Q- AND E-BAND CRYOGENICALLY-COOLABLE AMPLIFIERS USING ALINAS/GAINAS/INP HEMT'S

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ABSTRACT

Design, construction and performance of several cryogenically-coolable millimeter-wave amplifiers for radio astronomy applications, using AlInAs/GaInAs/InP HEMT's, are presented. The examples include a 40-50 GHz amplifier with an average noise temperature of about 15 K and a 60-80 GHz amplifier yielding a laboratory receiver noise temperature of 37 K at 60 GHz and 50 K at 75 GHz.

INTRODUCTION

Excellent noise performance of a number of AlInAs/GaInAs/InP HFET's was recently reported [1]-[8]. This study is a continuation of the investigation into cryogenic properties of InP-based devices for the purpose of ultra-low-noise, wideband amplification at cryogenic temperatures [1], [4], [8]. The major point of this study is a demonstration of cryogenic amplifiers and receivers with noise performance comparable to SIS receivers, but with instantaneous bandwidth which could be as large as 20 GHz.

DEVICE

The InP HEMT used in this study [3] consists of a 250-nm undoped AlInAs buffer, a 40-nm GaInAs channel, a 1.5-nm undoped spacer, an 8-nm AlInAs donor layer doped to approximately 7 x 10^{18} cm^{-3} and, finally, a 7-nm GaInAs doped cap, all grown lattice-matched to InP on a 2-inch semi-insulating substrate. Because of its simplicity, this particular HFET structure has been chosen for most of Hughes' low-noise work in the past several years. It typically exhibits an electron sheet density of 2.5 to 2.8 x 10^{12} cm^{-2} and a room-temperature mobility of 10,000 to 11,000 cm^2/Vs.

An example of the I-V characteristics of the .1 x 50 μm device at room and cryogenic temperatures is shown in Fig. 1, and corresponding dc measured transconductance characteristics are shown in Fig. 2. The equivalent circuit of this device is shown in Fig. 3. Finally, the equivalent drain temperature T_d (as defined in [9]), explaining the measured noise temperature at 40 GHz and T_a = 18 K for different bias currents, is shown in Fig. 4. In obtaining the values of T_d, the equivalent circuit of Fig. 3 was used under the assumption that the only element of the equivalent circuit changing with ambient temperature and drain current is the transconductance g_m. This oversimplified approach, in the absence of good cryogenic S-parameter measurements, is used to show the same qualitative dependence of T_d vs. drain current as demonstrated in a much more accurate room temperature experiment [10].

The data of Fig. 4 demonstrate how mutually compensating changes in f_T and T_d under change in drain current allow for a very shallow minimum of noise temperature. These data also demonstrate why the device behavior very close to the "pinch-off" determines the minimum noise temperature.

40-50 GHZ AND 60-80 GHZ AMPLIFIERS

Both amplifiers were realized in hybrid technology using pure PTFE substrates. The choice of "chip and wire" technology was dictated by the objective of achieving the lowest possible noise performance. This is still the best technology in view of the relatively high loss of on-the-chip matching network, as well as the relative immaturity of MMIC InP technology. The performance of the cryogenic, 40-50 GHz, five-stage amplifier is shown in Fig. 5. This amplifier employs the .1 x 50 μm device only in the input stage; the remaining stages employ .1 x 100 μm PM on GaAs devices.

A photograph of the 60-80 GHz five-stage amplifier is shown in Fig. 6. All stages utilized .1 x 50 μm InP devices. The gain and noise performance at room temperature is shown in Fig. 7. The measured noise temperature includes the contributions of the pyramidal horn and the receiver (T_n ~ 2000 K). It is worth observing that wide-bandwidth, low noise and high gain are achieved in rather small size, determined by the size of the WR-12 waveguide flange.

The performance of the amplifier at cryogenic temperatures was evaluated only in a receiver setting and the results are shown in Fig. 8. The receiver noise temperature was measured with hot (297 K) and cold (77 K) absorbers placed in front of the dewar window. The measured performance does

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include the contributions of dewar windows, pyramidal horn and about 1" of connecting WR-12 waveguide, amplifier, 10" of connecting output waveguide, all at 20 K ambient temperature, and the room temperature receiver (T_n ~ 2000 K). Noise temperatures of less than 40 K for frequencies up to 65 GHz and less than 50 K for frequencies up to 75 GHz are at least as good as those demonstrated with the best SIS receivers in this frequency range [11]. Illustrating this point, a comparison of the noise temperature of NRAO cryogenic receivers, using AlInAs/GaInAs/InP HEMT amplifiers cooled to 20 K, and SIS mixer receivers, cooled to 4 K, is shown in Fig. 9. The main differences between the current results and those previously published [1], [4] are much larger bandwidth and/or gain of the amplifiers and, consequently, much better receiver performance.

CONCLUSIONS

The cryogenically-coolable amplifiers using AlInAs/GaInAs/InP HEMT's establishing state-of-the-art performance in the 40-80 GHz frequency range have been demonstrated.

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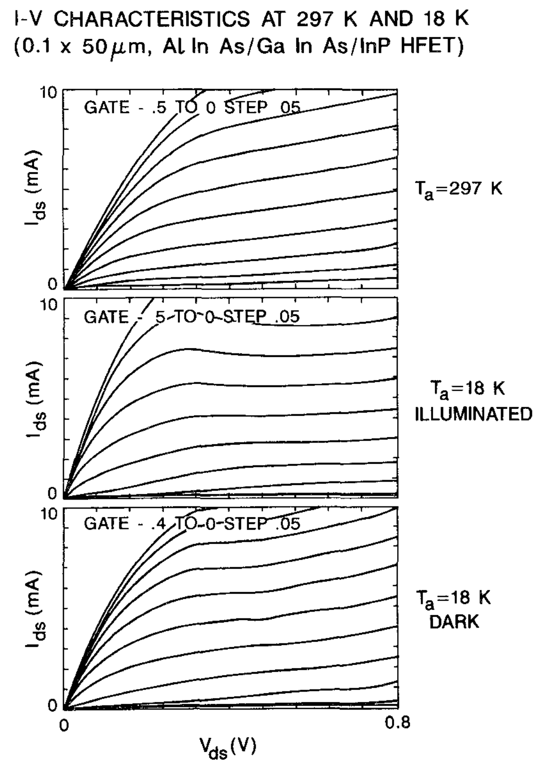


Fig. 1. Example of I-V characteristics of .1 x 50 μm AlInAs/GaInAs/InP HEMT at room and cryogenic temperatures.

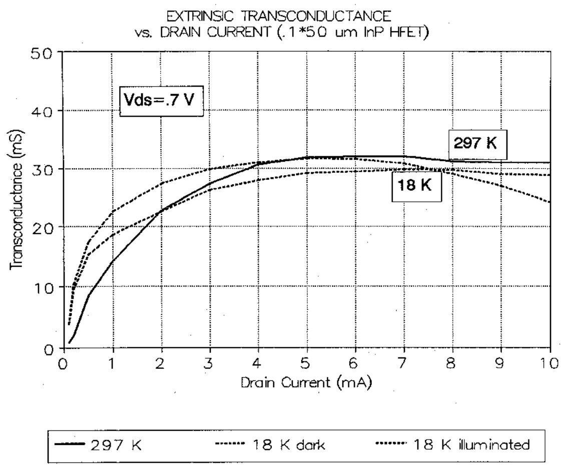


Fig. 2. D.C. measured extrinsic transconductance of .1 x 50 μm InP HEMT vs. drain current at different ambient temperatures.

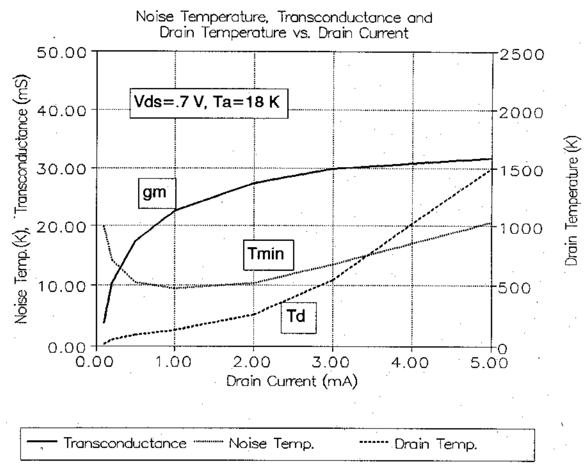
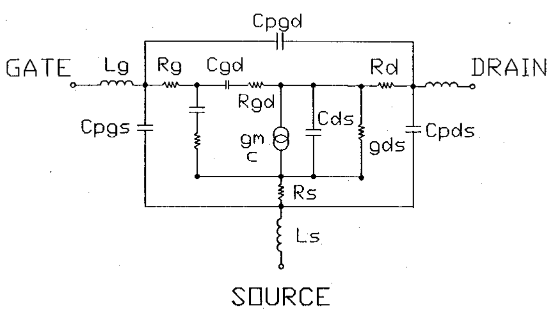


Fig. 4. The minimum noise temperature at 40 GHz, dc measured transconductance and equivalent drain temperature vs. drain current at the ambient temperature T_a = 18 K of .1 x 50 μm InP HEMT.

EQUIVALENT CIRCUIT OF LOW-NOISE InP HFET

GATE: 0.1 x 50 μm



INTRINSIC DEVICE	PARASITIC ELEMENTS
C_{gs} = 37.7 fF	R_g = 3.0 Ω
R_{gs} = 4.0 Ω	R_d = 12.0 Ω
C_{gd} = 2.9 fF	R_s = 8.0 Ω
R_{gd} = 400 Ω	C_{pgs} = 6.5 fF
g_m = 50.2 mS	C_{pgd} = 2.5 fF
τ = 0.6 ps	C_{pds} = 12.0 fF
C_{ds} = 5.2 fF	L_g = 33 pH
g_{ds} = 4.1 mS	L_d = 27 pH
	L_s = 6.0 pH

Fig. 3. An equivalent circuit of .1 x 50 μm InP HEMT at room temperature and V_{ds} = 1 V, I_{ds} = 7 mA.

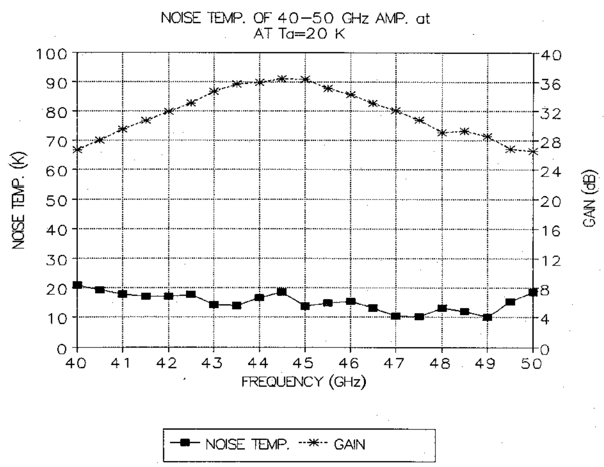


Fig. 5. The gain and noise characteristics of a 40-50 GHz amplifier at the ambient temperature of T_a = 18 K.

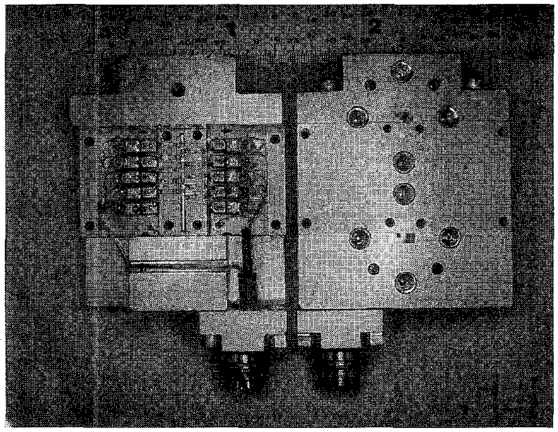


Fig. 6. A photograph of a 60-80 GHz amplifier with the cover plate removed.

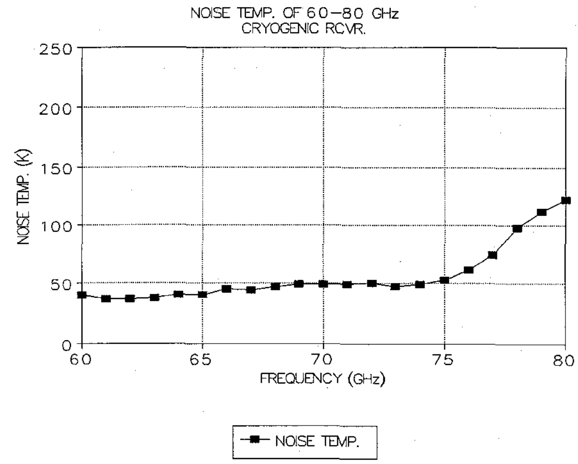


Fig. 8. The noise temperature of a laboratory 60-80 GHz receiver.

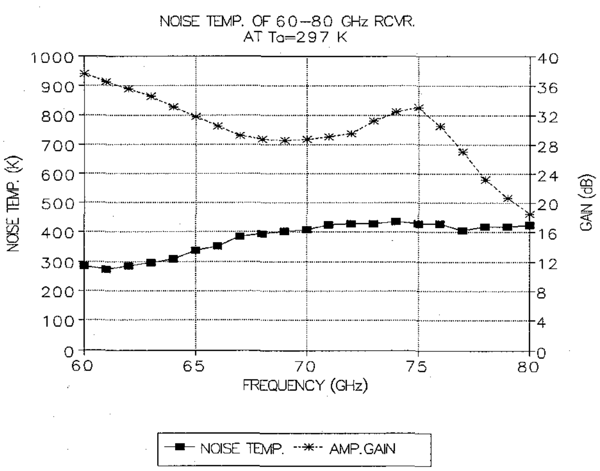


Fig. 7. Room temperature gain and noise temperature of a 60-80 GHz amplifier. Noise temperature includes the contributions of pyramidal horn and receiver ($T_n \sim 2000$ K).

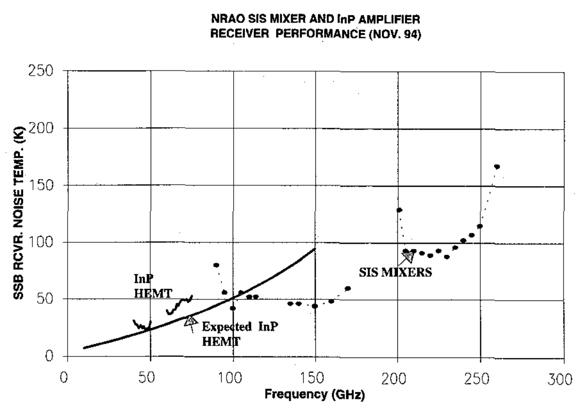


Fig. 9. Comparison of noise temperature of NRAO cryogenic receivers using InP HEMT amplifiers cooled to 20 K and SIS mixer receivers cooled to 4 K. (SIS mixer data courtesy of A. R. Kerr and S.-K. Pan.)