GaAs HEMT Low-Noise Cryogenic Amplifiers From C-Band to X-Band With 0.7-K/GHz Noise Temperature

Christophe Risacher and Victor Belitsky, *Member, IEEE*

***Abstract*—Cryogenic low-noise two-stage amplifiers were developed for frequency bands of 3.4–4.6 GHz, 4–8 GHz, and 8–9 GHz using commercial GaAs high electron mobility transistor. The performances are in very good agreement with simulations, and at a cryogenic temperature of 12 K, input noise temperatures get as low as 0.6 K/GHz (2.8 K for the 3.4–4.6 GHz LNA and 5 K for the 4–8 GHz and 8–9 GHz LNAs). Gain ranges from 25 to 28 dB. Ultralow noise temperature, low-power consumption, high reliability, and reproducibility make these devices adequate for series production and receiver arrays in, e.g., telescopes.**

***Index Terms*—Cryogenic amplifier, GaAs (high electron mobility transistor) HEMT, gain stability.**

I. Introduction

Since the introduction of the high electron mobility transistor (HEMT) in the 1980s [1], enormous progress has been made in the technology yielding lower noise temperatures. The use of InP HEMT has allowed cryogenic low-noise amplifiers to reach noise temperatures of 0.3 K/GHz for frequencies up to 100 GHz [2], [3]. This letter describes state-of-the-art GaAs-based LNA for cryogenic operation reaching 0.7 K/GHz using commercial Mitsubishi MGFC4419G p-HEMT. Noise temperature difference between the best InP and the presented GaAs-based LNAs up to X-band is then reduced to marginal 2 to 3 K. Therefore, it can be of interest to consider other factors than just the noise temperature limiting receiver sensibility, for example, the gain stability of the LNA.

II. LNA Design

Design was carried out using Agilent Advanced Design System (ADS). To achieve desirable accuracy of the modeling, the transistors were simulated using their S parameters and noise parameters at cryogenic temperature [4], [5] and special attention was paid to develop adequate models of the passive components, resistors, and capacitors. For example, the capacitor models include the series resistance and take into account series resonance as well as the first parallel resonance. In order to improve stability and input match, inductive feedback was employed using bond wires connecting the transistor source to the ground. The bond wire model was developed using three-dimensional (3-D) EM simulation Agilent High Frequency Structure Simulator.

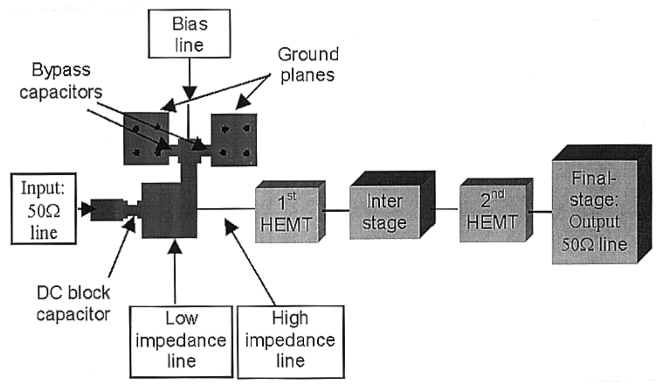

Fig. 1. Amplifier block diagram and the input circuitry schematic.

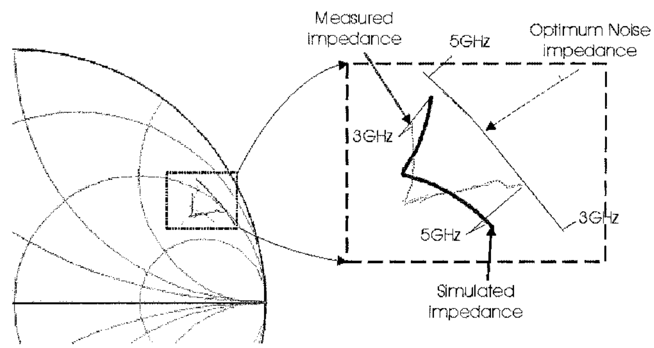

Fig. 2. Simulated and measured output impedance of the input circuitry for the 3.4–4.6 GHz LNA on the Smith chart. Agreement is very good and quite close to the optimum noise impedance of the HEMT.

The most critical part in the design is the amplifier input circuitry where a 50-Ω input line (from SMA connector) has to be transformed into a complex impedance varying with frequency that should be as close as possible to the optimum noise match of the transistors. The input circuitry uses a low impedance line, followed by a high impedance line with a tuning stub, which is part of the transistor gate bias line (Fig. 1). The input stage was built as a separate test unit and precise measurement with TRL calibration (Fig. 2) helped to adjust the performance of the entire amplifier by changing the bypass capacitor location (± 1 mm). The interstage and the output circuits were optimized for maximum gain, gain flatness, and output match. Fig. 3 shows details of assembled amplifiers.

We chose the option of having an isolator at the input of the amplifiers. This facilitates the design of the amplifier input cir-

Manuscript received July 12, 2002; revised September 23, 2002. The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

The authors are with the Department of Radio and Space Science at Chalmers University of Technology, Gothenburg, Sweden (e-mail: risacher@oso.chalmers.se; belitsky@oso.chalmers.se).

Digital Object Identifier 10.1109/LMWC.2003.810116

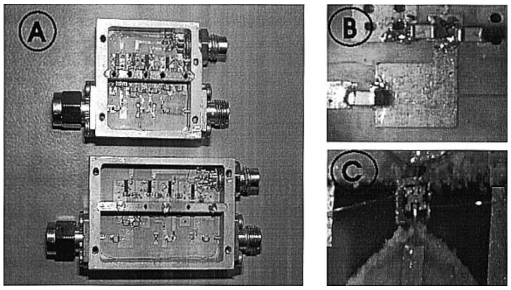

Fig. 3. (a) Photograph of LNA 3.4–4.6 GHz (bottom one) and LNA 4–8 GHz (top one). (b) Magnified view of the input circuitry of LNA 3.4–4.6 GHZ. Position of the capacitors along the tuning stub can be adjusted for tuning the noise performance. (c) Magnified view of a GaAs HEMT MGFC4419G. The bond wires from the source pads to the ground provide inductive feedback and improve stability.

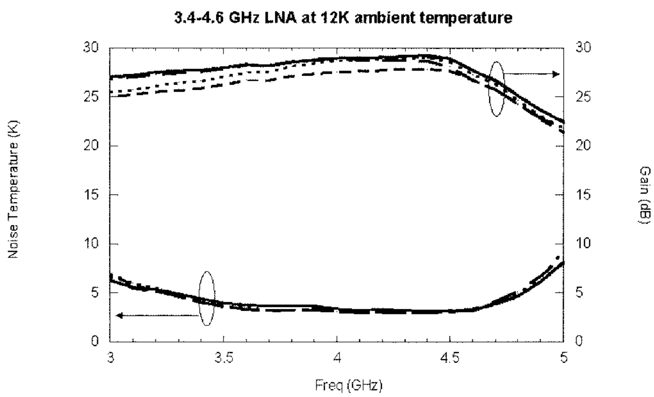

Fig. 4. Performance of series of six LNA, 3.4–4.6 GHz.

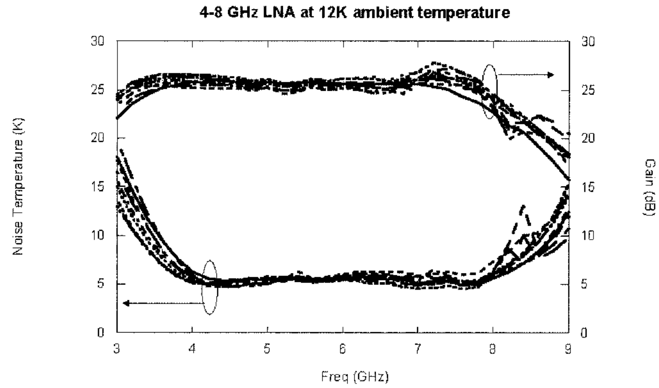

Fig. 5. Performance of series of 12 LNA, 4–8 GHz.

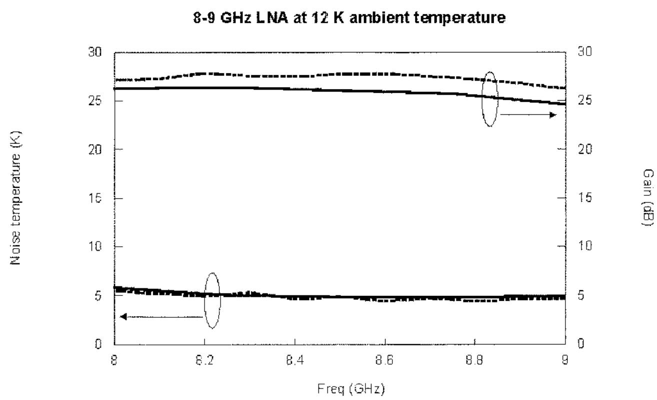

Fig. 6. Performance of two LNA for 8–9 GHz.

cuitry; its input reflection coefficient is required to be only less than −5 dB. But, the insertion loss of the isolator degrades the noise temperature of about 10% when connected to the amplifier.

III. LNA Characteristics

A. The 3.4–4.6 GHz LNA

When measured at a cryogenic temperature of 12 K, the 3.4–4.6 GHz GaAs-based LNA gives 28-dB gain and noise temperature of 2.8 K, with a total power consumption of 12 mW (optimized for the best noise performance). With power consumption reduced down to 4 mW, the amplifier has 26-dB gain and noise temperature of 3.3 K, which is still very good. Six pieces of this type of LNA were built and the plots in Fig. 4 depict the performances of the amplifiers.

Measurement was done with an isolator at the input of the amplifier, adding 0.3-0.5 K to the noise temperature. The performance of all the amplifiers is very consistent. The gain curves differ slightly because of different bond wire lengths from the source pads to the ground.

Although these amplifiers were optimized for cryogenic applications, they work very well at room temperature too. At 293 K, noise temperature is of 30–35 K and gain is 27 dB.

B. The 4–8 GHz LNA

The broadband 4–8 GHz LNA, when measured at cryogenic temperature of 12 K, gives 26 dB gain and noise temperature of 5 K with a total power consumption of 12 mW (optimized for the best noise performance). With the power consumption minimized to 4 mW, the amplifier has 24-dB gain and the noise temperature degrades only to 6 K. 12 pieces of this LNA were built and performances are plotted in Fig. 5.

At room temperature, these amplifiers have a noise temperature of 35–40 K, and gain is of 23–25 dB.

C. The 8–9 GHz LNA

The 8–9 GHz LNA is a slightly modified version of the 4-8 GHz LNA with a different input circuitry. It produces 27-dB gain with the noise temperature of 5 K and total power consumption of 12 mW (optimized for the best noise performance). Two pieces of this LNA were built and performances are plotted in Fig. 6.

At room temperature, the measured noise temperature is of 45 K and gain is of 22–25 dB.

IV. LNA Applications

The amplifiers presented in this paper could be used as general purpose amplifiers; however, our development targeted particular applications: the 3.4–4.6 GHz LNA will be used as cold IF amplifiers in 7-channel 85–115 GHz receivers installed at the Onsala Space observatory 20-m telescope. The 4–8 GHz LNA will also be used as IF amplifier for millimeter and sub-millimeter receivers under construction for APEX project (telescope to be built on Chilean Atacama desert). The 4–8 GHz amplifier

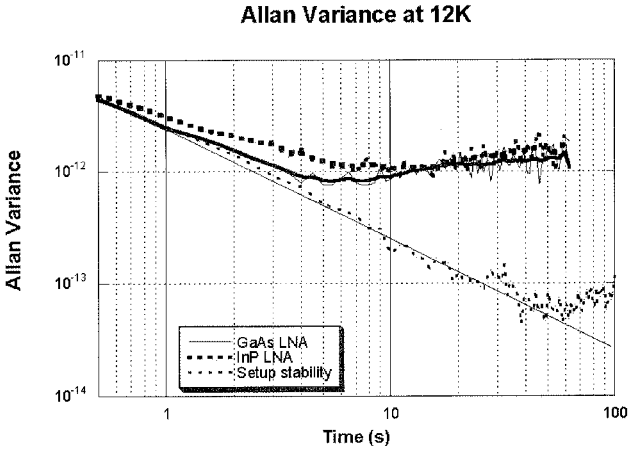

Fig. 7. Solid line is for GaAs based LNA; dashed line for InP based LNA. InP-based LNA deviates earlier than GaAs from the ideal curve. At 7s $1/f$ noise become dominant for both amplifiers.

will be employed as a frontend for dual-polarization C-band receiver at Onsala Observatory 20 and 25 m antennas. The 8–9 GHz LNA will be used for X-band receiver at Onsala 20 and 25 m antennas.

V. Gain Stability Tests

Gain fluctuations is an important parameter for radiometric applications of the developed LNAs. We measured the gain fluctuations on the 4–8 GHz LNA using alternatively the GaAs HEMT and an InP HEMT [6] as the first stage transistor. Measurement setup is described in [7]. For the GaAs-based LNA, normalized noise power spectrum at 1 Hz is $8.10^{-.5}$ $Hz^{-0.5}$ and for the InP-based LNA it is 15.10^{-5} $Hz^{-0.5}$. The results show that the GaAs-based LNA is slightly better than the InP-based LNA in term of gain stability, which is consistent with other published results [8]. This difference may come from relative immaturity of InP HEMT fabrication process. Fig. 7 displays the Allan Variance plot [9].

In some cases, e.g., for receivers using large detection bandwidth or integration time in a single run, and having gain fluctuations mainly due to the LNA itself, a better receiver sensitivity could be achieved using GaAs-based LNA rather than InP-based LNA despite having slightly higher noise temperature.

VI. Conclusion

GaAs HEMT two-stage low-noise amplifiers for cryogenic operation were developed, built, and tested at the temperature of 12 K. Measured noise temperature gets as low as 0.7 K/GHz for 3.4–4.6 GHz, 4–8 GHz, and 8–9 GHz units with the power consumption of about 12 mW. The latter can be reduced down to 4 mW with marginal penalties in the amplifiers' performance. The amplifier performance is comparable with the best results obtained with InP HEMTs at those frequencies, while the gain stability of the presented LNAs gives certain advantages for radiometric applications.

Acknowledgment

The authors would like to thank N. Wadelfalk, now at the California Institute of Technology, Pasadena, I. Angelov, P. Starski, N. Rorsman, all at Microwave Technology Department, Chalmers University, Gothenburg, Sweden, for very useful discussions and for providing them with Chalmers InP HEMT. They would also like to thank K.-Å. Johansson, Onsala Observatory, who was of great help in assembling and testing many of the amplifiers and Prof. R. Booth, who provided them with remarkable support and encouragement for successful completion of this work.

References

[1] T. Mimura, S. Hiyamizu, T. Fujii, and K. Nanbu, "A new field-effect transistor with selectively doped GaAs/n-$Al_xGa_{1-x}As$ heterojunctions," *Jpn. J. Appl. Phys.*, vol. 19, no. 5, pp. L225–227, 1980.

[2] R. Grundbacher *et al.*, "0.1/spl mu/m InP HEMT devices and MMIC's for cryogenic low noise amplifiers from X-band to W-band," in *Proc. Indium Phosphide Related Material 14th Conf.*, 2002, pp. 455–458.

[3] J. J. Bautista *et al.*, "Cryogenic, X-band and Ka-band InP HEMT based LNA's for the deep space network," in *Proc. IEEE Aerospace Conf.*, vol. 2, 2001, pp. 2/829–2/842.

[4] I. Angelov and N. Wadefalk, private communication.

[5] I. Angelov, N. Wadefalk, J. Stenarson, E. Kollberg, P. Starski, and H. Zirath, "On the performance of low noise low DC power consumption cryogenic amplifiers," in *Proc. IEEE Microwave Theory Tech.-Symp.*, 2000.

[6] A. Mellberg, N. Wadefalk, N. Rorsman, E. Chournas, J. Stenarson, I. Angelov, P. Starski, E. Kollberg, J. Grahn, and H. Zirath, "InP hemt-based, cryogenic, wideband LNA's for 4–8 GHz operating at very low DC-power," in *Proc. Indium Phosphide Related Material 14th Conf.*, 2002, pp. 459–462.

[7] C. Risacher and V. Belitsky, "Low noise cryogenic IF amplifiers for super heterodyne radio astronomy receivers," in *Proc. 13th Int. Symp. Space Terahertz Technol.*, Boston, MA, 2002.

[8] K. F. Sato *et al.*, "Low-frequency noise in GaAs and InP Schottky diodes," in *Proc. IEEE Microwave Theory Tech. Symp. Dig.*, 1998.

[9] D. W. Allan, "Statistics of atomic frequency standards," *Proc. IEEE*, vol. 54, pp. 221–230, Feb. 1966.