A MONOLITHIC Ka-BAND HEMT LOW-NOISE AMPLIFIER

C. Yuen, C. Nishimoto, M. Glenn, Y. C. Pao, S. Bandy and G. Zdasiuk

Varian Research Center
Device Laboratory
Palo Alto, CA 94303

ABSTRACT

A monolithic, single-stage HEMT low-noise amplifier has been developed for the 20-40 GHz band. This amplifier includes a single 0.25-µm gate-length HEMT active device with on-chip matching and biasing circuits. A gain of approximately 6 dB from 20 to 38 GHz and a noise figure of approximately 5 dB from 26.5 to 38 GHz were measured. These are the best reported results for a millimeter-wave amplifier over this bandwidth. The chip size is 2.2 mm x 1.1 mm.

INTRODUCTION

HEMTs have demonstrated their superior gain and noise figure performance over conventional MESFETs [1-3]. State-of-the-art gain and noise performance has been achieved from monolithic amplifiers [4] and from hybrid amplifiers [5] using HEMTs at frequencies below 20 GHz. In the Ka-band, reports were made on the monolithic amplifiers using MESFETs as active devices [6-8] and hybrid amplifiers were developed using HEMT devices for low-noise applications [10-12].

This paper describes the first monolithic, reactively-matched Ka-band low-noise amplifier using a 0.25-µm HEMT as the active device. The amplifier has achieved approximately 6-dB gain from 20-38 GHz and a 5-dB noise figure from 26.5-38 GHz, the best results reported to date.

DEVICE CONSIDERATIONS

Figure 1 shows the HEMT epitaxial growth structure used in this amplifier. These

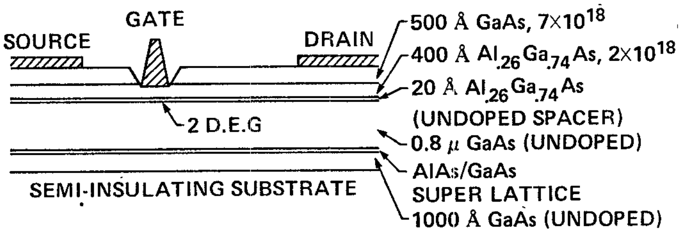

Fig. 1 Cross section of HEMT device.

HEMT layers were grown by MBE at 580°C on GaAs which was unintentionally doped n-type at about 1 x $10^{14}/cm^3$. A five-period AlAs/GaAs superlattice is grown midway into the buffer layer in an attempt to reduce dislocations and improve surface morphology.

Figure 2 shows the equivalent circuit model for a discrete 0.25 x 150-µm gate-length HEMT biased for minimum noise figure. The gate is π-configured and the source-drain

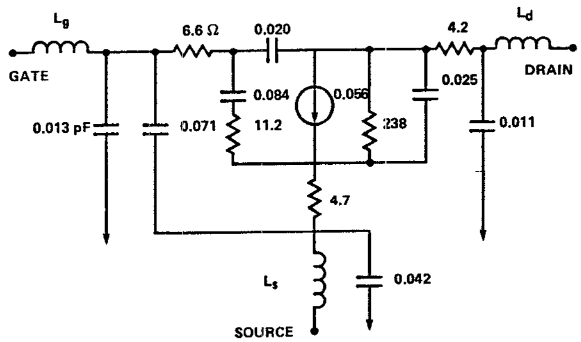

Fig. 2 Equivalent circuit model of 0.25 x 150-µm HEMT device biased for minimum noise condition.

IEEE 1988 Microwave and Millimeter-Wave Monolithic Circuits Symposium

spacing is 2.5 µm. The device was first characterized by the s-parameter measurements in the common-gate, common-source and common-drain configurations from 2-18 GHz. An equivalent circuit model is then constrained to fit the three sets of data.

This 0.25 x 150-µm HEMT has a measured minimum noise figure of 1.4 dB and associated gain of 12 dB at 18 GHz. The predicted F_{min} is 2.74 dB at 40 GHz. A MAG of 9 dB was measured at 38 GHz.

CIRCUIT DESIGN

A 20-40 GHz reactively-matched amplifier was designed using a single 0.25 x 140-µm HEMT. Figure 3 shows the schematic layout of this amplifier which uses shunt-shorted stubs and transmission lines as the input and output matching elements. The electrical lengths of the transmission lines are given at 40 GHz. Fifteen design parameters, including the matching and biasing circuit elements along with the gate periphery, were optimized for a maximum flat gain performance from 20 to 40 GHz using SUPERCOMPACT. The impedance of the matching elements was constrained to be within the range from 30 to 90 ohms for the purposes of practical realization and an acceptable loss. A simulated gain of 6.5 dB from 20 to 40 GHz was obtained, as shown by the dashed curve in Fig. 5.

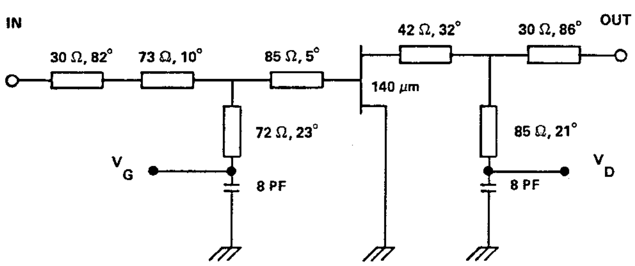

Fig. 3 Schematic circuit diagram for monolithic Ka-band amplifier. The electrical lengths of the transmission lines are given at 40 GHz.

AMPLIFIER FABRICATION

Standard processing techniques were used for most of the Ka-band HEMT amplifier fabrication. Isolation was achieved with a 2500 Å mesa etch. The 0.25-µm gate was written with a Cambridge EBMF 10.5 E-beam machine using PMMA resist. Sputtered SiO_2 layer of 2000 Å was used as the capacitor dielectric material. In order to achieve good RF grounding, 60 x 60-µm backside vias were incorporated using reactive ion etching. All other process steps used conventional metallization, liftoff and pulse-plating techniques.

Figure 4 shows a photograph of the Ka-band amplifier. The chip size is 2.2 x 1.1 mm, and the layout of the circuit is compatible with the Cascade Microtech RF wafer-probing technique.

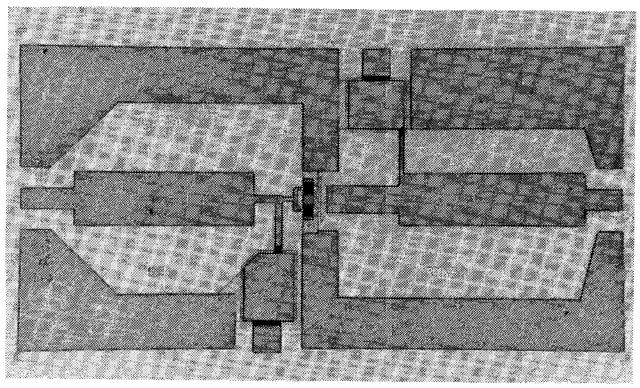

Fig. 4 Photograph of monolithic Ka-band amplifier. Chip size: 2.2 x 1.1 mm.

MEASURED GAIN PERFORMANCE

A gain of approximately 6 dB from 20-38 GHz (biased at V_d = 3V, V_g = -0.3V and I_{ds} = 15 mA) was measured using the Cascade Microtech RF wafer prober, as shown in Fig. 5. There is a measurement discontinuity at 26.5 GHz, where the measurement apparatus was changed. Measurement below 26.5 GHz was accomplished using the coax-based HP-8510 network analyzer with full error corrections. Above 26.5 GHz, the measurement was performed using the waveguide-based test setup and the HP-8756 scaler analyzer. The measured gain and bandwidth agree well with the simulated results, as shown in Fig. 5.

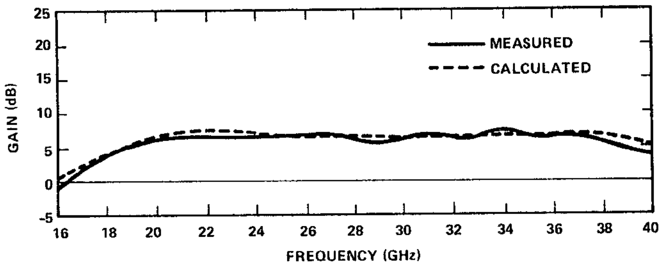

Fig. 5 Measured and simulated gain performance of the monolithic Ka-band amplifier.

The HEMT device is particularly suited for achieving high gain because of its higher transconductance and lower output conductance (per unit g_m) compared with the MESFET. The higher transconductance is a result of the increased saturated velocity of the two-dimensional electron gas layer and the fact that AlGaAs can be doped higher than GaAs without compromising the gate breakdown voltage (due to the larger bandgap). The lower output conductance is a result of the two-dimensional nature of the conduction electrons and the thinner epitaxial layer thickness. The 0.3 x 150-µm gate-length HEMT fabricated in our lab has an approximately 3-dB improvement in the measured gain performance than the MESFET of the same gate length [4], as shown in Fig. 6.

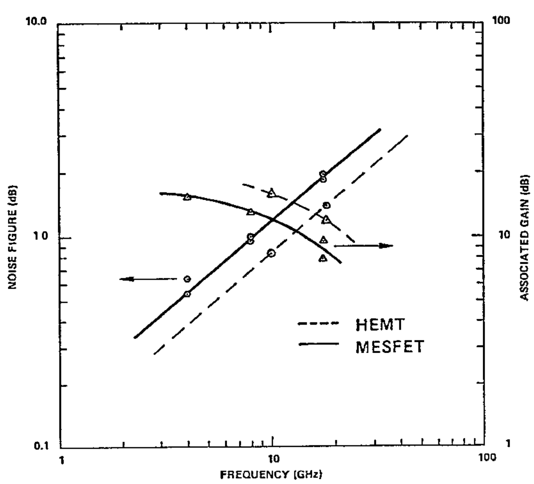

Fig. 6 Noise and associated gain performance comparison of 0.3 x 150-µm HEMT and MESFET.

MEASURED NOISE FIGURE PERFORMANCE

Figure 7 shows approximately 5-dB measured noise figure for the Ka-band amplifier from 26.5 to 38 GHz when biased at minimum noise bias condition. This is the lowest noise figure ever reported for either a MMIC [6] or a MIC [10] amplifier over the whole Ka-band. The amplifier noise figure was measured with a HP-R347B noise source and a HP noise measurement system using the waveguide test setup and the Cascade prober.

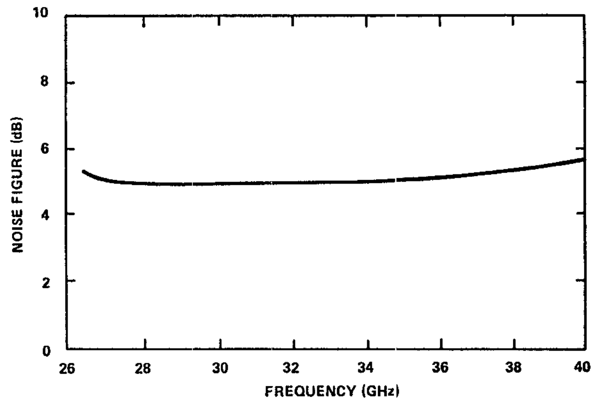

Fig. 7 Measured noise figure performance of the monolithic Ka-band amplifier.

The HEMT device is known for its low-noise performance and its suitability for broadband low-noise applications [4,13]. The lower noise figure performance for HEMTs compared to MESFETs (as shown in Fig. 6) is due to the higher cutoff frequency (i.e., higher g_m/C_{gs}) and the higher correlation coefficient, reducing the intrinsic noise figure in HEMT [13]. In addition, HEMTs have a lower noise conductance, which results in reduced sensitivity of the noise figure to changes in source impedance and therefore permits low-noise performance over a wider bandwidth [4,13].

DISCUSSION AND CONCLUSIONS

A monolithic low-noise amplifier using a HEMT as the active device has been developed in the Ka-band with about 6-dB gain from 20-38 GHz and about 5-dB noise figure from 26.5-38 GHz. These are the best reported results for a millimeter-wave amplifier over this bandwidth.

Advanced material such as GaAs/AlGaAs/InGaAs pseudomorphic heterojunction structures are currently under investigation for lower noise performance.

Devices with shorter gate length (i.e., 0.1-μm) and mushroom gate cross-section profile have been developed using E-beam lithography, which will improve the gain and noise performance of the amplifier further.

With improvements in the noise figure of the device along with the circuit topology designed for minimum noise, a noise figure below 4 dB from 20-40 GHz for a broadband amplifier should be achievable.

ACKNOWLEDGMENT

The authors would like to acknowledge the technical support given by B. Knapp and C. Shih. They also wish to thank Z. Tan for his assistance in the E-beam lithography.

REFERENCES

1. J. J. Berenz, W. Nakamo and K. Weller, "Low Noise High Electron Mobility Transistors", IEEE 1984 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, p. 83.

2. P. M. Smith, P. C. Chao, K. H. G. Duh, L. F. Lester, B. R. Lee and J. M. Ballingall, "Advances in HEMT Technology and Applications", 1987 IEEE MTT-S International Microwave Symposium Digest,. p. 749.

3. A. K. Gupta, E. A. Sovero, R. L. Pierson, R. D. Stein, R. T. Chen, D. L. Miller and J. A. Higgins, "Low Noise High Electron Mobility Transistors for Monolithic Microwave Integrated Circuits", IEEE Electron Dev. Lett. EDL-6(2), 81-82 (1985).

4. S. Bandy, C. Nishimoto, C. Yuen, R. LaRue, M. Day, J. Eckstein, Z. Tan, C. Webb and G. Zdasiuk, "A 2-20 GHz High-Gain Monolithic HEMT Distributed Amplifier", IEEE Trans. Microwave Theory and Tech., MTT-35(12), 1494 (1987).

5. Y. Ito, "0.8 to 18.0 GHz Hybrid Distributed Amplifier Using 0.25x200-μm MESFET and HEMT", 1987 International European Microwave Symposium, p. 832.

6. R. G. Pauley, P. G. Asher, J. M. Schellenberg and H. Yamasaki, "A 2 to 40 GHz Monolithic Distributed Amplifier", GaAs IC Symposium 1985 Technical Digest, p. 15.

7. M. J. Schindler, J. P. Wendler, A. M. Morris and P. A. Lamarre, "A 15 to 45 GHz Distributed Amplifier Using 3 FETs of Varying Periphery", GaAs IC Symposium 1986 Technical Digest, p. 67.

8. L. C. T. Liu, P. Riemenschneider, S. K. Wang and H. Kanber, "A 30 GHz Monolithic Two Stage Low Noise Amplifier", GaAs IC Symposium 1985 Technical Digest, p. 7.

9. J. Berenz, H. C. Yen, R. Esfandiari, K. Nakano, T. Sato, J. Velebir and K. Ip, "44 GHz Monolithic Low Noise Amplifier", IEEE MTT 1987 Microwave and Millimeter-Wave Monolithic Circuits Symposium, p. 15.

10. K. Shibata, B. Abe, S. Hori and K. Kamei, "Broadband HEMT Amplifier for 26.5-40.0 GHz", 1987 IEEE MTT-S Digest, p. 1011.

11. M. A. G. Upton, P. M. Smith and P. C. Chao, "HEMT Low-Noise Amplifier for Ka-Band", 1987 IEEE MTT-S Digest, p. 1007.

12. J. M. Schellenberg, M. V. Maher, S. K. Wang, K. G. Wang and K. K. Yu, "35 GHz Low Noise HEMT Amplifier", 1987 IEEE HEMT Digest, p. 44.

13. A. Cappy, "Noise Modeling and Measurement Techniques", IEEE Trans. Microwave Theory and Tech., 36(1), 1 (1988).