CRYOGENIC PERFORMANCE OF MONOLITHIC AMPLIFIERS FOR 85–115 GHz

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Abstract

MMIC amplifiers designed for low noise room temperature operation at 100 GHz have been tested at 13–25 K over the 85–115 GHz range. All measurements have been made in waveguide test fixtures in which a short length of either microstrip or CPW line connects a waveguide probe to the amplifier input terminals. A scalar feed horn and dewar window complete the input circuit. The lowest noise temperature measured has been 110 K at 103 GHz, with no correction for input loss. Better results are expected with other chips from this batch and with improvements in the input circuit.

Introduction

Cryogenic HEMT amplifiers have achieved noise temperatures nearly as low as any of the competitive techniques (including masers) at frequencies up to 50 GHz. These amplifiers are far easier to use than any of the alternatives, and so are preferred for almost all applications. Recently, very good room temperature results have been reported with monolithic amplifiers for the 100 GHz range, and these suggested that the cryogenic performance could be exceptional. These amplifiers have now become available in sufficient numbers that they could be used in a fairly large array receiver, and the ease of use makes such a receiver practical.

We have evaluated the cryogenic performance of one batch of monolithic amplifiers for the 100 GHz range. The amplifiers were built at Martin–Marietta Labs, and tested at the FCRAO at UMass. The amplifiers use four gain stages, each a 0.1 μm gate length AlGaAs/InGaAs/GaAs pHEMT [1], with all interconnections using grounded CPW line on a 100 μm substrate. Via holes at less than quarter wave spacing are used to prevent substrate modes. The chips are wired with all drains connected to a common terminal, while the gates may be biased separately. While the evaluation is still ongoing, the initial tests of these amplifiers are very encouraging. We have tested several devices at cryogenic temperatures, and all have operated with comparable performance. Four devices were in carriers built by Martin–Marietta, while two have been in a mount designed at FCRAO for these tests. In both the amplifier has waveguide inputs and outputs, with probe transitions to either 50 ohm CPW line or 50 ohm microstrip.

The waveguide to CPW transitions were built on GaAs, as with the rest of the chip so that matching to the MMIC was easy. However, the high dielectric constant made the transition to waveguide difficult at 115 GHz (with WR–10 waveguide), and the VSWR over the full band was not very low. This degrades the noise outside the 100–115 GHz range.

The waveguide to microstrip transitions use 0.13 mm duroid substrates aligned along the E plane of the waveguide. They were designed with the aid of the Hewlett Packard HFSS program, and worked exactly as designed, with a VSWR < 1.2 from 85–115 GHz. This mount is shown in Fig. 1. The transition from microstrip to CPW is predicted to be have a low VSWR, but the HFSS program shows that there is a potential for a resonance in the gap where the microstrip box meets the CPW. This can be suppressed by bridging the CPW ground plane over to the box around the microstrip.

The minimum noise temperature measured so far (in the mount with the duroid probes) is 110 K at 103 GHz (including window loss and second stage contributions) at a physical temperature of 13 K. The peak gain is about 30 dB. These results are shown in Fig. 2. The noise is higher than projected for optimized devices at this frequency (about 50 K), but these may not represent the best results obtainable. This same amplifier had a noise temperature of 160 K at 109 GHz at a physical temperature of 25 K, when measured earlier, with the results shown in Fig. 3. In between these measurements the amplifier suffered some damage that affected its tuning, and thereafter the optimum frequency was lowered by $\sim$7 GHz. However, in this process the minimum room temperature noise was unaffected, so the most likely explanation for the lower noise in the later measurements is the lower physical temperature. However there is also the possibility that some other problem affected the poorer set of data such as an out–of–band oscillation. This

amplifier shows a significant variation in the optimum bias with frequency. The results of Fig. 3 are for optimum bias at each frequency, while Fig. 2 is for fixed bias (set for minimum noise at 103 GHz). At extreme frequencies varying the bias is quite important; in the data in Fig. 3, if the bias is optimized at 112 GHz, then the noise at 85 GHz is 400 K (rather than 280 K as shown with optimum bias).

The minimum measured noise temperature of an amplifier with the CPW probes is 127 K at 109 GHz, at a physical temperature of 25 K. The dewar window and the following mixer add very little noise (1–3 K each), but the input CPW transition plus the waveguide and horn have a loss of ~0.8 dB (all at 25K) which is difficult to accurately measure. Assuming this loss, the noise of the amplifier referenced to its input is ~100 K. If this amplifier were cooled further to 13 K with results similar to the amplifier above, the expected noise would be 70 K. This suggests that there may be a some variation in performance between amplifiers. The gain peaks at 100 GHz, with 27 dB available at minimum noise bias. Illumination has only a small effect, which varies with frequency.

The MMIC is followed by a low noise cooled mixer with a tunable LO. This mixer has an IF of 1.15 GHz, so there is some loss of detail in the performance vs frequency, and a tendency for the noise data to be weighted toward the sideband with higher gain. The amplifier is preceded by a scalar feed horn and a very low loss vacuum window made of a sandwich of plastic film and GoreTex fabric. The noise temperature is measured using hot and cold loads outside this window.

The present technology for building monolithic amplifiers makes it difficult to predict the exact parameters that will be achieved with the HEMTs, particularly gate capacitance, and other circuit parameters have some potential variation. Thus the design of a monolithic amplifier for a precise application can involve some trial and error. It seems practical (and much less expensive) at present to take amplifiers whose performance is close to our needs, and then modify them. Such modifications are possible because typical circuit dimensions on these chips are reasonably large (1–2 mils), and cutting conductors and adding bond wires is well within the range of microassembly techniques. The advantage of starting with a MMIC is that nearly all of the circuitry can be used, saving considerable effort. Work now is aimed at characterizing the noise of these existing amplifiers, to see if it can be improved over much of the 85–115 GHz range. This characterization is done by presenting the amplifier with a known mismatch, in this case produced by a .020" thick plug of teflon in the waveguide ahead of the amplifier. The noise is measured at several positions of this plug (which is actually an impedance transformer), and the results fit to the standard four parameter noise model. Data for one amplifier is shown in Fig. 4, with the raw data in the upper graph, and the minimum

possible noise temperature in the lower. The smooth behavior in the minimum noise shows that this technique works very well, since data at each frequency is independent. The scatter in values is an indication of the errors in the fit. The other three noise parameters are uniquely determined as well, with similar accuracy.

In order to improve the wideband noise, it is necessary to eliminate some of the line length ahead of the first HEMT. In these chips, this extra line has little effect on the noise, since it is close to 50 Ω, but is $\lambda/2$ long. This line can simply be sawed off, without too much extra complexity in the use of the chip, except that it is necessary to provide a new gate bias connection. The process is essentially the same as building the input network for a discrete amplifier, except that we can use part of the existing input circuit, which makes assembly easier. We have successfully sawed off one chip, and installed it in a test block with gate bias. This chip operated much as expected except for a tendency to oscillate. Minimum noise was ~115 K at 117 GHz, but this might not be optimum because of the constraints on bias needed to prevent oscillation. Noise at lower frequencies showed a monotonic increase. In the process of stopping the oscillation, the chip was damaged, so no conclusive results were obtained.

Based on a preliminary analysis, a modified amplifier could have significantly flatter noise from 100 to 115 GHz, with a value close to the present minimum. For lower frequencies, down to 90 GHz, there should be some improvement, while noise at 85 GHz may be unchanged. Varying the bias should reduce the noise at 85 GHz down to ~200 K. This should largely meet the needs of radio astronomers, for whom the most important frequencies are 108–115 GHz. Other frequencies are used much less of the time.

Conclusions

Monolithic amplifiers have demonstrated low noise operation over moderate bandwidths in the 3 mm region. Noise temperatures below 100 K are expected with optimized input tuning. The amplifiers are fairly easy to use, and may be modified to tune over wider bandwidths. Gain is high enough over most of the band that they may be followed by relatively noisy mixers.

Acknowledgements

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Reference

[1] "High Gain Monolithic pHEMT W–band Four–stage Low Noise Amplifiers," D–W Tu, W.P. Berk, S.E. Brown, N.E. Byer, S.W. Duncan, A. Eskandarian, E. Fisher, D.M. Gill, B. Golja, B.C. Kane, S. Svensson, and S. Weinreb, to be published in *1994 IEEE Microwave and Millimeter Wave Monolithic Circuits Symposium*, San Diego, May 1994.

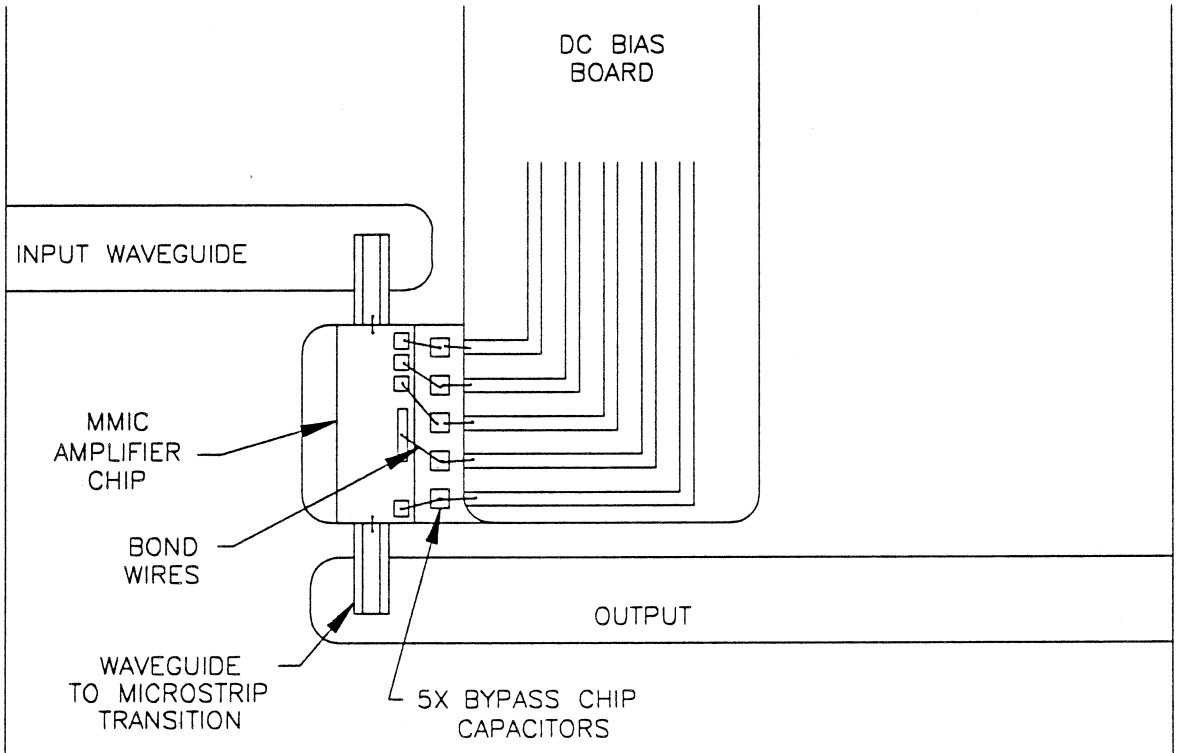

FIG. 1
100 GHz MMIC AMPLIFIER

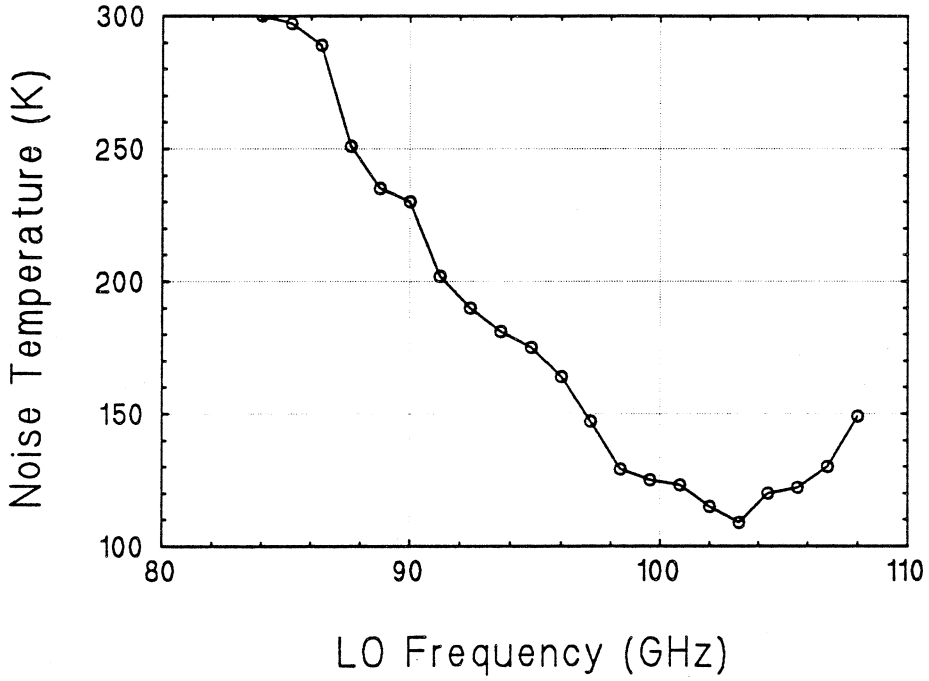

Fig. 2 Noise temperature of MMIC amplifier at 13 K. No corrections have been made for input losses or second stage contribution. Bias is fixed at all frequencies.

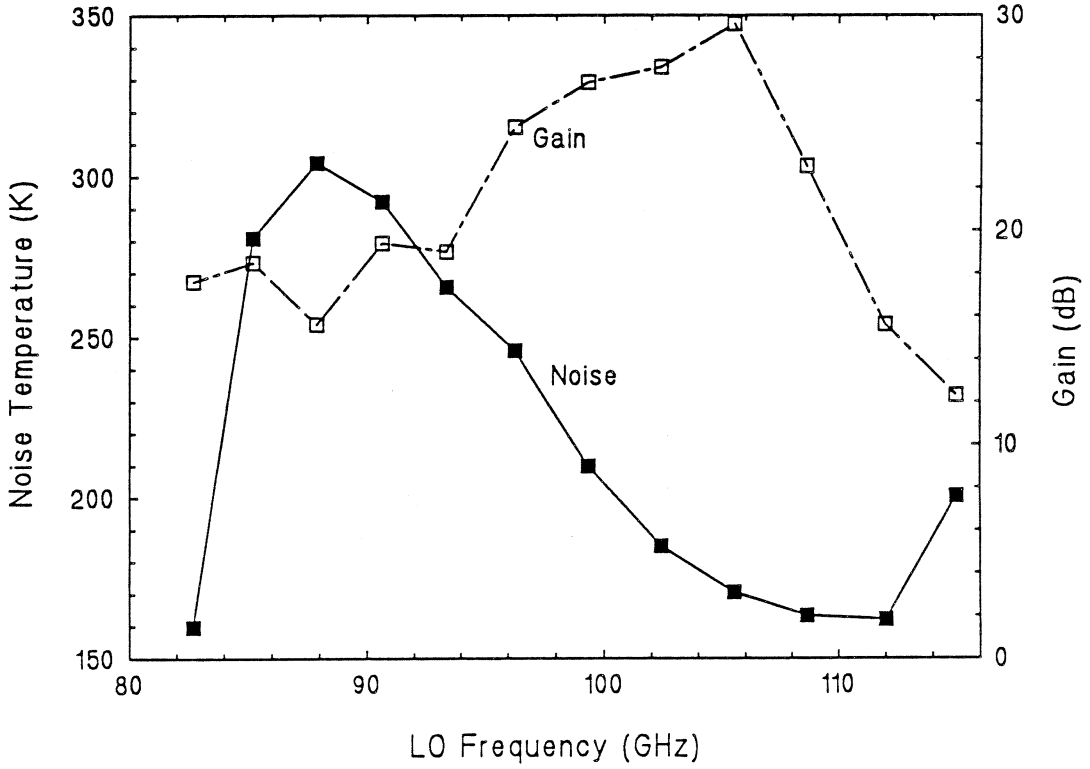

Fig. 3 Noise temperature and gain of MMIC amplifier at 25 K. Bias optimized at each frequency for minimum noise. No correction for input loss or second stage.

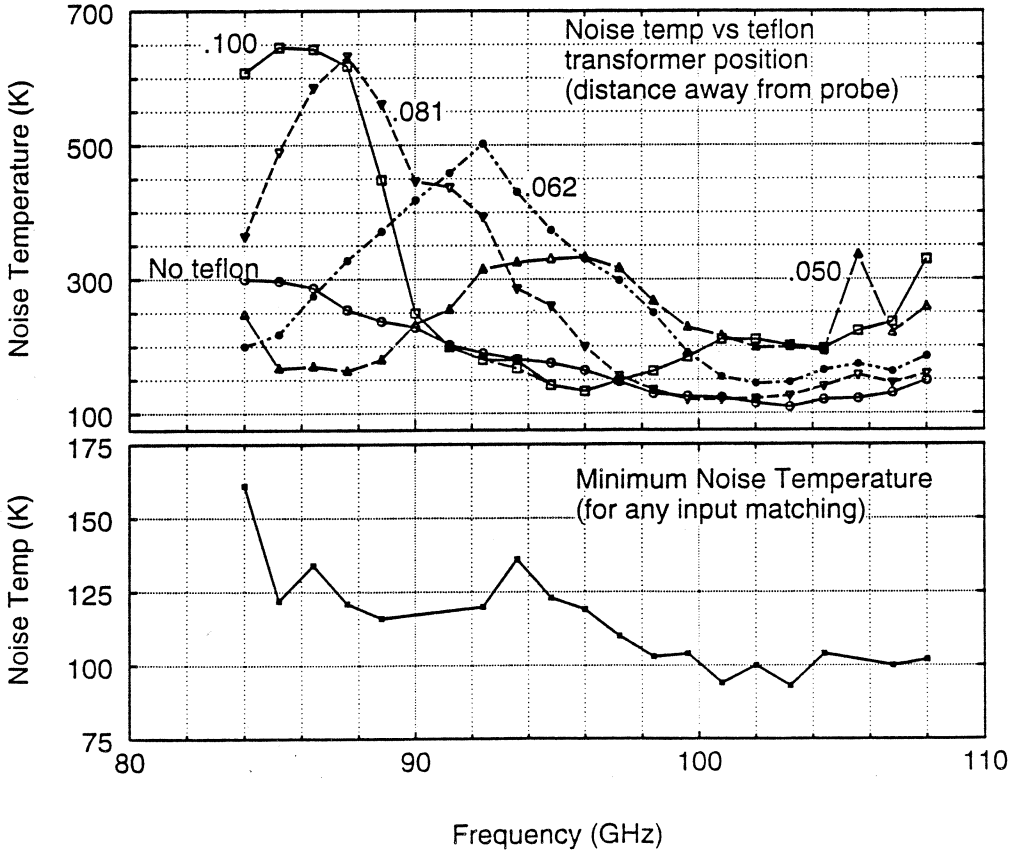

Fig. 4 Upper graph: Noise temperature of MMIC amplifier for various positions of an input transformer consisting of a $\lambda/4$ teflon slab.
Lower graph: Derived minimum noise temperature of amplifier for any input matching network. Graph includes corrections for second stage, but not for input loss.