Characterization of GaN-based Low Noise Amplifiers at Cryogenic Temperatures

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***Abstract*— In this paper, we present the first characterization of GaN-based Low-Noise Amplifiers (LNAs) at cryogenic temperatures for prospective use in radio-astronomy receivers. Both commercial and prototype LNAs fabricated in-house demonstrate a nine-fold improvement of their room-temperature noise performance when cooled to about 10 K. Very promising noise temperatures of about 8 K were measured without any specific optimization of the LNA design for cryogenic operation.**

I. Introduction

Since its first demonstration in 1994, GaN HEMT technology has matured, but mainly focusing on power amplification for radar and telecommunication applications.
GaN-based Low Noise Amplifiers (LNA) have received some attention due to their inherent added advantage in terms of robustness and enhanced linearity over InP and even GaAs pHEMT, which results in a system simplification by relaxing (and even eliminating) the requirements on limiters and filters in a radar or communication systems. For room temperature operation and cooled down to 60 K, GaN LNAs have already demonstrated noise performances similar to their GaAs counterparts [1]. Yet the performance of the GaN-based LNAs at cryogenic temperatures used for ultra-sensitive instruments, e.g., for radio astronomical applications, remains unexplored.

GaN, as a material, has recently been found to provide a good technological platform for cryogenic superconducting THz mixers and heterodyne receivers for radio-astronomy [2-3]. Also, recent works show that the behavior of GaN-based heterojunctions exhibit an enhancement of the electron mobility in the 2-dimensional electron gas, similar to GaAs and InP heterojunctions [4], when cooled down to cryogenic temperatures. Therefore, it is reasonable to assume that GaN-based LNAs would also demonstrate excellent noise performance at cryogenic temperatures and would be compatible and competitive for their use in radio-astronomy receivers.

This paper focuses on the characterization of the noise performance of GaN-based LNA at cryogenic temperatures for prospective use as a frontend at microwave frequencies and IF amplifiers in THz receiver systems. These initial measurements are carried on prototype LNAs fabricated in-house and commercially available devices designed for radar applications.

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II. Cryogenic Characterization on GaN-based LNAs

Two different low noise amplifiers were characterised, both packaged as MMIC and using SiC as substrate material: a prototype amplifier fabricated in-house [5] and a Qorvo TGA2611 amplifier. Both amplifiers featured two stages, yet the Qorvo amplifier consumed approximately half the power of our prototype LNA fabricated in-house . The LNAs were mounted into a fixture made of copper to ensure best possible cooling of the LNA chips. The fixture also included 50 Ohm transmission lines and SMA connectors as the interfaces to the RF measurement setup (Fig. 1).

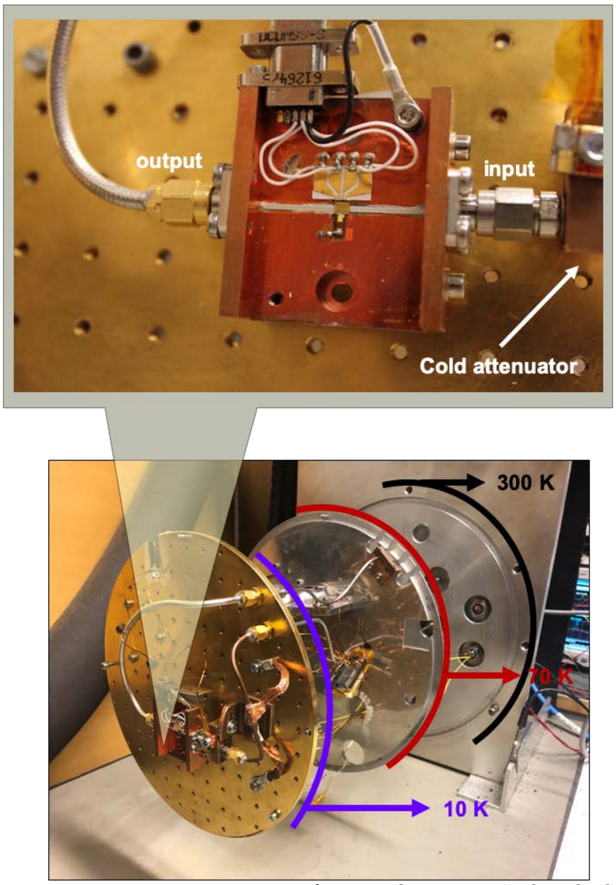

Fig 1. Cryogenic measurement setup featuring the cryostat (without lead) and LNA mounted on the fixture, attached to the 10 K plate.

The noise performance of the LNAs were measured in a cryogenic system comprising a cryostat equipped with a 2 stage close cycle-machine, which allows cooling down to about 10 K (Fig 1). The noise temperature measurements were performed by the standard Y-factor measurement technique and using the cold attenuator method [6] with an Agilent N4000A ENR noise diode and an Agilent MXA N9020A spectrum analyzer with Noise Figure Measurement option.

We carried out a simplified characterization of the cryostat losses and the temperature sensor to be used for the cold attenuator. The optimum noise performances of the different LNAs were determined by independently tuning the bias conditions of the different transistor stages at cryogenic temperature.

First, we recorded the average noise performance between 2 and 6 GHz when cooling down the LNAs from room temperature down to about 10 K. Fig.2 displays that both LNAs show a similar relative change in their noise temperature when cooling down from room temperature to 10 K.

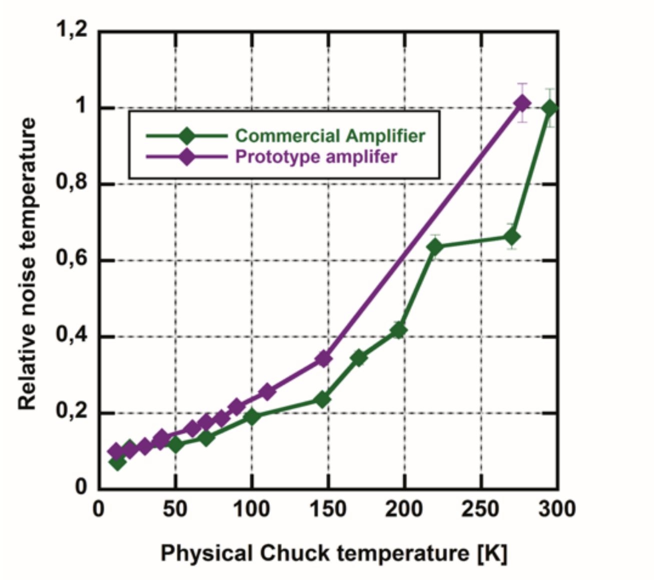

Fig.2 Relative noise temperature variation upon cooling of the LNAs

This behaviour is very similar to the one observed in InP or GaAs LNAs and can be ascribed to the enhancement of the electron mobility in the two-dimensional electron gas forming the channel of the HEMT, as shown in [4] and increasing conductivity of the imbedding circuitry.

The absolute noise performance of the Qorvo LNA over the 2-6 GHz frequency band is illustrated on Fig 3. Even though the device was designed for radar or telecom applications, it shows very decent noise performance. In fact, noise temperatures of about 8 K were measured without any specific optimization but tweaking with bias points when performing the characterization at cryogenic temperature.

This result is very encouraging and practically confirms the theoretical prediction and previous intermediate material performance measurements indication that GaN can be a compatible technology for low-noise amplification at cryogenic temperatures.

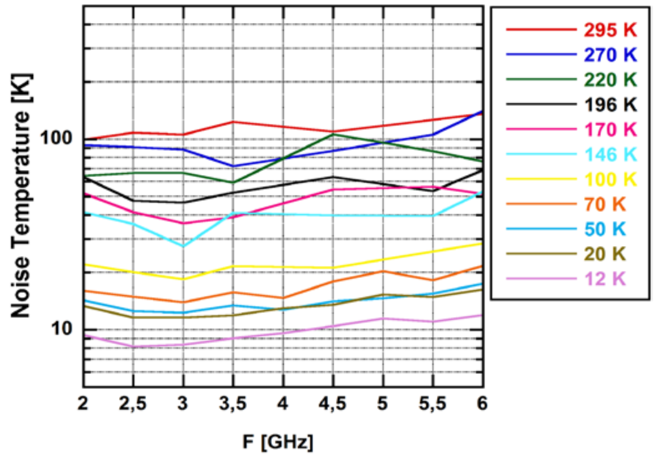

Fig. 3. 2-6 GHz noise performance at on the Qorvo LNA measured at different chuck temperature.

III. Conclusions

In this work, we presented the first characterization of the noise performance of GaN-based LNAs at cryogenic temperature. We have shown that GaN-based LNAs demonstrate a similar enhancement of their noise performance with temperature, as the LNAs based on GaAs or InP. Also, the 8K noise temperature obtained on the GaN LNAs, not even designed for cryogenic temperature shows that the noise performance of GaN-based LNAs could potentially be competitive with other III-V technologies with some optimization while offering advantage of handling more powerful signals (higher gain could be realized in one amplifier) and higher linearity.

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