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# Low-Noise VHF and L-Band GaAs FET Amplifiers

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*GaAs FET devices are typically used in low-noise amplifiers in the microwave region, where silicon transistors can't provide the required gain and noise performance. There are, however, many applications in the frequency range below 2000 MHz where the low noise figures and high gain of GaAs FETs can improve receiver sensitivity. This article describes a series of three low-noise amplifiers that use identical circuit topology. The only differences are in the proper choice of three inductors depending on the frequency of operation. The designs are centered at 450 MHz, 900 MHz and 1300 MHz, but can be scaled for any frequency within the region of 400 to 1600 MHz. Each amplifier has a usable bandwidth of about 30 to 40 percent.*

Using a high-gain, high-frequency GaAs FET at VHF poses special problems. Of greatest concern is the problem of designing the amplifier for unconditional stability. Typically, GaAs FETs have greater gain as frequency is decreased, e.g., 25 dB maximum stable gain at 500 MHz. A second problem is that matching the typical microwave GaAs FET at lower frequencies for minimum noise figure does not necessarily produce minimum input VSWR.

Achieving the lowest possible noise figure requires matching the device to $\Gamma_{opt}$ (the source match required for minimum noise figure). At higher microwave frequencies this will generally produce a reasonable input VSWR, since $\Gamma_{opt}$ and the complex conjugate of the device input reflection coefficient $S_{11}$ are usually close on the Smith Chart. At lower frequencies, special consideration needs to be given to the input circuit design and to the tradeoffs required to ensure low noise figure while still achieving moderate gain, low VSWR and unconditional stability.

## Design Technique

The Avantek ATF-10135, supplied in the commercial 0.085 inch "micro-X" metal/ceramic package, is used in these examples. Examination of the data sheet reveals that the device is capable of 0.4 dB noise figure at frequencies below 2 GHz with an associated gain of greater than 15 dB. The noise parameters and S-parameters of this transistor are summarized in Table 1.

Achieving the associated gain of which the device is capable is difficult since the device is not inherently stable. It is not enough that the amplifier be stable at the operating frequency — it must be stable at all frequencies. Any out-of-band oscillation will make the amplifier unusable.

The simplest technique to ensure broad-band stability is to resistively load the drain. Resistive loading produces a constant impedance on the device over a wide frequency range. In the case of the ATF-10135, a 47 ohm carbon resistor is used to load the output of the device, with the series inductance from the resistor leads also used to better match the device to 50 ohms. This produces acceptable gain while ensuring a good output match and retaining stability over as wide a bandwidth as possible.

Obtaining the lowest possible noise figure from the device requires that the input matching network convert the nominal 50 ohm source impedance to $\Gamma_{opt}$. This produces a deliberate impedance mismatch that, while minimizing amplifier noise figure, produces a high input VSWR. The ideal situation is

ATF-10135

Typical Scattering Parameters, Common Source, Vds=2V, Ids=20mA

| Frequency GHz | S11 Mag | S11 Ang | S21 dB | S21 Mag | S21 Ang | S12 dB | S12 Mag | S12 Ang | S22 Mag | S22 Ang |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | .98 | -18 | 14.5 | 5.32 | 163 | -34.0 | .020 | 78 | .35 | -9 |
| 1.0 | .93 | -33 | 14.3 | 5.19 | 147 | -28.4 | .038 | 67 | .36 | -19 |
| 2.0 | .79 | -66 | 13.3 | 4.64 | 113 | -22.6 | .074 | 59 | .30 | -31 |

Noise Parameters, Vds=2V, Ids=20mA

| Frequency * GHz | NF dB | Gamma Opt Mag | Gamma Opt Ang | Rn/50 |
|---|---|---|---|---|
| 0.45 | 0.35 | .93 | 12 | .80 |
| 0.90 | 0.36 | .87 | 21 | .70 |
| 1.30 | 0.38 | .81 | 31 | .62 |
| 2.00 | 0.40 | .70 | 47 | .46 |

* Noise parameters at frequencies below 2 GHz are extrapolated from measured data at higher frequencies.

**Table 1. Scattering and noise parameters for the Avantek ATF-10135 transistor, common source, $V_{DS}$= 2V, $I_{DS}$= 20mA.**

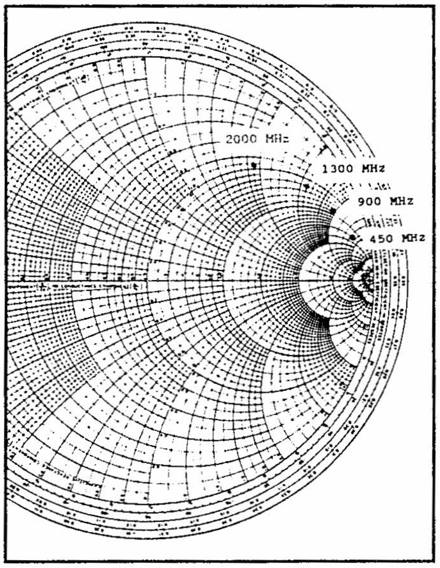



**Figure 1. ATF-10135 $\Gamma_{opt}$ vs. frequency, $V_{DS}$ = 2V and $I_{DS}$= 20mA.**

| Lead Length | NF | Gain | $\|S_{11}\|^2$ | $\|S_{22}\|^2$ | k | k (@ 9 GHz) |
|---|---|---|---|---|---|---|
| 0 inch | 0.46 dB | 20.1 dB | -5.4 dB | -8.0 dB | .75 | 2.79 |
| 0.1 inch | 0.48 dB | 17.2 dB | -14.3 dB | -16.0 dB | 1.30 | 1.94 |
| 0.2 inch | 0.52 dB | 14.9 dB | -10.6 dB | -18.4 dB | 1.55 | 0.92 |

**Table 2. Performance vs. source lead length at 900 MHz.**

| Frequency | | NF | Gain | $\|S_{11}\|^2$ | $\|S_{22}\|^2$ | k |
|---|---|---|---|---|---|---|
| 450 MHz | (Measured): | 0.45 dB | 21.3 dB | -8.0 dB | -7.6 dB | -- |
| | (Simulated): | 0.54 dB | 20.6 dB | -9.9 | -7.0 | 1.161 |
| 900 MHz | (Measured): | 0.40 dB | 16.5 dB | -10.7 dB | -14.4 dB | -- |
| | (Simulated): | 0.48 dB | 17.2 dB | -14.3 dB | -16.0 dB | 1.30 |
| 1300 MHz | (Measured): | 0.50 dB | 14.5 dB | -8.5 dB | -17.8 dB | -- |
| | (Simulated): | 0.45 dB | 15.7 dB | -13.0 dB | -19.3 dB | 1.20 |

**Table 3. Measured performance vs. computer simulation.**

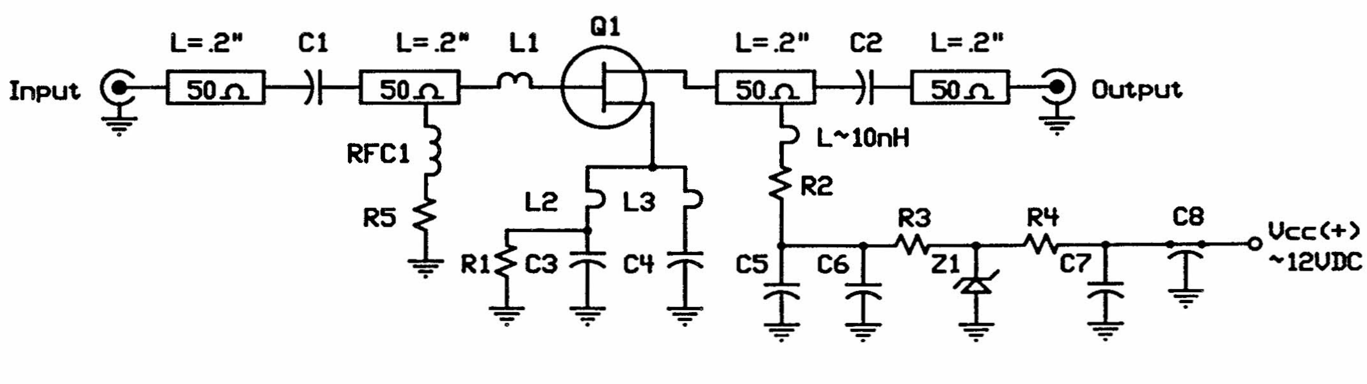
where $\Gamma_{opt}$ is the complex conjugate of $S_{11}$ (i.e., $S_{11}^*$). For this condition, minimum noise figure is achieved when the device is matched for minimum VSWR. This situation occurs predominantly above 2 GHz and tends to diverge at lower frequencies, where $S_{11}$ approaches 1.

High input VSWR has varying significance, depending on the application. Most noteworthy is the increased uncertainty of the noise figure measurement due to reflections between the noise source and amplifier input. Similarly, when the amplifier is connected to a receive antenna, high input VSWR creates added uncertainty in overall system performance. The effect is difficult to analyze unless an isolator is placed at the input to the amplifier. The use of an isolator, however, adds excessive loss and, at VHF frequencies, the size of the isolator is often prohibitively large. In the case of systems using pulse position modulation (PPM), reflections due to VSWR manifest themselves as displaced pulses, which create direction-finding errors.

To examine the alternatives, constant noise figure and constant gain circles can be constructed to assess the impact of trading increased noise figure for a decrease in input VSWR and a corresponding increase in amplifier gain. In most instances, the result is a much higher noise figure than really desired.

An option is to use source feedback. This subject has already been covered by several authors (References 1-3). Source feedback, in the form of source inductance, can improve input VSWR with minimal noise figure degradation. The drawback of utilizing source inductance is a gain reduction of up to several decibels. However, GaAs FET devices often have more gain than desired at low frequencies, so the penalty is not severe.

The effect of source inductance on amplifier input match is best studied with the help of a computer simulation. The computer was used to analyze $S_{11}$ of the amplifier with the proposed output matching network. $S_{11}$ was measured looking directly into the gate of the device with the source inductance added between the source and ground. With the Avantek ATF-10135 at 500 MHz, adding the




$I_D$ = 20 mA
$V_D$ = 1 V @ 450 and 900 MHz, 1.4 V @ 1300 MHz

Components common to all versions:

| | |
|---|---|
| Q1: | Avantek ATF-10135 low-noise GaAs FET |
| C1, C2: | 100 pF, 0.050-inch square chip capacitor |
| C3, C4: | 1000 pF, 0.050-inch square chip capacitor |
| C5: | 1000 pF, 0.110-inch or 0.050-inch square chip capacitor |
| C6: | 0.1 μF, 0.110-inch square chip capacitor |
| C7: | 1 μF electrolytic capacitor |
| C8: | 1000 pF feedthrough capacitor |
| L2, L3: | Source inductance: lead length on Q1 per table |
| R1: | 18-33Ω, 1/4-W carbon resistor--adjust for $I_D$ ≈ 20 mA |
| R2: | 47Ω, 1/4-W carbon resistor with 0.15" leads, tap 0.1" from Q1 |
| R3: | 68-120Ω, 1/4-W carbon resistor--adjust for $V_{DS}$ |
| R4: | 220Ω, 1/4-W carbon resistor |
| R5: | 100Ω, 1/4-W carbon resistor |
| Z1: | 1N752, 5.6-V Zener diode |

Components changed with frequency of operation:

| Frequency | 450 MHz | 900 MHz | 1300 MHz |
|---|---|---|---|
| RFC1: | 0.47 μH | 0.33 μH | 0.33 μH [min. molded RFC] |
| L1: | 8T #28, 1/8" I.D. close-wound | 3T #28, 1/8" I.D. | 3T #28, 0.050" I.D. |
| | | ←Spaced 1 wire diameter→ | |
| L2, L3 | 0.125" | 0.10" | .065" |

50Ω microstriplines are .080" wide on RT/Duroid 5880, .031"-thick

**Figure 2. Schematic of the GaAs FET amplifier circuit. The only change made to modify the operating frequency range from 400 to 1500 MHz is changing the values of RFC1 and L1.**

equivalent source inductance of two 0.10 inch leads causes the value of $S_{11}$ to decrease from 0.987 to 0.960. Angle remains relatively constant at about -16 degrees. Comparing $S_{11}$ to $\Gamma_{opt}$ at 500 MHz now shows them to be nearly identical. The result is that minimum noise figure and minimum VSWR will coincide more closely with one another when matching the device for minimum noise figure. Plotting $\Gamma_{opt}$ for the ATF-10135 device from 450 MHz through 2 GHz in Figure 1 shows that $\Gamma_{opt}$ lies very near the $R/Z_o$=1 curve. This implies that a series inductance will provide the necessary match to attain minimum noise figure.

The simplest way to incorporate source inductance is to use the device source leads. Using device leads as

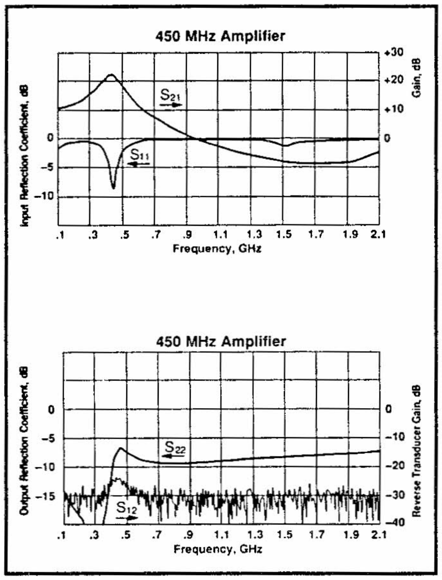



**Figure 3. Swept performance of the amplifier circuit with 450 MHz component values.**

inductors produces approximately 1.3 nH per 0.100 inch of source lead, or 0.65 nH for two source leads in parallel. With the help of Touchstone™, the effect of the lead inductance can be analyzed by simulating the inductance as a high-impedance transmission line. The TUNE mode was invaluable for determining the optimum lead length for a given performance. Table 2 shows the effect of lead length on gain, noise figure, stability, and input and output VSWR at 900 MHz. It is clear that lead lengths of 0.1 inch or less have a minor effect on noise figure while improving input match substantially. Gain does suffer, but this is not a major concern.

An added benefit of using source inductance is enhanced stability as evidenced by the Rollett stability factor, K. Excessive source inductance can have an adverse effect on stability at the higher frequencies. In the case of the 900 MHz amplifier, zero length source leads create potential instability at low frequencies while longer source lead length creates a potential instability at high frequencies; a 9 GHz, 0.100 inch source lead length is an optimum choice based on all parameters. The optimum source lead length varies with frequency of operation. In the case of the 450 MHz model, 0.125 inch lead length provides the best overall performance with K>1 at frequencies of 450 MHz and higher. According to Touchstone™, low frequency stability can be enhanced with 0.200 inch lead length at a penalty of 2.5 dB of inband gain. For the 1300 MHz model, 0.065 inch source lead length provides optimum performance with unconditional stability up to 11 GHz. Decreasing source lead length improves stability at 12 GHz while making K<1 at 400 MHz. For applications below 450 MHz, greater source inductance will no doubt be required to retain K>1 and to obtain a reasonable input VSWR.

The amplifier circuit actually built is shown in Figure 2. For simplicity, the FET is self-biased. The loss associated with the bypassed source resistor is no greater than 0.1 dB at these frequencies. Zener diode regulation worked well. Although there is interaction, the source resistor, R1, primarily sets the drain current while R3 sets the drain voltage. Improved regulation over temperature is possible with any of the popular active bias networks discussed in References 4 and 5. The active bias network sets both the drain voltage and drain current regardless of device variations.

## Measurements on Amplifiers

The performance of all three amplifiers is comparable to that predicted by the computer simulation. Table 3 summarizes the gain, noise figure and VSWR parameters. The actual noise figure is within 0.1 dB, and the gain within 1.2 dB of the prediction. The VSWR performance is not as good as predicted by the simulation, but still very acceptable. Stability is very good with no problems noted when cascading stages.

The swept gain plots (included in Figures 3-5) show the wide bandwidth of these amplifiers. Low noise figure is also retained over the bandwidths. The 450 MHz amplifier has less than 0.5 dB noise figure between 400 and 500 MHz

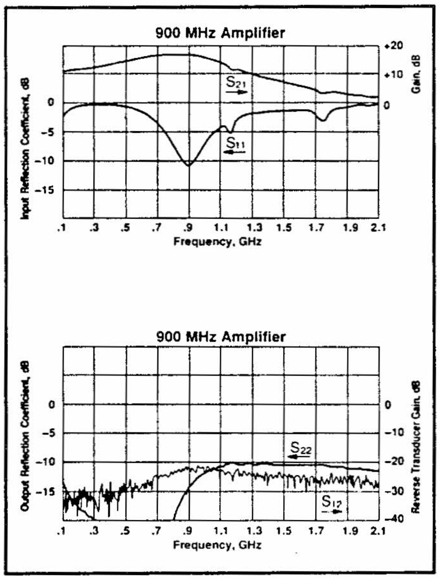



**Figure 4. Swept performance of the amplifier circuit with 900 MHz component values. (See Appendix 1 for the computer modeling of the circuit at 900 MHz.)**

while the 900 MHz amplifier has less than 0.6 dB noise figure between 800 and 1000 MHz. Similarly, the 1300 MHz amplifier has less than 0.65 noise figure from 1200 MHz to 1500 MHz.

At frequencies above 2 GHz, the ATF-10135 is rated for minimum noise figure when operated at $V_{DS}$ of 2 V, and $I_{DS}$ of 20 mA. At frequencies below 2 GHz, it was empirically determined that an additional 0.1 dB reduction in noise figure is possible if the device is rebiased. At 1300 MHz, the optimum $V_{DS}$ is 1.4 V, while at 450 and 900 MHz, 1 V gave the lowest noise figure.

The amplifiers were built on RT/Duroid™ 5880 dielectric material of 0.031 inch thickness. The 50 ohm microstriplines are 0.080 inch in width. Epoxy-glass dielectric material should also work if the microstripline widths are properly scaled.

The most critical factor in construction is assuring proper ground returns for the bypass capacitors. In this prototyping work, grounds for the bypass capacitors are obtained by using 0.1-inch-wide "z" wires to connect the top groundplane to the bottom groundplane. Plated through-holes (vias) are typically used in high-volume production.

For enclosures, standard Hammond or Bud diecast aluminum boxes are appropriate; the microstripline board fits nicely into the lid of a Hammond 1590A diecast aluminum box. Flange mount SMA- type connectors are suggested to ensure mechanical rigidity. The connector mounting hardware is used to provide a good mechanical and RF connection between the connector, the box and the groundplane side of the microstripline board.

## Amplifier Tuning

The inherent broad bandwidth of these amplifiers drastically reduces the time required to get them into operation. Setting up each amplifier is simple.

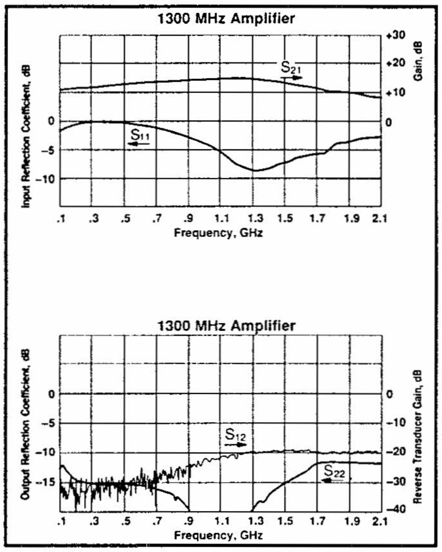



**Figure 5. Swept performance of the amplifier circuit with 1300 MHz component values.**

Once the device is set up for the proper DC operating parameters for the frequency of interest, noise figure and gain performance should be comparable to that shown in Table 3. If necessary, adjust the turns spacing on the input inductor for the desired input VSWR. This will automatically coincide with minimum noise figure and maximum gain. As shown in the foregoing data, the noise figure varies very little over a wide bandwidth, so it might be advantageous to tune for minimum input VSWR as opposed to noise figure. Without the source inductance, the input VSWR will be considerably higher.

The simple series L/R matching network in the output circuit forces a good broadband low VSWR output match. Due to the finite amount of reverse isolation of the device, the output match is affected by the input match and vice versa. Therefore the frequency of best output VSWR is somewhat dependent on where the input network is optimum.

## Using the Design at Other Frequencies

The basic amplifier design can be adapted for any frequency in the 400 to 1600 MHz range. Merely scaling the input inductor for the desired frequency will allow operation on a different frequency. The graph shown in Figure 6 gives some idea of the relationship of L

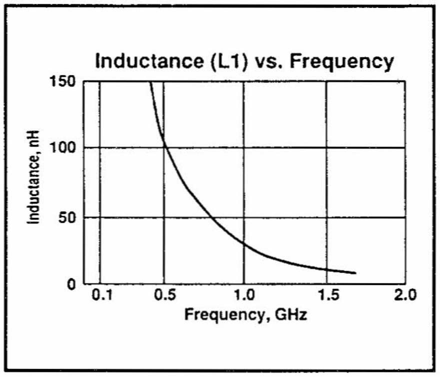



**Figure 6. Inductance of L1 vs. frequency in the amplifier circuit.**

vs. frequency — source feedback should be adjusted accordingly. The ATF-10135 has been used successfully in circuits operating at as low as 150 MHz with similar results.

## Conclusion

The results show that high-frequency GaAs FETs can be used very successfully in the 400 to 1600 MHz frequency range. This same technique can be used down to 150 MHz and up to 1.7 GHz with similar results. Conventional microstripline matching techniques will still offer the best performance above 1.76 GHz.

The single-element match in the input network provides very good performance in this frequency range and offers the greatest bandwidth. There is no doubt that noise figure and input VSWR performance can be further enhanced by the use of a two-element matching network. A shunt capacitor can be used on the device side of the input inductor, but this may necessitate additional tuning for very little improvement in performance. Present noise figure performance is already within 0.1 dB of that specified in the data sheet.

Improved VSWR performance at the expense of increased noise figure can be achieved by a further increase in source inductance. Overall amplifier performance is best analyzed with the help of the computer.

When using any GaAs FET in the VHF region, it becomes even more difficult to obtain broadband stability due to the high gain available from the device. For this reason, a broadband resistive load was chosen for the output network as opposed to the typical L/C tank circuit. Some gain is sacrificed for the added benefit of increased stability.

[Appendix 1 follows on p. 48]

## References

1. L. Besser, "Stability Considerations of Low Noise Transistor Amplifiers With Simultaneous Noise and Power Match," *Low Noise Microwave Transistors and Amplifiers*, H. Fukui, Editor, IEEE Press, 1981, pp. 272-274.
2. G.D. Vendelin, "Feedback Effects on the Noise Performance of GaAs MESFETs," *Low Noise Microwave Transistors and Amplifiers*, H. Fukui, Editor, IEEE Press, 1981, pp. 294-296.
3. D. Williams, W. Lum, S. Weinreb, "L-Band Cryogenically Cooled GaAs FET Amplifiers," *Microwave Journal*, October 1980, p. 73.
4. G. Gonzalez, *Microwave Transistor Amplifiers*, Prentice-Hall, 1984, pp. 131-133.
5. G.D. Vendelin, *Design of Amplifiers and Oscillators by the S-Parameter Method,* Wiley, 1982, pp. 53-59.

**About the Author**

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```
Touchstone (TM) - Configuration( 100 1500 100 16437 2364 1000 1 3294 )
               900AMP.CKT    Thu Dec 29 15:19:38 1988
DIM
        FREQ  GHZ
        IND   NH
        CAP   PF
        LNG   IN
VAR
        LL=0.1
        CC=1000

CKT
        MSUB    ER=2.1  H=.031  T=.001  RHO=1  RGH=0
        MLIN  1   2   W=.080  L=.2
        SLC   2   3   L=.5  C=100
        MLIN  3   4   W=.080  L=.2
        IND   4   5   L\40
        IND   4   6   L=330
        RES   6   0   R=100
        DEF2P 1   5   NAIN

        S2PA  5   8   9   A:\S_DATA\10135N.S2P
        DEF3P 5   8   9   NA2P

        MLIN  9   10   W=.020  L^LL
        MLIN  9   11   W=.020  L^LL
        SLC   11  12   L=.5  C^CC
        RIBBON 12  0   W=.1  L=.031  RHO=1
        SLC   10  13   L=.5  C^CC
        RIBBON 13  0   W=.1  L=.031  RHO=1
        RES   10   0   R=47
        DEF1P 9    NASER

        MLIN  8   14  W=.080  L=.1
        IND   14  15  L=10
        RES   15  16  R=47
        SLC   16  0   L=.5   C=1000
        SLC   16  0   L=.5   C=10000
        MLIN  14  17  W=.080  L=.1
        SLC   17  18  L=.5    C=100
        MLIN  18  19  W=.080  L=.2

        DEF2P 8    19   NAOUT

        NAIN  1    5
        NA2P  5    8    9
        NASER 9
        NAOUT 8    19
        DEF2P 1    19   AMP
FREQ
        !STEP  .900
        SWEEP 0.100  12.0   .2
        !STEP   9.0
OUT
        AMP  DB[S11]
        AMP  DB[S22]
        AMP  DB[S21]
        AMP  DB[S12]
        AMP  DB[NF]
        AMP  K
OPT
        AMP  DB[NF]<.2
       !AMP  DB[S21]>25
```

Touchstone (TM) - Configuration( 100 1500 100 16437 2364 1000 1 3294 )
900AMP.OUT Thu Dec 29 15:47:35 1988 LL = 0.0 inch.

| FREQ-GHZ | DB[S11] AMP | DB[S22] AMP | DB[S21] AMP | DB[S12] AMP | DB[NF] AMP | K AMP |
|---|---|---|---|---|---|---|
| 0.10000 | -1.524 | -11.737 | 9.624 | -49.925 | 3.093 | 14.219 |
| 0.30000 | -0.172 | -14.979 | 11.608 | -40.835 | 2.243 | 0.667 |
| 0.50000 | -0.366 | -15.660 | 14.535 | -33.837 | 1.769 | 0.571 |
| 0.70000 | -2.267 | -14.581 | 19.363 | -26.114 | 0.906 | 0.681 |
| 0.90000 | -5.390 | -8.046 | 20.141 | -23.061 | 0.458 | 0.755 |
| 1.10000 | -1.162 | -8.603 | 13.754 | -27.446 | 0.994 | 0.834 |
| 1.30000 | -0.501 | -8.961 | 9.020 | -30.305 | 2.500 | 0.901 |
| 1.50000 | -0.287 | -8.887 | 5.603 | -32.024 | 4.413 | 0.941 |
| 1.70000 | -0.189 | -8.665 | 2.926 | -33.147 | 6.302 | 0.965 |
| 1.90000 | -0.135 | -8.397 | 0.721 | -33.919 | 7.999 | 0.980 |
| 2.10000 | -0.105 | -8.131 | -1.093 | -34.450 | 9.893 | 0.998 |
| 2.30000 | -0.087 | -7.897 | -2.617 | -34.832 | 11.983 | 1.021 |
| 2.50000 | -0.074 | -7.707 | -3.958 | -35.116 | 13.864 | 1.044 |
| 2.70000 | -0.066 | -7.565 | -5.147 | -35.323 | 15.567 | 1.069 |
| 2.90000 | -0.059 | -7.477 | -6.203 | -35.467 | 17.119 | 1.095 |
| 3.10000 | -0.055 | -7.438 | -7.127 | -35.608 | 18.540 | 1.123 |
| 3.30000 | -0.051 | -7.450 | -7.939 | -35.749 | 19.841 | 1.154 |
| 3.50000 | -0.049 | -7.525 | -8.668 | -35.846 | 21.025 | 1.190 |
| 3.70000 | -0.048 | -7.669 | -9.324 | -35.905 | 22.082 | 1.231 |
| 3.90000 | -0.047 | -7.888 | -9.916 | -35.935 | 22.995 | 1.278 |
| 4.10000 | -0.047 | -8.185 | -10.486 | -35.974 | 23.700 | 1.334 |
| 4.30000 | -0.047 | -8.568 | -11.030 | -36.023 | 24.271 | 1.400 |
| 4.50000 | -0.048 | -9.054 | -11.521 | -36.051 | 24.769 | 1.473 |
| 4.70000 | -0.048 | -9.665 | -11.969 | -36.068 | 25.182 | 1.554 |
| 4.90000 | -0.049 | -10.427 | -12.384 | -36.082 | 25.493 | 1.642 |
| 5.10000 | -0.050 | -11.039 | -12.795 | -36.099 | 25.680 | 1.733 |
| 5.30000 | -0.050 | -11.411 | -13.204 | -36.109 | 25.721 | 1.822 |
| 5.50000 | -0.051 | -11.888 | -13.595 | -36.112 | 25.597 | 1.911 |
| 5.70000 | -0.051 | -12.522 | -13.973 | -36.120 | 25.286 | 1.999 |
| 5.90000 | -0.051 | -13.358 | -14.344 | -36.141 | 24.770 | 2.086 |
| 6.10000 | -0.051 | -14.065 | -14.735 | -36.281 | 25.014 | 2.189 |
| 6.30000 | -0.050 | -13.942 | -15.155 | -36.505 | 25.978 | 2.303 |
| 6.50000 | -0.049 | -13.465 | -15.585 | -36.694 | 26.698 | 2.405 |
| 6.70000 | -0.048 | -13.038 | -16.022 | -36.848 | 27.219 | 2.497 |
| 6.90000 | -0.047 | -12.889 | -16.465 | -36.968 | 27.582 | 2.578 |
| 7.10000 | -0.045 | -12.468 | -16.950 | -37.152 | 27.826 | 2.666 |
| 7.30000 | -0.043 | -11.527 | -17.471 | -37.406 | 27.980 | 2.757 |
| 7.50000 | -0.041 | -10.671 | -17.981 | -37.633 | 28.058 | 2.831 |
| 7.70000 | -0.039 | -9.917 | -18.473 | -37.828 | 28.076 | 2.886 |
| 7.90000 | -0.037 | -9.264 | -18.941 | -37.983 | 28.043 | 2.918 |
| 8.10000 | -0.035 | -8.574 | -19.381 | -38.158 | 28.247 | 2.935 |
| 8.30000 | -0.033 | -7.817 | -19.801 | -38.375 | 28.690 | 2.939 |
| 8.50000 | -0.032 | -7.117 | -20.198 | -38.571 | 29.092 | 2.923 |
| 8.70000 | -0.030 | -6.473 | -20.564 | -38.740 | 29.459 | 2.887 |
| 8.90000 | -0.028 | -5.884 | -20.896 | -38.875 | 29.792 | 2.829 |
| 9.10000 | -0.027 | -5.480 | -21.208 | -39.036 | 30.092 | 2.792 |
| 9.30000 | -0.026 | -5.251 | -21.505 | -39.223 | 30.359 | 2.780 |
| 9.50000 | -0.025 | -5.059 | -21.762 | -39.366 | 30.597 | 2.760 |
| 9.70000 | -0.024 | -4.904 | -21.973 | -39.457 | 30.806 | 2.729 |
| 9.90000 | -0.023 | -4.787 | -22.131 | -39.490 | 30.988 | 2.690 |
| 10.1000 | -0.022 | -4.781 | -22.305 | -39.521 | 31.146 | 2.682 |
| 10.3000 | -0.022 | -4.889 | -22.499 | -39.546 | 31.281 | 2.707 |
| 10.5000 | -0.022 | -5.051 | -22.633 | -39.496 | 31.389 | 2.724 |
| 10.7000 | -0.021 | -5.278 | -22.702 | -39.363 | 31.471 | 2.731 |
| 10.9000 | -0.021 | -5.592 | -22.698 | -39.141 | 31.527 | 2.725 |
| 11.1000 | -0.022 | -5.895 | -22.636 | -38.936 | 31.559 | 2.715 |
| 11.3000 | -0.022 | -6.179 | -22.526 | -38.765 | 31.566 | 2.704 |
| 11.5000 | -0.022 | -6.588 | -22.346 | -38.514 | 31.545 | 2.685 |
| 11.7000 | -0.023 | -7.172 | -22.090 | -38.175 | 31.495 | 2.656 |
| 11.9000 | -0.025 | -8.018 | -21.755 | -37.746 | 31.416 | 2.615 |
| 12.0000 | -0.025 | -8.585 | -21.556 | -37.496 | 31.365 | 2.590 |

Touchstone (TM) - Configuration( 100 1500 100 16437 2364 1000 1 3294 )
900AMP.OUT Thu Dec 29 15:40:06 1988 LL = 0.1 inch

| FREQ-GHZ | DB[S11] AMP | DB[S22] AMP | DB[S21] AMP | DB[S12] AMP | DB[NF] AMP | K AMP |
|---|---|---|---|---|---|---|
| 0.10000 | -1.545 | -11.796 | 9.619 | -50.033 | 3.090 | 14.596 |
| 0.30000 | -0.321 | -14.549 | 11.407 | -40.783 | 2.240 | 1.148 |
| 0.50000 | -0.919 | -14.361 | 13.751 | -33.875 | 1.770 | 1.151 |
| 0.70000 | -4.230 | -14.979 | 16.816 | -27.388 | 0.912 | 1.262 |
| 0.90000 | -14.264 | -15.983 | 17.206 | -24.221 | 0.482 | 1.297 |
| 1.10000 | -2.997 | -12.778 | 13.040 | -25.844 | 1.044 | 1.305 |
| 1.30000 | -1.244 | -11.060 | 8.888 | -27.571 | 2.563 | 1.287 |
| 1.50000 | -0.681 | -9.960 | 5.626 | -28.677 | 4.470 | 1.252 |
| 1.70000 | -0.431 | -9.130 | 2.993 | -29.383 | 6.340 | 1.215 |
| 1.90000 | -0.297 | -8.462 | 0.796 | -29.848 | 8.013 | 1.178 |
| 2.10000 | -0.222 | -7.933 | -1.029 | -30.187 | 9.883 | 1.156 |
| 2.30000 | -0.176 | -7.521 | -2.569 | -30.458 | 11.948 | 1.148 |
| 2.50000 | -0.145 | -7.192 | -3.924 | -30.664 | 13.803 | 1.142 |
| 2.70000 | -0.122 | -6.939 | -5.122 | -30.819 | 15.480 | 1.140 |
| 2.90000 | -0.106 | -6.755 | -6.183 | -30.935 | 17.006 | 1.141 |
| 3.10000 | -0.094 | -6.631 | -7.108 | -31.039 | 18.404 | 1.142 |
| 3.30000 | -0.085 | -6.562 | -7.917 | -31.135 | 19.685 | 1.144 |
| 3.50000 | -0.078 | -6.556 | -8.641 | -31.203 | 20.849 | 1.148 |
| 3.70000 | -0.073 | -6.612 | -9.290 | -31.250 | 21.890 | 1.156 |
| 3.90000 | -0.069 | -6.734 | -9.874 | -31.280 | 22.790 | 1.167 |
| 4.10000 | -0.066 | -6.926 | -10.434 | -31.328 | 23.482 | 1.185 |
| 4.30000 | -0.064 | -7.188 | -10.966 | -31.391 | 24.041 | 1.211 |
| 4.50000 | -0.062 | -7.530 | -11.443 | -31.450 | 24.531 | 1.241 |
| 4.70000 | -0.062 | -7.965 | -11.877 | -31.511 | 24.941 | 1.275 |
| 4.90000 | -0.061 | -8.508 | -12.277 | -31.583 | 25.254 | 1.313 |
| 5.10000 | -0.061 | -8.948 | -12.678 | -31.659 | 25.443 | 1.356 |
| 5.30000 | -0.060 | -9.213 | -13.080 | -31.713 | 25.482 | 1.399 |
| 5.50000 | -0.060 | -9.540 | -13.464 | -31.754 | 25.358 | 1.441 |
| 5.70000 | -0.059 | -9.972 | -13.835 | -31.795 | 25.053 | 1.480 |
| 5.90000 | -0.058 | -10.549 | -14.198 | -31.847 | 24.548 | 1.517 |
| 6.10000 | -0.057 | -11.226 | -14.579 | -32.041 | 24.815 | 1.565 |
| 6.30000 | -0.055 | -11.550 | -14.992 | -32.335 | 25.802 | 1.627 |
| 6.50000 | -0.054 | -11.539 | -15.418 | -32.572 | 26.538 | 1.681 |
| 6.70000 | -0.052 | -11.397 | -15.856 | -32.733 | 27.070 | 1.725 |
| 6.90000 | -0.050 | -11.323 | -16.303 | -32.809 | 27.437 | 1.754 |
| 7.10000 | -0.047 | -11.157 | -16.793 | -32.973 | 27.694 | 1.790 |
| 7.30000 | -0.045 | -10.667 | -17.320 | -33.277 | 27.873 | 1.840 |
| 7.50000 | -0.042 | -10.119 | -17.842 | -33.564 | 27.976 | 1.882 |
| 7.70000 | -0.040 | -9.563 | -18.349 | -33.828 | 28.020 | 1.916 |
| 7.90000 | -0.037 | -9.033 | -18.837 | -34.065 | 28.014 | 1.940 |
| 8.10000 | -0.035 | -8.476 | -19.298 | -34.330 | 28.253 | 1.954 |
| 8.30000 | -0.032 | -7.880 | -19.739 | -34.652 | 28.741 | 1.964 |
| 8.50000 | -0.030 | -7.323 | -20.155 | -34.984 | 29.198 | 1.966 |
| 8.70000 | -0.028 | -6.813 | -20.541 | -35.320 | 29.626 | 1.961 |
| 8.90000 | -0.026 | -6.358 | -20.886 | -35.656 | 30.030 | 1.948 |
| 9.10000 | -0.024 | -6.097 | -21.211 | -35.949 | 30.405 | 1.934 |
| 9.30000 | -0.022 | -6.019 | -21.526 | -36.175 | 30.748 | 1.919 |
| 9.50000 | -0.021 | -5.991 | -21.804 | -36.358 | 31.069 | 1.897 |
| 9.70000 | -0.019 | -6.021 | -22.040 | -36.494 | 31.370 | 1.869 |
| 9.90000 | -0.018 | -6.117 | -22.232 | -36.577 | 31.650 | 1.834 |
| 10.1000 | -0.017 | -6.402 | -22.470 | -36.581 | 31.930 | 1.807 |
| 10.3000 | -0.016 | -6.857 | -22.784 | -36.502 | 32.210 | 1.791 |
| 10.5000 | -0.015 | -7.329 | -23.094 | -36.379 | 32.473 | 1.775 |
| 10.7000 | -0.015 | -7.737 | -23.415 | -36.235 | 32.721 | 1.761 |
| 10.9000 | -0.015 | -7.938 | -23.766 | -36.101 | 32.955 | 1.753 |
| 11.1000 | -0.015 | -7.862 | -24.143 | -35.997 | 33.189 | 1.738 |
| 11.3000 | -0.015 | -7.509 | -24.566 | -35.917 | 33.423 | 1.719 |
| 11.5000 | -0.016 | -6.824 | -25.080 | -35.897 | 33.643 | 1.714 |
| 11.7000 | -0.017 | -5.926 | -25.702 | -35.970 | 33.847 | 1.727 |
| 11.9000 | -0.018 | -4.969 | -26.440 | -36.157 | 34.035 | 1.762 |
| 12.0000 | -0.019 | -4.507 | -26.851 | -36.297 | 34.122 | 1.790 |

## Appendix 1.

This is the Touchstone™ run for simulating the amplifier operating at 900 MHz. The first printout shows the configuration. The first printout of amplifier performance is for source lead length of approximately 0 (as short as possible), the second for lead length of 0.1 inch (the optimum value).