A 75-116-GHz LNA with 23-K Noise Temperature at 108 GHz

Mikko Varonen, Rodrigo Reeves, Pekka Kangaslahti, Lorene Samoska, Kieran Cleary, Rohit Gawande, Andy Fung, Todd Gaier, Sander Weinreb, Anthony C. S. Readhead, Stephen Sarkozy, and Richard Lai

[1]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91011, USA*

[2]*California Institute of Technology, Pasadena, CA 91125 USA*

[3]*Northrop Grumman Corporation, Redondo Beach, CA 90278, USA*

Abstract — In this paper we present the design and measurement results, both on-wafer and in package, of an ultra-low-noise and wideband monolithic microwave integrated circuit (MMIC) amplifier in the frequency range of 75 to 116 GHz. The three-stage amplifier packaged in a WR10 waveguide housing and fabricated using a 35-nm InP HEMT technology achieves a record noise temperature of 27 K at 108 GHz when cryogenically cooled to 23 K. The measured gain is 22 to 27 dB for frequency range of 75 to 116 GHz. Furthermore, the amplifier utilizes four finger devices with total gate width of 60 um resulting for improved linearity.

Index Terms — InP HEMT, MMIC, low-noise amplifier, cryogenic.

I. Introduction

Low-noise amplifiers (LNAs) are important components in millimeter-wave applications such as receivers for communications systems, passive remote sensing, Earth science radiometry, transceivers for radar instruments, and radio astronomy. The evolution of InP HEMT and metamorphic HEMT devices to sub-50-nm gate length have enabled amplifiers to operate at exceptionally high frequencies [1], [2]. Cryogenically cooling of HEMT amplifiers leads to large reduction in noise and is sometimes used to improve the sensitivity of radiometers for astrophysics and Earth observation instruments. Recent cryogenic results of 35-nm InP HEMT MMIC's have led to record noise in W-band and G-band [3]–[5].

In this paper we present an ultra-low-noise LNA that is designed to cover the whole W-band and also an important astronomical banssh d of 84 GHz to 116 GHz. The amplifier demonstrates a 23-K noise temperature at 108 GHz when cryogenically cooled to 27 K. Noise performances of cryogenically cooled amplifiers have followed mainly the prediction done by Pospieszalski already in 1991 [6], [7]. Our result is well below this prediction, therefore, showing the potential of the 35-nm InP HEMT technology for ultra-low-noise performance. Furthermore the amplifier utilizes four finger devices with a total gate periphery of 60 um resulting in improved linearity. Therefore, we consider that this amplifier achieves state-of-the-art performance in terms of bandwidth, noise temperature, gain, and linearity so far reported for cryogenically cooled amplifiers around W-band.

II. MMIC Technology and LNA Design

The amplifier was designed in a 35-nm InP MMIC technology, using InAs composite channel (IACC) HEMTs which have demonstrate maximum oscillation frequencies in excess of 1 THz. The process has scaled passive components to support the increase operation frequency, including 600pF/mm^2 metal-insulator-metal (MIM) capacitors, 20 and 100 ohm/sq thin film resistors (TFRs), two layers of interconnect with airbridge option, and device passivation. The wafer is thinned down to 50 um with metal back-plane to suppress substrate modes.

The selection of an appropriate gate width for a transistor is an essential part of a low noise amplifier design flow. This can be done by first selecting an optimum unit gate width for a single finger and then placing these fingers in parallel to form a transistor. Apart from differences because of distributed effects of connecting wiring, altering the number of fingers does not affect the gain [8] or minimum noise [9] of the transistor. Therefore, changing the number of fingers can be used to select appropriate device impedances for matching and the output power capability of the transistor. In our case an optimum width for low-noise performance of a single finger in a common-source topology is around 15 um and a four-finger device with a total gate periphery of 60 um was chosen as a suitable device for the amplifier design. The selection was based on simulations of a two-finger scalable HEMT model and our previous experimental data.

A three-stage amplifier was designed in microstrip environment. The simplified schematic and micrograph of the amplifier is shown in Fig. 1 and Fig. 2, respectively. The input and output are matched on-chip with series low-impedance transmission line. A series resistor is employed at the output for improved stability and broadband output matching. Interstage matching is performed with series high impedance transmission lines. Two vias are used for grounding the sources of each HEMT. Short circuited shunt stubs are used for biasing. Bias lines include resistor capacitor networks to ensure low frequency and out of band stability.

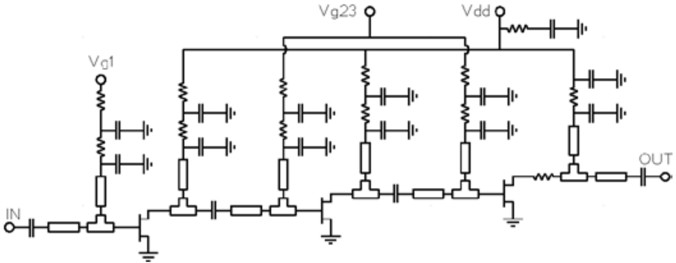

Fig. 1. Simplified schematic of the low-noise amplifier.

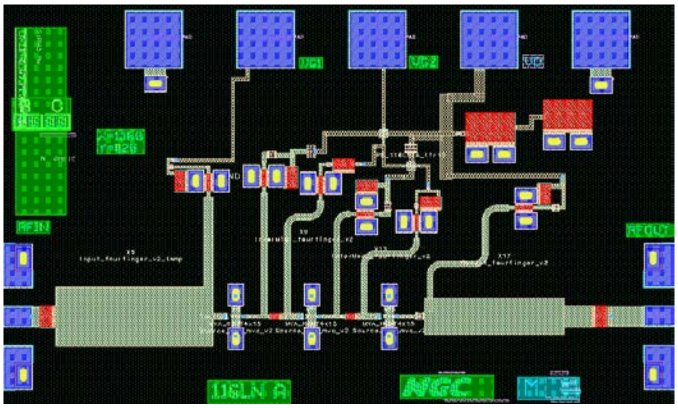

Fig. 2. Micrograph of the low-noise amplifier. The chip size is ? um x ? um.

The amplifier was packaged in an in-house developed WR10 waveguide housing. An E-plane transition shown in Fig. 3 was used for converting the waveguide signal to microstrip mode and matching the waveguide impedance to 50 ohm input for the amplifier. The inductive effect of the wire bond was resonated out with a short section of a low-impedance line that acts as a shunt capacitor.

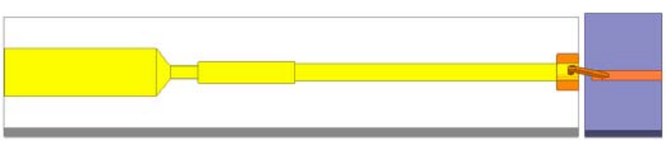

Fig. 3. Layout of the E-plane transition.

III. Measurement Results

A. On-wafer measurement

Cryo results from Caltech or RT from JPL? Rodrigo?

B. Packaged amplifier measurements

RT and cryo results from Caltech. Rodrigo?

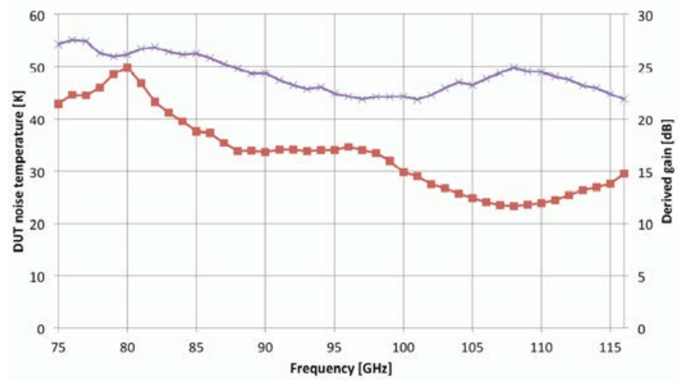

Fig. 3. Measured cryogenic noise and derived gain of the LNA at 27-K ambient.

IV. Conclusion

In this paper we present an ultra-low-noise LNA that is designed to cover the whole W-band and also an important astronomical band of 84 GHz to 116 GHz. The amplifier demonstrates a record 23-K noise temperature at 108 GHz when cryogenically cooled to 23 K. We consider that this amplifier achieves state-of-the-art performance in terms of bandwidth, noise temperature, gain, and linearity so far reported for cryogenically cooled amplifiers around W-band.

Acknowledgement

This work was performed in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The work of M. Varonen was supported by Oak Ridge Associated Universities through the NASA Postdoctoral Program (NPP) and by Alfred Kordel Foundation.

We would like to thank Ms. Mary Soria and Ms. Heather Owen of JPL for assembly expertise.

References

[1] W. R. Deal, X. B. Mei, V. Radisic, K. Leong, S. Sarkozy, B. Gorospe, J. Lee, P. H. Liu, W. Yoshida, J. Zhou, M. Lange, J. Uyeda, and R. Lai, "Demonstration of a 0.48 THz Amplifier Module," *IEEE Microwave and Wireless Components Letter*, vol. 20, pp. 289-291, May 2010.

[2] A Tessmann, A. Leuther, R. Loesch, M. Seelmann-Eggebert, and H. Massler, "A metamorphic HEMT S-MMIC amplifier with 16.1 dB gain at 460 GHz," in *2010 IEEE Compound Semiconductor Integrated Circuit Symp. Dig.*, Monterey, CA, Oct. 2010, pp. 1-4.

[3] L. Samoska, M. Varonen, R. Reeves, K. Cleary, R. Gawande, P. Kangaslahti, T. Gaier, R. Lai, and S. Sarkozy, "W-band cryogenic InP MMIC LNAs with noise below 30K," *in 2010 IEEE MTT-S Int. Microwave Symp. Dig.*, Montreal, Canada, June 2012, pp. 1-3.

[4] E. W. Bryerton, X. B. Mei, Y.-M. Kim, W. Deal, W. Yoshida, M. Lange, J. Uyeda, M. Morgan, and R. Lai, "A W-band low-

noise amplifier with 22K noise temperature," in *2009 IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, MA, June 2009, pp. 681-684.

[5] M. Varonen, P. Larkoski, A. Fung, L. Samoska, P. Kangaslahti, T. Gaier, R. Lai, and S. Sarkozy, "160-270-GHz InP HEMT MMIC low-noise amplifiers" in *2012 IEEE Compound Semiconductor Integrated Circuit Symp. Dig.*, La Jolla, CA, Oct. 2012.

[6] M. W. Pospieszalski, "HFET'S and receivers for the millimeter-wave array," National Radio Astronomy Observatory Millimeter Array Memo, no. 67, August 12, 1991.

[7] M. W. Pospieszalski, "Cryogenic amplifiers for Jansky very large array receivers," *2012 IEEE 19th International Conference on Microwave Radar and Wireless Communications (MIKON)*, Warsaw, Poland, May 2012, pp.748-751.

[8] J. Lange, "Noise characterization of linear twoports in terms of invariant parameters," *IEEE Journal of Solid-State Circuits*, vol. sc-2, pp. 37-40, June 1967.

[9] I. D. Robertson and S. Lucyszyn, RFIC and MMIC design and technology. London, United Kingdom: The Institution of Electrical Engineers, 2001, ch. 5.2.