we present a four-stage Ka-band amplifier with an InP HEMT front-end operating at 12 K physical temperature, which is of particular interest for JPL's Deep Space Network. The amplifier exhibits up to two times lower noise temperature compared to previously reported cryogenic HEMT amplifiers at this frequency band [5], [7].

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II. Device Description

The InP HEMT process has been described in detail previously [8]. The wafers were grown using MBE on 2-inch semi-insulating InP substrates. The highlights of the InP HEMT profile are the $In_{0.6}Ga_{0.4}As$ pseudomorphic channel and the planar-doped silicon donor layer in the InAlAs for higher breakdown and device aspect ratio. 0.1-μm gates were fabricated and Pt/Ti/Pt/Au gate metallization was use to enhance the Schottky barrier height [9]. The typical InP HEMT devices have a pinchoff voltage of −0.1 to −0.4 V, a Schottky barrier height of 0.6 V, and a source-drain breakdown voltage of 2 V. Typical transconductances of 1200 mS/mm, cutoff frequency of 240 GHz, and maximum oscillation frequency of 400 GHz were obtained with these devices. Examples of the I-V characteristics for an InP HEMT at cryogenic (18 K) temperatures with and without light are shown in Fig. 1(a) and (b). The I-V characteristics are rather insensitive to red LED illumination, indicating a low trap density and high material quality. The low trap density does contribute to a nominal shift of 50–100 mV in the device threshold voltage when InP HEMT's are cooled to cryogenic temperatures [5].

III. Amplifier Design and Performance

The cryogenic InP HEMT model was based on room temperature S-parameter measurements of device biased at optimum low noise conditions ($V_d = 1\,\mathrm{V}, I_d = 8\,\mathrm{mA}$). The changes in noise parameters are described by changes in the equivalent gate and drain temperatures in accordance with the Pospieszalski model [10]. This particular model was used because no cryogenic S-parameter data was available on the devices. The four-stage receiver, shown in Fig. 2, consisted of a front-end low noise four-finger 80-μm InP HEMT and commercial Fujitsu GaAs HEMT's for the three subsequent stages. The InP HEMT was biased at V_d = 0.6 V and I_d = 3.5 mA at cryogenic operation for a total DC power dissipation of only 2.1 mW.

The measured noise performance reported here was referenced at the input waveguide flange outside of the refrigerator. At room temperature, the amplifier exhibits 170-K noise temperature (2.0 dB) and 24–27 dB associated gain (shown in Fig. 3(a)). When cooled, the amplifier exhibits 20–25 K uncorrected noise temperature at a physical temperature of 12 K with 30–33 dB associated gain (shown in Fig. 3(b)). The system noise contribution from the input waveguide flange to the input of the LNA fixture based on previous measurements is typically 4 K at cryogenic temperatures [7]. The noise

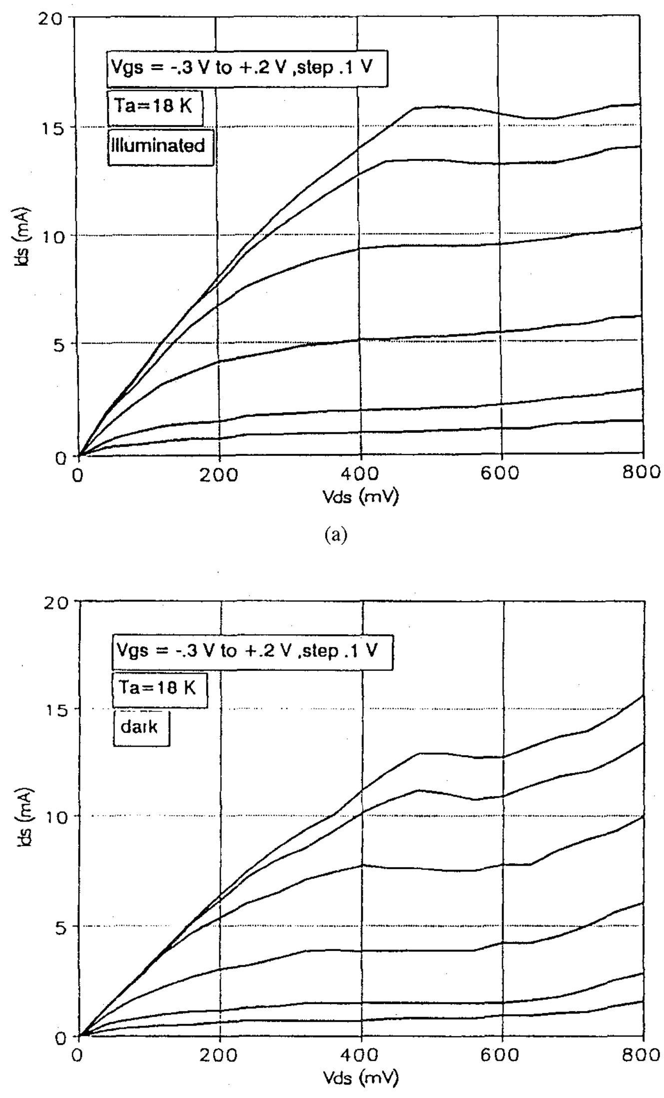

Fig. 1. I_d versus V_d characteristics for InP HEMT operated at 18 K (a) with and (b) without light.

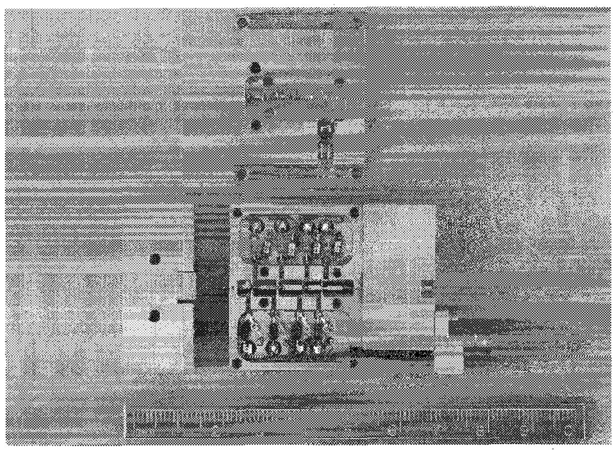

Fig. 2. Photograph of four-stage hybrid InP HEMT front-end low noise amplifier.

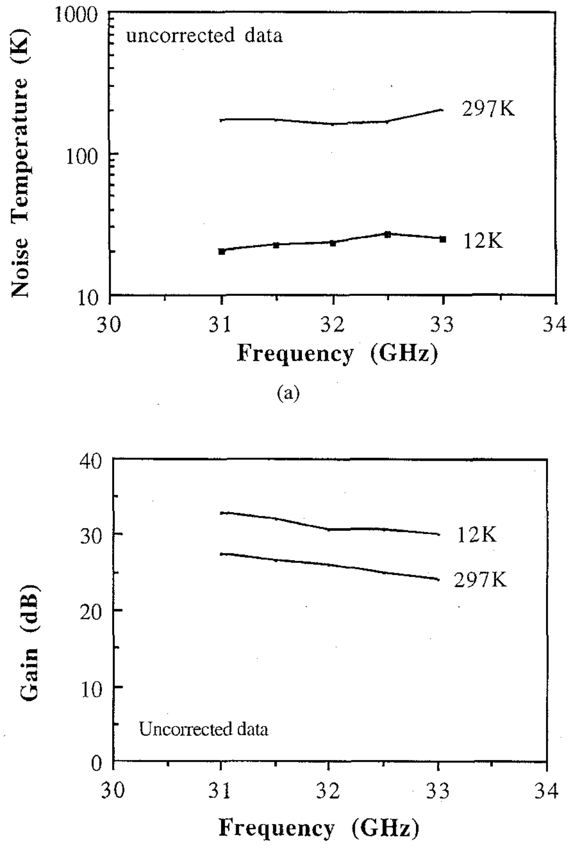

Fig. 3. Measured noise temperature and gain characteristics of the four-stage Ka-band amplifier with an InP HEMT front-end operated at (a) room temperature and (b) 12-K physical temperature.

performance of this amplifier is a factor of two lower noise temperature compared to previously reported InP HEMT and GaAs HEMT versions at this frequency range. It should also be noted that only bias tuning was employed to minimize the noise temperature of the amplifier.

Although we have achieved improved cryogenic noise performance at Ka-band, these results do not represent the ultimate capability of the device. For the performance to be competitive with MASER technology, the noise temperature needs to be reduced to less than 10 K at Ka-band. One area that can be crucial to achieve this performance is to improve the cryogenic modeling of the device. Also, wire bond tuning of a cryogenically operated amplifier is significantly more cumbersome compared to a room-temperature-operated amplifier. In the Pospieszalski model developed for this demonstration, the equivalent circuit elements such as G_m and C_{gs} generated from room temperature S-parameter measurements are directly used in the model. On-wafer measurements of InP HEMT's at 77 K and below have shown that these circuit elements change with temperature [6]. Future design iterations will use improved device models through cryogenic S-parameter measurements and improved amplifier designs to achieve the noise performance goals.

IV. Conclusion

We have demonstrated the design and performance of a four-stage Ka-band cryogenic amplifier using a front-end 0.1-μm gate length InP HEMT. The amplifier demonstrated 20–25 K uncorrected noise temperature from 31–33 GHz with 32–34 dB associated gain at 12-K ambient temperature and represents a two times improvement in noise temperature compared to previous demonstrations. Further improvement of noise temperature below 10 K at this frequency band is expected with further designs and improved device models.

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