A 7 to 11 GHz AlInAs/GaInAs/InP MMIC Low Noise Amplifier

Steven E. Rosenbaum, Chia S. Chou, Catherine M. Ngo, Lawrence E. Larson, Takyiu Liu, and Mark A. Thompson

Hughes Research Laboratories
3011 Malibu Canyon Road
Malibu, CA 90265

Abstract

Two-stage Monolithic Microwave Integrated Circuit (MMIC) low-noise amplifiers (LNAs) have been fabricated using 0.15 µm gatelength InP-based AlInAs/GaInAs High Electron Mobility Transistors (HEMTs). The LNAs showed less than 1.2 dB noise figure and 21 to 22 dB gain over the 7 to 11 GHz band. While discrete devices have shown comparable or lower noise figures at spot frequencies, these results are believed to be the best reported to date for a broadband MMIC amplifier at these frequencies.

I. Introduction

Advanced airborne active array radars will require Transmit/Receive (T/R) Modules that operate over the 7 to 11 GHz band with high output powers and low noise figures [1]. A key element in these modules is an LNA with flat gain and low noise figure across the entire band. A number of GaAs-based MMIC LNAs have been reported in this frequency range with higher noise figures in the 1.5 to 3 dB range [2-4], and narrow-band GaAs-based MMIC LNAs have been reported at these frequencies with even lower noise figures.

In this paper, we report on an InP-based MMIC LNA with less than 1.2 dB noise figure and greater than 22 dB gain across the band. In addition to superior performance, the gain and noise figure flatness are also better than any previous results. We will describe the fabrication technology, the design procedure, and the experimental results.

II. Device Structure and Circuit Fabrication

A schematic cross-section of the device structure is shown in Fig. 1. The AlInAs/GaInAs HEMT structure is grown on an iron-doped, semi-insulating (100) InP substrate. An undoped AlInAs buffer layer is used to separate the active channel from the epitaxial layer substrate interface. The buffer layer also provides a high-band-gap barrier to ensure a sharp device pinch-off. The active layer is undoped 400-Å-thick GaInAs. It is followed by an 80-Å-thick heavily doped AlInAs donor layer $n=5\times10^{18}$ cm^{-3}. A 200-Å-undoped AlInAs layer is then incorporated to enhance the Schottky barrier of the gate. Finally, the structure is capped by a heavily doped GaInAs contact layer. The sheet charge density n_s and the mobility at 300 K are approximately 3.0×10^{12} cm^{-2} and 10,000 cm^2 V^{-1}s^{-1}, respectively.

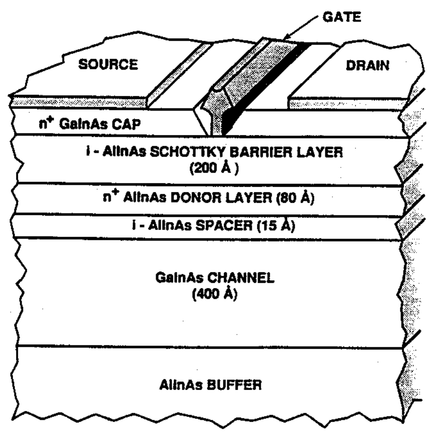

Figure 1. Cross-section of AlInAs/GaInAs HEMT.

Circuit fabrication begins with the deposition of Ni/AuGe/Ag/Au metallization. The source-to-drain spacing is 2 µm. After alloying, contact resistances are less than 0.20 Ω mm. This is followed by an isolation implant. The resulting probe-to-probe resistance is greater than 1×10^6 Ω. The gate is a 0.15-µm T-gate defined by a Phillips Beamwriter (EBPG-4). The structure consists of a 0.15 µm footprint and a top of approximately 0.6 µm to reduce gate metal resistance. The Ti/Pt/Au gate metallization is performed immediately after gate recess, and gate fabrication is completed by a standard lift-off technique. Silicon monoxide is used for Metal-Insulator-Metal (MIM) capacitors. The final step is a gold plating process for airbridge fabrication, which increases the transmission lines' metal thickness to further improve their conductivity.

III. Design

The design goal is a 7 to 11 GHz MMIC LNA with greater than 20 dB gain and less than 1.5 dB noise figure over the band. The gain ripple is to be less than or equal to 1 dB peak-to-peak. The MMICs are designed to be tested using on-wafer microwave probes. We determined that for ease of impedance matching at the frequency of interest, 300 µm gatewidth devices would be employed as the active elements.

HEMT noise parameters and scattering (S-) parameters are measured on-wafer with microwave probes using the Hewlett-Packard 8510 C Automatic Vector Network Analyzer and ATN Microwave Noise Parameter Test system. The S-parameters are measured from 1 to 26 GHz. A plot of F_{min} and associated gain G_a versus frequency for the 2 to 18 GHz measurement range is shown in Fig. 2. The F_{min} at

9 GHz is 0.45 dB. The noise parameters and S-parameters are used to design the input, output, and inter-stage matching networks for the HEMT LNA.

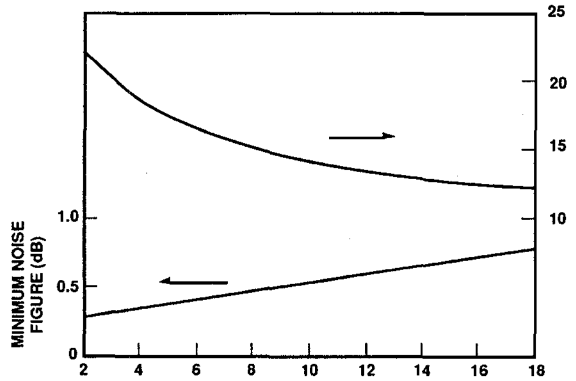

Figure 2. F_{min} and G_a versus frequency of 300 µm HEMT.

The design consists of two one-stage LNAs in cascade to form the complete two-stage circuit. The topology was chosen for maximum compaction, while maintaining at least two substrate thicknesses (~200 µm) separation between adjacent lines to minimize coupling and crosstalk. Inductive feedback in the sources of each HEMT is used to help gain flatness and improve the noise match. The output is deliberately mismatched at the low end of the band to flatten the amplifier gain with a minimum of matching sections. A photograph of the circuit is shown in Fig. 3.

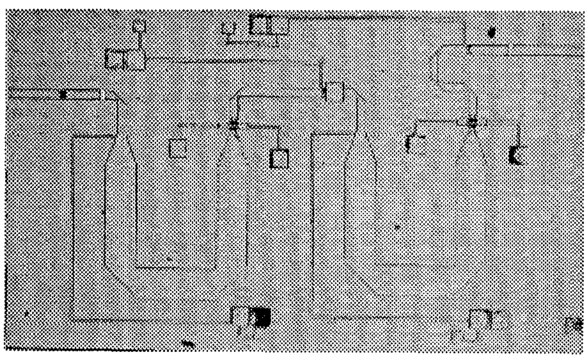

Figure 3. Photograph of 7 to 11 GHz MMIC LNA.

IV. Results

The LNA S-parameters and noise parameters are measured on-wafer from 6.5 to 11.5 GHz. The measurement is made using the HP8510C automatic network analyzer and ATN NP5 noise parameter measurement system. The noise figure of the amplifier is less than 1.2 dB across the 7 to 11 GHz frequency band; the noise figure reaches a minimum of less than 1 dB within the band. The gain is between 22 and 23 dB gain over the same band. A plot of gain and noise figure of the measured amplifier and of the initial design simulation is shown in Fig. 4. There was excellent agreement between the measured and simulated noise figure. The measured gain is somewhat higher due to a larger than expected HEMT transconductance.

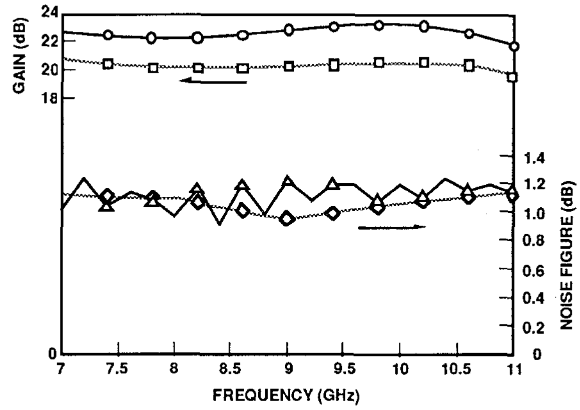

Figure 4. Gain and Noise Figure of 7 to 11 GHz MMIC LNA (□, ◊: simulated and O, Δ: measured)

V. Conclusions

We have designed and fabricated 7 to 11 GHz MMIC InP-based two-stage LNAs with between 22 and 23 dB gain and less than 1.2 dB noise figure. The LNAs are fabricated using InP-based AlInAs/GaInAs HEMTs. The measured and simulated results are in close agreement. We believe these results to be the best reported to date for a broadband MMIC low-noise amplifier.

VI. Acknowledgments

The authors acknowledge the support of Terry Cisco and Don Parker at Hughes Aircraft Radar Systems Group in this work. We also thank Ron Lundgren at Hughes Research Laboratories for his assistance, both technical and administrative. Also, thanks go to Freddie Williams for layout suggestions, Ross Lohr for circuit layout, and Debbie Pierson for post-processing of the circuits.

References

[1] D. McQuiddy, R. Gassner, P. Hull, J. Mason, and J. Bedinger, "Transmit/Receive Module Technology for X-Band Active Array Radar," Proceedings of the IEEE, vol. 79, no. 3, pp. 308-341, March 1991.

[2] N. Shiga, S. Nakajima, K. Otobe, T. Sekiguchi, N. Kuwata, K. Matsuzaki, and H. Hayashi, "X-band MMIC Amplifier with Pulse-Doped GaAs MESFETs," IEEE 1991 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, pp. 65-68, 1991.

[3] B. Nelson, W. Jones, E. Archer, B. Allen, M. Dufault, D. Streit, P. Liu, and F. Oshita, "Octave Band InGaAs HEMT MMIC LNAs to 40 GHz," IEEE 1990 GaAs IC Symposium Digest, pp. 165-168, 1990.

[4] N. Ayaki, T. Shimura, K. Hosogi, T. Kato, Y. Nakajima, M. Sakai, Y. Kohno, H. Nakano, and N. Tanino, "A 12 GHz-Band Super Low-Noise Amplifier Using a Self-Aligned Gate MESFET," IEEE 1989 Microwave and Millimeter-Wave Monolithic Circuits Symposium Digest, pp. 7-10, 1989.