2-18 GHz Ultra-wideband Cryogenic Amplifier with 4 K Noise Temperature

Isaac López-Fernández*[1], Juan D. Gallego[1], Carmen Diez[1], Inmaculada Malo[1], Ricardo I. Amils[1], Ralf Flückiger[2] and Diego Marti[2]

***Abstract*—A cryogenic low noise amplifier with 4 K average noise temperature in the 2-18 GHz band has been developed with new high performance InP devices. This amplifier meets the demands of ALMA next generation receivers, doubling the present IF bandwidth with state-of-the-art noise performance. A balanced configuration is feasible to improve the input return loss.**

Keywords—Broadband amplifiers, cryogenic amplifiers, InP, high electron mobility transistors (HEMTs), low-noise amplifiers, submillimeter wave receivers, radio astronomy

I. Introduction

One of the priorities of modern radio astronomical receivers is to achieve ever larger instantaneous bandwidths. The goal for ALMA (Atacama Large Millimeter/Sub-millimeter Array) 2030 development roadmap [1] is to implement an IF of 16 GHz which would provide 32 GHz per polarization in 2SB receivers. The Event Horizon Telescope (EHT) consortium aims for the next generation sub-millimeter receivers are similar. The front-end critical component to fulfill these planned upgrades is the cryogenic LNA, given that SIS mixers have already demonstrated IF bandwidths spanning up to 20 GHz [2]. These demands are not exclusive of high frequency receivers, but also of centimeter wave radio telescopes with the LNA before down-conversion, although the feed fractional bandwidth also plays a limiting role here.

Yebes Observatory amplifier group designed some years ago a 2-14 GHz LNA for the front-end of wideband VLBI (Very Long Baseline Interferometry) receivers which is being widely used by VGOS (VLBI Geodetic Observing System) qualified antennas, generally combined with high performance custom made cryogenic 3 dB 90° hybrids in a balanced configuration [3]. More recently, and fruit of a long-term and extensive collaboration with Diramics, a new generation of InP HEMT transistors in 100 nm technology has been developed that incorporate improvements which translate in a very significant leap in performance.

The availability of these active devices and the need for an extension in IF bandwidth motivated the design of a new amplifier based on the existing 2-14 GHz LNA, optimizing its noise performance, and widening the bandwidth to 2-18 GHz. This represents a fractional bandwidth of 9:1 (almost a decade). A prototype unit was built and tested.

II. Design

The key modifications that were introduced in the previously mentioned experimental HEMT devices are the improvement of stability and cryogenic noise performance. Better stability is achieved by pad metallization reduction and the use of a two-finger layout in combination with source air bridges. Noise temperature was improved mainly by the optimization of the gate to channel distance, through extensive on-wafer cryogenic DC measurements and cryogenic noise characterization of devices on test amplifiers.

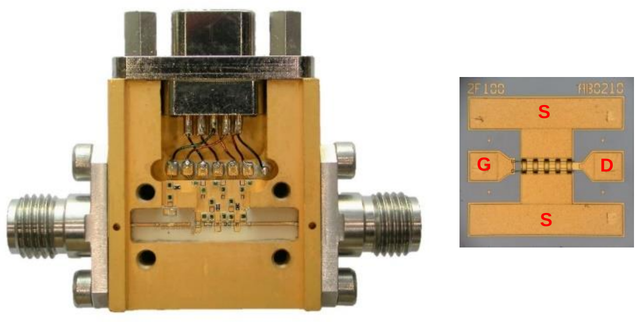
The design requires three common-source stages in order to achieve the desired levels of gain and noise optimization and was built in hybrid microstrip technology (chip & wire) with independent bias for each of the stages. This fabrication methodology grants access to high number degrees of freedom allowing fine performance optimization. Assembly and manufacturing procedures were followed similar to those of the IF amplifiers for ALMA bands 5, 7 and 9 [4].

Only the first stage transistor comes from the enhanced batch, and the gate periphery selected to maximize wide band noise matching was 200 µm. The other stages have HRL transistors with 150 µm total gate widths. Figs. 1(a) and 1(b) show a picture of the LNA and of the first stage optimized Diramics device, respectively. Another significant feature of the design was the use of a small quartz chip spiral inductor to couple the first stage gate bias, improving the noise contribution and gain equalization of other approaches (like big resistors or wideband conical inductors). All this, together with precise cryogenic modeling of devices and components allowed obtaining the state-of-the-art results and similarity to the simulated performance that is presented in Fig. 2 and Fig. 3.

III. Results

The cryogenic noise and gain of the amplifier was characterized using two different measurement methods: a variable temperature cryogenic load [5] and the cold attenuator method [6] at 6 K and 15 K ambient temperature, with better than 0.5 K average noise temperature discrepancy between both methods (a 1 K noise difference was measured between 6 and 15 K ambient with the variable temperature cryogenic load).

Average noise temperature of 4.1 K was obtained at 6 K, not exceeding 5 K in the 2-18 GHz band. The amplifier also exhibits a flat gain around 31.8 dB (less than 1.6 dBpp



(a) (b)

Fig. 1. (a) Photograph of the three-stage 2-18 GHz CLNA without cover. Dimensions excluding connectors are 20×22×9 mm. (b) 2×100 µm gate finger InP HEMT in 100 nm technology used in the 1st stage of the amplifier.

*i.lopez@oan.es

[1]Observatorio de Yebes, CDT (IGN), Guadalajara, 19141, Spain; [2]Diramics AG, Steinhausen, 6312, Switzerland.

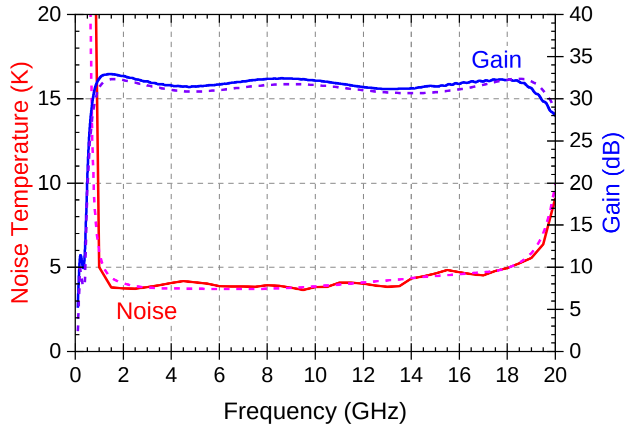


Fig. 2. Measured (solid lines) and simulated (dashed lines) gain and noise temperature of the LNA at 6 K ambient.

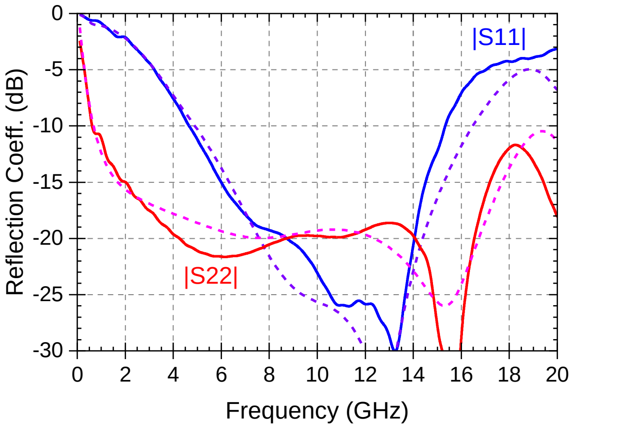


Fig. 3. Measured (solid lines) and simulated (dashed lines) input and output reflection of the LNA at 15 K ambient.

ripple). As shown in Fig. 2, the design easily covers 1-19 GHz with similar performance (4.2 K noise, gain flatness below 1.8 dBpp). To the best of our knowledge, this is the lowest noise temperature reached in an 18 GHz wide band.

Cryogenic S parameters were also measured at 15 K as in [6], obtaining better than -15 dB output reflection (Fig. 3). Input matching of InP HEMT based LNAs with very large fractional band is challenging at the low frequency end and requires trade-offs in noise temperature [7]. Applications demanding minimum input return loss can address this problem at the cost of complexity and power dissipation by employing balanced architectures (the alternative of using a cryogenic isolator is not practical for such large fractional bandwidths). The needed 3 dB 90° 2-18 GHz hybrid has not been designed yet but could be produced by scaling the existing one developed by our group for the 1.5-15.5 GHz band [8].

The input 1 dB compression point at 3 GHz is -40.5 dBm. The amplifier is unconditionally stable in the band and the absence of high frequency oscillations was verified by DC curves measuring. Power dissipation is 17.7 mW and although it was not a design goal it can be reduced by redesigning the bias networks and including optimized transistors in the second and third stages.

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