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Cryogenic Performance of DRP 25-40 GHz MMIC Amplifier

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1. Introduction

This report describes the cooled performance of a two stage monolithic microwave integrated circuit (MMIC) amplifier (AMP73) designed by the MMIC Design and Test (MMIC D&T) group and fabricated by the GaAs Prototyping Facility at the CSIRO Division of Radiophysics (DRP). This device was not designed for cryogenic operation.

The amplifier unit supplied by the MMIC D&T group has 2.4mm connectors for the RF input and output. The gates and drains of the HEMTs in the MMIC are paralled, so there are only two feed throughs to bias the HEMTs.

Fig. 1 shows the predicted performance of the amplifier circuit. The amplifier was designed to operate in the band 30-40 GHz, with a noise minimum at 35 GHz. Fig. 2 shows the amplifier performance plots of the packaged device supplied by the MMIC D&T group. This amplifier was chosen because it is useable down to 25 GHz and can therefore be used on the existing noise measurement setup.

The cooled amplifier tests were done in two frequency bands: the first between 22 and 26 GHz confirmed that the amplifier still worked when cooled, and the second between 31 and 39 GHz where the amplifier performance was predicted to be good. The tests in the higher frequency band presented a considerable challenge as the receiver/downconverter used was optimized for the 37-39 GHz band, and some of the other components used had SMA connectors which do not work well above 26 GHz. As a consequence, the results presented here for the amplifier performance in the 31 - 39 GHz band are less accurate than I would like.

2. Amplifier Performance in the 22 - 26 GHz band

The cooled amplifier tests in the 22 - 26 GHz band confirmed that the amplifier still worked when cooled. The amplifier was tested at 15 K with a PAMTECH model PTH 1077K cryogenically coolable input isolator.

When the amplifier was cooled from 300 K to 15 K, the gain at 25 GHz increased from 10 dB to 15 dB, and the noise figure at 25 GHz decreased from 6.5 dB to 2.8 dB (the noise temperature decreased from 1000 K to 250 K). The room temperature noise figure compares well with the simulation, Fig. 1, which predicts a noise figure of 6 dB at 25 GHz.

3. Test Setup for merasurement in the 31 - 39 GHz band

An amplifier/mixer receiver was used to measure the amplifier performance in the 31 - 39 GHz band. The lower sideband image reject mixer works at the second harmonic of the local oscillator and the IF output of the mixer was at 1 GHz. Although the receiver was designed to work with a local oscillator of 19 - 20 GHz, a range of 16 - 20 GHz was required to measure the amplifier performance in the 31 - 39 GHz band. As the receiver input is not well matched over the 31 - 39 GHz band, a waveguide input isolator was used. A waveguide to 2.4 mm coaxial adapter was used to couple the amplifier output into the isolator and receiver. Fig. 3 shows the noise figure of the receiver plus noise figure meter. Note that the receiver noise figure increases sharply at frequencies below 34 GHz.

To measure the noise figure at, say, 38 GHz, with a lower sideband conversion and an IF of 1 GHz, the local oscillator needs to be set to 19.5 GHz. The noise figure meter controls the local oscillator, but as the noise figure meter can not be programmed for a harmonic mixer, we must select the measurement frequency so the noise figure meter will set the correct local oscillator frequency. Thus, to measure the noise figure at, say, 38 GHz, the noise figure meter is asked to measure the noise figure at an RF frequency of 18.5 GHz. The measurement range of 31 - 39 GHz corresponds to a noise figure meter range of 15 - 19 GHz.

The noise diode used was a Noise Com model NC5128 waveguide noise source with a waveguide to 2.4 mm coaxial adapter. Initally it was found that there was a large periodic variation in the measured noise figure of the amplifier. When the output of the noise source was reduced, using a 10 dB pad (with 2.9 mm connectors), the size of the periodic variation in the measured noise figure was reduced. The losses in the waveguide to coaxial adapter and pad were measured by Graham Smith and Aisling Fitzpatric using an HP8510 network analyser. The loss of the waveguide to 2.4 mm coaxial adapter was 0.15 dB, and the loss of the 10 dB pad with 2.4 mm to 3.5 mm adapters was 10.4 dB.

The ENR of the noise source was corrected for these losses and entered into the noise figure meter at the appropriate frequency – for example, the corrected ENR at 38 GHz was entered as the ENR at 18.5 GHz.

4. Amplifier Performance in the 31 - 39 GHz band

Initially the amplifier was connected directly to the test setup. Fig. 4(a) shows the room temperature gain and noise figure of the amplifier at V_{DS} = 3 V and I_D = 20 mA. The minimum noise figure was 4.5 dB at 34 GHz, with an associated gain of about 9 dB. The gain ripple seen in Fig. 4(a) is probably due to missmatches in the measurement system.

The amplifier was then placed in a dewar to measure its performance at cryogenic temperatures. Fig. 4(b) shows the room temperature gain and noise temperature of the amplifier in the dewar. The test signal was coupled in and out of the dewar using hermetic SMA coaxial feedthroughs and copper lined, stainless steel input and output coaxial lines with SMA connectors. The noise on the traces of Fig. 4(b) is attributed to the poor return loss of the SMA connectors on the feedthroughs and coaxial lines. The measurements of Fig. 4(b) have been corrected assuming a 2 dB loss in the input hermetic feedthrough and coaxial line, and a 5 dB loss in the output. The value assumed for the output may be a little high, but I was trying to show a midband gain of about 9 dB, which is the gain I measured on the bench.

The losses in the hermetic feedthrough and input coaxial line were measured by Graham Smith and Aisling Fitzpatric using an HP8510 network analyser which had been calibrated using 2.4 mm connectors. The results are shown in Fig. 5. Between 25 and 35 GHz the measured attenuation of the coaxial line is higher than might be expected, but the input and output return losses are less than 10 dB, so some of the loss may be due to reflection, and not absorbtion, of the incoming power. I have used a simple expression (1) to approximate the loss in the input coaxial line.

$$L = 0.2 + 0.36*F \qquad (1)$$

where frequency, F, is in GHz and loss, L, is in dB.

The measurement of the hermetic feedthrough (Fig. 5(b)) included the loss in two 2.4 mm to 3.5 mm adapters. An SMA female-to-female adapter was measured at the same time as the hermetic feedthrough, and the measured attenuation of the adapter is also indicated in Fig. 5(b). The loss of the hermetic feedthrough was taken to be the difference between these two measurements.

Fig. 6 shows the measured loss of the hermetic feedthrough plus the loss in the input coaxial line given in (1), which will be referred to as the *measured total loss*, and a loss derived by comparing the noise figures measured on the bench and in the dewar, which will be referred to as the *estimated total loss*. I would expect these two estimates to agree if the RF path were well matched. Fig. 6 also shows the total loss we would derive if we were to assign a fixed loss of 0.6 dB to the hermetic feedthrough.

When the amplifier was cooled to 15 K, the amplifier noise figure was derived by correcting the noise figure measured at the flange dewar for the losses in the hermetic feedthrough and the input coaxial line. The loss in the input coaxial line is expected to decrease to 0.67 of its loss at room temperature, and to be at an average temperature of 155 K. The loss in the hermetic feedthrough is the same as it is at room temperature.

I have described three possible estimates of the total loss between the dewar flange and the amplifier, and each of these can be used to correct the dewar flange noise figure of the cooled amplifier. Plots of the resulting noise figure estimates are shown in Fig. 7.

The larger the loss corrected for, the better the amplifier looks. The loss of the hermetic feedthrough inferred from the estimated total loss is negative at some frequencies, but around 36 GHz, the measured total loss is much higher than the estimated total loss. I believe that Fig. 7(c), where we were to attribute a fixed loss of 0.6 dB to the hermetic feedthrough is the best estimate of the noise figure of the cooled amplifier.

The measurements described above were made with V_{DS} = 3 V and I_D = 20 mA. While the amplifier was operating at 15 K, the drain current was increased to 22 mA and decreased to 15 mA. In both cases the noise figure increased by about 1.5 dB.

5. Conclusion

These tests have shown that the device technology supplied by the MMIC D&T group can be successfully cooled. When the amplifier was cooled, the gain increased and noise figure decreased. More accurate results could have been obtained if the coaxial connectors used in the test setup had all been 2.4 mm connectors and a broader bandwidth receiver/mixer had been used.

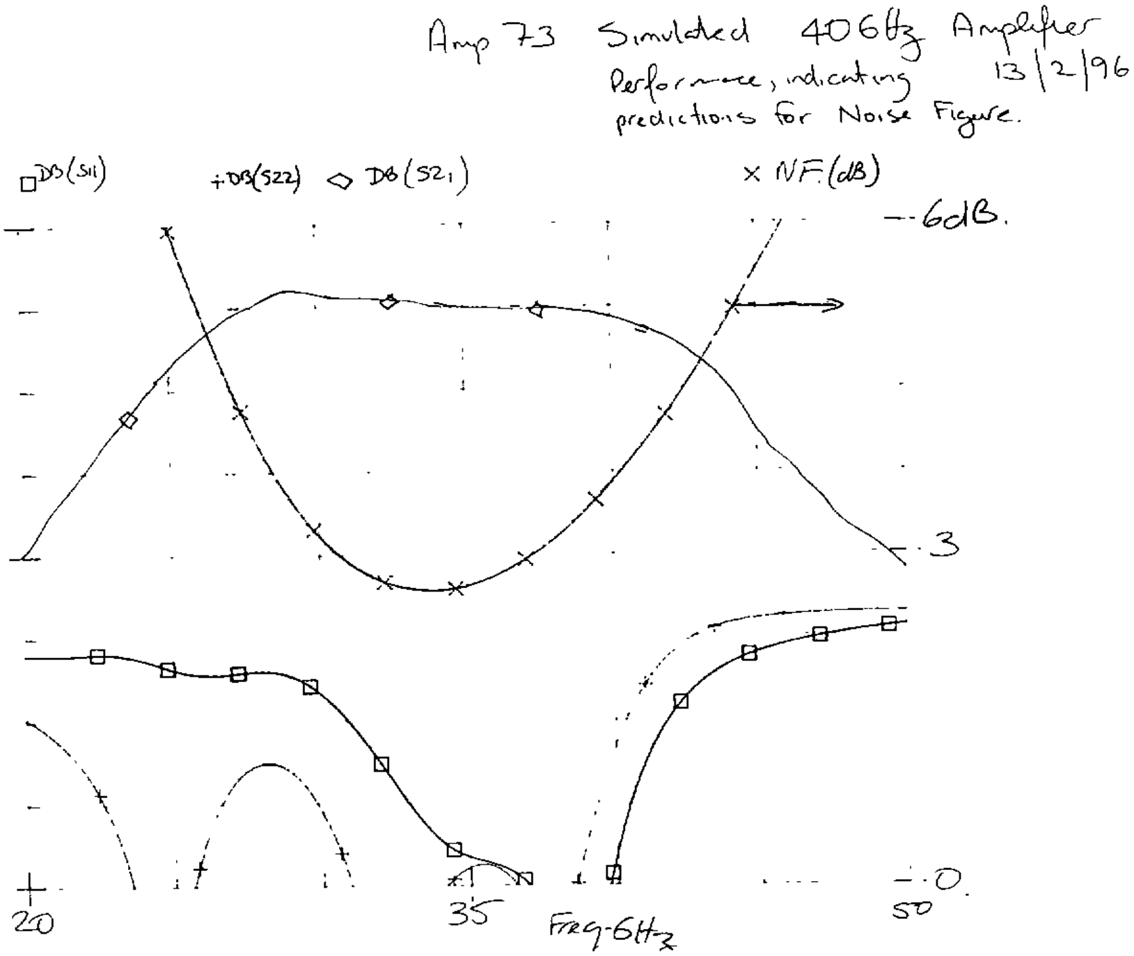


Fig. 1. Predicted performance of the amplifier.

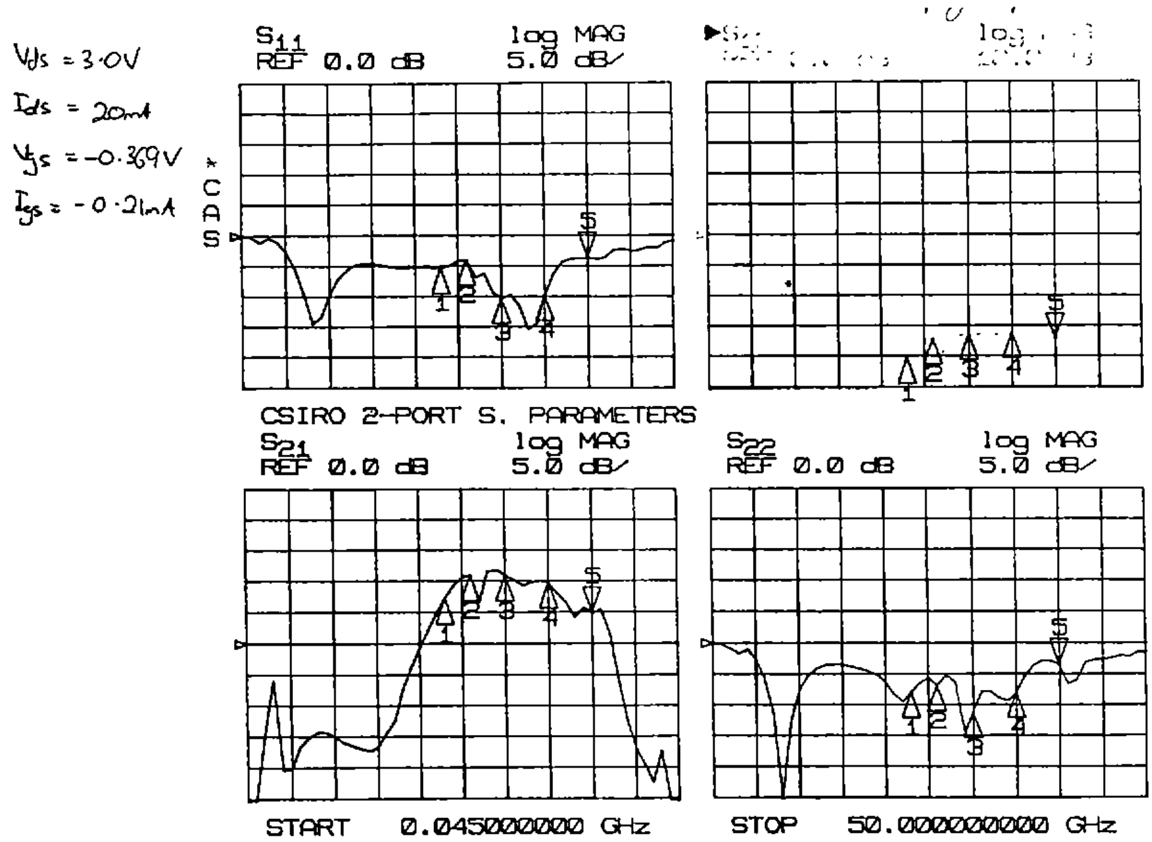


Fig. 2. Amplifier performance plots supplied by the MMIC D&T group (V_{DS} =3 V, I_D = 20 mA).

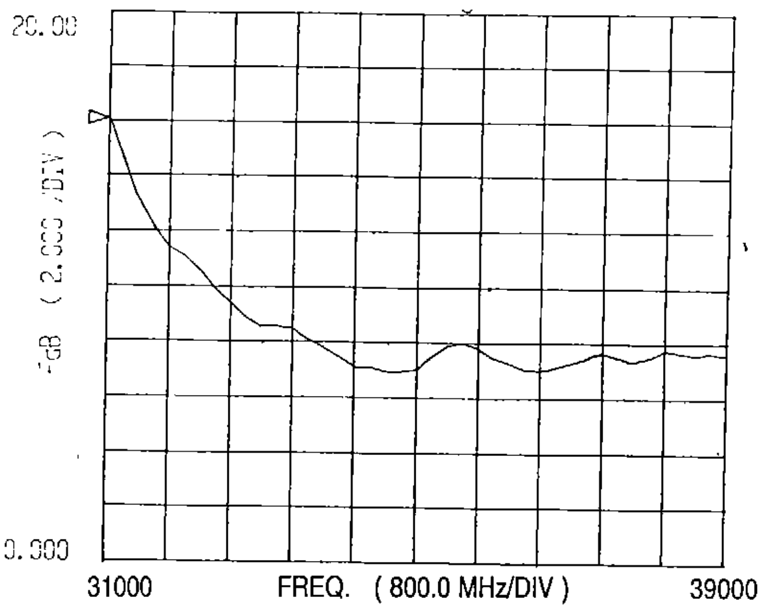
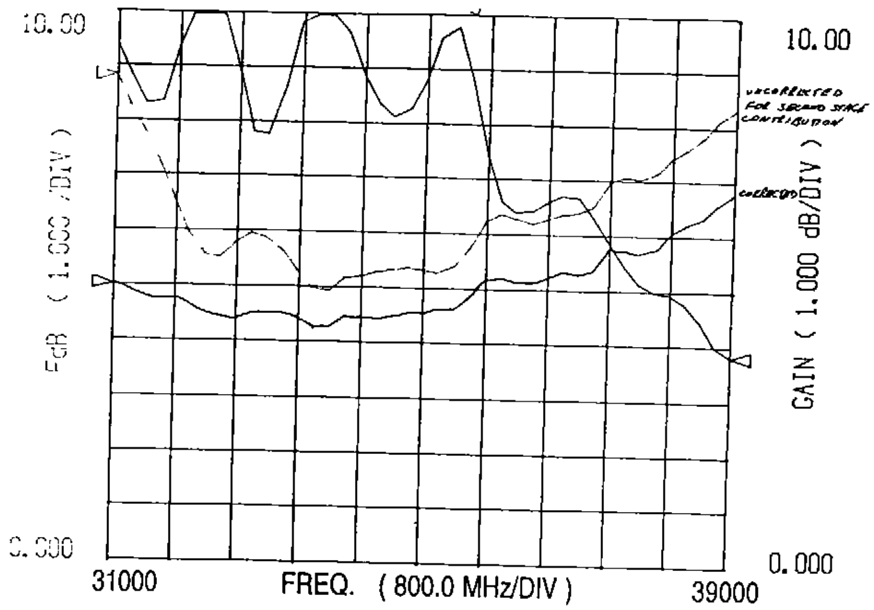
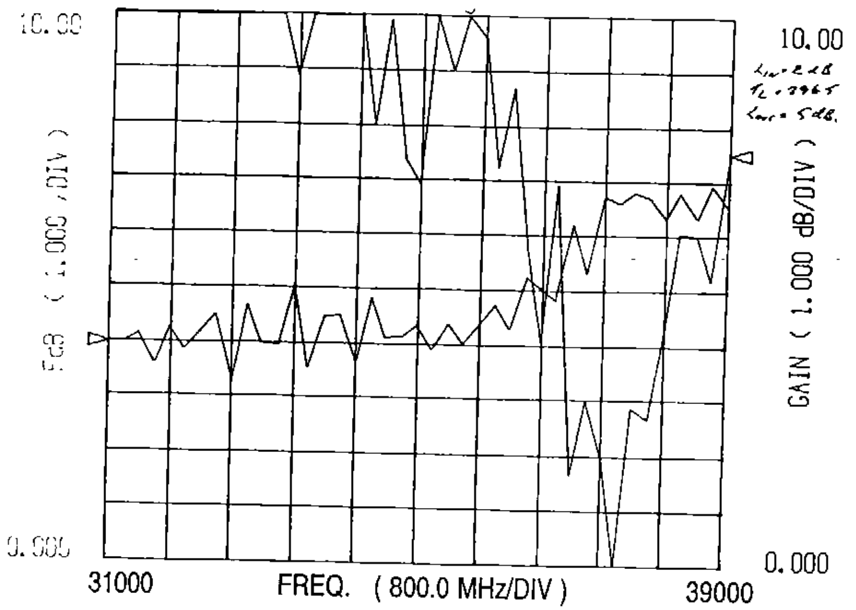


Fig. 3 Noise figure of the receiver plus noise figure meter.

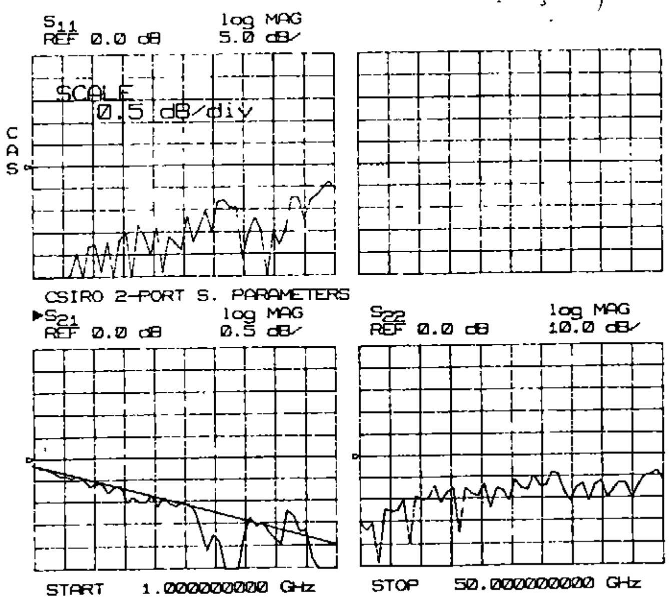


(a)

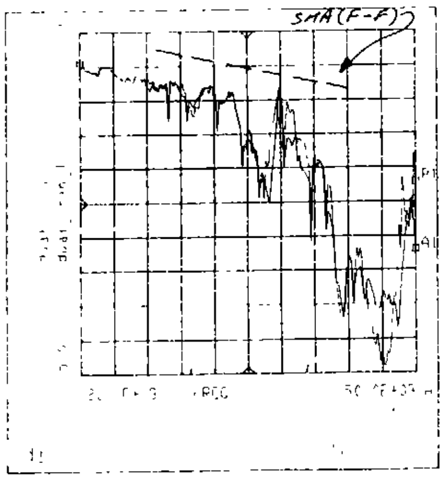


(b)

Fig. 4 Room temperature gain and noise figure of the amplifier at $V_{DS} = 3$ V and $I_D = 20$ mA.
(a) On bench
(b) In dewar
(input loss correction = 2 dB, output loss correction = 5 dB)



(a)



(b)

Fig. 5 Losses measured using an HP8510 network analyser
(a) input coaxial line
(b) SMA hermetic feedthrough.

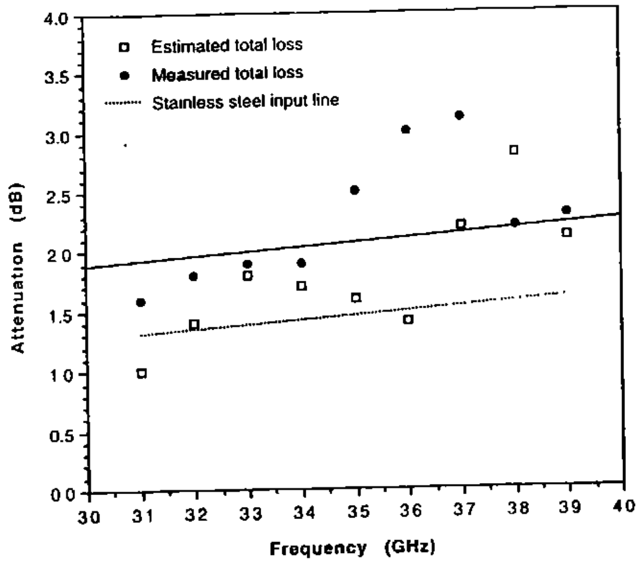
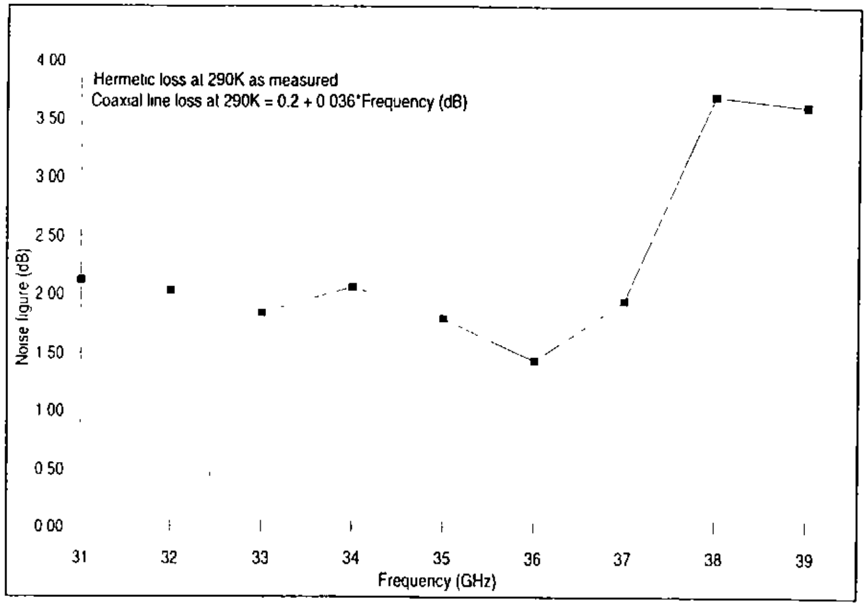
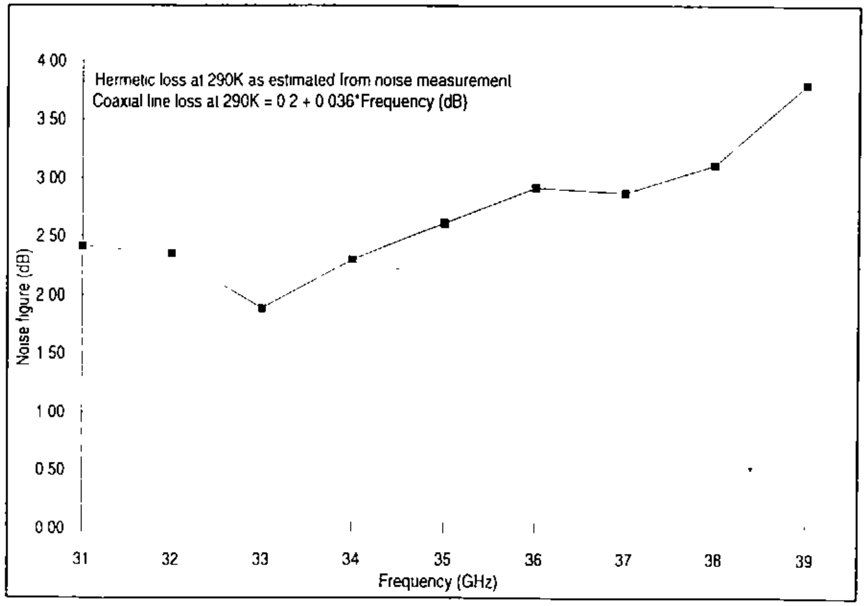


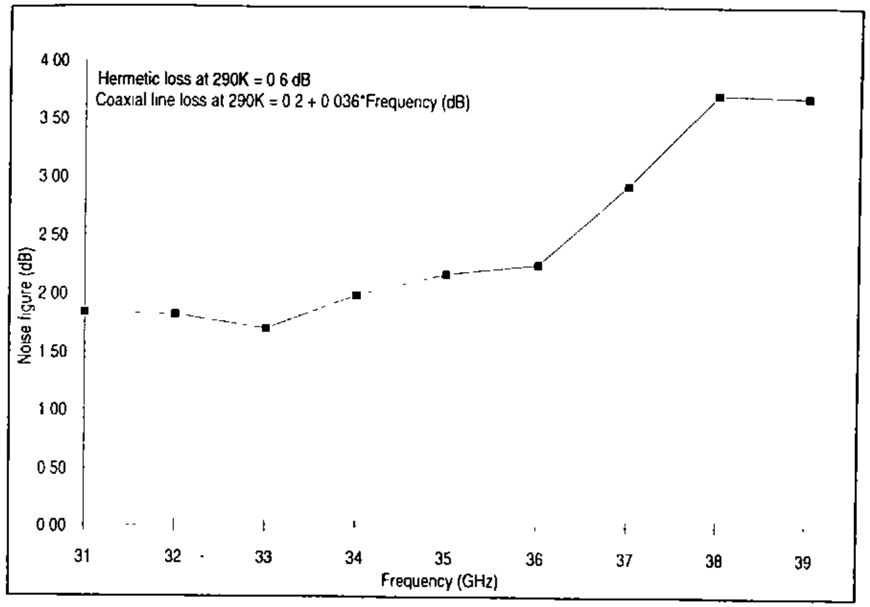
Fig. 6 Measured total loss of the hermetic feedthrough plus the loss in the input coaxial line given by (1),
estimated total loss, derived by comparing the noise figures measured on the bench and in the dewar, and
a total loss derived by assigning a fixed loss of 0.6 dB to the hermetic feedthrough.
Also shown is the approximation to the loss in the input coaxial line given by (1).



(a)



(b)



(c)

Fig. 7 Noise figure of amplifier operating at 15 K, with loss correction based on
(a) measured total loss of the hermetic feedthrough plus the loss in the input coaxial line given in (1),
(b) estimated total loss, derived by comparing the noise figures measured on the bench and in the dewar
(c) total loss if we were to attribute a fixed loss of 0.6 dB to the hermetic feedthrough and use (1) to estimate the loss in the input coaxial line.