

12. Microwave and Millimeter Wave Techniques

Academic and Research Staff

Prof. B.F. Burke, Prof. R.L. Kyhl, Dr. D.H. Roberts

Graduate Students

B.R. Allen, C.L. Bennett, A.C. Briancon, J.A. Garcia-Barreto, P.E. Greenfield, J.N. Hewitt, V. Dhawan, C.R. Lawrence, J.H. Mahoney

12.1 Cooled FET Amplifiers at 8 and 15 GHz

National Aeronautics and Space Administration (Contract NAG3-215)

Bernard F. Burke

MESFETS increasingly dominate the microwave amplifier field. The inherently low noise of the field effect is aided by the fact that majority carrier devices can operate at cryogenic temperatures with a 3 to 4 fold reduction in noise.¹⁻⁹ The operating frequencies for this study were chosen for their interest to radio astronomy. Specifically, 8.45 GHz is the proposed frequency for space VLBI,¹⁰ and 15 GHz is of importance for background radiation observations.¹¹

The astronomical requirements of over 1 GHz bandwidth and under 100° K noise temperature are challenging design goals in the intermediate step of fabricating a reliable, cryogenically cooled low noise FET amplifier. The amplifier doubles as a test jig in the experimental study of FET gain and noise properties at high frequencies and low temperatures. Design features include easy device replacement and alternate versions for chip and packaged transistors to enable comparative study. For packages, duroid (teflon) substrate and solder connections are employed; the chip version is functionally identical, but eliminates solder joints and uses quartz substrate for the microstrip circuits. Impedances are tunable over a wide range, using broadband open-circuited stub lines. Substrate processing techniques including vacuum evaporation, plating and photolithographic etching were developed to enable rapid realization of any desired microstrip pattern.

The conclusions drawn are as follows: packaged transistors feature easy handling but suffer from parasites and from unpredictable thermal behavior. Solder joints are occasional failure sites when thermally cycled, but special alloy solders can eliminate this problem. Chips have no package parasitics and are in direct thermal contact with the cold stage. However, the necessary bonding procedures are complex and have low yield since bare FETs are easily degraded by mishandling. The peeling of metallization off the bonding pads when thermally cycled (between 300° K and 20° K) seems to be a persistent problem. Accurate characterization of scattering and noise parameters is

difficult on existing equipment. For packaged transistors at 8 – 9 GHz,¹³ where network analyzer data is reliable, the results are as follows: T_{\min} , the minimum noise temperature, is reduced by a factor of 3 on cooling most FETs from 300° K to 77° K; Z_{opt} ($= R_{\text{opt}} + j X_{\text{opt}}$), the input impedance for realizing T_{\min} , has its real part (R_{opt}) decreased by a factor of 1.5 – 2 and its imaginary part (X_{opt}), approximately unchanged; the noise conductance (g_n) is halved, which reduces the sensitivity of noise temp T to deviations of input impedance $Z (= R + j X)$ from Z_{opt} , via the equation $T = T_{\min} + T_o \frac{g_n}{R} |Z - Z_{\text{opt}}|^2$ (T_o is the ambient temperature). Similar behavior is found at 15 GHz, but some varieties of device show much less improvement, for reasons as yet uncertain. Extensive study of a variety of transistors including more accurate impedance and noise measurement is needed to separate the contributions and identify the temperature dependences of the various known FET noise mechanisms.

This study involved devices with 1/2 micron gate lengths. New devices with 1/4 micron gates, soon to be available, will be active well beyond 30 GHz. These will require precision circuit techniques and measurements for the full realization of their potential.^{14,15}

References

1. R. Pucel, H. Haus, and H. Starz, "Signal and Noise Properties of Gallium Arsenide Microwave Field Effect Transistors," Advances in Electronics and Electron Physics, (Academic Press, New York, 1975).
2. W. Baechtold, "Noise Behavior of Ga-As FETs with Short Gate Lengths," IEEE Trans. Electron Devices **ED-19**, 5, (1972).
3. H. Fukui, "Optimal Noise Figure of Microwave Ga-As MESFETs," IEEE Trans. Electron Devices **MTT-27**, 7, (1979).
4. H. Fukui, "Design of Microwave Ga-As MESFETs for Broadband Low-noise Amplifiers," IEEE Trans. Microwave Theory Tech. **ED-26**, 7, (1979).
5. S. Weinreb, "Low Noise Cooled Ga-As FET Amplifiers," IEEE Trans. Microwave Theory Tech. **MTT-28**, 10, (1980).
6. C. Liechti and R. Larrick, "Performance of Ga-As MESFETs at Low Temperatures," IEEE Trans. Microwave Theory Tech. **MTT-24**, 1, (1976).
7. D. Williams, W. Lum, and S. Weinreb, "L-Band Cryogenically Cooled Ga-As FET Amplifiers," Microwave Journal **23**, 10, (1980).
8. S. Weinreb, D. Fenstermacher, and R. Harris, "Ultra-Low Noise 1.2 to 1.7 GHz Cooled Ga-As FET Amplifiers," IEEE Trans. Microwave Theory Tech. **MTT-30**, 6, (1982).
9. G. Tomasetti, S. Weinreb, and K. Wellington, Electronics Division Internal Report No. 222, National Radio Astronomy Observatory, Charlottesville, Virginia.
10. R.A. Preston, et al., "The Future of VLBI Observatories in Space," M.I.T. Radio Astron. Contributions, 1982, No. 5.
11. R. Weiss, "Observations of the Cosmic Microwave Background," Annual Rev. Astron. Astrophys., 1982.
12. C.H. Oxley, et al., "Q-Band Microstrip Techniques," IEEE Colloquium Digest, January 1982.
13. A.C. Briançon, "A 8.45 GHz Ga-As FET Amplifier," S.M. Thesis, Department of Electrical Engineering and Computer Science, M.I.T., May 1983.
14. C.H. Oxley, A. Peake, and R. Bennett, "Q-Band Ga-As FET Single Stage Amplifier," Electron.

14. C.H. Oxley, A. Peake, and R. Bennett, "Q-Band Ga-As FET Single Stage Amplifier," *Electron. Lett.* 18, 6, (1982).
15. H. Mizuno, "Ga-As FET Mount Structure Design for 30 GHz-Band Low Noise Amplifiers," *IEEE Trans. Microwave Theory Tech.* MTT-30, 6 (1982).

