

NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

ELECTRONICS DIVISION TECHNICAL NOTE NO. 151

Title: **LOW-NOISE, 1.25 GHz, COOLED, HEMT AMPLIFIER**

Author(s): Changlong Xu

Date: April 6, 1989

DISTRIBUTION:

GB

GB Library
R. Lacasse
R. Weimer
D. Schiebel
E. Childers
C. Brockway
J. Coe
R. Norrod
S. White
G. Behrens
R. Fisher
F. Crews
B. Peery
Changlong Xu

CV

ER Library
IR Library
M. Balister
C. Burgess
S-K Pan
A. R. Kerr
N. Bailey
S. Srikanth
L. D'Addario
N. Horner

TU

Library Downtown
Library Mountain
J. Payne
R. Freund
J. Lamb
D. Emerson
P. Jewell
J. Cochran
A. Perfetto

VLA

VLA Library
P. Napier
J. Campbell
W. Brundage

LOW-NOISE, 1.25 GHz, COOLED, HEMT AMPLIFIER

Changlong Xu

April 6, 1989

1. Introduction

This report describes the design and measurement results of a cryogenic cooled L-band HEMT amplifier. The three-stage amplifier exhibits an average noise temperature of 2.1 K across the 1.0 to 1.5 GHz band with an associated gain of 34.8 ± 0.7 dB and minimum return loss of 10 dB.

2. Circuit Description

The MGF-4303-650 HEMT, model number 79AH, is used in the first stage. In order to obtain the real part of the optimum source impedance, the HEMT was mounted in a single-stage amplifier and the noise temperature measured for five different values of source resistance, at five different values of drain current, at both room and cryogenic temperature. The results are shown in Figures 1 and 2. A computer program has been written which uses a set of measured noise temperature data to compute the noise parameter of a two-port network. The program, given in the appendix, computes the noise parameter by minimizing the mean square error between the calculated and measured noise temperature.

The function used by the program is:

$$T_n = T_{\min} + \frac{T_0 G_n}{R} (R - R_{\text{opt}})^2$$

$X = X_{\text{opt}}$ is assumed to be satisfied.

The noise parameters resulting from measured data by the program for different values of drain current are given in Table 1 and Table 2 on the following page.

Using the function and data in Tables 1 and 2 we can calculate the noise temperature that the least square error fits to the measured data. The curves and data points in Figure 1 and Figure 2 are related to the calculated and measured noise temperature, respectively.

It can be seen that the optimum drain currents for 300 K and 15 K are 9.0 mA and 4.5 mA, respectively. But the R_{opt} is near 50Ω at both 300 K and 15 K.

Based on the above experimental result, the input circuit of the amplifier consists of a 50Ω transmission line and an additional shunt quarter-wave line which is designed to increase the bandwidth.

The input circuit is constructed on high dielectric constant material, DUROID 6010.5. The thickness of the substrate is 0.025 inch.

TABLE 1

Noise Parameters at 300 K

 $(V_D = 2.5 \text{ V})$

Noise Parameter	I_D (mA)				
	3.0	4.5	6.0	7.5	9.0
T_{\min} (K)	26.58	23.86	22.49	21.51	21.40
R_{opt} (Ω)	45.41	51.00	52.45	53.53	52.85
G_n (mmho)	1.53	1.09	1.01	0.99	0.99

TABLE 2

Noise Parameters at 15 K

 $(V_D = 2.5 \text{ V})$

Noise Parameter	I_D (mA)				
	2.1	3.0	3.9	4.5	6.0
T_{\min} (K)	0.78	0.53	0.53	0.49	0.95
R_{opt} (Ω)	47.06	46.70	47.06	48.47	48.31
G_n (mmho)	0.13	0.16	0.18	0.19	0.22

The schematic diagram of the three-stage amplifier is shown in Figure 3.

3. Amplifier Performance

The measured noise and gain performance of the amplifier is given in Figure 4. The minimum noise temperature is 1.5 K. A noise temperature variation of less than 1 K over a 400 MHz bandwidth is achieved.

The amplifier input return loss vs. frequency at 15 K is shown in Figure 5.

4. Tuning

The amplifier input return loss should be tested first using a network analyzer. Then the noise temperature and gain are measured with the noise test setup.

1. Drain-bias voltage is initially set at 3.0 V and drain currents for stages 1, 2 and 3 are set at 4.5 mA, 9.0 mA, 9.0 mA, respectively.
2. The amplifier input return loss, noise temperature and gain depend on the tuning of inductor L_1 . The length of L_1 needs to be trimmed little by little to minimize the noise temperature and maximize the input return loss at the designed frequency.
3. The frequency offset between minimum noise temperature frequency F_n and optimum input match frequency F_m is a noticeable problem. Several papers [1], [6]-[10] demonstrated that an acceptable compromise on F_n and F_m would be reached by using inductive series feedback. The F_n and F_m may close to each other by proper adjustment of the source lead inductance of the HEMT. The way of mounting the source lead is shown in Figure 6.

It is easy to change source lead inductance by moving the grounding shim. Using dielectric film, we can change the distributive capacitance to ground of source lead to improve the input return loss at high frequency. Finally, both noise temperature and input return loss are acceptable. However, it should be mentioned that not only F_m and F_n but also the gain and stability factor will be changed by reactive feedback. Therefore, special attention should be given to stability of the amplifier.

ACKNOWLEDGEMENT

I am very grateful to Roger D. Norrod for inviting me to NRAO and for his guidance. I would like to thank Bob Simmons for assembling the amplifier. I would also like to express my thanks to all the people in Green Bank who made my stay so pleasant and rewarding.

REFERENCES

- [1] S. Weinreb, "Low-Noise, Cooled, GASFET Amplifiers," IEEE Trans. Microwave Tech. Vol. MTT-28, pp. 1041-1054, October 1980.
- [2] S. Weinreb, D. Fenstermacher, R. Harris, "Ultra Low-Noise, 1.2-1.7 GHz, Cooled GASFET Amplifiers," EDIR No. 220, September 1981.
- [3] R. D. Norrod, R. J. Simon, "Low-Noise, 4.8 GHz, Cooled GaAs FET Amplifier," EDIR No. 259, February 1986.
- [4] M. Pospieszalski, "Low-Noise, 8.0-8.8 GHz, Cooled, GASFET Amplifier," EDIR No. 254, December 1984.
- [5] Manuel Sierra, "15 GHz Cooled GaAs FET Amplifier--Design Background Information," EDIR No. 229, June 1982.
- [6] Les Besser, "Stability Considerations of Low-Noise Transistor Amplifier with Simultaneous Noise and Power Match," IEEE MTT-S International Microwave Symposium Digest, pp. 327-329, 1975.
- [7] George Vendelin, "Feedback Effect on the Noise Performance of GaAs MESFET'S," IEEE International Microwave Symposium, 1975.
- [8] K. Hartmann, M.J.O. Strutt, "Changes on the Four Noise Parameters Due to General Changes of Linear Two-port Circuits," IEEE Trans. on ED, October 1973.
- [9] R. W. Thill, W. Kennan, N. K. Osbrink, "A Low-Noise GaAs FET Preamplifier for 21 GHz Satellite Earth Terminals," Microwave Journal, pp. 75-84, March 1983.
- [10] D. D. Heston, R. E. Lehmann, "X-Band Monolithic Variable Gain Series Feedback LNA," IEEE 1988 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, pp. 79-81, 1988.

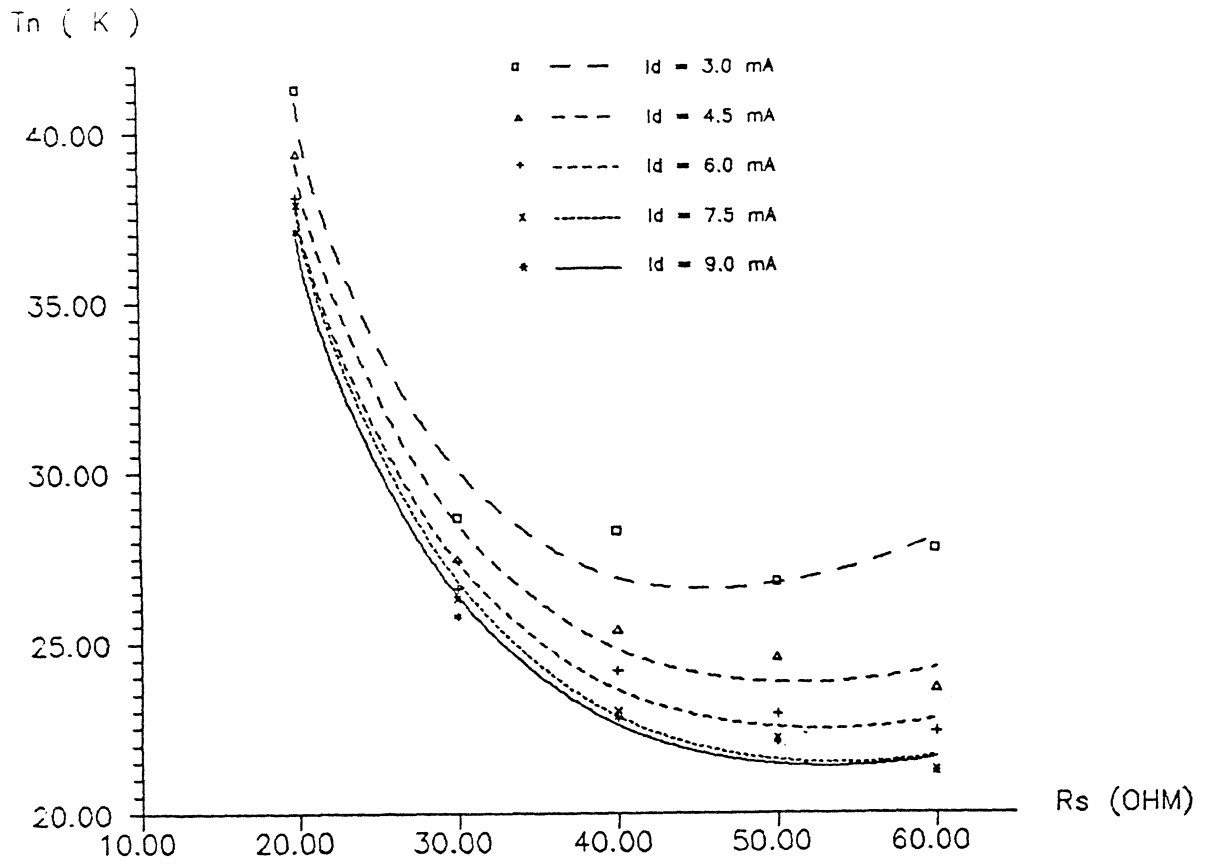


Figure 1. Noise Temperature vs. Source Resistance at 300 Kelvin

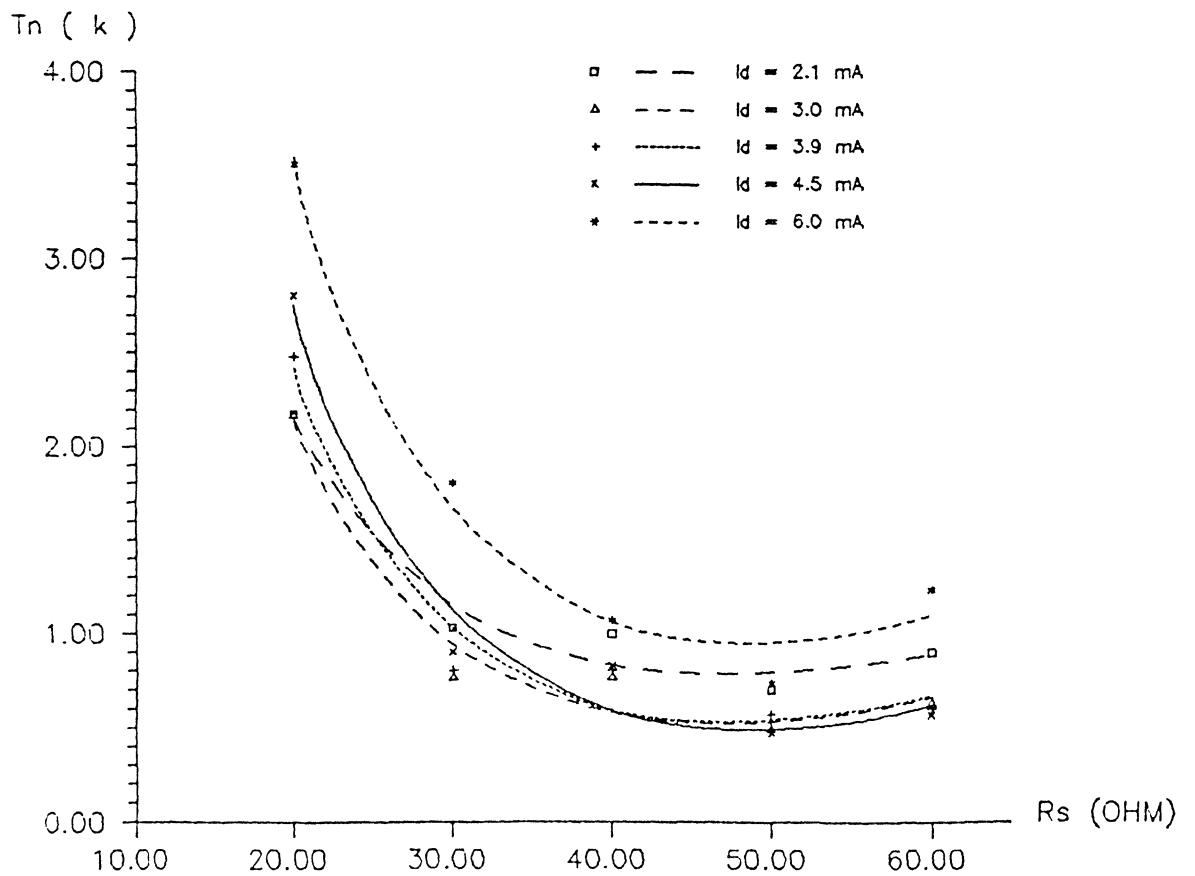
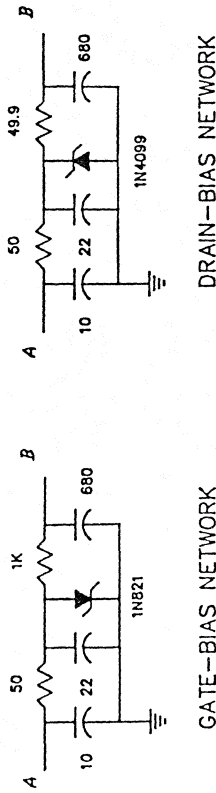
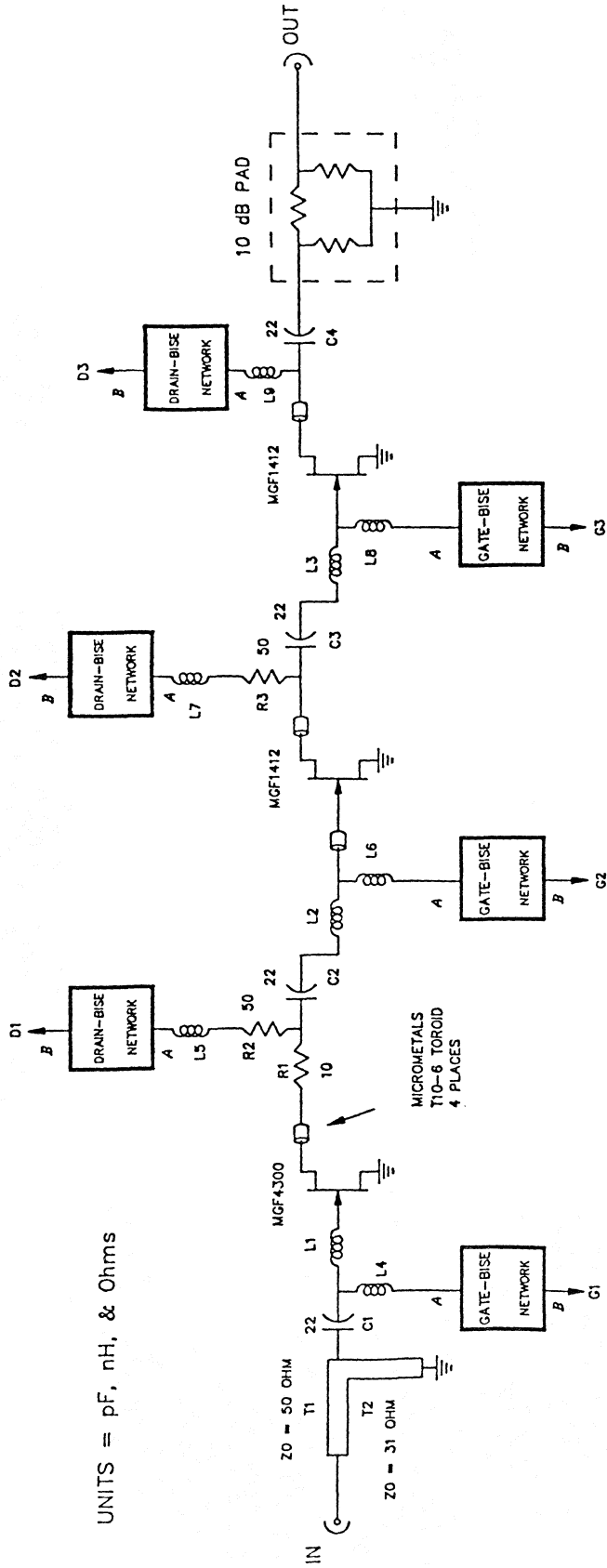


Figure 2. Noise Temperature vs. Source Resistance at 15 Kelvin



INDUCTOR	L1	L2	L3	L4	L5	L6	L7	L8	L9
TURNS	3	0	0	5	2	5	0	2	3

ALL WOUND WITH 0.28 mm DIAMETER WIRE.

Figure 3. Amplifier schematic. Bias voltages are supplied from a separate regulator which adjusts gate voltage for constant drain current.

1) 1.25 GHz AMP OPTIMUM BIAS FOR NOISE AT 15K

03/19/89 21:05:57 T_{eff} = 15.8 T_{meas} = 12.9
 T_{avg} = 2.1 T_{lo} = 1.5 @ 1300.0 GL = 34.1 GH = 35.4
 Bias: 3.5, 4.4, -0.398 3.5, 9.0, -0.960 2.0, 8.9, -0.480
 LED Voltage = 0.05 V

03/19/89 21:07:11

F (MHz)	Noise (K)	Gain (dB)	Trx (K)	Tcorr (K)	Nscr (K)
1000.0	4.5	34.8	200.2	0.1	89.0
1050.0	3.2	34.1	191.7	0.1	88.6
1100.0	2.4	34.3	183.2	0.1	88.3
1150.0	2.0	34.4	184.0	0.1	88.4
1200.0	1.7	34.3	184.7	0.1	88.6
1250.0	1.5	34.6	188.0	0.1	88.7
1300.0	1.5	34.7	191.3	0.1	88.9
1350.0	1.5	35.0	193.1	0.1	88.6
1400.0	1.5	35.2	194.8	0.1	88.3
1450.0	1.7	35.4	199.8	0.1	88.3
1500.0	2.0	35.4	204.8	0.1	88.2

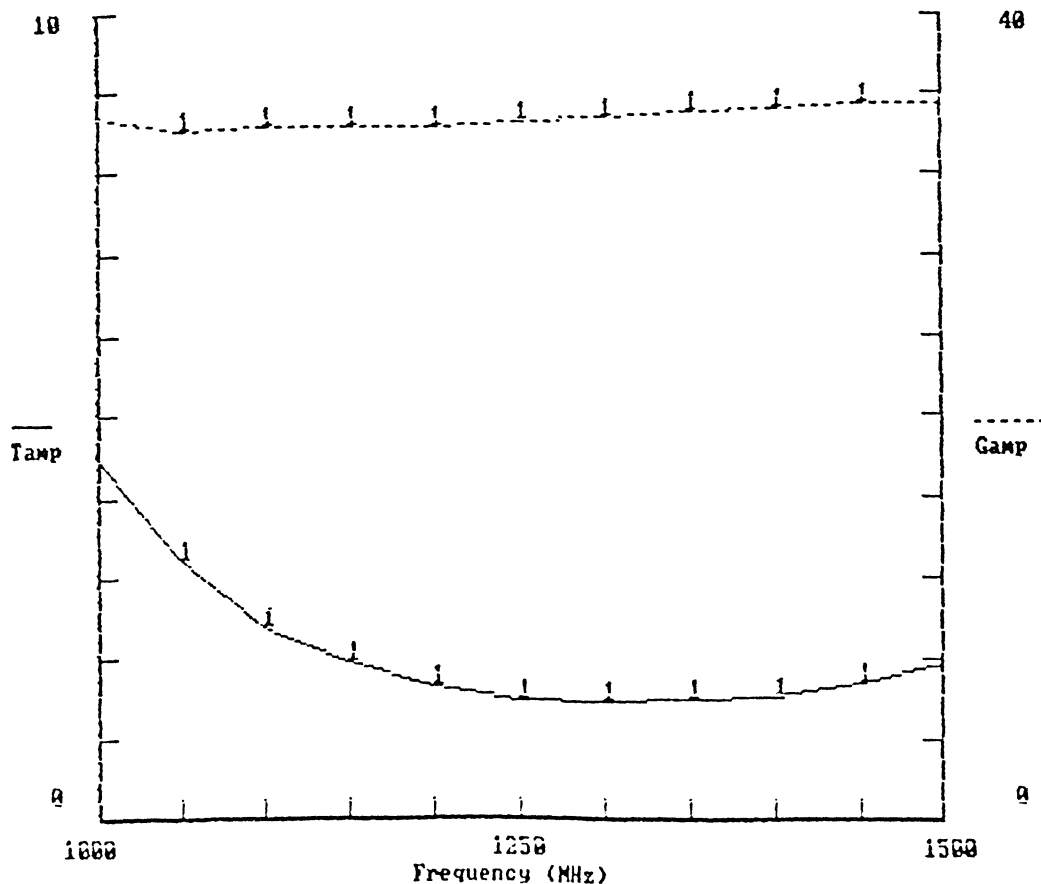
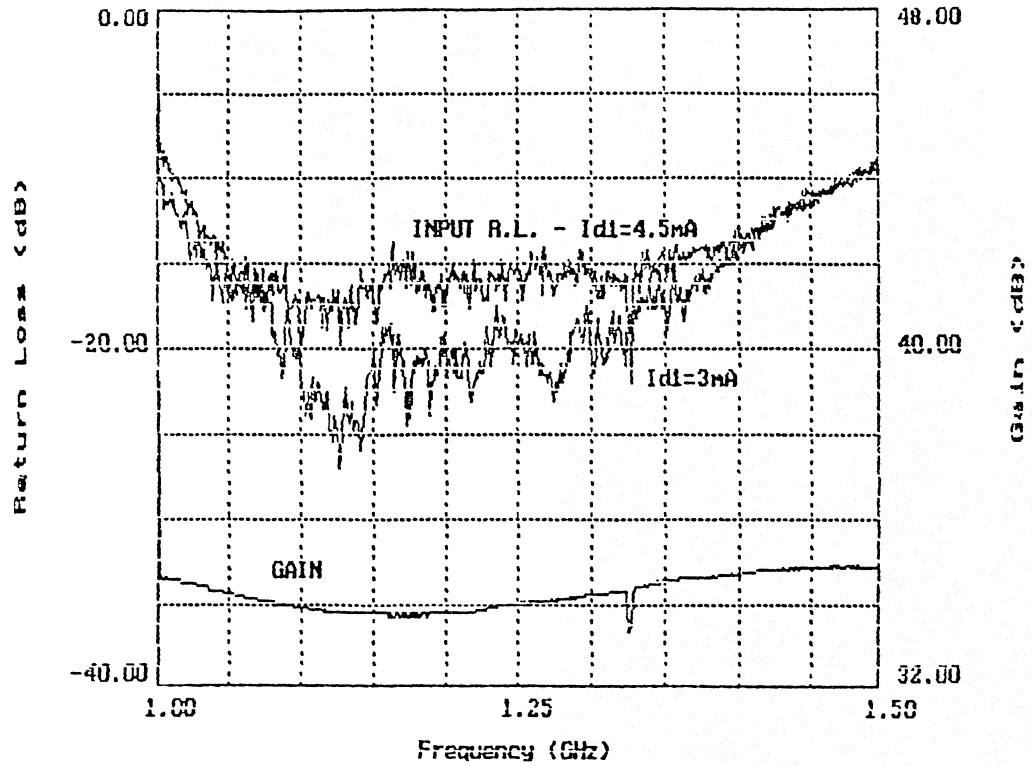


Figure 4. Noise temperature and gain at 15 K.



1.25 GHZ AMP AT 15K

Figure 5. Input return loss at 15 K.

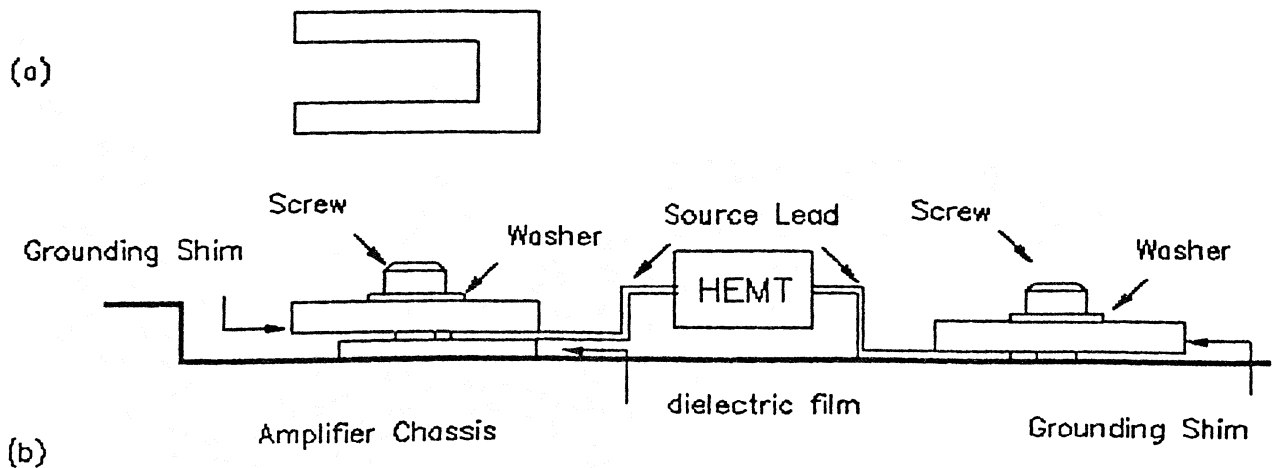


Figure 6. (a) Grounding Shim
(b) Schematic Drawing of the Realization of the Source Lead Inductance Adjustment

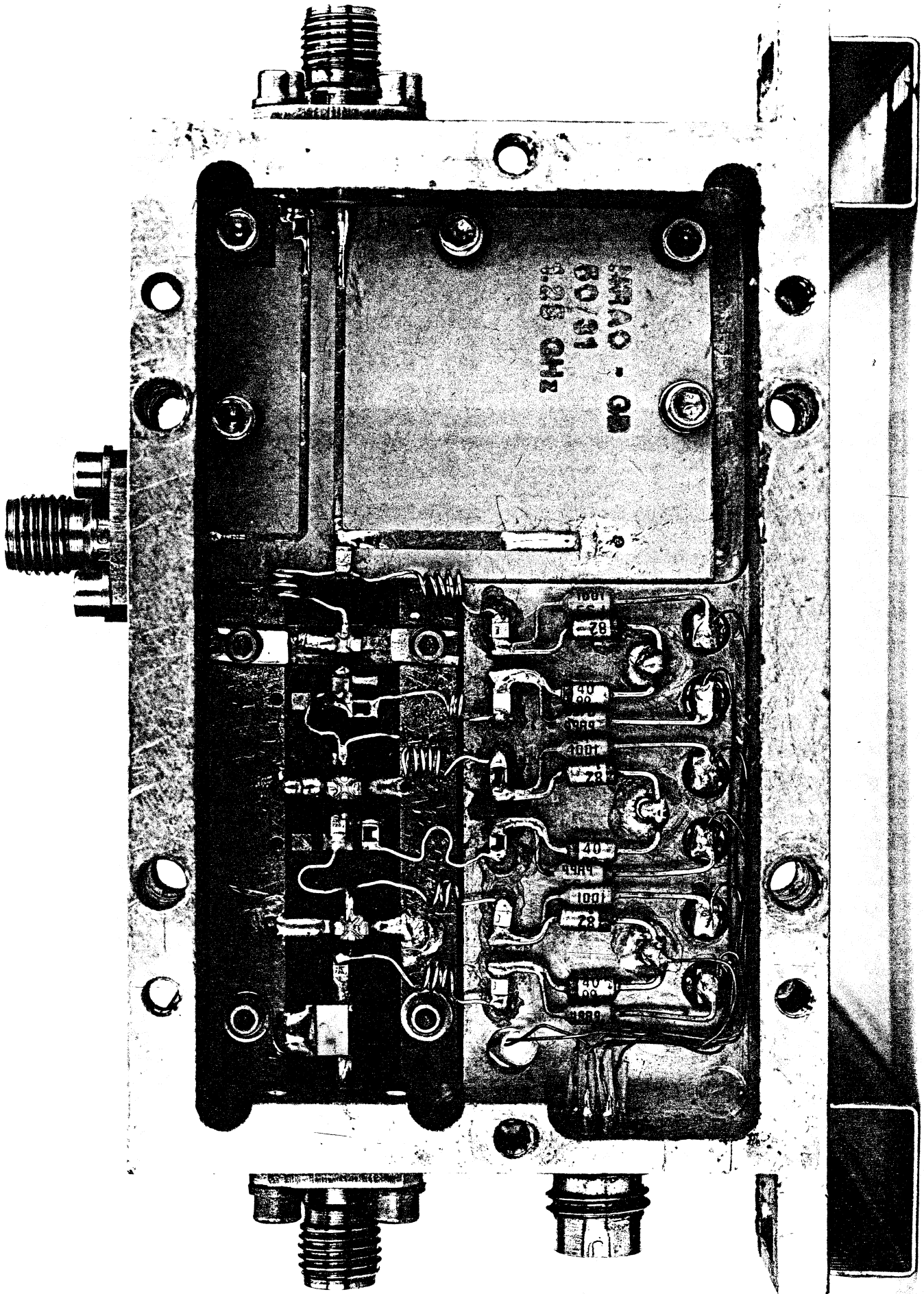


Figure 7. Photograph of Low-Noise, 1.25 GHz, Cooled, HEMT Amplifier.

APPENDIX

Program for Extracting Noise Parameters from Measured Noise Temperature Data.

```

dimension Tn(5),Rs(5)
real Ids
print *
print *, 'Input Te, F'
read(*,*)Te,F
write(*,10)Te,F
print *
print *, 'Input Vds, Ids'
read(*,*)Vds,Ids
write(*,50)Vds,Ids
print *
print *, 'Input T1,T2,T3,T4,T5'
read(*,*)T1,T2,T3,T4,T5
data R,T,G,A,B,C,D,Tr,Tg,Rr,Rg,Gg/12*0.0/
data R1,R2,R3,R4,R5/20.0,30.0,40.0,50.0,60.0/
print *
write(*,100)R1,R2,R3,R4,R5
write(*,150)T1,T2,T3,T4,T5
10  format(1x,'Te (Kelvin) = ',f5.1,10x,'F (GHz) = ',f4.2)
50  format(1x,'Vds (Volt) = ',f4.1,12x,'Ids (mA) = ',f4.1)
100 format(1x,'R (Ohm)',8x,5f7.1)
150 format(1x,'T (Kelvin)',5x,5f7.2)
200 R=R+R1+R2+R3+R4+R5
    T=T+T1+T2+T3+T4+T5
    G=G+1.0/R1+1.0/R2+1.0/R3+1.0/R4+1.0/R5
    A=A+R1**2+R2**2+R3**2+R4**2+R5**2
    B=B+1.0/(R1**2)+1.0/(R2**2)+1.0/(R3**2)+1.0/(R4**2)+1.0/(R5**2)
    C=C+T1*R1+T2*R2+T3*R3+T4*R4+T5*R5
    D=D+T1/R1+T2/R2+T3/R3+T4/R4+T5/R5
    Rg=R*G-25.0
    Rr=R*R-5.0*A
    Gg=G*G-5.0*B
    Tr=T*R-5.0*C
    Tg=T*G-5.0*D
    Root=sqrt((Rr*Tg-Rg*Tr)/(Gg*Tr-Rg*Tg))
    Gn=(1.0/290.0)*(Gg*Tr-Rg*Tg)/(Gg*Rr-Rg*Rg)
    Tmin=1.0/5.0*(T-290.0*Gn*(R-10.0*Root+Root**2*G))
data Rs(1),Rs(2),Rs(3),Rs(4),Rs(5)/20.0,30.0,40.0,50.0,60.0/
do 210 j=1,5
210 Tn(j)=Tmin+290.0*Gn*(Root-Rs(j))**2/Rs(j)
    continue
write(+,220)(Tn(j),j=1,5)
220 format(1x,'Tn(kelvin)',5x,5f7.2)
print *
write(+,250)Root,Gn,Tmin

```

```

250     format(1x,'Ropt (Ohm) = ',f6.2,5x,'Gn (1/Ohm) = ',f7.5,5x,
1     'Tmin (Kelvin) = ',f6.2)
      open(1,file='f2.data',status='unknown')
      write(1,320)Te,F
      write(1,380)Vds,Ids
      write(1,300)
300     format(1x,i5)
      write(1,400)R1,R2,R3,R4,R5
      write(1,500)T1,T2,T3,T4,T5
      write(1,520)(Tn(j),j=1,5)
320     format(1x,'Te (Kelvin) = ',f5.1,10x,'F (GHz) = ',f4.2)
380     format(1x,'Vds (Volt) = ',f4.1,12x,'Ids (mA) = ',f4.1)
400     format(1x,'R (Ohm)',8x,5f7.1)
500     format(1x,'T (Kelvin)',5x,5f7.2)
520     format(1x,'Tn(Kelvin)',5x,5f7.2)
      write(1,550)
550     format(1x,i5)
      write(1,600)Ropt,Gn,Tmin
600     format(1x,'Ropt (Ohm) = ',f6.2,5x,'Gn (1/Ohm) = ',f7.5,5x,
1     'Tmin (Kelvin) = ',f6.2)
      end

```