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15 GHz COOLED GaAsFET AMPLIFIER – DESIGN BACKGROUND INFORMATION

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15 GHz COOLED GaAsFET AMPLIFIER — DESIGN BACKGROUND INFORMATION

Manuel Sierra

I. Noise Parameters of FET's

Measurement and Analysis Procedure

In order to obtain the noise parameters of FET's used in a 3-stage amplifier a one stage amplifier has been constructed and the noise measured for a set of five source impedances and five values for the bias current.

The input and output networks have been made with a $\lambda/4$ sliding transformer over a 50 ohm transmission line, as shown in Figure 1. With this mount, it is easy to change the source impedance by changing the diameter of the $\lambda/4$ transform or the dielectric surrounding it, which changes the absolute value of the reflection coefficient, or by moving this transformer along the 50 ohm line, which changes the phase. Nevertheless, for the noise parameter measurements, the transformer position has been selected to get a minimum noise at the design frequency (14.9 GHz) for each transformer impedance.

Usually, the amplifier input is tuned for minimum noise at only one bias and at room temperature, and some frequency variations in the minimum noise can be expected. Taking this minimum, that must happen not too far from the design frequency, it is assumed that at that point the source reactance is optimum ($X_s = X_{opt}$), and the noise parameters not too far from those at the design frequency. When three or more source impedances have been tried, is is possible to determine the three noise parameters by adjusting the theoretical parabolic

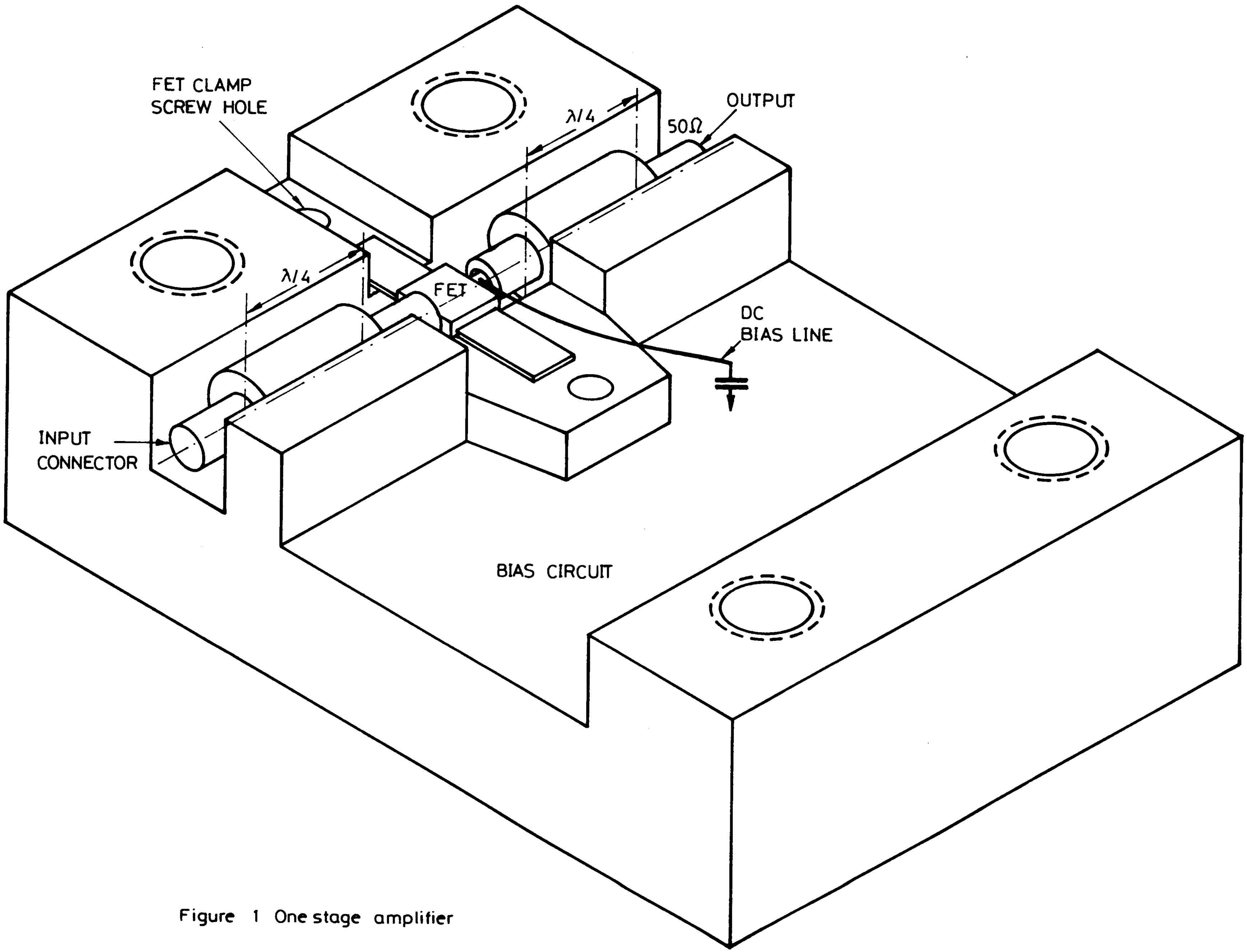


Figure 1 One stage amplifier

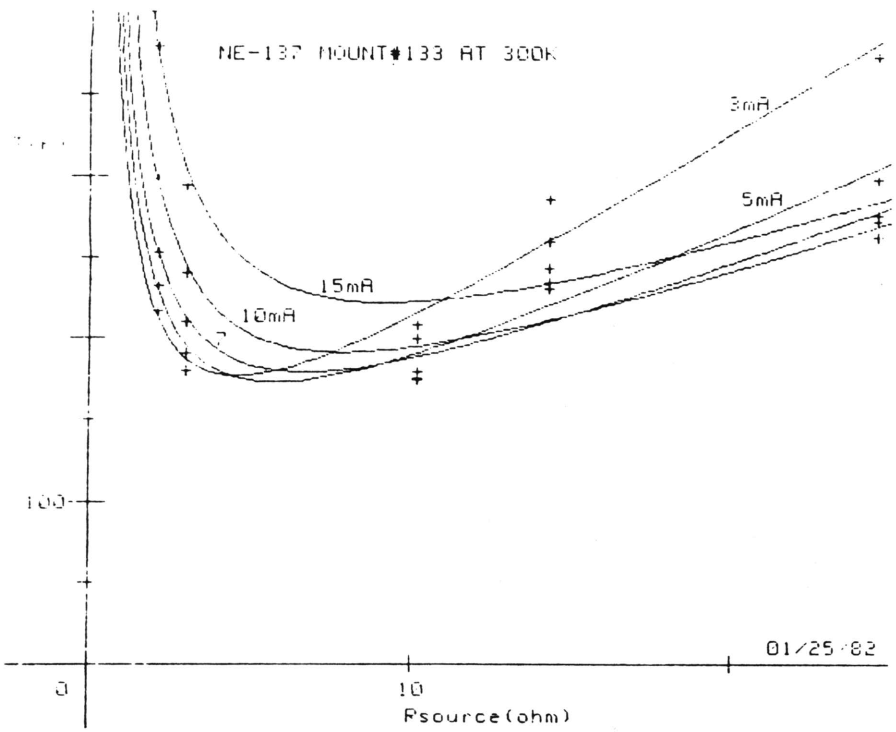
function. This has been done with the aid of the computer program "Ropt 1" discussed in Appendix 1. The program adjusts the values of R_{opt}, T_{min} and G_n for the least quadratic error method and presents the final values as well as the mean square error on temperature.

For all these measurements, the output network is matched for maximum return loss; this allows high gain and, hence, lower errors in the second stage noise cancellation.

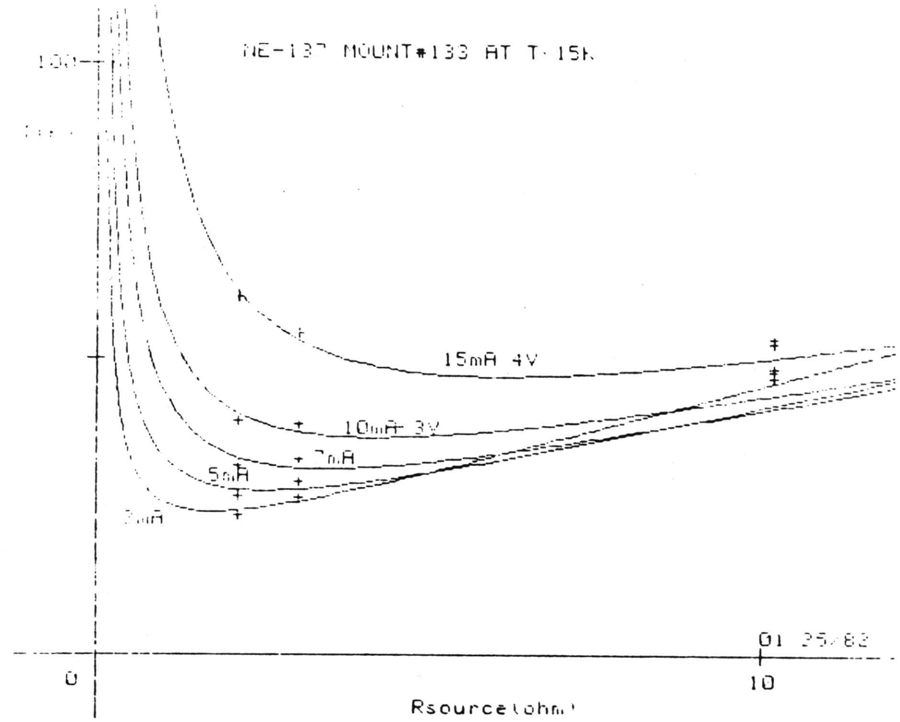
Noise Parameters for NE-137 and MGF-1412

Measuring the NE-137 FET, five transformers have been used, with 10, 12, 22, 26 and 36 ohm characteristic impedance. We also took the noise corresponding to five different bias currents, from 3 to 15 mA and the drain voltage that leads to a minimum noise at each current. For the NE-137, the drain voltage does not affect the noise, at least between 2.5 and 5 volts, and the small variations for low current have a minimum noise around 3 or 4 volts. It is important to note that the output match is more affected by the drain voltage, and that also affects the second stage noise. This means that the optimum voltage in noise measurements usually remains the same as the one selected for the output tuning.

The final results for the packaged NE-137 at 15K and room temperature are shown in Figure 2, where the noise temperature is plotted versus the source resistance, using the drain current as a parameter. It can be seen that at room temperature, the optimum current is around 5 mA and $R_{opt} \simeq 4$ ohms. At 15K the optimum current drops to values under 3 mA and the optimum source resistance to under 2 ohms, but taking into account that the gain also drops very fast for low currents, the optimum noise measure occurs around 3 mA.



Bias	15 mA, 3V	10 mA, 3V	7 mA, 3V	5 mA, 3V	3 mA, 3V
T_{min} (K)	221.7	191.1	179.1	172.8	176.7
R_{opt} (ohm)	9.18	7.84	6.65	5.74	4.58
G_n (mmhos)	22.3	23.4	25.9	31.5	43.2
Mean square error (K)	14.4	12.9	11.3	13.0	14.7



Bias	15 mA, 4V	10 mA, 3V	7 mA, 3V	5 mA, 3V	3 mA, 3V
T_{min}	46.9	36.5	31.4	27.7	24.2
R_{opt}	6.05	4.18	3.42	2.52	1.73
G_n (mmhos)	6.91	7.15	7.89	8.64	10.67
Mean square erorr (K)	2.91	3.90	4.53	4.84	5.40

Fig. 2. Noise temperature at 300K (left) and 15K (right) for NE13783 as function of generator resistance and drain current. The table gives the noise parameters determined from the figure.

The drain voltage has little effect upon the noise, and usually is selected in order to have the best output match or to optimize the second stage noise when using more than a one-stage amplifier.

From the MGF-1412 measurements, the same temperature dependence can be seen in the noise parameters and in the optimum bias current. The most important difference between this and the NE-137 is the greater drain voltage dependence of the MGF-1412 noise; an optimum voltage can be clearly found for each drain current. Usually the optimum voltage increases as the current increases, keeping the gate voltage fairly constant except for very low currents.

It looks like the noise parameters of the MGF-1412's are related to both drain current and gate voltage through two independent functions, at least in the most important range of bias.

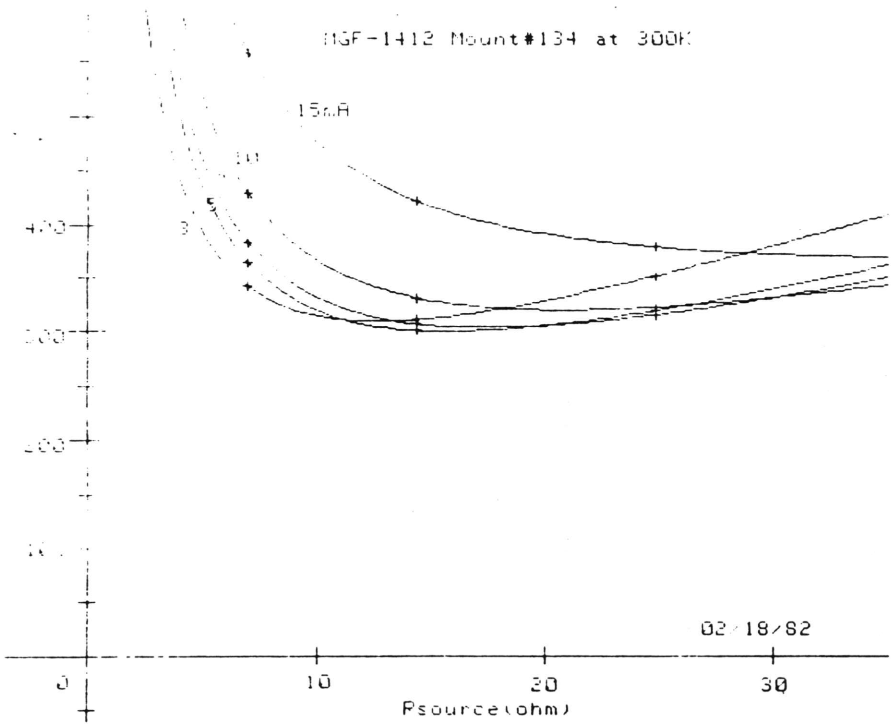
The optimum source reactance has been estimated from circuit modeling and assumed constant; the frequency where the minimum noise appears changes only a small amount when the bias or physical temperatures are changed.

The MGF-1412 measurements are shown in Figure 3 with values at 15K and room temperature.

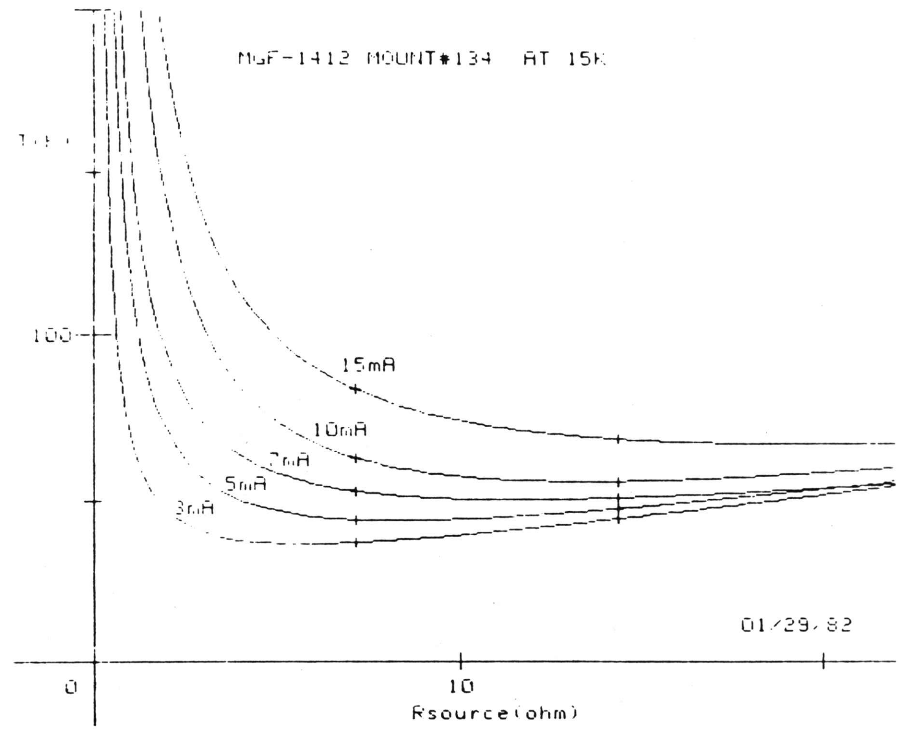
In Appendix 2 are presented the circuit and noise parameter models used in the computer programs for these two FET's. The frequency variation of the noise parameters has also been estimated from the frequency behavior of chip noise predicted by Pucel.

Errors in the Noise Measurements

Due to the low gain of these transistors at 15 GHz, large errors can be expected in one-stage amplifier measurements if all additional noise contributions are not taken into account.



Bias	15 mA, 5.5V	10 mA, 5.5V	7 mA, 5V	5 mA, 4V	3 mA, 3.5V
T_{min} (K)	367.3	318.5	302.7	299.2	308.5
R_{opt} (ohm)	38.0	20.8	17.4	15.8	12.7
G_n	4.78	13.7	17.6	19.8	24.1



Bias	15 mA, 5.5V	10 mA, 5V	7 mA, 4V	5 mA, 4V	3 mA, 3.5V
T_{min}	67.2	55.7	50.2	43.8	36.7
R_{opt}	19.6	13.4	11.5	8.3	5.7
G_n	2.59	4.47	3.35	4.83	5.10

Fig. 3. Noise temperature at 300K (left) and 15K (right) for MGF-1412 as function of generator resistance and drain current. The table gives the noise parameters determined from the figure.

We are going to analyze here only the errors due to the noise source calibration and the second-stage noise cancellation, assuming that the rest has little influence in the final error.

In order to avoid changes in the noise source impedance when switching, and also to get a lower off temperature, a 20 dB cooled pad is used following the noise source. The total losses from the noise source to the amplifier input have been measured and the equivalent off and on temperatures are computed.

Assuming that the noise diode calibration has no errors, the error due to the pad attenuation can be computed as follows:

$$\frac{\Delta T}{\Delta\alpha} \simeq .25\ (T + T_{off})\ \mathrm{K/dB} \tag{1}$$

where T is the measured temperature and $\Delta\alpha$ is the attenuation error in dB (<1). T_{off} is the equivalent off temperature.

Another noise contribution came from the receiver or second stage. This additional noise is taken into account measuring the second stage noise and computing its contribution to the total noise. In fact, measuring first the equivalent noise and gain of the receiver (T_R, G_R) and then the total noise and gain (T_T, G_T), the receiver noise contribution is done by

$$T_e = \frac{T_R}{G_{av}} = T_R \cdot \frac{G_R}{G_T} \tag{2}$$

where G_{av} is the available gain of the amplifier. In equation (2), it is assumed that the receiver performance (noise and gain) remains the same when driven by the noise source and when driven by the amplifier.

The difference between the reflection coefficient of the noise source and the amplifier output causes an error in the receiver performance. Let us assume, as shown in Figure 4, that the receiver is driven by a circulator with input reflection coefficient Γ_R and physical temperature T_c. The error in the receiver noise contribution can be written as follows (see Appendix 3):

$$\Delta T = \frac{T_c(|\Gamma_2|^2 - |\Gamma_s|^2)}{G_m} \cdot \left| \frac{1 - \Gamma_s\Gamma_R}{1 - \Gamma_2\Gamma_R} \right|^2 - \frac{T_R}{G_m} \left(1 - \left| \frac{1 - \Gamma_s\Gamma_R}{1 - \Gamma_2\Gamma_R} \right|^2 \right)$$

where G_m is the measured gain $G_m = G_T/G_R$ and the reflection coefficients are defined as shown in Figure 4.

The noise source is usually well matched and then the first term is positive and is the noise generated in the circulator load and reflected in the amplifier output. The second term depends on the relative phases of the reflection coefficie and can be either positive or negative. The extreme values for this error when $\Gamma_s \simeq 0$ can be written as follows:

$$\Delta T_{max} \simeq \frac{T_c|\Gamma_2|^2 + T_R(2|\Gamma_2\Gamma_R|)}{G_m(1 + |\Gamma_2\Gamma_R|)^2}$$

$$\Delta T_{min} \simeq \frac{T_c|\Gamma_2|^2 - T_R(2|\Gamma_2\Gamma_R|)}{G_m(1 + |\Gamma_2\Gamma_R|)^2}$$

In order to minimize these errors, the amplifier output has been matched at least with 15 dB return loss and a cooled circulator as well as the receiver input circulator have been used.

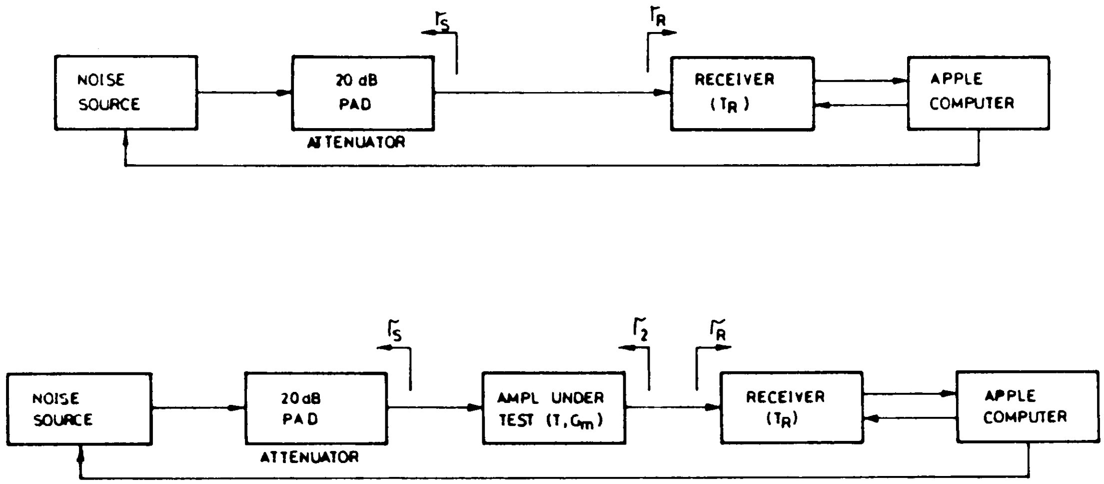


Fig. 4. Test set for computer measurement of amplifier gain and noise temperature. Top configuration is for "CAL" mode which determines receiver gain and noise temperature; lower configuration is for "TEST" mode which determines amplifier gain and noise temperature.

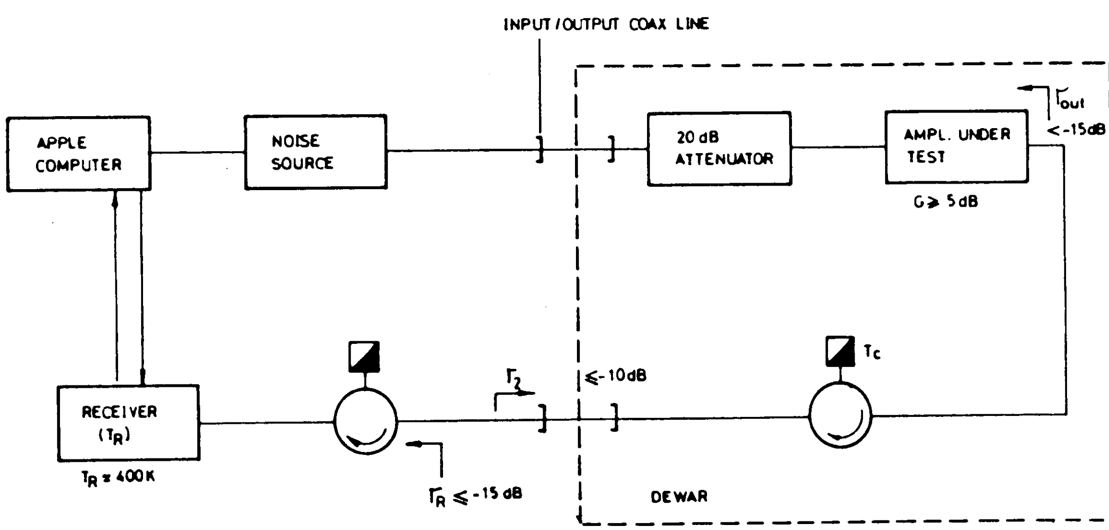


Fig. 5. Test setup for measurement of cryogenically cooled amplifier.

The final mount for cooled measurements is shown in Figure 5 where most parameters are specified. The final error limits are listed in Table 1.

TABLE I. Measurement Errors

Physical Temperature	300K		15K	
Noise source NDB	-5.58 ± .05		5.56 ± .1	
Noise source error	≤ 10K		≤ 2.4K	
Amplifier gain	> 4dB	> 7dB	> 5dB	> 8dB
Cooled isolator noise	+ 3.8	+ 1.9	+ .15	+ .06
Second isolator noise			+ 3.8	+ 9.5
Second stage noise error	± 10.2	± 5.1	± 14.6	± 5.8

Package and Chip Noise Parameters

Having a model for the FET package, it is possible to compute the chip nois parameters and see how they agree with the theoretical predictions or other frequency measurements.

The package model has been computed for the MGF-1412 from S parameters and low frequency package measurements as discussed in [1]. The NE-137 package model has been computed from the chip and packaged FET S-parameters.

The models are shown in Appendix 2. The chip noise parameters for the NE-137 and MGF-1412 are also shown in Table II. Two bias currents are used to compute these parameters, the recommended and the minimum noise current, both at 15K and at room temperature.

TABLE II. Chip Noise Parameters

NE-137	300K		15K	
Bias	10 mA, 3V	5 mA, 3V	10 mA, 3V	3 mA, 3V
T_{min}	182	164	34.1	21.3
R_{opt}	6.6	4.9	3.4	1.23
X_{opt}	27.3	27.6	27.4	27.5
G_n (mmhos)	26.5	35.7	8.2	12.1

MGF-1412	300K		15K	
Bias	10 mA, 5.5 V	5 mA, 4V	10 mA, 5V	3 mA, 3.5V
T_{min}	289	267	49.2	28.3
R_{opt}	12.5	10.8	8.7	3.5
X_{opt}	16.3	19.2	18.9	22.3
G_n (mmhos)	20.8	26.4	6.3	6.2

From the chip noise parameters and assuming the theoretical frequency variation, it is possible to compute the noise parameter frequency dependence of the packaged FET. This has been done in Figures 6-13 for both transistors at room temperature and cooled. It is interesting to note that noise parameters of the packaged transistors are much different from those of the chip at high frequencies. The noise temperature is not affected by the package input circuit but is affected by the source inductance in such a way that the noise measure remains constant.

Looking at these figures, it is reasonable that it is not possible to compare the noise parameters at different frequencies if the mount or surrounding

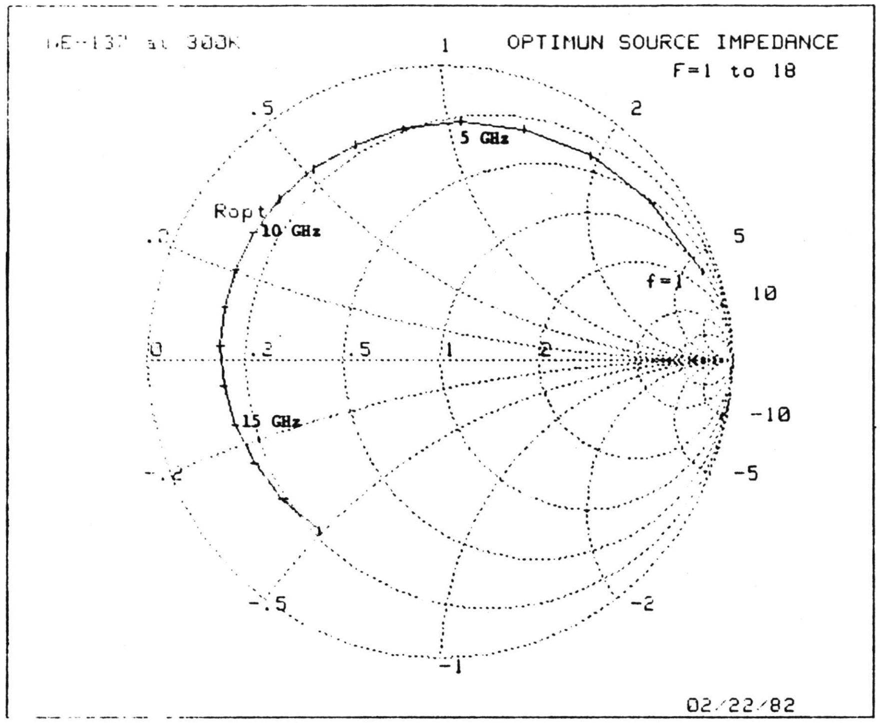


Fig. 6. Optimum source impedance at 300K for the NE137 in steps of 1 GHz from 1 to 18 GHz.

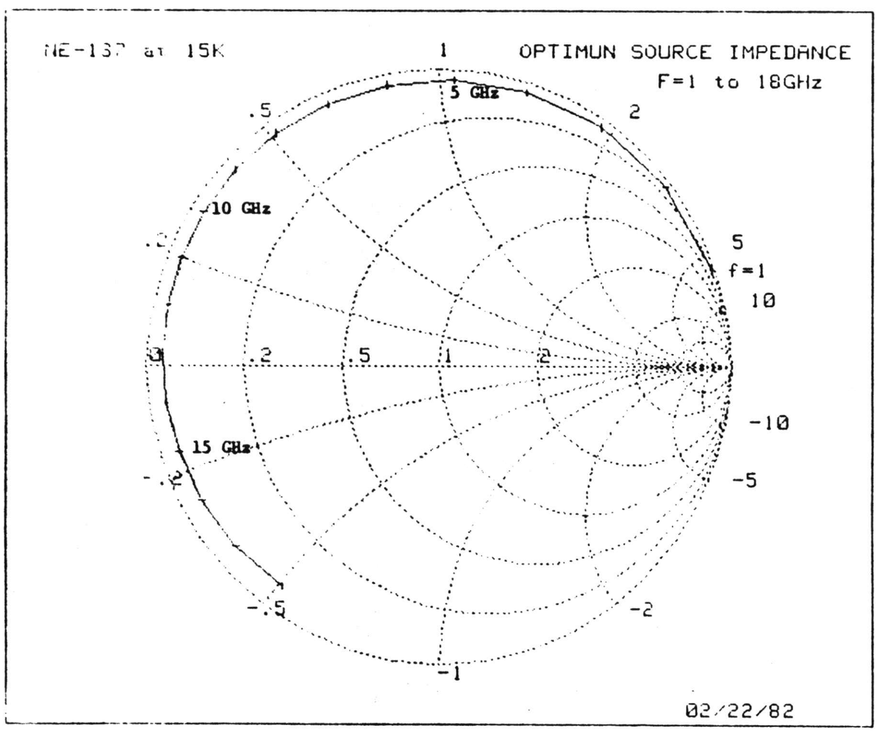


Fig. 8. Optimum source impedance at 15K for the NE137 in steps of 1 GHz from 1 to 18 GHz.

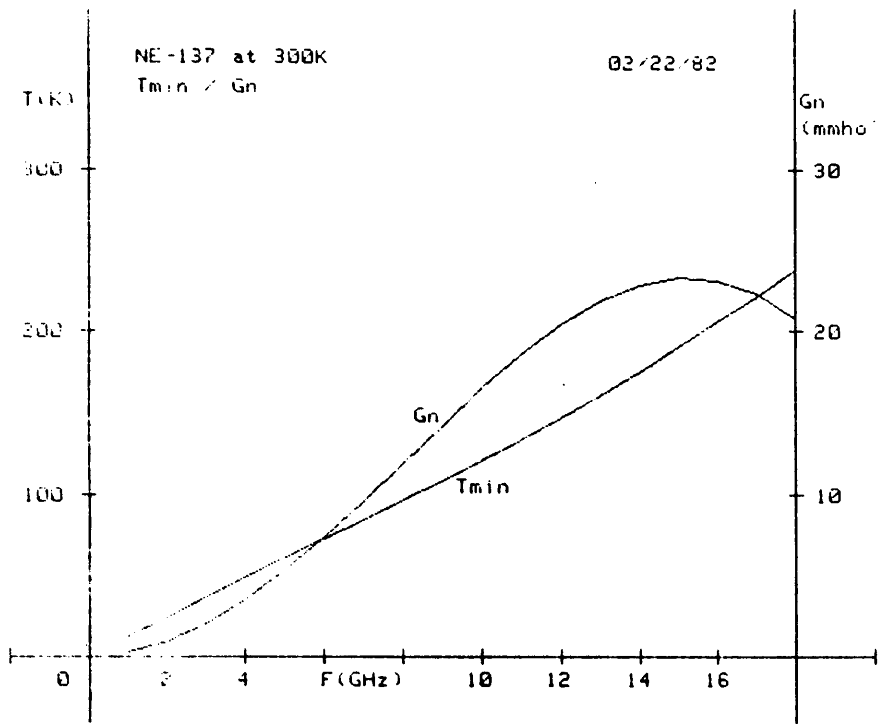


Fig. 7. Noise parameters, T_{min} and g_n, for the NE137 at 300K in the 1 to 18 GHz frequency range.

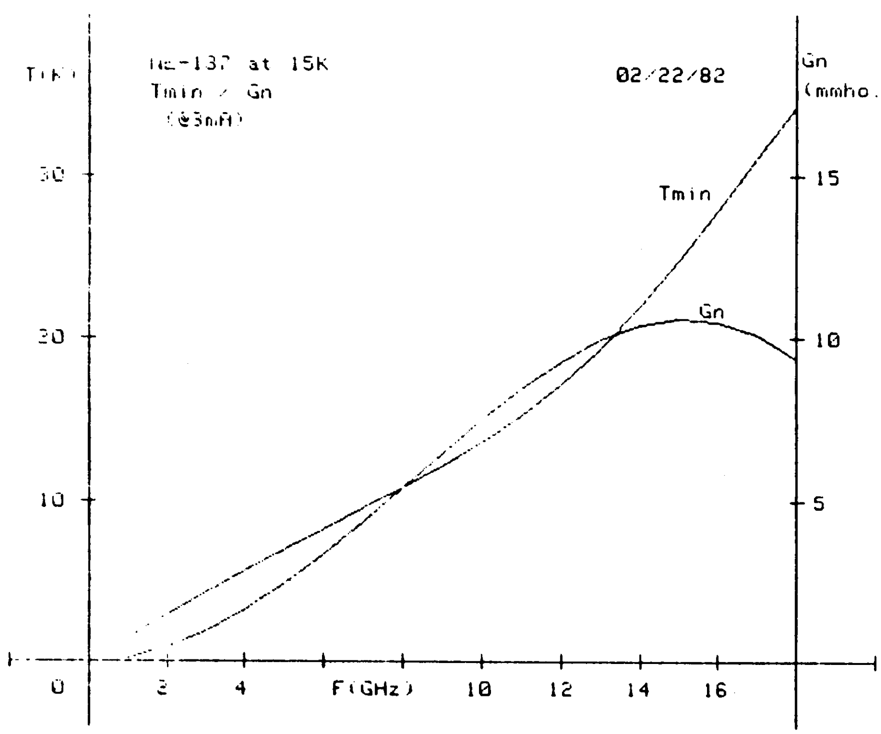


Fig. 9. Noise parameters, T_{min} and g_n, for the NE137 at 15K in the 1 to 18 GHz frequency range.

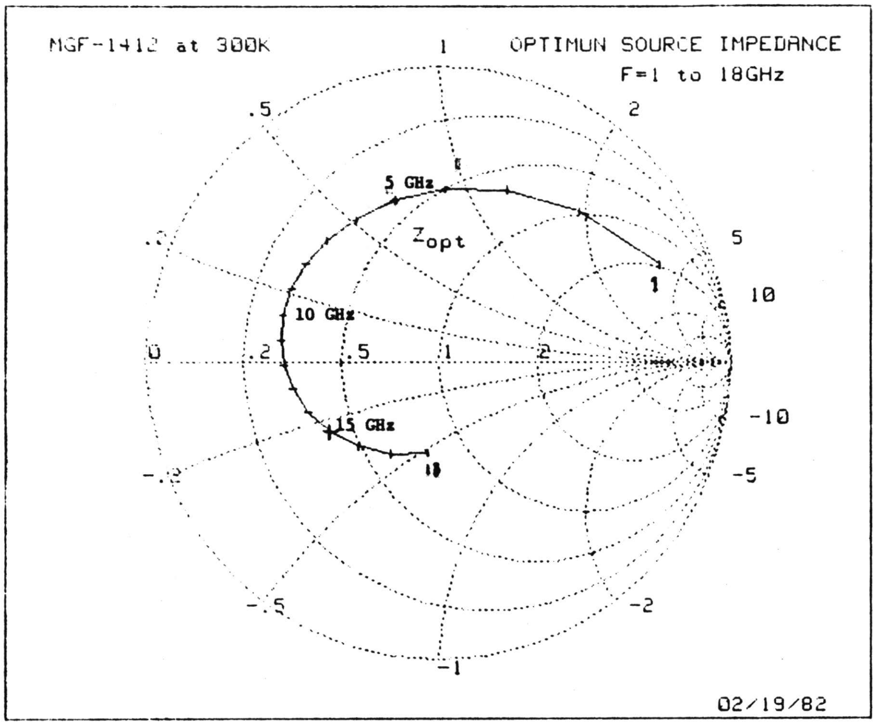


Fig. 10. Optimum source impedance at 300K for the MGF-1412 i steps of 1 GHz from 1 to 18 GHz.

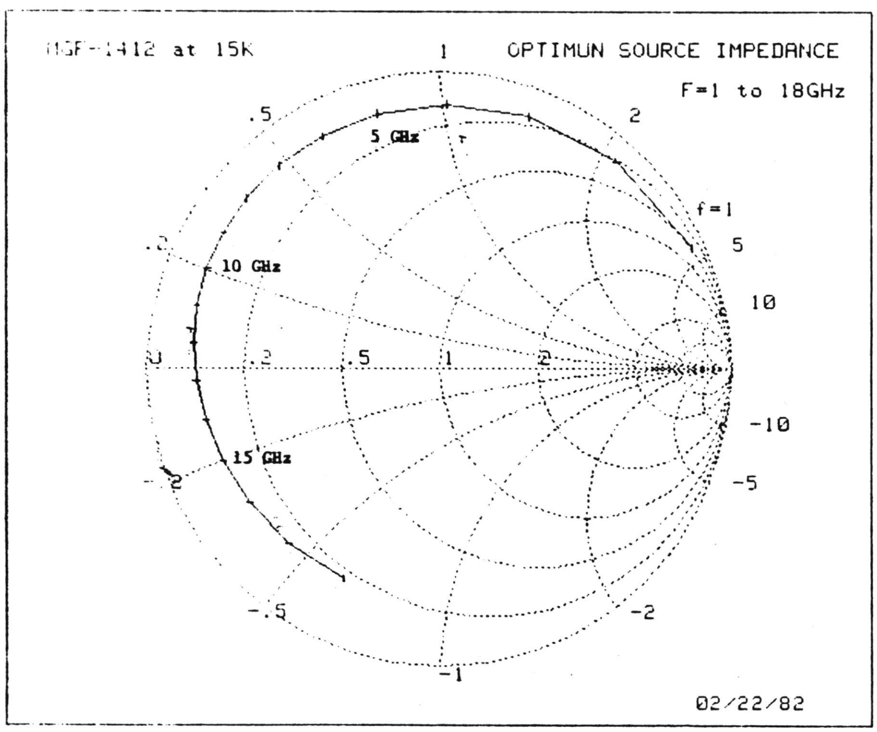
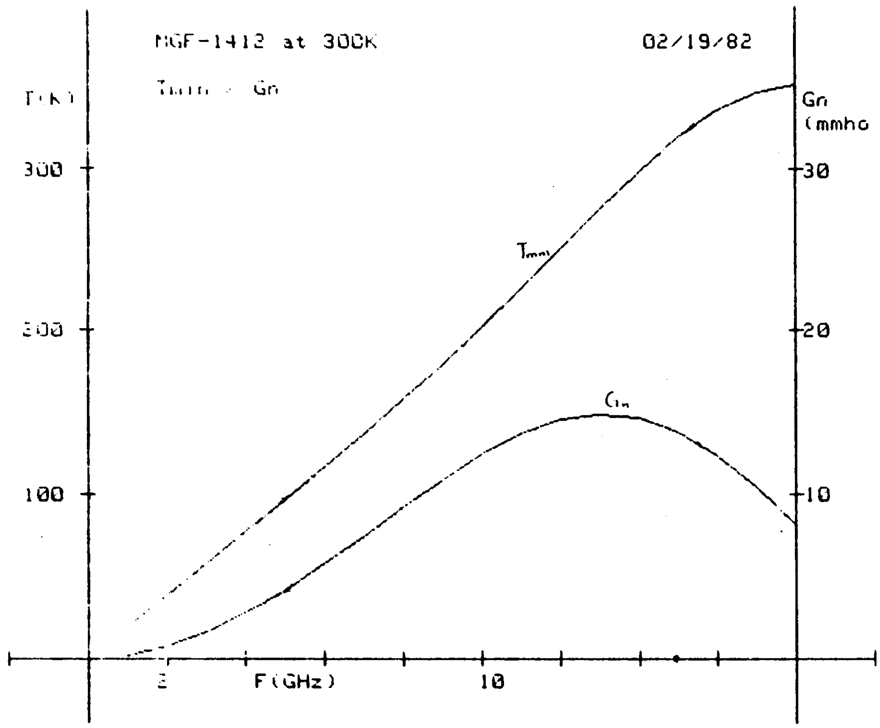
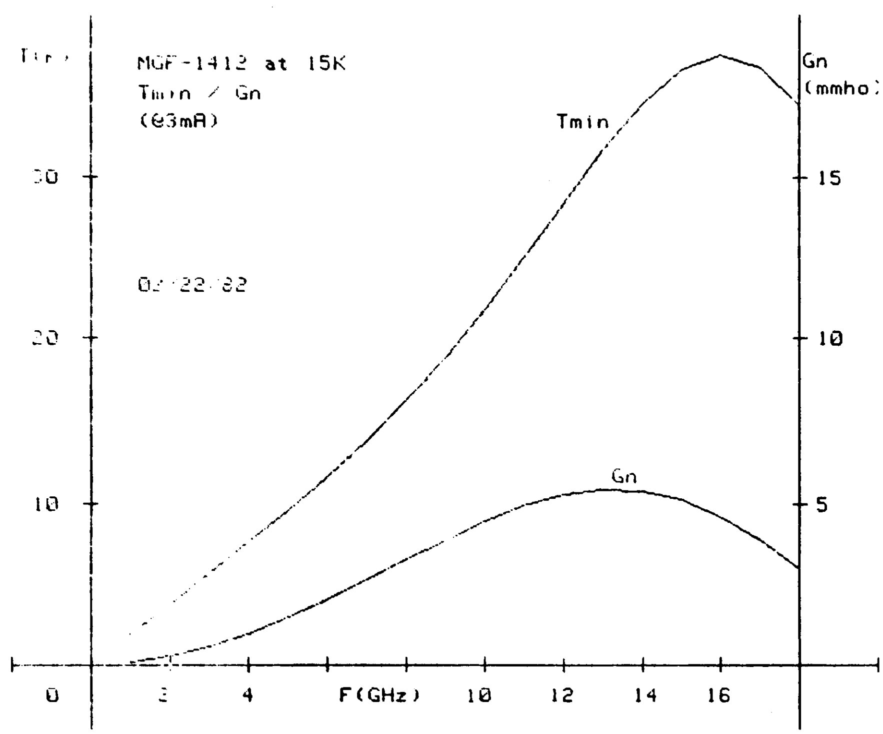


Fig. 12. Optimum source impedance at 15K for MGF-1412 in ste of 1 GHz from 1 to 18 GHz.



11. Noise parameters, T_{min} and g_n, at 300K for the MGF-141 in the 1 to 18 GHz frequency range.



13. Noise parameters, T_{min} and g_n, for the MGF-1412 at 15K in the 1 to 18 GHz frequency range.

circuit where the transistor has been measured are not the same. The only parameter that can be estimated is the noise measure that does not change with any reactive feedback.

II. Amplifier Design

Technology

The final amplifier has been realized with the same technology as the one-stage test mount previously described. The main transmission line is a coaxial line formed by the square outer conductor machined as a groove in the chassis, and a circular inner conductor supported by a .05 inch thick polystyrene support to prevent movement along the line [2].

The input and output network used for each stage is formed by a $\lambda/4$ transmission line with a lower than 50Ω characteristic impedance in cascade with a 50Ω transmission line. With this coupling network, it is always possible to get any desired impedance.

The D.C. blocking capacitors are formed by inserting the FET leads into the coaxial inner conductor lined with #22-PTFE teflon tubing. This forms a series transmission line that has around 38 ohm characteristic impedance and 1.8 effective dielectric constant. The open-circuited end has around .04 pF fringing capacitance.

Although it is possible to match any desired impedance with the described network, the frequency response depends on the selected circuit, getting a narrower bandwidth as the 50 ohm transmission line becomes longer. In order to have the proper distance between the slug and the FET ($L \leq \lambda/16$), the series transmission line length has been adjusted. At 15 GHz the optimum generator reactance becomes capacitive because of the package inductive effects, and it is necessary to use shorter than $\lambda/4$ series lines as D.C. blocking.

D.C. bias is applied to the FET by $\lambda/4$ wires from the chip bypass capacitors and a proper D.C. protecting circuit is used, as shown in Figure 14.

Design

A 14.4 to 15.4 GHz low-noise amplifier was required as a first stage for the front ends of the Very Large Array radio telescope. The unit must be optimized for minimum noise and have 20 dB gain with no more than 2 dB ripple over the band. An input match is not required since the input will be connected through a circulator.

From these specifications and previous one-stage measurements, it can be seen that at least three stages are required. The first and second stages are driven for minimum noise and the third one can be matched either for minimum noise or maximum gain depending on the final gain.

The first stage input network is then selected to have a minimum noise (Z_{opt}) and from the transistor parameters, it is possible to know the output impedance (Z_{out}). In order to have the optimum source impedance for the second stage, the inter-stage network must transform the first stage output impedance (Z_{out}) to Z_{opt}. This condition provides two equations for computing the network, leaving one of the three parameters free (lossless network).

Going from Z_{out} to 50Ω and then to Z_{opt} as shown in Figure 14, the third parameter is easily identified with the 50-ohm transmission line length. This length can be selected in order to adjust the frequency performance or minimize the input reflection.

This solution is not the only one, of course. Any other solution can be good, but this one has the advantage that all parameters can be selected from one-stage measurements, and it is easy to mount and adjust.

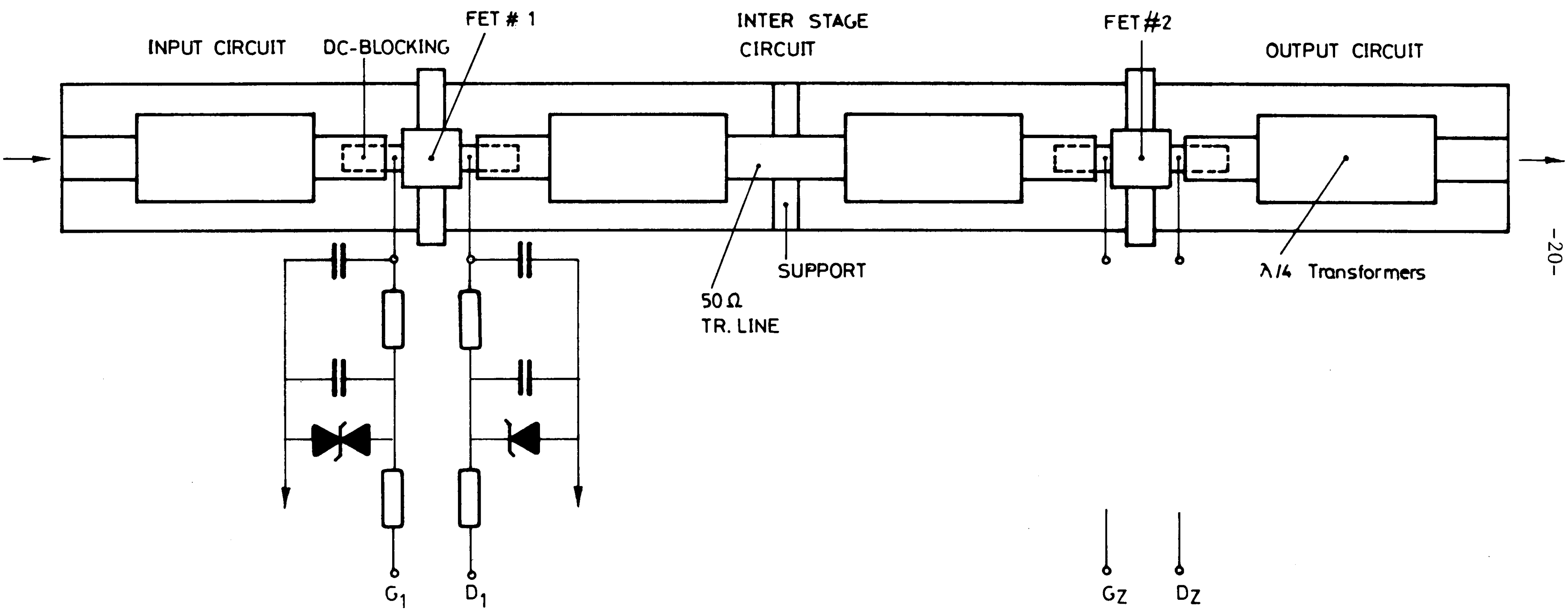


Fig. 14. Inter-stage circuit.

In order to determine the length between transformers for maximum bandwidth and have a theoretical model for the amplifier performances, some computer programs have been developed, based on the transistor models and using FARANT subroutines [3].

At first two programs were developed to compute the optimum transformer impedance and inter-stage distances. The first one (Man #4) computes the inter-stage circuit to get a maximum input return loss at the design frequency. This condition also assures the maximum amplifier gain at the design frequency. It then computes the frequency response for a two-stage amplifier. Having a bad input match or at least not enough match to avoid isolators, we would rather select this third parameter to achieve the maximum bandwidth, doing this with a cut-and-try method aided by the Amp #1 program.

Finally, an analysis program was developed to allow final adjustment of the computer model before or at the same time as the experimental amplifier (Amp #2).

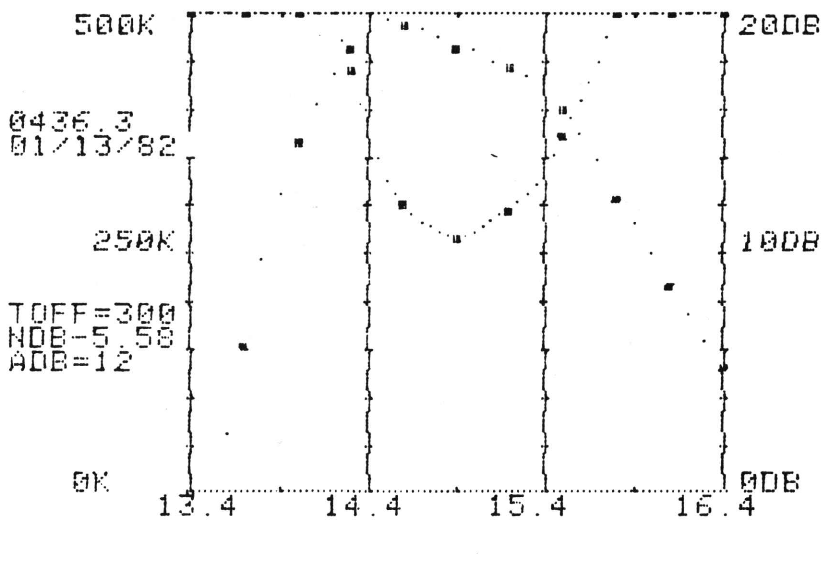
The last two programs work with one, two or three stage amplifiers as desired. The programs are listed in Appendix 3.

Experimental Results

The three stage amplifier using the NE-137 as first stage and two MGF-1412's as second and third stages was built and optimized for minimum noise and flat gain in the band. The noise temperature and gain are shown in Figure 15 for both 300K and 15K operation. The optimum temperature around the design frequency is 40K and has an average temperature of 49K over a 1 GHz bandwidth. The gain is over 24 dB which allows a 4 dB output attenuator to match the amplifier to the following stage.

The amplifier is stable for any input and output load, but an isolator is necessary to improve the input match.

1) #112 WITH 15 OHM. INPUT TR.
0436.3 01/13/82 TAV=299.8 TLO=263.3 @ 14900 GL=16.7 GH=19.7 T=296.
4.98,5.2,-1.224 4.02,14.8,-.543 3.98,14.6,-1.239



1) #112 WITH 15 OHM. INPUT TR.
0659.7 01/13/82 TAV=65.8 TLO=55.2 @ 14800 GL=22.2 GH=24.3 T=10.9K
4.98,5.2,-1.923 4.02,14.9,-.463 4.01,14.6,-1.405

2) OPTIMUN BIAS
0709.7 01/13/82 TAV=48.6 TLO=40.6 @ 14800 GL=23.7 GH=25.7 T=11K
3.97,5.1,-1.745 5.51,14.8,-.58 5.5,19.5,-1.4

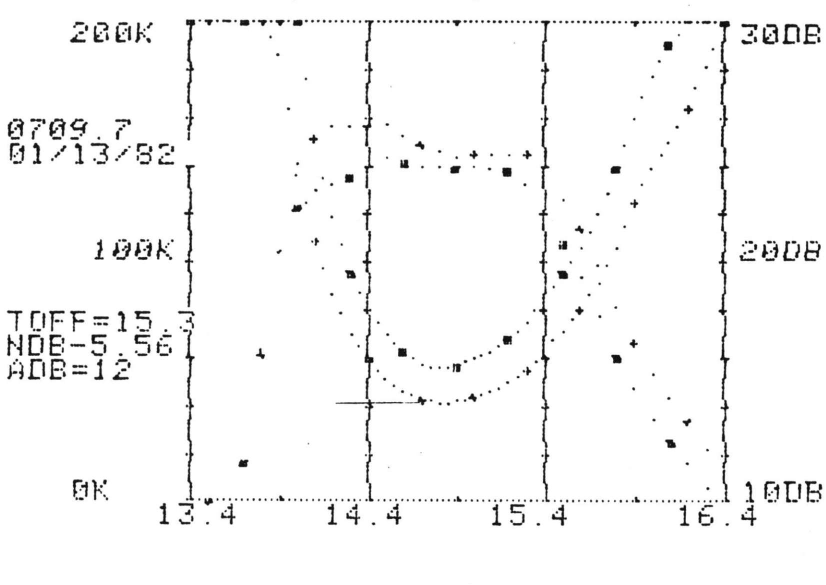


Fig. 15. Gain and noise temperature of amplifier #112 at 300K (top) and 20K (bottom) with 15 ohm input quarter-wave transformer. The 20K results are shown for first stage drain voltages of 5 volts and 4 volts (optimum).

REFERENCES

[1] Sander Weinreb, "Low-Noise Cooled GASFET Amplifiers," IEEE Trans. on Microwave Theory and Tech., vol. MTT-28, no. 10, October 1980.

[2] G. Tomassetti, S. Weinreb, and K. Wellington, "Low-Noise 10.7 GHz Coo GaAs FET Amplifier," Electronics Letters, vol. 17, no. 25/26, pp. 949-951, December 10, 1981.

[3] D. L. Fenstermacher, "A Computer-Aided Analysis Routine Including Optimization for Microwave Circuits and Their Noise," NRAO Elect Division Internal Report No. 217, July 1981.

Appendix I

Program "R_{opt} 1" for HP-9845A Computer

Equations

This program computes the noise parameters (other than X_{opt}) from a set of N measurements ($N \geq 3$) by minimizing the mean square error between the calculate and measured noise temperatures. The function to be adjusted is:

$$T(R) = T_{min} + T_o G_n (R - R_{opt})^2 / R \qquad (1)$$

where T_o = 290K and T_{min}, G_n and R_{opt} are unknowns. Having N points T_i, R_i where i = 1 to N, the mean square error is:

$$E = \Sigma (T(R_i) - T_i)^2$$

and the rms error of the fit, in degrees Kelvin, is $\sqrt{E/N}$. The set of three equations that allows us to compute the noise parameters is:

$$\partial E / \partial T_{min} = 0$$

$$\partial E / \partial R_{opt} = 0$$

$$\partial E / \partial G_n = 0$$

Letting $\Delta t_i = T_{min} + T_o G_n (R_i - R_{opt})^2 / R_i - T_i$, this set of equations can be interpreted as:

$$\Sigma \Delta t_i = 0$$

$$\Sigma \Delta t_i / R_i = 0$$

$$\Sigma \Delta t_i \cdot R_i = 0$$

The unknowns can be extracted from these three equations and finally written as follows:

$$R_{opt}^{2} = \frac{R_r T_g - R_g T_r}{G_g T_r - R_g T_g}$$

$$T_o G_n = \frac{T_g}{R_g + R_{opt}^{2} G_g} = \frac{G_g T_r - R_g T_g}{G_g R_r - R_g^{2}}$$

$$T_{min} = \frac{1}{N} [T - T_o G_n (R - 2R_{opt} N + R_{opt}^{2} G)]$$

where $R = \Sigma R_i$, $G = \Sigma 1/R_i$, $T = \Sigma T_i$, and

$$R_r = (\Sigma R_i)^2 - N \Sigma R_i^{2}$$

$$R_g = \Sigma R_i \Sigma 1/R_i - N^2$$

$$G_g = (\Sigma 1/R_i)^2 - N \Sigma 1/R_i^{2}$$

$$T_r = \Sigma T_i \Sigma R_i - N \Sigma T_i R_i$$

$$T_g = \Sigma T_i \Sigma 1/R_i - N \Sigma T_i/R_i$$

How the Program Works

The program reads the number of points and values from data statements computes the three noise parameters and the final error in temperature and presents the function T(R) in graphics mode.

Two operation modes are allowed:

Option = 0: uses the data as temperature and source resistance values

Option = 1: uses the data as temperature, $\lambda/4$ transformer impedance and 50 ohm line length (inches)

From this, it is clear that three values are required for each point and that the third one is not used in the zero option.

The scale in the plotting can be changed easily through the variables X_{ma} and Y_{max} that are the maximum values for horizontal and vertical dimensions of the plot.

```
10   ! THIS PROGRAM COMPUTES THE MINIMUN TEMPERATURE AND OPTIMUN
20   ! SOURCE RESISTOR FROM A SET OF N MEASUREMENTS WITH THE
30   ! MINIMUN CUADRATIC ERROR
40   PRINT LIN(2),"Ropt 1 as of 12/10/81"
50   OPTION BASE 1
60   ! DATA must be placed in 470 to 510 as follows: N,T1,R1,L1,T2
70   ! Select Option=0 for Ri=Rsource and Option=1 for R=Rtransfor
 L=50 ohm line length
80   INPUT "Option=",Option
81   Fo=15
85   Qlam=11.8028527/(2*Fo)
90   DIM Temp(20),Res(20),Long(20)
100  READ N
110  REDIM Temp(N),Res(N),Long(N)
120  R=G=T=Rr=Gg=Tr=Tg=0
130  FOR I=1 TO N
140  READ Temp(I),Res(I),Long(I)
150  IF Option=0 THEN 170
152  L=PI*Long(I)/(2*Qlam)
160  Res(I)=Res(I)^2*(1+TAN(L)^2)/(50*(1+((Res(I)/50)^2*TAN(L))^2)
170  R=R+Res(I)
180  G=G+1/Res(I)
190  T=T+Temp(I)
200  Rr=Rr+Res(I)^2
210  Gg=Gg+1/Res(I)^2
220  Tr=Tr+Temp(I)*Res(I)
230  Tg=Tg+Temp(I)/Res(I)
240  NEXT I
250  Rr=R^2-N*Rr
260  Rg=R*G-N^2
270  Gg=G^2-N*Gg
280  Tr=T*R-N*Tr
290  Tg=T*G-N*Tg
300  Ropt=SQR(ABS((Rg*Tr-Rr*Tg)/(Rg*Tg-Gg*Tr)))
310  Gn=Tr/(Rr+Ropt^2*Rg)
320  Tmin=T/N-Gn*(R/N-2*Ropt+G*Ropt^2/N)
330  Error=0
340  FOR I=1 TO N
350  Error=Error+(Tmin+Gn*(Ropt-Res(I))^2/Res(I)-Temp(I))^2
360  NEXT I
370  Error=SQR(Error/N)
380  Gn=Gn/290
390  INPUT "Print title in less than 18 characters",A$
400  PRINT LIN(1),TAB(20);A$
410  PRINT "         ----------------------------------"
420  PRINT LIN(1),"Minimun temperature Tmin=";Tmin
430  PRINT "Optimun resistece   Ropt=";Ropt
440  PRINT "Noise conductance   Gn  =";Gn
450  PRINT "Mean square error   Err =";Error
460  PRINT LIN(1),"     ------------------------------------"
470  DATA 3
480  DATA 75.5,34,.07
490  DATA 46.9,22,.055
500  DATA 31.7,12,.052
510  DATA 66.7,34,0
520  GRAPHICS
521  Xmax=12
522  Ymax=110
530  SCALE -.1*Xmax,Xmax,-.1*Ymax,Ymax
540  AXES 10,50,0,0,5,2,5
550  LINE TYPE 1
560  LORG 6
570  MOVE -.03*Xmax,-.03*Ymax
580  LABEL USING "K";"0"
590  MOVE 10,-.03*Ymax
600  LABEL USING "K";"10"
```

```
610  MOVE .5*Xmax,-.07*Ymax
620  LABEL USING "K";"Rsource(ohm)"
630  LORG 8
640  MOVE -.03*Xmax,100
650  LABEL USING "K";"100"
660  MOVE -.03*Xmax,.8*Ymax
670  LABEL USING "K";"T(K)"
680  LORG 5
690  FOR I=1 TO N
700  MOVE Res(I),Temp(I)
710  LABEL USING "K";"+"
720  NEXT I
730  FOR Ri=.01*Xmax TO Xmax STEP .01
740  Ti=Tmin+290*Gn*(Ri-Ropt)^2/Ri
750  PLOT Ri,Ti
760  NEXT Ri
770  PAUSE
771  RESTORE
772  GOTO 100
790  END
```

Appendix 1. Program "R_{o}

Appendix 2

NE-137 and MGF-1412 Models

The circuit models used in the computer programs for the NE-137 and MGF-1412 FET's are shown in Figures A2-1 and A2-2, where the package is outside the dotted lines.

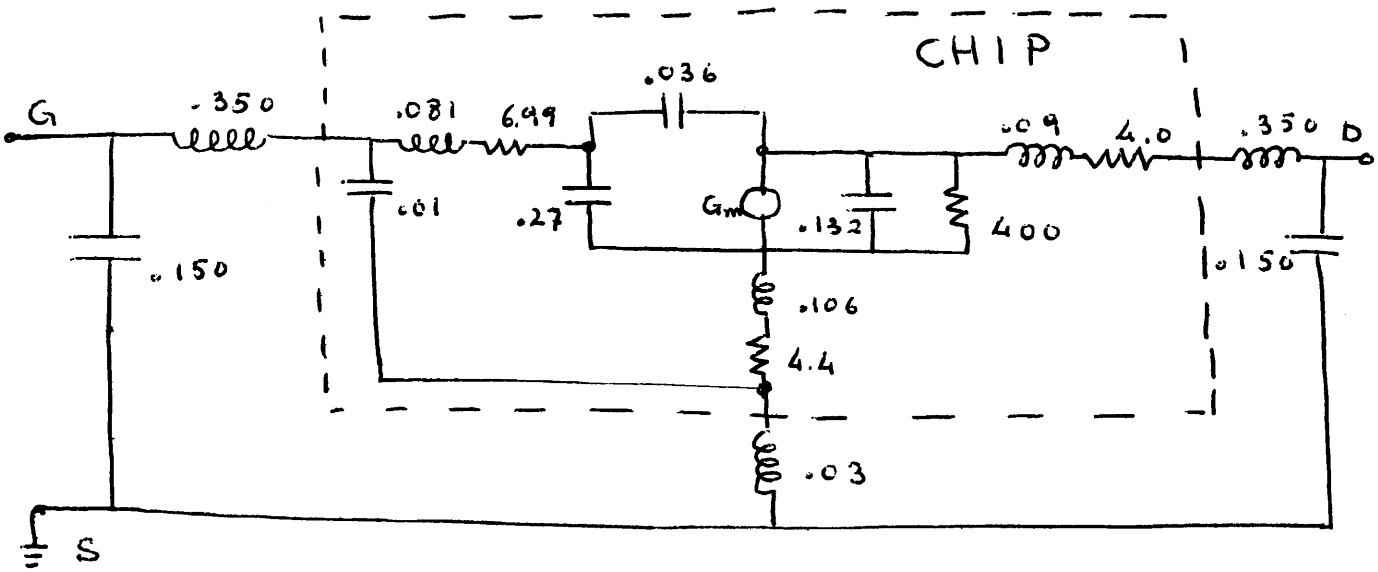
The scattering parameters computed from these models and the computer program which calculates the transistor performances at any frequency are included in Figures A2-3 to A2-6.

The computer description of the circuit models is as follows:

```
7955 Fet:! NE 137 Model at 300K          01/27/82
7960   DISP "Analyzing the ckt model . . . .   FREQ =";F
7965   CALL Rlc(A(*),"S",0,0,.036."S",0)                      !C2
7970   CALL Source(B(*),"V","C",45.6,1E7,400.9,1.28)          !gm,R4,T
7975   CALL Par(B(*),A(*))
7980   CALL Rlc(A(*),"S",0,0,.270,"P",0)                      !C1
7985   CALL Cas(A(*),B(*))
7990   CALL Rlc(B(*),"S",0,0,.132,"P",0)                      !C3
7995   CALL Cas(A(*),B(*))
8000   CALL Rlc(B(*),"S",4.4,.106,0,"P",0)                    !R2,L2
8005   CALL Ser(B(*),A(*))
8010   CALL Rlc(A(*),"S",6.99,.081,0,"S",0)                   !R1,L1
8015   CALL Cas(A(*),B(*))
8020   CALL Rlc(B(*),"S",4,.090,0,"S",0)                      !R3,L3
8025   CALL Cas(A(*),B(*))
8030   CALL Rlc(B(*),"S",0,0,.01,"P",0)                       !C4
8035   CALL Cas(B(*),A(*))                                    !NE 13700 in [B
8066   Tmin=182*F/15
8067   Ropt=6.64*15/F
8068   Xopt=27.03*15/F
8069   Gn=26.5*(F/15)^2
8070   CALL Nload(B(*),4,Tmin,Ropt,Xopt,Gn)
8071   CALL Rlc(A(*),"S",0,.350.0,"S",0)                      !Packaging L's
8072   CALL Cas(B(*),A(*))
8075   CALL Cas(A(*),B(*))
8076   CALL Rlc(B(*),"S",0,0,.150,"P",0)                      !Packaging C's
8077   CALL Cas(A(*),B(*))
8078   CALL Cas(B(*),A(*))
8079   CALL Rlc(A(*),"P",0,.03,0,"P",0)                       !Source L-C
8080   CALL Ser(A(*),B(*))
8165   DISP
8170 RETURN
```

```
7955 Fet1: AGF-1412 model
7960   DISP "Analyzing the ckt model . . . .    FREQ =";F
7965   CALL Rlc(A(*),"S",0,0,.031,"S",0)                       !C2
7970   CALL Source(B(*),"V","C",44.0,1E7,500.0,5)              !gm,R4,T
7975   CALL Par(B(*),A(*))
7980   CALL Rlc(A(*),"S",0,0,.500,"P",0)                       !C1
7985   CALL Cas(A(*),B(*))
7990   CALL Rlc(B(*),"S",0,0,.350,"P",0)                       !C3
7995   CALL Cas(A(*),B(*))
8000   CALL Rlc(B(*),"S",2.3,.009,0,"P",0)                     !R2,L2
8005   CALL Ser(B(*),A(*))
8010   CALL Rlc(A(*),"S",4,.100,0,"S",0)                       !R1,L1
8015   CALL Cas(A(*),B(*))
8020   CALL Rlc(B(*),"S",3,.050,0,"S",0)                       !R3,L3
8025   CALL Cas(A(*),B(*))
8030   CALL Rlc(B(*),"S",0,0,.01,"P",0)                        !C4
8035   CALL Cas(B(*),A(*))                                     !Chip model in
8036   Tmin=290*F/15
8037   Ropt=12.5*15/F
8038   Xopt=16.3*15/F
8039   Gn=20.8*(F/15)^2
8040   CALL Nlnad(B(*),4,Tmin,Ropt,Xopt,Gn)                    !Noise model at
8065   CALL Rlc(A(*),"S",0,.300,0,"S",0)                       !Packaging L's
8070   CALL Cas(B(*),A(*))
8075   CALL Cas(A(*),B(*))
8076   CALL Rlc(B(*),"S",0,0,.450,"P",0)                       !Packaging Cout
8079   CALL Cas(A(*),B(*))
8080   CALL Rlc(B(*),"S",0,0,.250,"P",0)                       !Packaging Cin
8081   CALL Cas(B(*),A(*))
8082   CALL Rlc(A(*),"P",0,.03,0,"P",0)                        !Source L-C
8083   CALL Ser(A(*),B(*))
8165   DISP
8170 RETURN
8260 SUBEND
```

NE-137.



|Gm| = 45.6   τ = 1.28 ps.

Fig. A2-1. Circuit model of NE13783.

MGF-1412

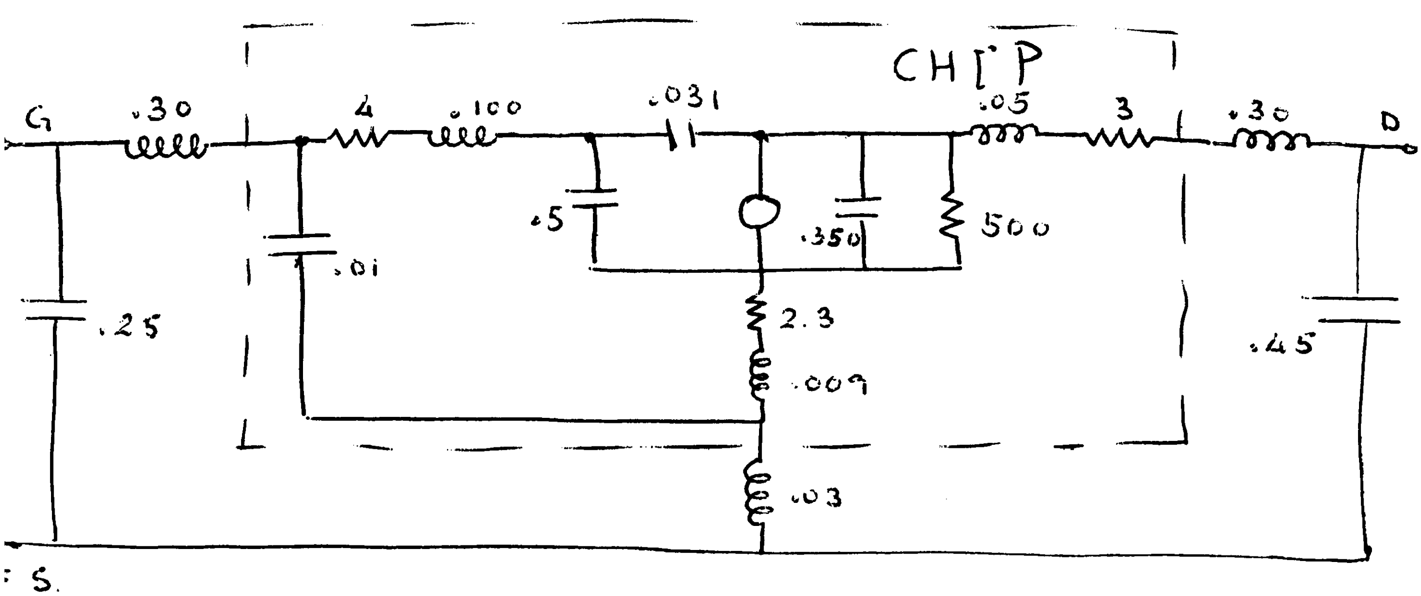


Fig. A2-2. Circuit model of MGF-1412.

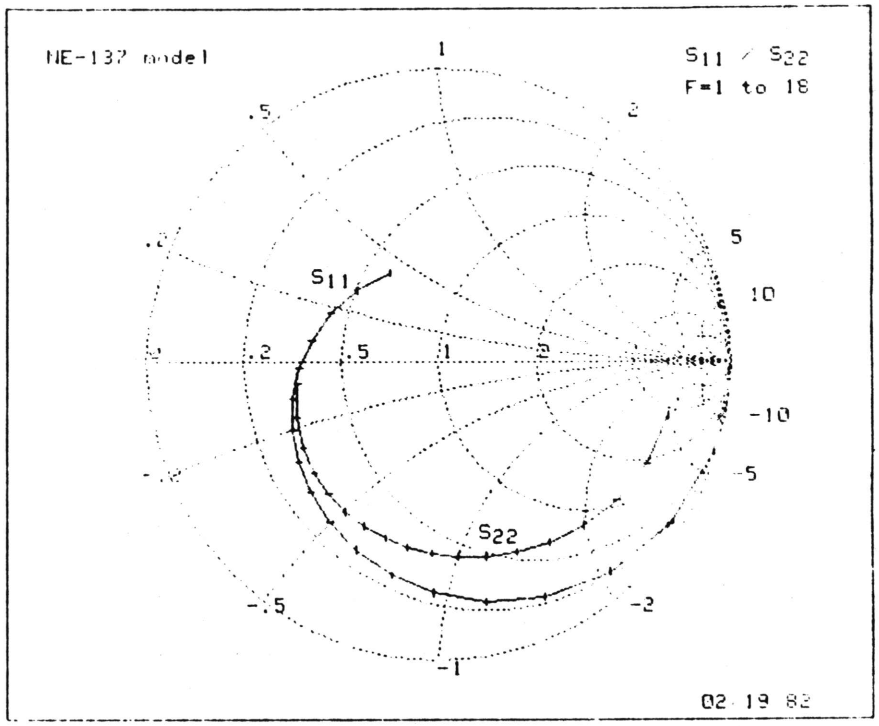


Fig. A2-3. S11 and S22 of NE13783 model.

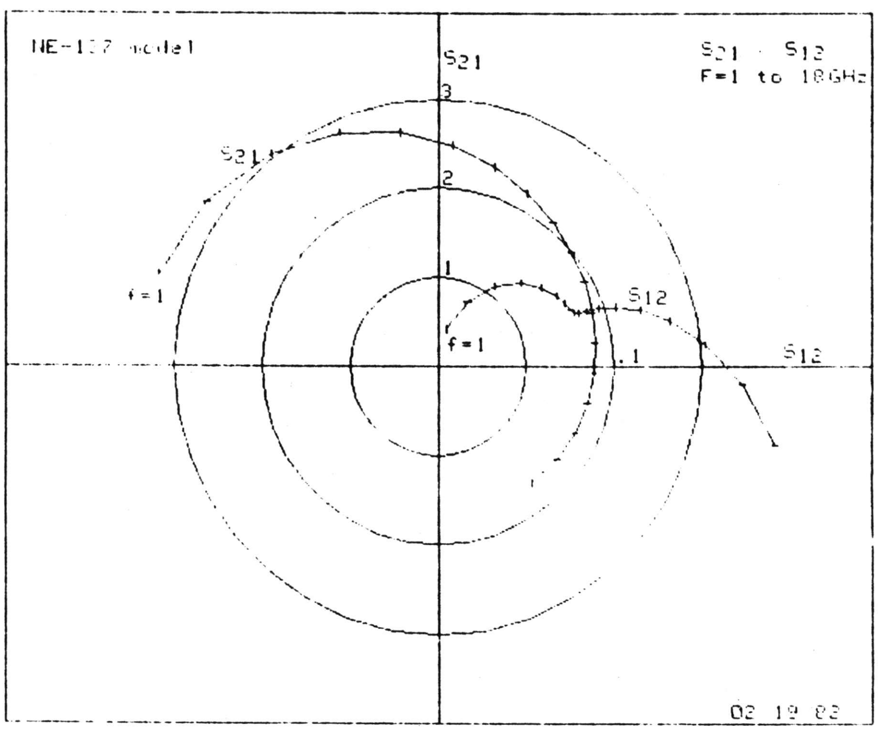


Fig. A2-4. S21 and S12 of NE13783 model.

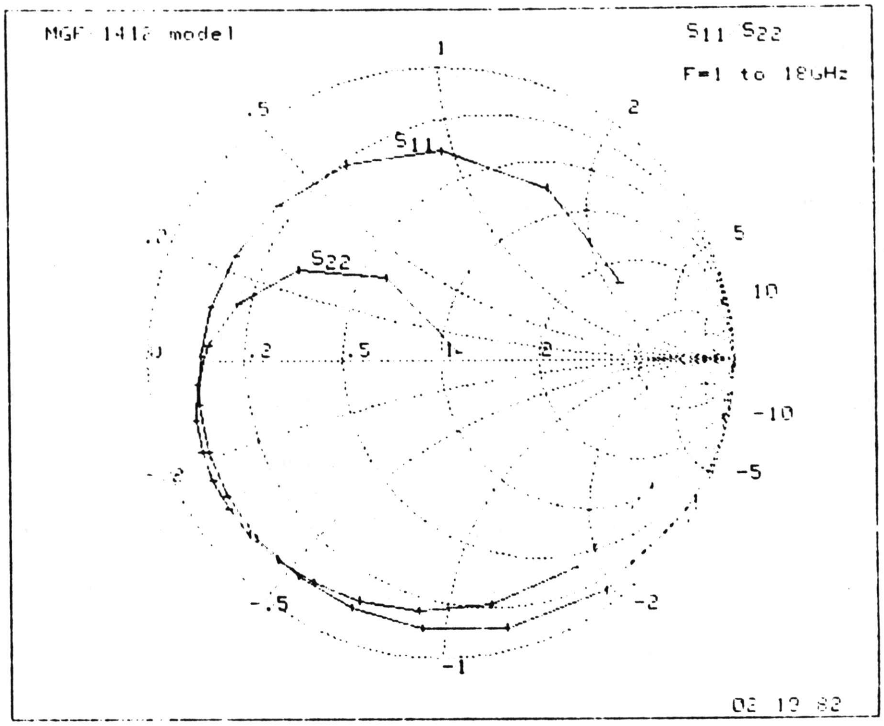


Fig. A2-5. S11 and S22 of MGF-1412 model.

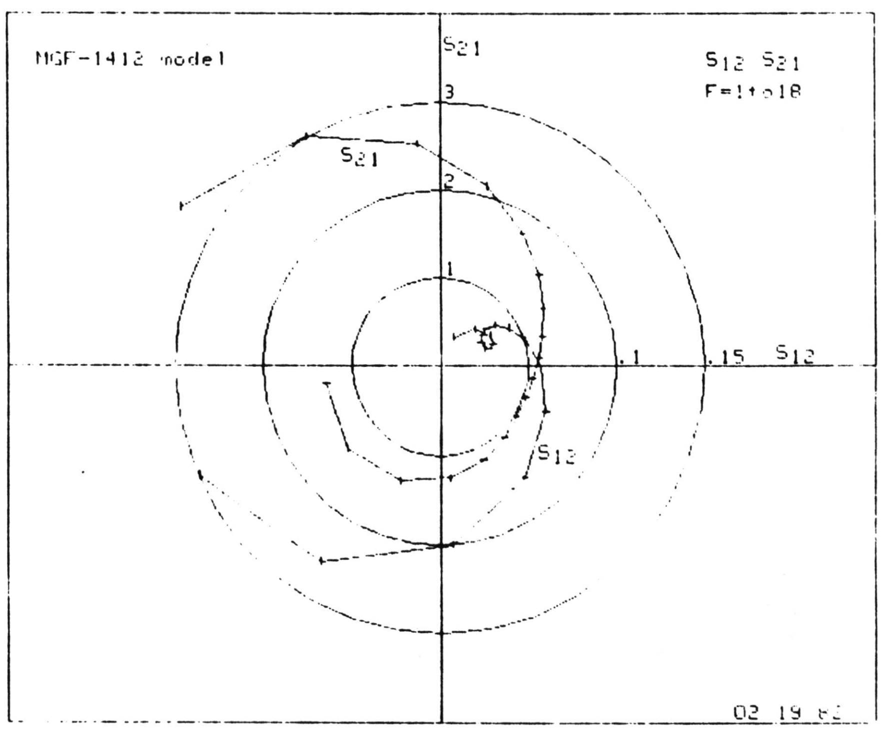


Fig. A2-6. S12 and S21 of MGF-1412 model.

Appendix 3

Noise Measurement Errors

In this analysis we are going to look only at the errors in the noise measurements due to the second stage or receiver noise when it is taken int account and substracted from the total noise measured.

Let us define the receiver as shown in Fig. 4 where R_{ij} are the scatte parameters and n_{20}, n_{2i} are the noise waves at the receiver input.

In the calibration process, the power in the load can be written as:

$$P_L = |R_{21}|^2 \cdot \frac{[T_{2i} + T_{20}|\Gamma_s|^2 + 2\mathrm{Re}(\Gamma_s \zeta_2) + T_s(1 - |\Gamma_s|^2)]}{|1 - \Gamma_s R_{11}|^2}$$

or $P_L = G_R(T_R + T_s)(1 - |\Gamma_s|^2)$ where

$$G_R = \left| \frac{R_{21}}{1 - \Gamma_s R_{11}} \right|^2$$

$$T_R = \frac{T_{2i} + T_{20}|\Gamma_s|^2 + 2\mathrm{Re}(\Gamma_s \zeta_2)}{1 - |\Gamma_s|^2}$$

$$T_{2i} = \overline{|n_{2i}|^2}$$

$$T_{20} = \overline{|n_{20}|^2}$$

$$\zeta_2 = \overline{n_{20} n_{2i}^*}$$

Using two source temperatures (T_1, T_o), with excess noise $N_s = T_1/T_o - 1$, the receiver temperature and gain can be computed as follows:

$$T_R = T_o \left(\frac{N_s}{N_R} - 1 \right)$$

$$G_R = \frac{1}{1 - |\Gamma_s|^2} \cdot \frac{P_o}{T_o} \left(\frac{N_R}{N_s} \right)$$

where $N_R = \frac{P_1}{P_o} - 1$, $P_o = P_L(T_s = T_o)$ and $P_1 = P_L(T_s = T_1)$

In the most general situation, the device under test can be described as shown in Figure A3-2. When it has been inserted, the power in the load is:

$$P_L' = \frac{|R_{21}|^2}{|1 - \Gamma_2 R_{11}|} \left[T_{2i} + |\Gamma_2|^2 \cdot T_{20} + 2\mathrm{Re}(\Gamma_2 \cdot \zeta_2) \right.$$

$$\left. + \frac{|S_{21}|^2}{|1 - \Gamma_1 \Gamma_s|^2} \left(T_{1i} + T_{10}|\Gamma_s|^2 + 2\mathrm{Re}(\Gamma_s \zeta_1) + T_s(1 - |\Gamma_s|^2) \right) \right]$$

or $P_L' = G_{Re}[T_{Re}(1 - |\Gamma_2|^2) + G_A(T_A + T_s)(1 - |\Gamma_s|^2)]$

where

$$G_{Re} = \frac{|R_{21}|^2}{|1 - \Gamma_2 R_{11}|^2}$$

$$G_A = \frac{|S_{21}|^2}{|1 - \Gamma_s \Gamma_1|^2}$$

$$T_{Re} = \frac{T_{2i} + T_{20}|\Gamma_e|^2 + 2\mathrm{Re}(\Gamma_2 \zeta_2)}{1 - |\Gamma_2|^2}$$

$$T_A = \frac{T_{1i} + T_{10}|\Gamma_s|^2 + 2\mathrm{Re}(\Gamma_s \zeta_1)}{1 - |\Gamma_s|^2}$$

In the same way as in the calibration process, the total input noise and gain can be computed as:

$$T_T = T_o\left(\frac{N_s}{N_A} - 1\right)$$

$$G_T(1 - |\Gamma_s|^2) = \frac{P_o'}{T_o} \cdot \frac{N_A}{N_s} \quad .$$

where $N_A = \frac{P_1'}{P_o'} - 1$, $P_o' = P_L'(T_s = T_o)$ and $P_1' = P_L'(T_s = T_1)$

Using the gain and noise definitions as before, it follows that:

$$T_T = T_A + T_{Re} \cdot \frac{(1 - |\Gamma_2|^2)}{G_A(1 - |\Gamma_s|^2} = T_A + \frac{T_{Re}}{G_{av}}$$

$$G_T = G_{Re} \cdot G_A$$

It can be seen that the values for the receiver noise and gain used in these equations are not exactly the same values measured in the calibration process.

First, the computed gain is

$$G_{av}' = G_T/G_R$$

or using the available gain as before

$$G_A = G_{av}'\left[\frac{(1 - |\Gamma_s|^2)\ |1 - \Gamma_2 R_{11}|^2}{(1 - |\Gamma_2|^2)\ |1 - \Gamma_s R_{11}|^2}\right]$$

On the other hand, the receiver noise changes as the source impedance does, and the real noise can be written as a function of the measured one as follows:

$$T_{Re} = (T_R + \Delta T) \cdot \frac{1 - |\Gamma_s|^2}{1 - |\Gamma_2|^2}$$

where $\Delta T = \frac{1}{1 - |\Gamma_s|^2} \left[T_{20}(|\Gamma_2|^2 - |\Gamma_2|^2) + 2\mathrm{Re}\left(\zeta_2(\Gamma_2 - \Gamma_s)\right) \right]$

The final error in the amplifier noise temperature is:

$$\Delta T_A = \Delta T \cdot \frac{1}{G'_{av}} \left| \frac{1 - \Gamma_s R_{11}}{1 - \Gamma_2 R_{11}} \right|^2 - \frac{T_{Rm}}{G'_{av}} \left(1 - \left| \frac{1 - \Gamma_s R_{11}}{1 - \Gamma_2 R_{11}} \right|^2 \right)$$

where the first term is mainly due to the variation in the receiver noise temperature when changing its source impedance and the second one is due to the error in the amplifier available gain and the second stage noise contribution.

If the second stage is connected through an isolator at temperature T_i and the noise source is well-matched, as usually happens, the error can be written as follo

$$\Delta T_A \simeq \frac{T_i \cdot |\Gamma_2|^2}{G|1 - \Gamma_2 R_{11}|^2} - \frac{T_{Rm}}{G} \left(1 - \frac{1}{|1 - \Gamma_2 R_{11}|^2} \right)$$

which is limited, depending on the sign of Γ_2 and R_{11} phases by the maximum and minimum values as follows:

$$\Delta T_{Amax} = \left(T_i |\Gamma_2|^2 + 2T_{Rm} |\Gamma_2 R_{11}| \right) \cdot \frac{1}{G \cdot (1 + |\Gamma_2 R_{11}|)^2}$$

$$\Delta T_{Amin} = \left(T_i |\Gamma_2|^2 - 2T_{Rm} |\Gamma_2 R_{11}| \right) \cdot \frac{1}{G(1 + |\Gamma_2 R_{11}|)^2}$$

where G = amplifier measured gain.

Appendix 4

Amplifier Design Computer Programs

The most important programs which compute the matching networks and analyze the amplifier frequency response are presented in this appendix.

Two-Stage Amplifier Design "Man #4"

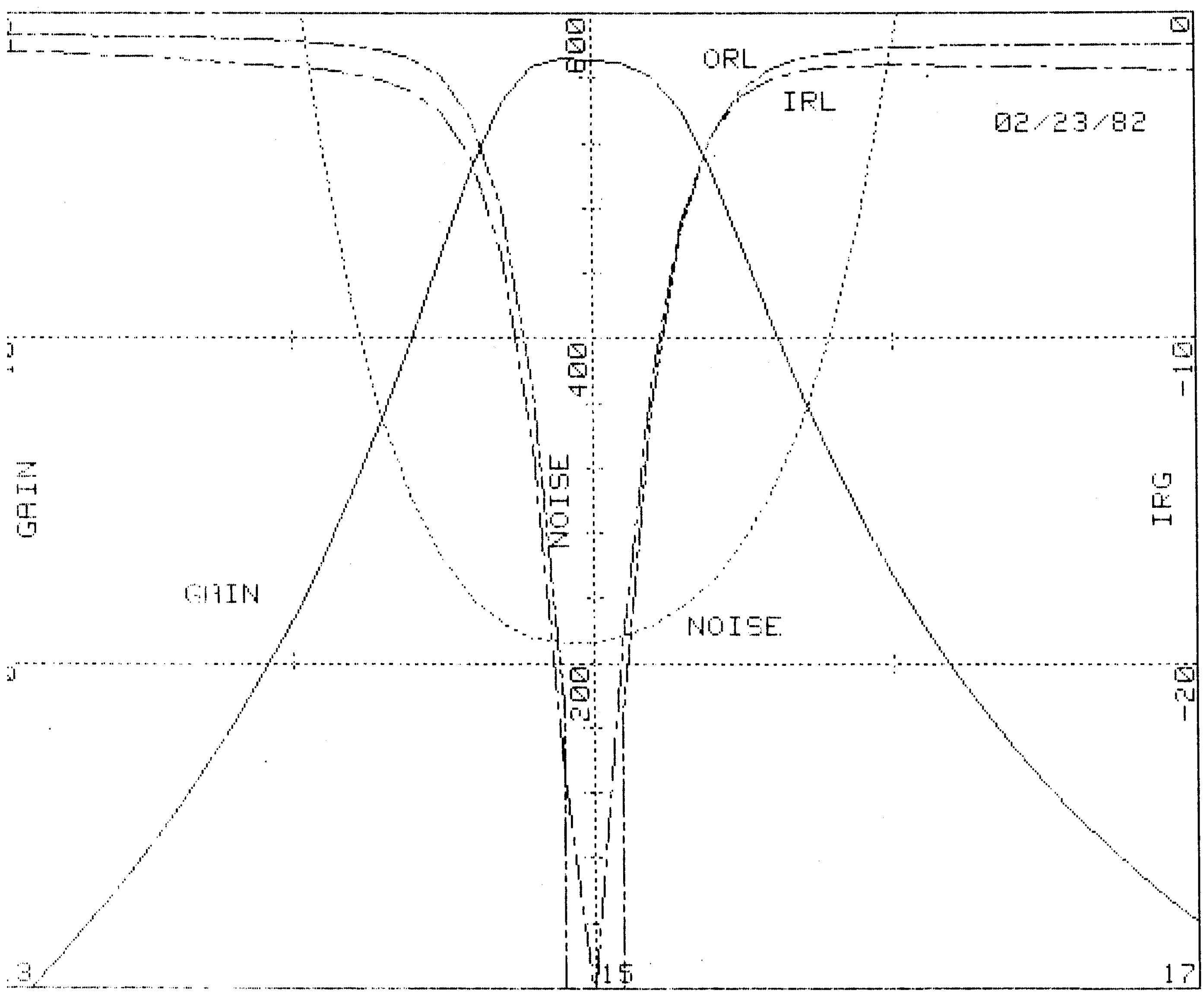
This program computes a two-stage amplifier for minimum noise and optimizes the input return loss changing the inter-stage free parameter.

The method is as follows:

1. Compute the transistor model and get R_{opt}.
2. Loading the input with R_{opt}, compute R_{out}.
3. Compute the input return loss for three values of the inter-stage "trombone line" (free parameter).
4. As the three values for the input reflection coefficient must be in a circle, it is easy to know the minimum and go back with this point to the inter-stage circuit.
5. Compute the circuit parameters and print these.
6. Compute the frequency response and plot it.

The list and usual printout are presented here for the NE-137 room temperature amplifier model (two-stage).

```
      Man#4 as of 8/20/81
esign frequency= 15          Source L1= .03                    Source L2= .03
ptimun noise impedance=
                              First stage  Zopt= 7.74900446231    j 22.0042182449
                              Second stage Zopt= 7.74900446231    j 22.0042182449
rombone length= .170983     Rin1= 52.218    Xin1=-2.33208
ine number 1    Zo= 17.9864            Length= .196714
ine number 2    Zo= 50                 Length= .0528602
ine number 3    Zo= 50                 Length= .0920018
ine number 4    Zo= 12.9635            Length= .196714
ine number 5    Zo= 50                 Length= .170983
ine number 6    Zo= 17.9864            Length= .196714
ine number 7    Zo= 50                 Length= .0528602
ine number 8    Zo= 50                 Length= .0920018
ine number 9    Zo= 12.9635            Length= .196714
```



```
      Man#4 as of 8/20/81
6195 SUB Cktanalysis(J(*),Fvalue,Opt)
6205 PRINT LIN(2);TAB(10);"Man#4 as of 8/20/81"
6215 OPTION BASE 1
6225 COM Nogo,Zo,F,Count,SHORT Dat(51,18)   ![DAT] HOLDS FREQ, CKT AND NOISE DA
6235 DIM A(6,4),B(6,4),C(6,4),D(6,4),E(4,4),Y(9),Z(8),W(9)
6245 STANDARD
6255 Count=Nogo=0           !#FREQS CURRENTLY STORED IN DATA BASE
6265 Zt=50
6275 Zo=50
6285 DEG                      !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
6295 REM USER'S PROGRAM SHOULD BEGIN ON THE NEXT LINE, USING AN INCREMENT OF 1
6305 ! This program computes a two-stage amp. matched for optimun noise
6315 ! and output return loss in both stages, and select the interstage
6325 ! line length (Trombone line) for optimun input match @ Fo.
6335 Fo=15
6345 F1=13
6355 F2=17
6365 Df=.100
6375 F=Fo
6385 Qlam=11.8028527/(4*F)
6395 INPUT "Source L1 and L2 =",L1,L2
6405 L=L1
6415 GOSUB Fet
6425 MAT C=A
6435 CALL Ntrans(C(*),4)
6445 Ropt1=C(6,2)
6455 Xopt1=C(6,3)
6465 L=L2
6475 GOSUB Fet
6485 CALL Ntrans(A(*),4)
6495 Ropt2=A(6,2)
6505 Xopt2=A(6,3)
6515 PRINT "Design frequency=";F;TAB(30);"Source L1=";L1;TAB(60);"Source L2=";
6525 PRINT "Optimun noise impedance="
6535 PRINT TAB(30);"First stage  Zopt=";Ropt1;"  j";Xopt1
6545 PRINT TAB(30);"Second stage Zopt=";Ropt2;"  j";Xopt2
6555 CALL Zio(C(*),Ropt1,Xopt1,0,0,0,0,Z(3),Z(4),1)
6565 CALL Zio(A(*),Ropt2,Xopt2,0,0,0,0,Z(7),Z(8),1)
6575 CALL Gammaz(-1,C,D,Ropt1,Xopt1)
6585 Y(1)=Zo*SQR((1-C)/(1+C))
6595 W(1)=Qlam
6605 Y(2)=Zo
6615 W(2)=(1-D/180)*Qlam
6625 Zo=Zt
6635 CALL Gammaz(-1,C,D,Z(3),Z(4))
6645 Y(3)=Zo
6655 W(3)=(1+D/180)*Qlam
6665 Y(4)=Zo*SQR((1-C)/(1+C))
6675 W(4)=Qlam
6685 CALL Gammaz(-1,C,D,Ropt2,Xopt2)
6695 Y(6)=Zo*SQR((1-C)/(1+C))
6705 W(6)=Qlam
6715 Y(7)=Zo
6725 W(7)=(1-D/180)*Qlam
6735 Zo=50
6745 CALL Gammaz(-1,C,D,Z(7),Z(8))
6755 Y(9)=Zo*SQR((1-C)/(1+C))
6765 W(9)=Qlam
6775 Y(8)=Zo
6785 W(8)=(1+D/180)*Qlam
6795 L=L1
6805 K=1
6815 GOSUB Circuit
```

```
        =A

6845 K=2
6855 GOSUB Circuit
6865 CALL Zio(A(*),0,0,50,0,Z(5),Z(6),0,0,1)
6875 E=0
6885 FOR K=1 TO 3
6895   Zo=Zt
6905   CALL Gammaz(-1,A,B,Z(5),Z(6))
6915   H=B-2*E
6925   CALL Gammaz(1,A,H,E(1,K),E(2,K))
6935   Zo=50
6945   CALL Zio(C(*),0,0,E(1,K),E(2,K),E(3,K),E(4,K),0,0,1)
6955   CALL Gammaz(-2,E(1,K),E(2,K),E(3,K),E(4,K))
6965   E(3,K)=E(1,K)^2+E(2,K)^2
6975   E=E+60
6985 NEXT K
6995 D=(E(2,1)-E(2,3))*(E(1,1)-E(1,2))-(E(2,1)-E(2,2))*(E(1,1)-E(1,3))
7005 IF D=0 THEN 7105
7015 E(1,4)=E(2,1)*(E(3,3)-E(3,2))+E(2,2)*(E(3,1)-E(3,3))+E(2,3)*(E(3,2)-E(3,1)
7025 E(2,4)=E(1,1)*(E(3,3)-E(3,2))+E(1,2)*(E(3,1)-E(3,3))+E(1,3)*(E(3,2)-E(3,1)
7035 E(1,4)=E(1,4)/(2*D)
7045 E(2,4)=-E(2,4)/(2*D)
7055 R=SQR((E(1,4)-E(1,1))^2+(E(2,4)-E(2,1))^2)
7065 D=SQR(E(1,4)^2+E(2,4)^2)
7075 E(3,4)=E(1,4)*(1-R/D)
7085 E(4,4)=E(2,4)*(1-R/D)
7095 GOTO 7135
7105 D=(E(2,1)*E(1,2)-E(2,2)*E(1,1))/((E(1,1)-E(1,2))^2+(E(2,1)-E(2,2))^2)
7115 E(3,4)=(E(2,1)-E(2,2))*D
7125 E(4,4)=(E(1,2)-E(1,1))*D
7135 CALL Gammaz(2,E(3,4),E(4,4),C,D)
7145 CALL Zio(C(*),0,0,Z1,Z2,C,D,0,0,-1)
7155 Zo=Zt
7165 CALL Gammaz(-1,G,H,Z1,Z2)
7175 IF ABS(A-G)<1E-6 THEN 7215
7185   PRINT "Gamma in both ends of the trombone line don't match"
7195   PRINT "Left end abs. gamma=";G;"Right end abs. gamma=";A
7205   PAUSE
7215 E=(B-H)*Qlam/180
7225 IF E<0 THEN E=E+2*Qlam
7235 Zo=50
7245 PRINT "Trombone length=";DROUND(E,6);
7255 PRINT "    Rin1=";DROUND(C,6);"    Xin1=";DROUND(D,6)
7265 INPUT "Do you want to change the trombone length?",A$
7275 IF A$="N" THEN 7305
7285 INPUT "Trombone length=",E
7295 PRINT "New trombone length =";E
7305 Y(5)=Zt
7315 W(5)=E
7325 FOR K=1 TO 9
7335   PRINT "Line number";K;"  Zo=";DROUND(Y(K),6),"Length=";DROUND(W(K),6)
7345 NEXT K
7355 FOR F=F1 TO F2 STEP Df
7365   L=L2
7375   K=2
7385   GOSUB Circuit
7395   MAT C=A
7405   L=L1
7415   K=1
7425   GOSUB Circuit
7435   CALL Trline(B(*),Y(5),W(5),1)
7445   CALL Cas(B(*),C(*))
7455   CALL Cas(A(*),B(*))
7465   CALL Saveckt(A(*),4,4,-1)
7475   CALL Nperformance(A(*),0,50,0,50,0,G,1)
```

```
   5 NEXT F
   5 GRAPHICS
7505 SCALE F1,F2,-30,0
7515 C=4/236.2                                          !GHz/mm
7525 D=30/162.5                                         !dB/mm
7535 LINE TYPE 3
7545 AXES 1,2,Fo,-10
7555 AXES 1,10,Fo,-20
7565 LINE TYPE 5
7575 FOR K=1 TO Count
7585   PLOT Dat(K,1),10*LGT(Dat(K,2)^2+Dat(K,3)^2)      !S11 is dot-dashe
7595 NEXT K
7605 PENUP
7615 LINE TYPE 3
7625 FOR K=1 TO Count
7635   PLOT Dat(K,1),Dat(K,14)/20-30                    !noise is dashed
7645 NEXT K
7655 PENUP
7665 LINE TYPE 1
7675 FOR K=1 TO Count
7685   PLOT Dat(K,1),10*LGT(Dat(K,6)^2+Dat(K,7)^2)-20   !S21 is solid
7695 NEXT K
7705 PENUP
7715 LINE TYPE 7
7725 FOR K=1 TO Count
7735 PLOT Dat(K,1),10*LGT(Dat(K,8)^2+Dat(K,9)^2)        !S22 is dble dot
7745 NEXT K
7755 LORG 1
7765 G=1
7775 LINE TYPE 1
7785 FOR F=F1 TO F2 STEP 2
7795   IF F<F2 THEN 7825
7805     G=-1
7815     LORG 7
7825   MOVE F+G*C,D-30
7835   LABEL USING "K";F
7845 NEXT F
7855 LDIR 90
7865 FOR G=-20 TO 0 STEP 10
7875   MOVE F2-C,G-D
7885   LABEL USING "K";G
7895   MOVE Fo-C,G-D
7905   LABEL USING "K";20*(G+30)
7915 NEXT G
7925 LORG 4
7935 MOVE F2-5*C,-15
7945 LABEL USING "K";"IRG"
7955 MOVE Fo-5*C,-15
7965 LABEL USING "K";"NOISE"
7975 LORG 6
7985 MOVE F1+5*C,-15
7995 LABEL USING "K";"GAIN"
8005 LORG 9
8015 FOR G=-20 TO 0 STEP 10
8025   MOVE F1+C,G-D
8035   LABEL USING "K";G+20
8045 NEXT G
8055 LDIR 0
8065 FRAME
8075 PAUSE
8085 GOTO 7495
8095 SUBEXIT
8105 Circuit:!
8115   GOSUB Fet
8125   CALL Trline(B(*),Y(5*K-3),W(5*K-3),1)
8135   CALL Cas(B(*),A(*))
```

```
8145   CALL Trline(A(*),Y(5*K-2),W(5*K-2),1)
8155   CALL Cas(B(*),A(*))
8165   CALL Trline(A(*),Y(5*K-4),W(5*K-4),1)
8175   CALL Cas(A(*),B(*))
8185   CALL Trline(B(*),Y(5*K-1),W(5*K-1),1)
8195   CALL Cas(A(*),B(*))
8205   RETURN
8215 Fet:! NE-137 Model at 300K          01/27/82
8220   DISP "Analyzing the ckt model . . . .   FREQ =";F
8225   CALL Rlc(A(*),"S",0,0,.036,"S",0)                        !C2
8230   CALL Source(B(*),"V","C",45.6,1E7,400.9,1.28)            !gm,R4,T
8235   CALL Par(B(*),A(*))
8240   CALL Rlc(A(*),"S",0,0,.270,"P",0)                        !C1
8245   CALL Cas(A(*),B(*))
8250   CALL Rlc(B(*),"S",0,0,.132,"P",0)                        !C3
8255   CALL Cas(A(*),B(*))
8260   CALL Rlc(B(*),"S",4.4,.106,0,"P",0)                      !R2,L2
8265   CALL Ser(B(*),A(*))
8270   CALL Rlc(A(*),"S",6.99,.081,0,"S",0)                     !R1,L1
8275   CALL Cas(A(*),B(*))
8280   CALL Rlc(B(*),"S",4,.09,0,"S",0)                         !R3,L3
8285   CALL Cas(A(*),B(*))
8290   CALL Rlc(B(*),"S",0,0,.01,"P",0)                         !C4
8295   CALL Cas(B(*),A(*))                                      !NE 13700 in [B]
8300   Tmin=182*F/15
8305   Ropt=6.64*15/F
8310   Xopt=27.33*15/F
8315   Gn=26.5*(F/15)^2
8320   CALL Nload(B(*),4,Tmin,Ropt,Xopt,Gn)                     !Noise model
8325   CALL Rlc(A(*),"S",0,.350,0,"S",0)                        !Packaging L's
8330   CALL Cas(B(*),A(*))
8335   CALL Cas(A(*),B(*))
8336   CALL Rlc(B(*),"S",0,0,.150,"P",0)                        !Packaging C's
8337   CALL Cas(A(*),B(*))
8338   CALL Cas(B(*),A(*))
8339   CALL Rlc(A(*),"P",0,L,0,"P",0)                           !Source L
8340   CALL Ser(A(*),B(*))
8344   CALL Trline(B(*),120,.196,1)                             !Bias line
8345   CALL Rlc(D(*),"P",50,0,1,"P",0)
8350   CALL Cas(B(*),D(*))
8355   CALL Branch(B(*),"P")
8360   CALL Cas(A(*),B(*))
8365   CALL Cas(B(*),A(*))
8395   CALL Trline(A(*),38,.085,1.8)                            !Output coupling
8400   CALL Branch(A(*),"S")
8405   CALL Cas(B(*),A(*))
8410   CALL Trline(A(*),38,.085,1.8)                            !Input coupling
8415   CALL Branch(A(*),"S")
8420   CALL Cas(A(*),B(*))
8425   DISP
8430 RETURN
8435 END
```

One to Three Stage Amplifier Design ("Amp #1")

This program allows one to compute the one, two or three stage amplifier, matching each stage for minimum noise or maximum gain as desired.

It does not compute the inter-stage "trombone line" that must be entered during the program execution to allow other than the input match adjustments.

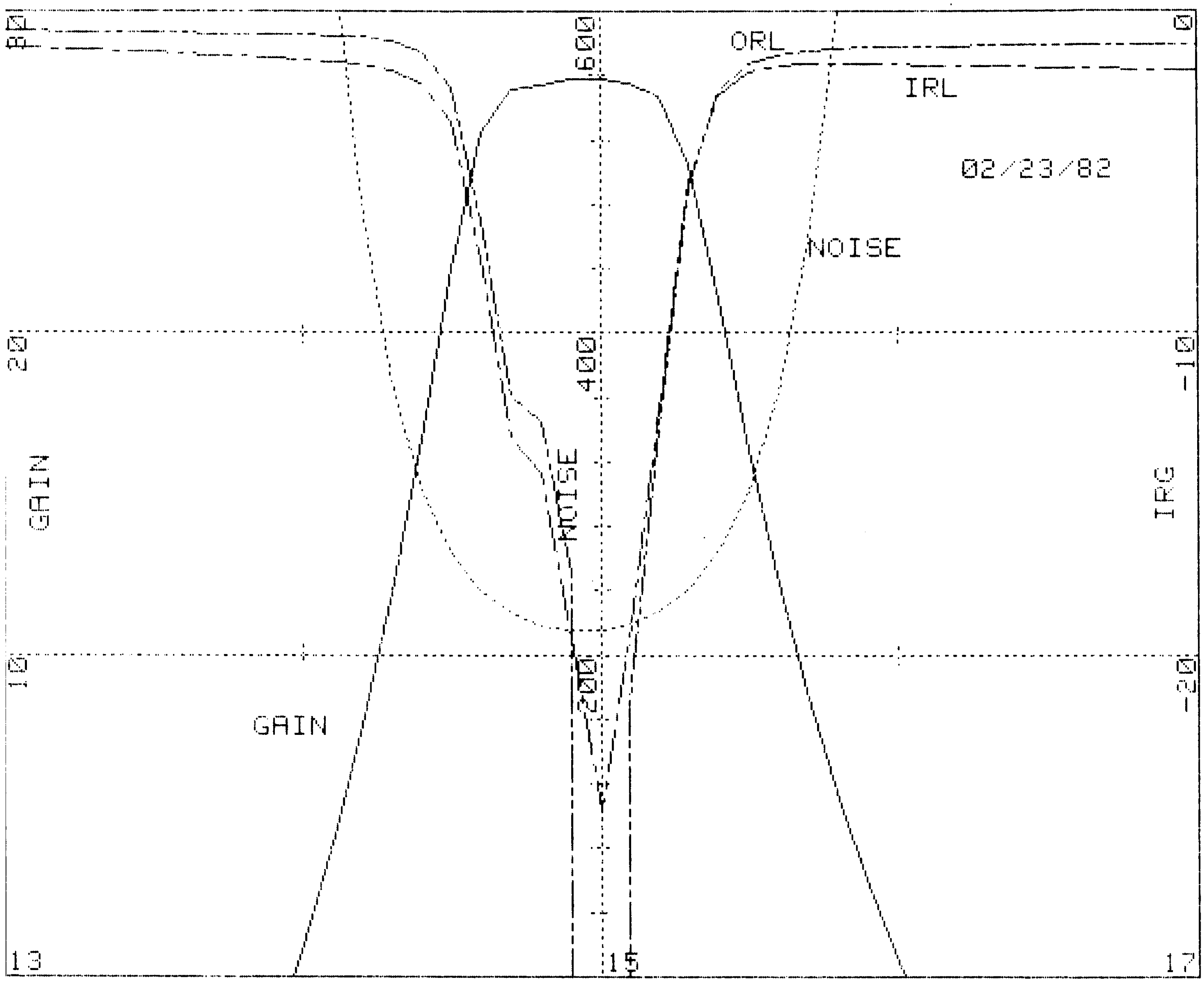
The list and usual printout are presented.

```
        Amp#1 as of 9/16/81
Design frequency = 15
Stage # 1                    Source L1= .03                Source C1= 0
        Minimun noise    Z= 7.749   22.0042 Tmin= 190.665 Ga  = 9.28587
        Maximun gain     Z= 5.90394  20.7877 Ta   = 196.333 Gmax= 9.35016
        Min. N. Measure  Z= 7.62539  21.9072 Ta   = 190.687 Ga  = 9.29371

Stage # 2                    Source L1= .03                Source C1= 0
        Minimun noise    Z= 7.749   22.0042 Tmin= 190.665 Ga  = 9.28587
        Maximun gain     Z= 5.90394  20.7877 Ta   = 196.333 Gmax= 9.35016
        Min. N. Measure  Z= 7.62539  21.9072 Ta   = 190.687 Ga  = 9.29371

Stage # 3                    Source L1= .03                Source C1= 0
        Minimun noise    Z= 7.749   22.0042 Tmin= 190.665 Ga  = 9.28587
        Maximun gain     Z= 5.90394  20.7877 Ta   = 196.333 Gmax= 9.35016
        Min. N. Measure  Z= 7.62539  21.9072 Ta   = 190.687 Ga  = 9.29371

Line number 1    Zo= 17.8563            Length= .196714
Line number 2    Zo= 50                 Length= .0526249
Line number 3    Zo= 50                 Length= .092043
Line number 4    Zo= 12.883             Length= .196714
Line number 5    Zo= 50                 Length= .2
Line number 6    Zo= 17.8563            Length= .196714
Line number 7    Zo= 50                 Length= .0526249
Line number 8    Zo= 50                 Length= .092043
Line number 9    Zo= 12.883             Length= .196714
Line number 10    Zo= 50                Length= .2
Line number 11    Zo= 17.8563           Length= .196714
Line number 12    Zo= 50                Length= .0526249
Line number 13    Zo= 50                Length= .092043
Line number 14    Zo= 12.883            Length= .196714
```


80
600
0
ORL
IRL
02/23/82
NOISE
20
400
-10
GAIN
NOISE
IRG
10
200
-20
GAIN
13
15
17

```
     Cktanalysis(J(*),Fvalue,Opt)
  ...inT LIN(2);TAB(10);"Amp#1 as of 9/16/81"
6215 OPTION BASE 1
6225 COM Nogo,Zo,F,Count,SHORT Dat(51,18)  ![DAT] HOLDS FREQ, CKT AND NOISE D
6235 DIM A(6,4),B(6,4),C(6,4),D(6,4),Y(15),W(15),L(3),Cap(3)
6245 STANDARD
6255 Count=Nogo=0          !#FREQS CURRENTLY STORED IN DATA BASE
6265 Zo=50
6275 DEG                             !DEFAULT FOR TRIG FUNCTIONS IS DEGREES
6285 REM USER'S PROGRAM SHOULD BEGIN ON THE NEXT LINE, USING AN INCREMENT OF
6295 ! This program computes one, two or three stage amp. tuned for
6305 ! minimun noise, maximun gain or minimun noise figure.
6315 N=3
6325 Fo=15
6335 F1=13
6345 F2=17
6355 Df=.100
6365 F=15
6375 Qlam=11.8028527/(4*Fo)
6385 INPUT "Source L1 and C1 =",L(1),Cap(1)
6395 IF N=1 THEN 6435
6405 INPUT "Source L2 and C2 =",L(2),Cap(2)
6415 IF N=2 THEN 6435
6425 INPUT "Source L3 and C3 =",L(3),Cap(3)
6435 PRINT "Design frequency =";F
6445 FOR K=1 TO N
6455   Ls=L(K)
6465   Cs=Cap(K)
6475   GOSUB Fet
6485   CALL Ntrans(A(*),1)
6495   CALL Mtrans(A(*),1)
6505   Ro=SQR(A(6,1)/A(6,2))
6515   X1=A(6,4)*Ro/A(6,1)
6525   R1=SQR(1-X1^2)
6535   K1=A(6,3)*Ro/A(6,1)
6545   Tmin=2*290*A(6,1)*(K1+R1)/Ro
6555   S1=2*(A(1,1)*A(1,3)+A(1,2)*A(1,4))/Ro
6565   S2=2*(A(3,1)*A(3,3)+A(3,2)*A(3,4))*Ro
6575   T1=A(1,1)*A(3,3)+A(1,2)*A(3,4)+A(1,3)*A(3,1)+A(1,4)*A(3,2)
6585   T2=A(1,2)*A(3,3)-A(1,1)*A(3,4)+A(1,4)*A(3,1)-A(1,3)*A(3,2)
6595   Kf=S1*S2-T2^2
6605   Ks=1
6615   IF (Kf<0) OR (T1<0) THEN Ks=-1
6625   IF Ks>0 THEN 6645
6635   PRINT "K<1 Simultaneus match is not possible"
6636   GOTO 6675
6645   R2=SQR(S1*S2-T2^2)/S2
6655   X2=-T2/S2
6665   Gmax=1/(T1+SQR(S1*S2-T2^2))
6675   A=(S1+S2-2*K1*(T1-1)+2*X1*T2)^2-4*(S1*S2-(T1-1)^2-T2^2)*(1-K1^2-X1^2)
6685   D=(T1-1-K1*S2)^2+(T2+X1*S2)^2
6695   R3=((S2-S1-SQR(A))*(T1-1-K1*S2)-2*(K1*T2+X1*(T1-1))*(T2+X1*S2))/(2*D)
6705   X3=((S2-S1-SQR(A))*(T2+X1*S2)+2*(K1*T2+X1*(T1-1))*(T1-1-K1*S2))/(2*D)
6715   PRINT "Stage #";K;TAB(30);"Source L1=";Ls;TAB(60);"Source C1=";Cs
6725   Ga=2*R1/(S2*(R1^2+X1^2)+2*(R1*T1+X1*T2)+S1)
6735   PRINT TAB(10);"Minimun noise    Z=";DROUND(R1*Ro,6);DROUND(X1*Ro,6);
6745   PRINT "Tmin=";DROUND(Tmin,6);"Ga  =";DROUND(10*LGT(Ga),6)
6755   IF Ks<0 THEN 6795
6765   Ta=Tmin+290*A(6,1)*((R2-R1)^2+(X2-X1)^2)/(R2*Ro)
6775   PRINT TAB(10);"Maximun gain     Z=";DROUND(R2*Ro,6);DROUND(X2*Ro,6);
6785   PRINT "Ta  =";DROUND(Ta,6);"Gmax=";DROUND(10*LGT(Gmax),6)
6795   Ta=Tmin+290*A(6,1)*((R3-R1)^2+(X3-X1)^2)/(Ro*R3)
6805   Ga=2*R3/(S2*(R3^2+X3^2)+2*(R3*T1+X3*T2)+S1)
6815   PRINT TAB(10);"Min. N. Measure Z=";DROUND(R3*Ro,6);DROUND(X3*Ro,6);
6825   PRINT "Ta  =";DROUND(Ta,6);"Ga  =";DROUND(10*LGT(Ga),6)
6835   PRINT
```

```
         elect the optimun source impedance desired, using K,R1,R2,
         t=R3
6865   Xopt=X3
6875   CALL Zio(A(*),Ropt*Ro,Xopt*Ro,0,0,0,0,R,X,1)
6885   CALL Gammaz(-1,C,D,Ropt*Ro,Xopt*Ro)
6895   Y(5*K-4)=Zo*SQR((1-C)/(1+C))
6905   W(5*K-4)=Qlam
6915   Y(5*K-3)=Zo
6925   W(5*K-3)=(1-D/180)*Qlam
6935   CALL Gammaz(-1,C,D,R,X)
6945   Y(5*K-2)=Zo
6955   W(5*K-2)=(1+D/180)*Qlam
6965   Y(5*K-1)=Zo*SQR((1-C)/(1+C))
6975   W(5*K-1)=Qlam
6985   IF K=N THEN 7035
6995   ! Insert here the phisical length of the line between this stage
7005   ! and the next one
7015   INPUT "Trombone line following this stage ?",W(5*K)
7025   Y(5*K)=Zo
7035 NEXT K
7045 FOR K=1 TO 5*N-1
7055   PRINT "Line number";K;"  Zo=";DROUND(Y(K),6),"Length=";DROUND(W(K),6)
7065 NEXT K
7075 FOR F=F1 TO F2 STEP Df
7085   FOR K=1 TO N
7095     Ls=L(K)
7105     Cs=Cap(K)
7115     GOSUB Circuit
7125     IF K=N THEN 7155
7135     CALL Trline(B(*),Y(5*K),W(5*K),1)
7145     CALL Cas(A(*),B(*))
7155     IF K=1 THEN 7185
7165     CALL Cas(C(*),A(*))
7175     GOTO 7195
7185     MAT C=A
7195   NEXT K
7205   CALL Saveckt(C(*),4,4,-1)
7215   CALL Nperformance(C(*),0,50,0,50,0,G,1)
7225 NEXT F
7235 GRAPHICS                                                   !GGGGGGGG
7245 SCALE F1,F2,-30,0
7255 C=4/236.2                                        !GHz/mm
7265 D=30/162.5                                       !dB/mm
7275 LINE TYPE 3
7285 AXES 1,2,Fo,-10
7295 AXES 1,10,Fo,-20
7305 LINE TYPE 5
7315 FOR K=1 TO Count
7325   PLOT Dat(K,1),10*LGT(Dat(K,2)^2+Dat(K,3)^2)        !S11 is dot-dashed
7335 NEXT K
7345 PENUP
7355 LINE TYPE 3
7365 FOR K=1 TO Count
7375   PLOT Dat(K,1),Dat(K,14)/20-30                       !noise is dashed
7385 NEXT K
7395 PENUP
7405 LINE TYPE 1
7415 FOR K=1 TO Count
7425   PLOT Dat(K,1),10*LGT(Dat(K,6)^2+Dat(K,7)^2)-30     !S21 is solid
7435 NEXT K
7445 PENUP
7455 LINE TYPE 7
7465 FOR K=1 TO Count
7475 PLOT Dat(K,1),10*LGT(Dat(K,8)^2+Dat(K,9)^2)           !S22 is dble dot da
7485 NEXT K
7495 LORG 1
```

```
      =1
      LINE TYPE 1
      FOR F=F1 TO F2 STEP 2
7535    IF F<F2 THEN 7565
7545      G=-1
7555      LORG 7
7565    MOVE F+G*C,D-30
7575    LABEL USING "K";F
7585 NEXT F
7595 LDIR 90
7605 FOR G=-20 TO 0 STEP 10
7615    MOVE F2-C,G-D
7625    LABEL USING "K";G
7635    MOVE Fo-C,G-D
7645    LABEL USING "K";20*(G+30)
7655 NEXT G
7665 LORG 4
7675 MOVE F2-5*C,-15
7685 LABEL USING "K";"IRG"
7695 MOVE Fo-5*C,-15
7705 LABEL USING "K";"NOISE"
7715 LORG 6
7725 MOVE F1+5*C,-15
7735 LABEL USING "K";"GAIN"
7745 LORG 9
7755 FOR G=-20 TO 0 STEP 10
7765    MOVE F1+C,G-D
7775    LABEL USING "K";G+30
7785 NEXT G
7795 LDIR 0
7805 FRAME
7815 PAUSE
7825 GOTO 7235
7835 SUBEXIT
7845 Circuit:!
7855    GOSUB Fet
7865    CALL Trline(B(*),Y(5*K-3),W(5*K-3),1)
7875    CALL Cas(B(*),A(*))
7885    CALL Trline(A(*),Y(5*K-2),W(5*K-2),1)
7895    CALL Cas(B(*),A(*))
7905    CALL Trline(A(*),Y(5*K-4),W(5*K-4),1)
7915    CALL Cas(A(*),B(*))
7925    CALL Trline(B(*),Y(5*K-1),W(5*K-1),1)
7935    CALL Cas(A(*),B(*))
7945    RETURN
7955 Fet:! NE-137 Model at 300K          01/27/82
7960    DISP "Analyzing the ckt model . . . .    FREQ =";F
7965    CALL Rlc(A(*),"S",0,0,.036,"S",0)                         !C2
7970    CALL Source(B(*),"V","C",45.6,1E7,400.9,1.28)             !gm,R4,T
7975    CALL Par(B(*),A(*))
7980    CALL Rlc(A(*),"S",0,0,.270,"P",0)                         !C1
7985    CALL Cas(A(*),B(*))
7990    CALL Rlc(B(*),"S",0,0,.132,"P",0)                         !C3
7995    CALL Cas(A(*),B(*))
8000    CALL Rlc(B(*),"S",4.4,.106,0,"P",0)                       !R2,L2
8005    CALL Ser(B(*),A(*))
8010    CALL Rlc(A(*),"S",6.99,.081,0,"S",0)                      !R1,L1
8015    CALL Cas(A(*),B(*))
8020    CALL Rlc(B(*),"S",4,.090,0,"S",0)                         !R3,L3
8025    CALL Cas(A(*),B(*))
8030    CALL Rlc(B(*),"S",0,0,.01,"P",0)                          !C4
8035    CALL Cas(B(*),A(*))                                       !NE 13700
8040    Tmin=182*F/15
8045    Ropt=6.64*15/F
8050    Xopt=27.33*15/F
8055    Gn=26.5*(F/15)^2
```

```
8060   CALL Nload(B(*),4,Tmin,Ropt,Xopt,Gn)                 !Noise model
8065   CALL Rlc(A(*),"S",0,.350,0,"S",0)                    !Packaging L's
8070   CALL Cas(B(*),A(*))
8075   CALL Cas(A(*),B(*))
8076   CALL Rlc(B(*),"S",0,0,.150,"P",0)                     !Packaging C'
8077   CALL Cas(A(*),B(*))
8078   CALL Cas(B(*),A(*))
8079   CALL Rlc(A(*),"P",0,Ls,Cs,"P",0)                     !Source L-C
8080   CALL Ser(A(*),B(*))
8084   CALL Trline(B(*),120,.196,1)                         !Bias line
8085   CALL Rlc(D(*),"P",50,0,1,"P",0)
8090   CALL Cas(B(*),D(*))
8095   CALL Branch(B(*),"P")
8100   CALL Cas(A(*),B(*))
8105   CALL Cas(B(*),A(*))
8135   CALL Trline(A(*),38,.085,1.8)                         !Output coupli
8140   CALL Branch(A(*),"S")
8145   CALL Cas(B(*),A(*))
8150   CALL Trline(A(*),38,.085,1.8)                         !Input couplin
8155   CALL Branch(A(*),"S")
8160   CALL Cas(A(*),B(*))
8165   DISP
8170 RETURN
8175 END
```

<u>One to Three Stage Amplifier Analysis ("Amp #2")</u>

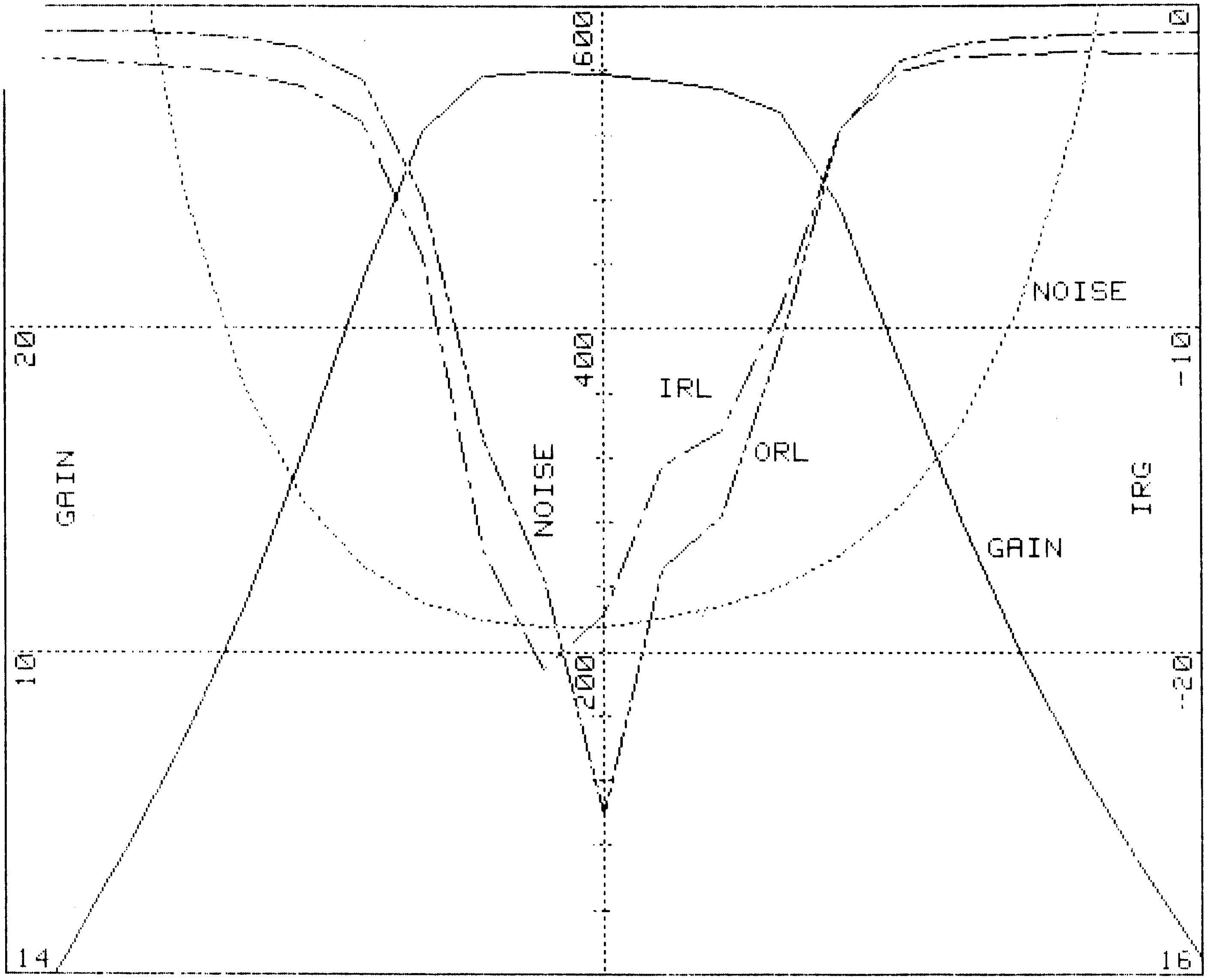
The program allows the analysis of a one-, two- or three-stage amplifier wit all the circuit parameters selected by the user.

It is possible to use it in two different modes by computing the frequency response (option = 0) or getting the spot center frequency response (option = 1) that allows a faster analysis and change in the circuit parameter.

Amp#2 as of 9/24/81

Amp#2 as of 9/24/81

```
Source feedback FET # 1                  Ls= .03                 Cs= 0
Source feedback FET # 2                  Ls= .03                 Cs= 0
Source feedback FET # 3                  Ls= .03                 Cs= 0
LINE # 1              Zo= 18             Lengh= .1967
LINE # 2              Zo= 50             Lengh= .053
LINE # 3              Zo= 50             Lengh= .092
LINE # 4              Zo= 12             Lengh= .1967
LINE # 5              Zo= 50             Lengh= .171
LINE # 6              Zo= 18             Lengh= .196
LINE # 7              Zo= 50             Lengh= .052
LINE # 8              Zo= 50             Lengh= .092
LINE # 9              Zo= 12             Lengh= .196
LINE # 10             Zo= 50             Lengh= .171
LINE # 11             Zo= 18             Lengh= .196
LINE # 12             Zo= 50             Lengh= .052
LINE # 13             Zo= 50             Lengh= .092
LINE # 14             Zo= 12             Lengh= .196
```


600
400
200
20
10
0
-10
-20
GAIN
NOISE
IRL
ORL
NOISE
GAIN
IRG
14
16

```
     Cktanalysis(J(*),Fvalue,Opt)
    NT LIN(2);TAB(10);"Amp#2 as of 9/24/81"
    'ON BASE 1
6210 COM Nogo,Zo,F,Count,SHORT Dat(51,18)  ![DAT] HOLDS FREQ, CKT
6215 DIM A(6,4),B(6,4),C(6,4),D(6,4),Y(15),W(15),L(3),Cap(3)
6220 STANDARD
6225 Count=Nogo=0          !#FREQS CURRENTLY STORED IN DATA BASE
6230 Zo=50
6235 DEG                       !DEFAULT FOR TRIG FUNCTIONS IS DEGR
6240 N=3
6241 Option=0
6245 Fo=15
6250 F1=14
6255 F2=16
6260 Nf=21
6265 Df=(F2-F1)/(Nf-1)
6270 DIM Fe(3,21,12)
6275 Qlam=11.8028527/(4*Fo)
6280 INPUT "Source L1 and C1 =",L(1),Cap(1)
6285 IF N=1 THEN 6305
6290 INPUT "Source L2 and C2 =",L(2),Cap(2)
6295 IF N=2 THEN 6305
6300 INPUT "Source L3 and C3 =",L(3),Cap(3)
6305 FOR I=1 TO Nf
6310   F=F1+(I-1)*Df
6315   FOR K=1 TO N
6320     Ls=L(K)
6325     Cs=Cap(K)
6330     GOSUB Fet
6335     CALL Ntrans(A(*),1)
6340     FOR J=1 TO 4
6345       Fe(K,I,J)=A(1,J)
6350       Fe(K,I,J+4)=A(3,J)
6355       Fe(K,I,J+8)=A(6,J)
6360     NEXT J
6365   NEXT K
6370 NEXT I
6375 RESTORE
6380 FOR K=1 TO 5*N-1
6385   READ Y(K),W(K)
6390 NEXT K
6395 W5=W(5)
6400 W10=W(10)
6405 Count=0
6410 W(5)=W5-W(3)-W(7)
6415 W(10)=W10-W(8)-W(12)
6425 IF Option=0 THEN 6435
6430 I1=INT((Nf+1)/2)
6435 FOR I=1 TO Nf
6440   IF Option=1 THEN I=I1
6445   F=F1+(I-1)*Df
6450   FOR K=1 TO N
6455     GOSUB Circuit
6460     IF K=N THEN 6475
6465     CALL Trline(B(*),Y(5*K),W(5*K),1)
6470     CALL Cas(A(*),B(*))
6475     IF K=1 THEN 6490
6480     CALL Cas(C(*),A(*))
6485     GOTO 6495
6490     MAT C=A
6495   NEXT K
6500   CALL Saveckt(C(*),4,4,-1)
6505   CALL Nperformance(C(*),3,50,0,50,0,G,1)
6510   IF Option=1 THEN I=Nf
6515 NEXT I
6520 IF Option=0 THEN 6560
```

```
        =10*LGT(Dat(1,2)^2+Dat(1,3)^2)
        =10*LGT(Dat(1,6)^2+Dat(1,7)^2)
[illegible]=10*LGT(Dat(1,8)^2+Dat(1,9)^2)
6535 Tem=Dat(1,14)
6540 PRINT DROUND(S11,6);DROUND(S21,6);DROUND(S22,6);DROUND(Tem,4)
6541 PRINT W(2);W(3);W(5);W(7);W(8);W(10);W(12);W(13)
6545 INPUT "?",J1,J2
6546 IF J1=0 THEN Option=0
6547 IF J1=0 THEN 6405
6548 IF J1<0 THEN Y(ABS(J1))=J2
6550 IF J1>0 THEN W(J1)=W(J1)+J2
6555 GOTO 6405
6560 GRAPHICS                                                        !GGGGGGGGG
6565 SCALE F1,F2,-30,0
6570 C=4/236.2                                                 !GHz/mm
6575 D=30/162.5                                                !dB/mm
6580 LINE TYPE 3
6585 AXES 1,2,Fo,-10
6590 AXES 1,10,Fo,-20
6595 LINE TYPE 5
6600 FOR K=1 TO Count
6605   PLOT Dat(K,1),10*LGT(Dat(K,2)^2+Dat(K,3)^2)             !S11 is dot-dashed
6610 NEXT K
6615 PENUP
6620 LINE TYPE 3
6625 FOR K=1 TO Count
6630   PLOT Dat(K,1),(Dat(K,14)+300*((Dat(K,8)^2+Dat(K,9)^2)/10^(Dat(K,15)/10))
/20-30                           !noise is dashed
6635 NEXT K
6640 PENUP
6645 LINE TYPE 1
6650 FOR K=1 TO Count
6655   PLOT Dat(K,1),10*LGT(Dat(K,6)^2+Dat(K,7)^2)-30          !S21 is solid
6660 NEXT K
6665 PENUP
6670 LINE TYPE 7
6675 FOR K=1 TO Count
6680 PLOT Dat(K,1),10*LGT(Dat(K,8)^2+Dat(K,9)^2)               !S22 is dble dot dash
6685 NEXT K
6690 LORG 1
6695 G=1
6700 LINE TYPE 1
6705 FOR F=F1 TO F2 STEP 2
6710   IF F<F2 THEN 6725
6715     G=-1
6720     LORG 7
6725   MOVE F+G*C,D-30
6730   LABEL USING "K";F
6735 NEXT F
6740 LDIR 90
6745 FOR G=-20 TO 0 STEP 10
6750   MOVE F2-C,G-D
6755   LABEL USING "K";G
6760   MOVE Fo-C,G-D
6765   LABEL USING "K";20*(G+30)
6770 NEXT G
6775 LORG 4
6780 MOVE F2-5*C,-15
6785 LABEL USING "K";"IRG"
6790 MOVE Fo-5*C,-15
6795 LABEL USING "K";"NOISE"
6800 LORG 6
6805 MOVE F1+5*C,-15
6810 LABEL USING "K";"GAIN"
6815 LORG 9
6820 FOR G=-20 TO 0 STEP 10
```

```
      VE F1+C,G-D
      BEL USING "K";G+30
6835 NEXT G
6840 LDIR 0
6845 FRAME
6850 PAUSE
6855 INPUT "Do you want to print this solution?",A$
6856 INPUT "Option =",Option
6860 IF A$="N" THEN 6900
6865 FOR K=1 TO N
6870   PRINT "Source feedback FET #";K,"Ls=";L(K),"Cs=";Cap(K)
6875 NEXT K
6880 FOR K=1 TO 5*N-1
6885   PRINT "LINE #";K,"Zo=";Y(K),"Lengh=";W(K)
6890 NEXT K
6895 PAUSE
6900 ! GCLEAR
6901 EXIT GRAPHICS
6902 IF Option=1 THEN 6405
6905 GOTO 6275
6910 SUBEXIT
6915 Circuit:!
6920   FOR J=1 TO 4
6925     A(1,J)=Fe(K,I,J)
6930     J1=4*(J/2-INT(J/2))-1+J
6935     A(2,J1)=(-1)^J1*A(1,J)
6940     A(3,J)=Fe(K,I,J+4)
6945     A(4,J1)=(-1)^J1*A(3,J)
6950     A(6,J)=Fe(K,I,J+8)
6955     A(5,1)=A(5,2)=1
6960   NEXT J
6965   CALL Trline(B(*),Y(5*K-3),W(5*K-3),1)
6970   CALL Cas(B(*),A(*))
6975   CALL Trline(A(*),Y(5*K-2),W(5*K-2),1)
6980   CALL Cas(B(*),A(*))
6985   CALL Trline(A(*),Y(5*K-4),W(5*K-4),1)
6990   CALL Cas(A(*),B(*))
6995   CALL Trline(B(*),Y(5*K-1),W(5*K-1),1)
7000   CALL Cas(A(*),B(*))
7005   RETURN
7010 Fet:! NE-137 Model at 300K        01/27/82
7015   DISP "Analyzing the ckt model . . . .   FREQ =";F
7020   CALL Rlc(A(*),"S",0,0,.036,"S",0)                       !C2
7025   CALL Source(B(*),"V","C",45.6,1E7,400.9,1.28)           !gm,R4,T
7030   CALL Par(B(*),A(*))
7035   CALL Rlc(A(*),"S",0,0,.270,"P",0)                       !C1
7040   CALL Cas(A(*),B(*))
7045   CALL Rlc(B(*),"S",0,0,.132,"P",0)                       !C3
7050   CALL Cas(A(*),B(*))
7055   CALL Rlc(B(*),"S",4.4,.106,0,"P",0)                     !R2,L2
7060   CALL Ser(B(*),A(*))
7065   CALL Rlc(A(*),"S",6.99,.081,0,"S",0)                    !R1,L1
7070   CALL Cas(A(*),B(*))
7075   CALL Rlc(B(*),"S",4,.090,0,"S",0)                       !R3,L3
7080   CALL Cas(A(*),B(*))
7085   CALL Rlc(B(*),"S",0,0,.01,"P",0)                        !C4
7090   CALL Cas(B(*),A(*))                                     !NE 13700 in [B
7095   Tmin=182*F/15
7100   Ropt=6.64*15/F
7105   Xopt=27.33*15/F
7110   Gn=26.5*(F/15)^2
7115   CALL Nload(B(*),4,Tmin,Ropt,Xopt,Gn)                    !Noise model
7120   CALL Rlc(A(*),"S",0,.350,0,"S",0)                       !Packaging L's
7125   CALL Cas(B(*),A(*))
7130   CALL Cas(A(*),B(*))
7131   CALL Rlc(B(*),"S",0,0,.150,"P",0)                        !Packaging C'
```

```
7132    CALL Cas(A(*),B(*))
7133    CALL Cas(B(*),A(*))
7134    CALL Rlc(A(*),"P",0,Ls,Cs,"P",0)                  !Source L-C
7135    CALL Ser(A(*),B(*))
7139    CALL Trline(B(*),120,.196,1)                      !Bias line
7140    CALL Rlc(D(*),"P",50,0,1,"P",0)
7145    CALL Cas(B(*),D(*))
7150    CALL Branch(B(*),"P")
7155    CALL Cas(A(*),B(*))
7160    CALL Cas(B(*),A(*))
7190    CALL Trline(A(*),38,.085,1.8)                      !Output coupli
7195    CALL Branch(A(*),"S")
7200    CALL Cas(B(*),A(*))
7205    CALL Trline(A(*),38,.085,1.8)                      !Input couplin
7210    CALL Branch(A(*),"S")
7215    CALL Cas(A(*),B(*))
7220    DISP
7225 RETURN
7240 DATA  18,.1967                  !Line # 1
7245 DATA  50,.0530                  !Line # 2
7250                ! FET # 1
7255 DATA  50,.092                   !Line # 3
7260 DATA  12,.1967                  !Line # 4
7265 DATA  50,.315                   !Line # 5 inter-stage
7270 DATA  18,.196                   !Line # 6
7275 DATA  50,.052                   !Line # 7
7280                ! FET # 2
7285 DATA  50,.092                   !Line # 8
7290 DATA  12,.196                   !Line # 9
7295 DATA  50,.315                   !Line #10 inter-stage
7300 DATA  18,.196                   !Line #11
7305 DATA  50,.052                   !Line #12
7310                ! FET # 3
7315 DATA  50,.092                   !Line #13
7320 DATA  12,.196                   !Line #14
7325 SUBEND
```