A CRYOGENIC 43-GHz-BAND LOW-NOISE AMPLIFIER FOR RADIO ASTRONOMY

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ABSTRACT

This paper describes the first development of a cryogenic millimeter-wave-band HEMT low-noise amplifier for radio astronomy application. To ensure stable operation, the amplifier was designed using S-parameters measured at a cryogenic temperature of 30 K. Very low noise temperature is obtained over wide frequency range from 41.3 to 44.5 GHz by adopting a balanced amplifier configuration with a waveguide-type 3 dB hybrid. Minimum and maximum noise temperatures within the frequency range are 65 and 95 K, at an ambient temperature of 30 K and amplifier gain of 11.5 dB.

INTRODUCTION

Several papers have reported advantages of a HEMT low-noise amplifier in millimeter-wave-band (1)-(3). Since radio astronomy application keenly required further reduction of a noise temperature, for the requirement. The cryogenic HEMT amplifier, however, has not yet been reported in millimeter-wave-band.

On the other hand, M. W. Pospieszalski, et al. have reported unstable DC characteristics of HEMT devices at a cryogenic temperature (4). Though the unstable DC characteristics suggest degradation of a microwave performance, no report shows S-parameters measured at a cryogenic temperature. Authors have measured the parameters as well as DC characteristics at a cryogenic temperature. Using the parameters, a cryogenic 43-GHz-band low-noise amplifier has been designed. Thus the fabricated amplifier has attained ultra-low-noise characteristics.

DEVICE DESCRIPTION

The devices are low-noise HEMTs with a gate

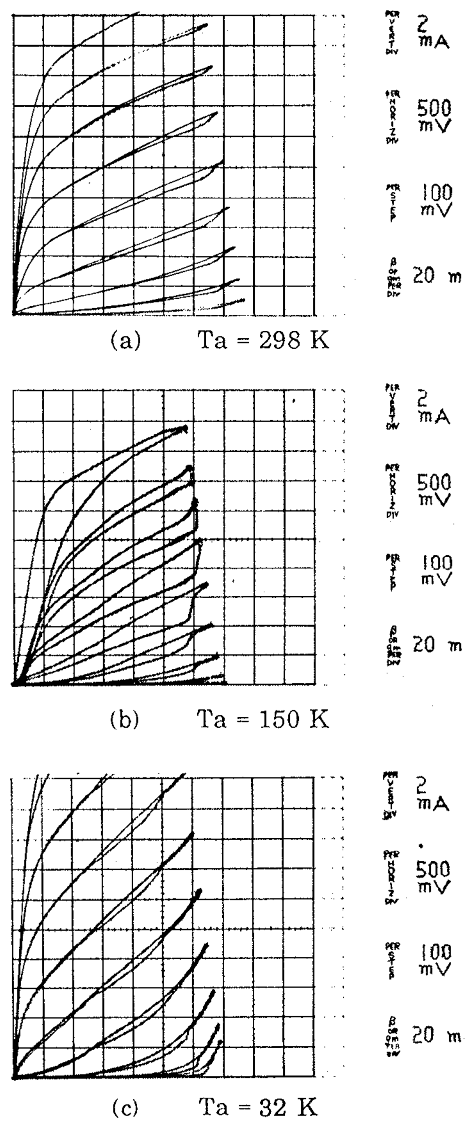

Fig.1 HEMT DC characteristics at different ambient temperatures in darkness.

length of 0.25 μm and a gate width of 100 μm (5). The DC characteristics were measured in darkness and under illumination. A whitelight (halogen lamp, approximately 1000 lx) was used for illumination. Fig. 1 shows the DC characteristics at different ambient temperatures in darkness. At 150 K hystereses are observed (Fig. 1b). Under illumination the drain-source currents of the device increase, but hystereses still present. At 32 K the hystereses are almost negligible and the mutual conductance is 1.5 times greater than that at room temperature.

The S-parameters were measured at room temperature using a wafer probe a 0.5 to 25.5 GHz range. Fig. 2a shows the consequence of S-parameter measurements. The cryogenic S-parameters were measured on a chip carrier fixed on a cold stage of closed-cycle helium refrigerator (Model 21SC, CTI). Fig. 2b shows the calculated S-parameters at the cryogenic temperature used in the experiments. Fig. 3 shows and equivalent circuit of the device and Table 1 is a list of the circuit element values.

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In order to achieve a stable amplifier, its stability must be considered at all frequencies. Output stability circles and the locus of the output matching circuit from 0.5 to 2.5 GHz are shown in Fig. 4.

For sufficient input/output impedance matching at cryogenic temperatures, waveguide-type hybrids have been used for the amplifier's input/output sections. An enclosure was made of Super-Invar, which has a small coefficient of thermal expansion, and constructed unit amplifiers on Kovar carriers that have almost same thermal expansion coefficient as that of the alumina-ceramic substrate. Fig. 5 is a schematic of the amplifier.

Fig. 6 is a block diagram of the measurement system. The noise figure of the system is 7 dB from 40 to 46 GHz. The HEMT amplifier is enclosed in a vacuum dewar and fixed on a 30 K cold stage cooled by a closed-cycle helium refrigerator (Model 350, CTI). The ambient temperature dependence of the gain and noise temperatures are shown in Fig. 7.

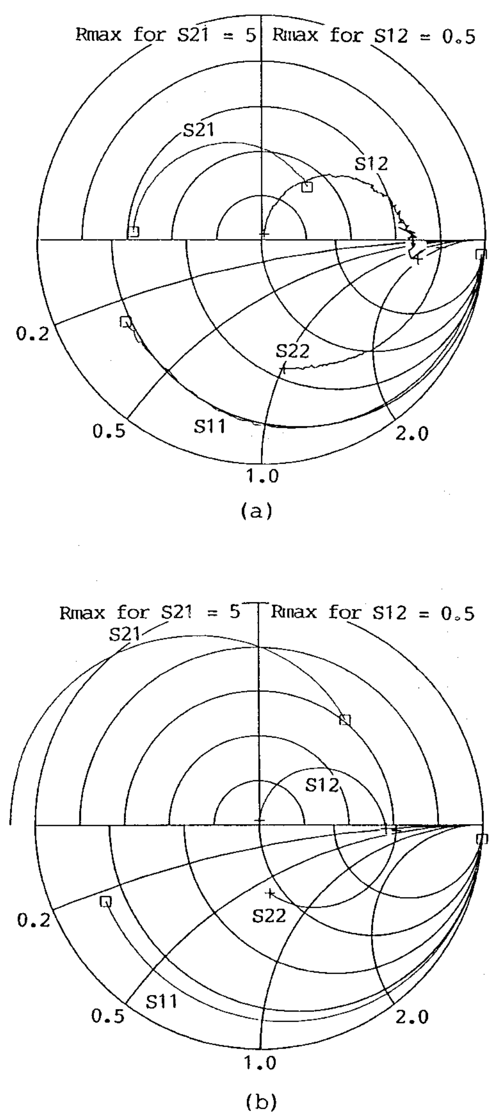

Fig.2 S-parameters of the device over a frequency range from 0.5 to 25.5 GHz. (a) Measured S-parameters at room temperature. (b) Calculated S-parameters at cryogenic temperature.

Frequency characteristics of the gain and noise tempratures at a cryogenic temperature are shown in Fig. 8. The amplifier has a gain of 10.5 dB, a noise temperature of 125 K from 41.3 to 44.5 GHz, and a minimum noise temperature of 95 K, including the effects of the dewar's input/output sections. The noise temperatures of input/output waveguides and pressure windows ara shown in Table 2. The calculated minimum noise temperature of the amplifier is about 65 K and the gain is 11.5 dB at 30 K ambient

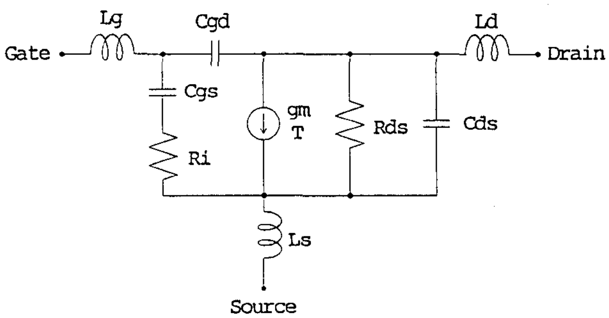

Fig.3 Device equivalent circuit.

Table1 Equivalent circuit values

	Room temp.	Cryo. temp.
Lg (nH)	0.082	0.105
Ls (nH)	0.016	0.007
Ld (nH)	0.086	0.056
Cgd (pF)	0.021	0.017
Cgs (pF)	0.144	0.134
Cds (pF)	0.055	0.049
Ri (Ω)	8.246	0.155
Rds (Ω)	492.3	207.6
gm (mS)	0.032	0.069
T (ps)	1.931	3.332

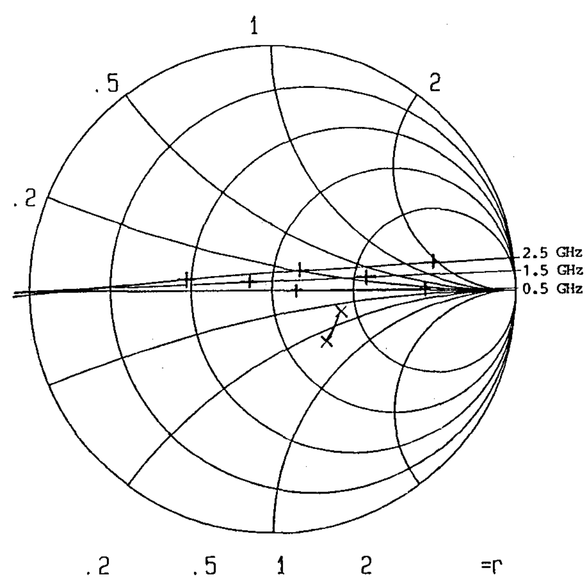

Fig.4 Stability circles of the device and designed output impedance locus of the matching circuit from 0.5 to 2.5 GHz. Plus : output stability circles, cross : output impedance locus.

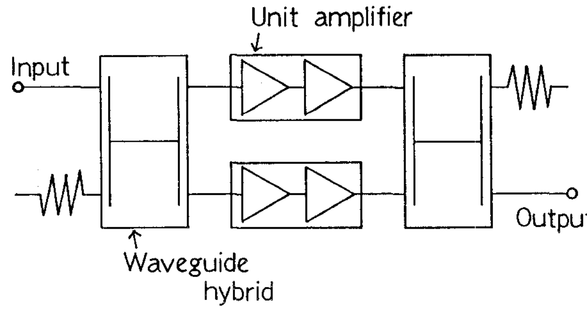

Fig.5 Amplifier configuration.

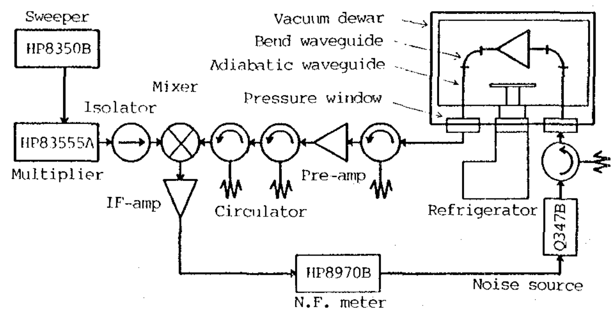

Fig.6 Block diagram of the measurement system.

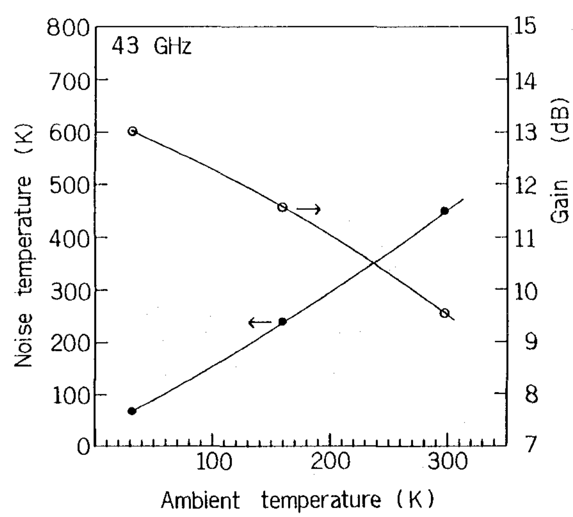

Fig.7 Ambient temperature dependence of gain and noise temperature.

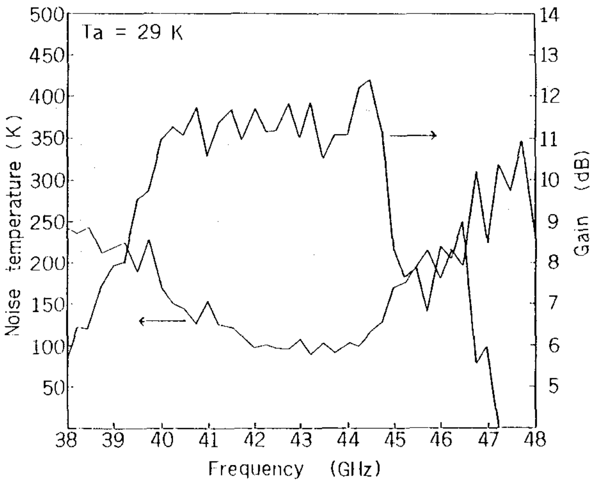

Fig.8 Frequency characteristics of gain and noise temperature at a cryogenic temperature.

Table2 Equivalent noise temperature of input/output section

	Loss at 298 K (dB)	Cryogenic experiment Ambient temp. (K)	Loss (dB)	Noise temp. (K)
Input :				
Pressure window	0.27	298	0.27	19.1
Adiabatic waveguide	0.19	192	0.12*	5.7
Bend waveguide	0.16	59	0.03*	0.4
Output :				
Bend waveguide	0.23	72	0.06*	0.1
Adiabatic waveguide	0.19	205	0.13*	0.4
Pressure window	0.27	298	0.27	1.2
Waveguide out of dewar	0.41	298	0.41	1.9
Total	1.72	-	1.29	28.8

*Calculated values.

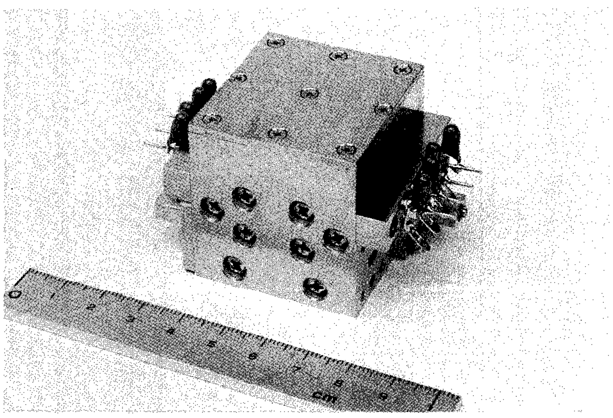

Fig.9 A photograph of the amplifier.

temperature. A photograph of the amplifier is shown in Fig. 9.

CONCLUSION

The authors have evaluated the DC characteristics and S-parameters of a HEMT with a gate length of 0.25 μm and a gate width of 100 μm operated at cryogenic temperatures. The cryogenic HEMT's S-parameters used in the design of a cryogenic 43-GHz low-noise amplifier for radio astronomy application. The amplifier has a gain of 11.5 dB, a maximum noise temperature of 95 K within the frequency range from 41.3 to 44.5 GHz, and a minimum noise temperature of about 65 K at 42.5 GHz.

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