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

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## 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 ar 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:

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

$X = X_{opt}$ 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 50 Ω at both 300 K and 15 K.

Based on the above experimental result, the input circuit of the amplifier consists of a 50 Ω 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 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 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 Fn 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.

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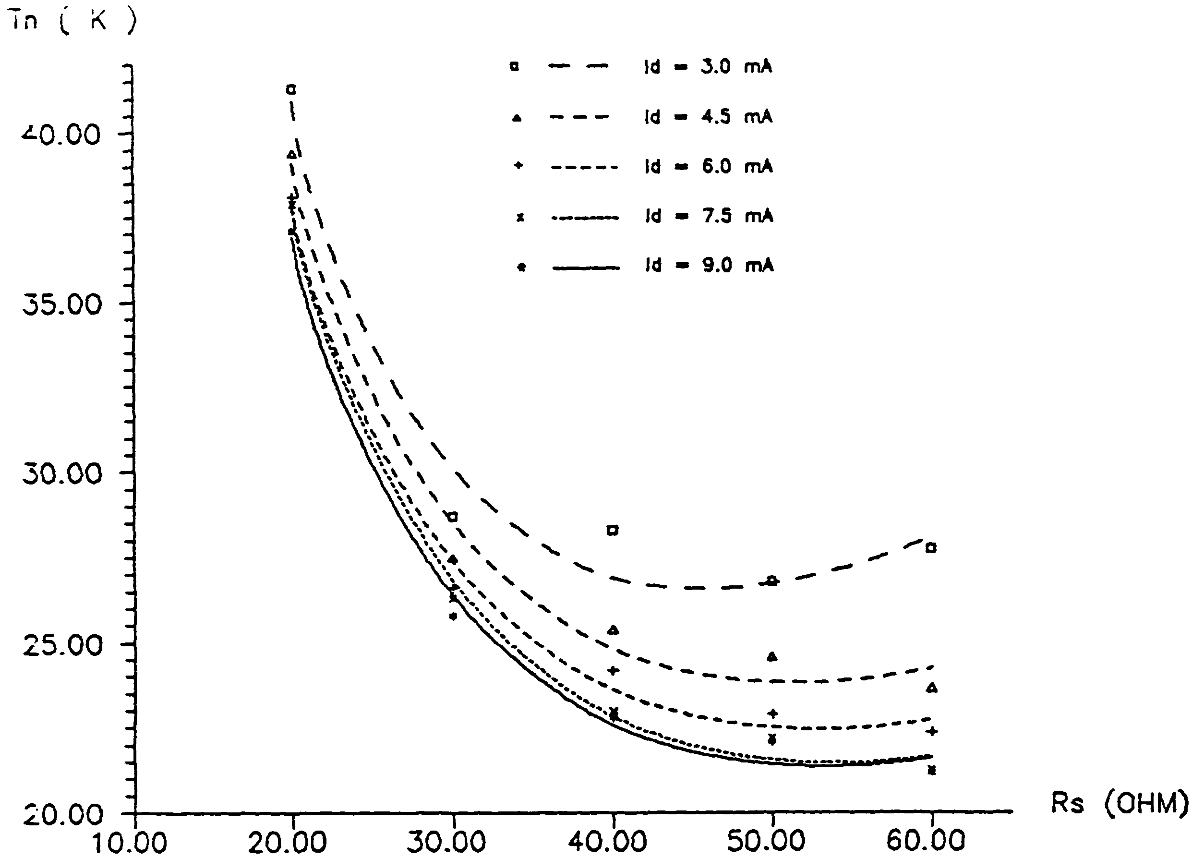



Figure 1. Noise Temperature vs. Source Resistance at 300 Kelvin

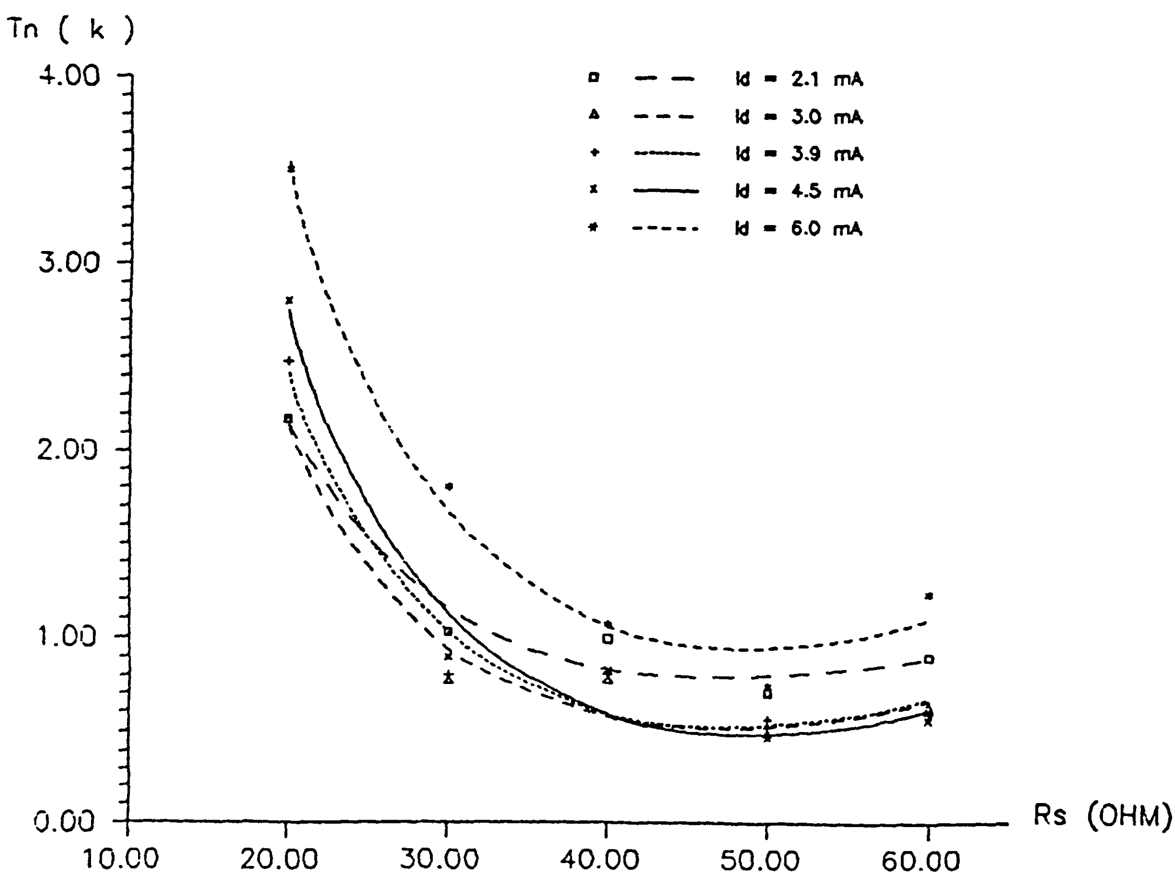
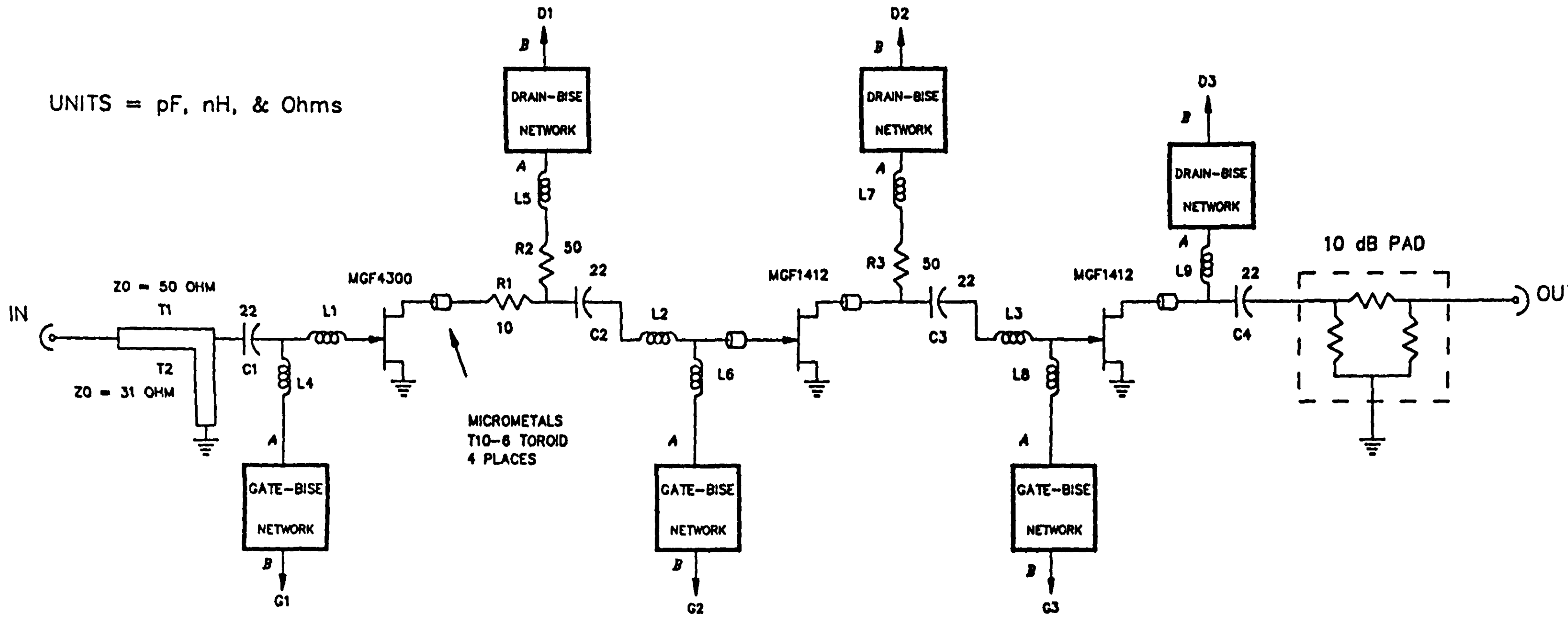
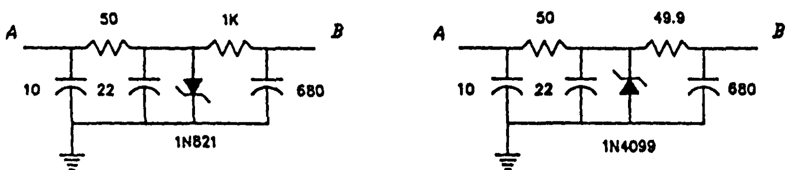



Figure 2. Noise Temperature vs. Source Resistance at 15 Kelvin




GATE-BIAS NETWORK

DRAIN-BIAS NETWORK

| 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 Toff = 15.8 Tmeas = 12.9
Tavg = 2.1 Tlo = 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) | Nsor(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 |

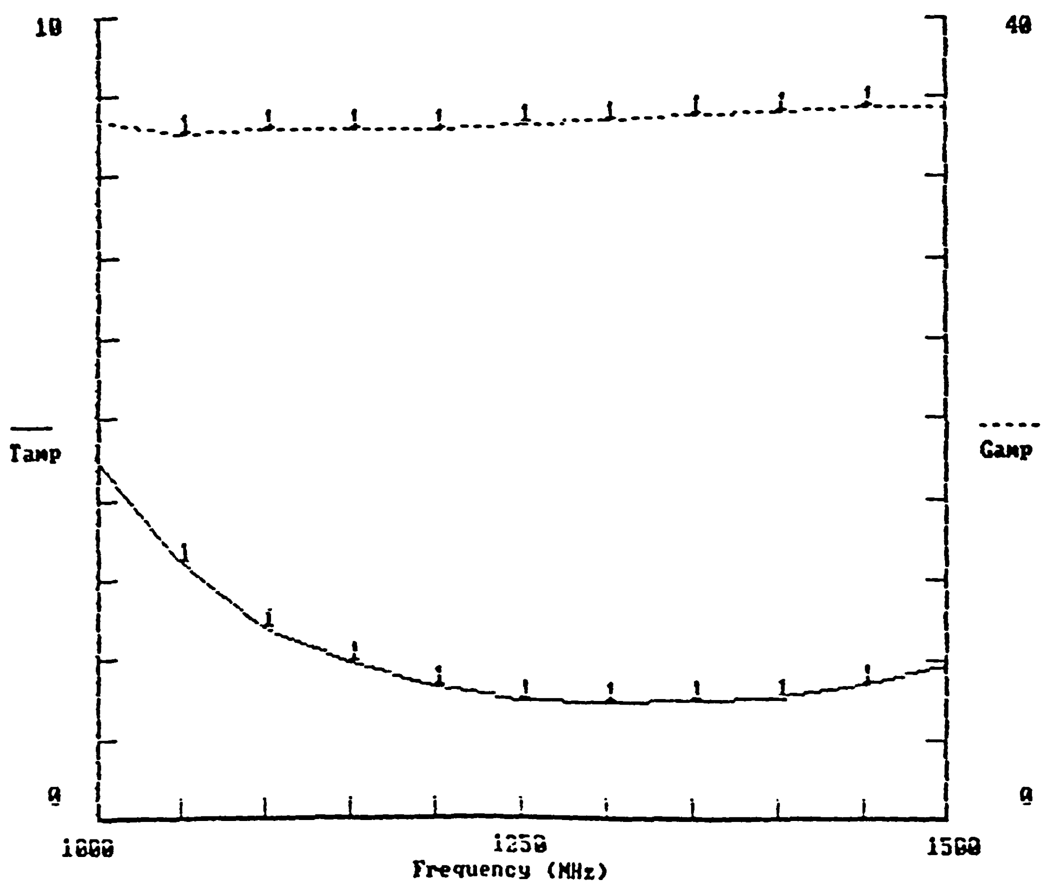



Figure 4. Noise temperature and gain at 15 K.

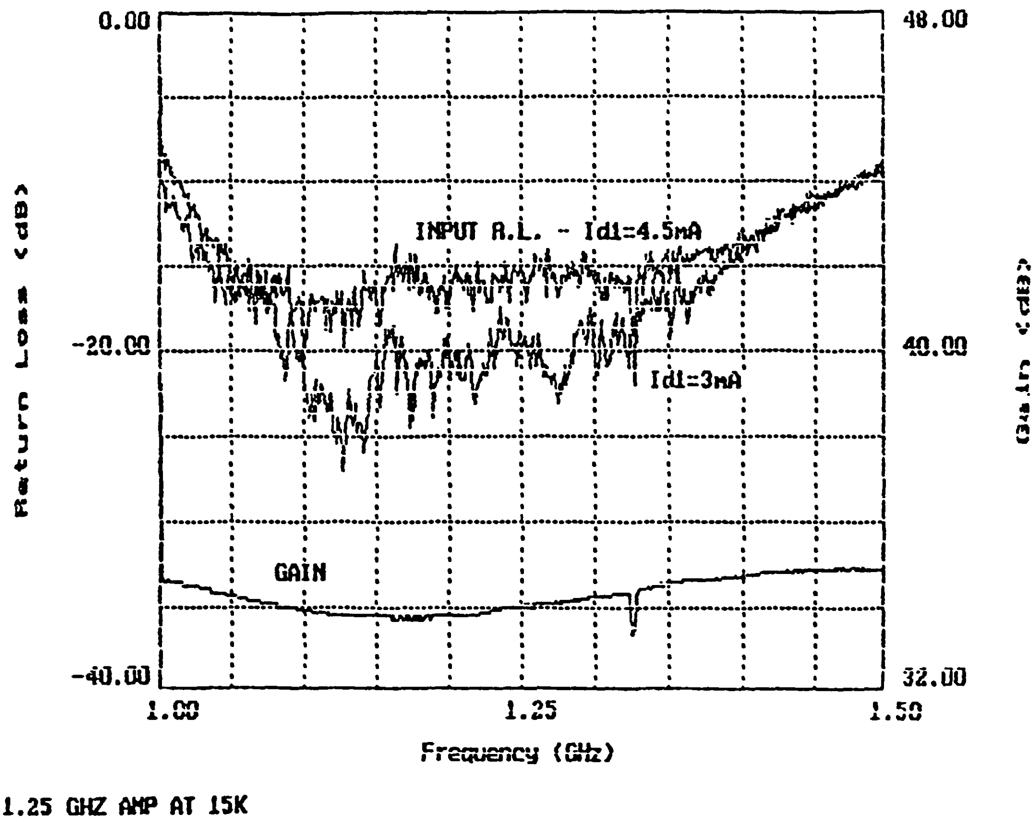



Figure 5. Input return loss at 15 K.

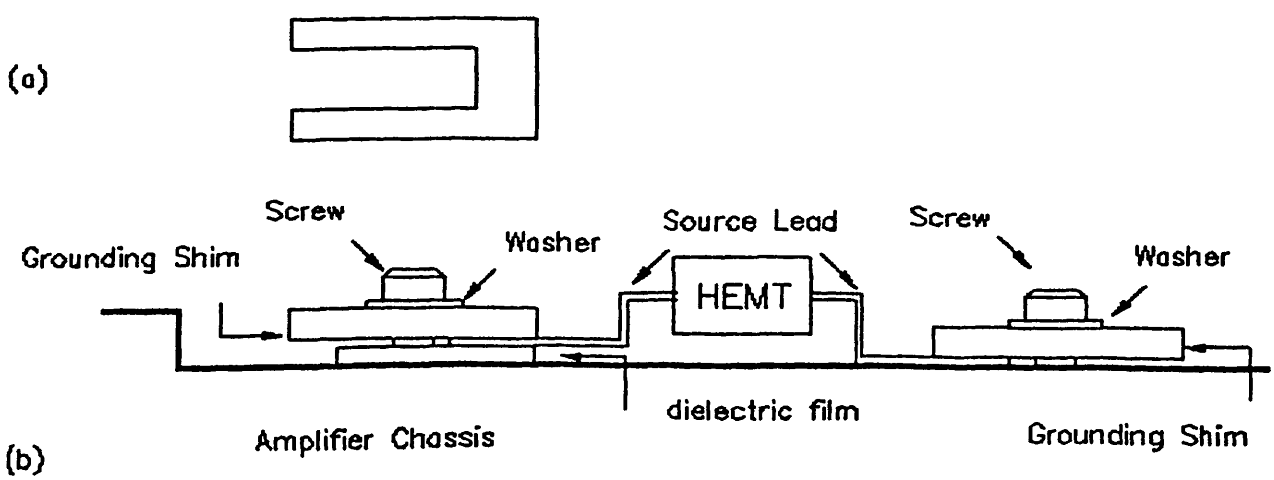



Figure 6. (a) Grounding Shim
(b) Schematic Drawing of the Realization of the Source Lead Inductance Adjustment

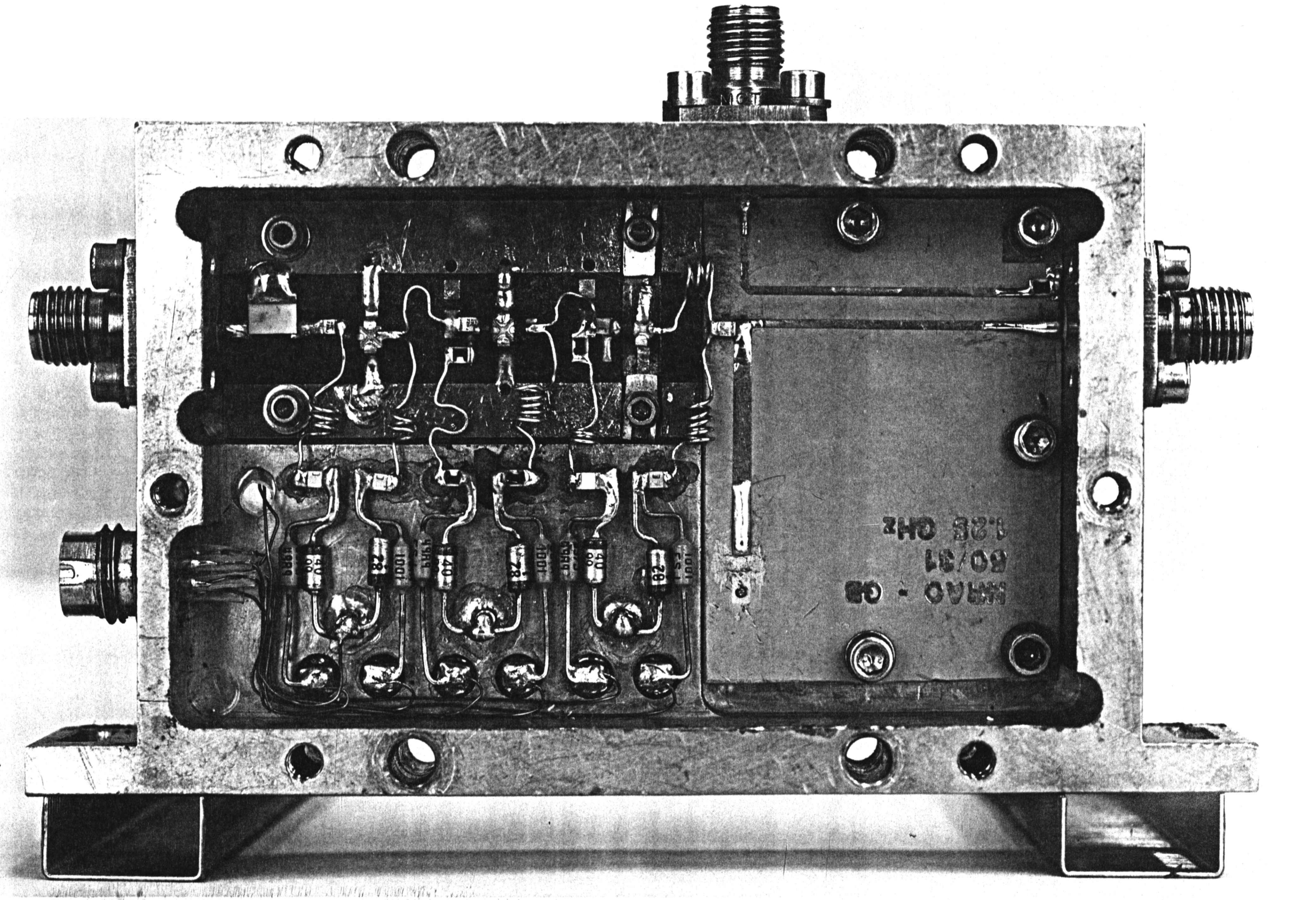


Figure 7. Photograph of Low-Noise, 1.25 GHz, Cooled, HEMT Amplifier.

## 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
        Ropt=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+Ropt**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
        Tn(j)=Tmin+290.0*Gn*(Root-Rs(j))**2/Rs(j)
210     continue
        write(*,220)(Tn(j),j=1,5)
220     format(1x,'Tn(Kelvin)',5x,5f7.2)
        print *
        write(*,250)Ropt,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
```