Analysis of the Amplification System of ALMA Band

N. Reyes[a], C. Jarufe[a], F. P. Mena[a]*, J. Pizarro[b], L. Bronfman[b], J. May[b]
[a]Electrical Engineering Department, Universidad de Chile, Av. Tupper 2007, Santiago, Chile;
[b]Astronomy Department, Universidad de Chile, Camino El Observatorio 1515, Santiago, Chile

ABSTRACT

At Universidad de Chile we have started a program for the development of a prototype receiver for Band 1 (31-45 GHz) of the Atacama Large Millimeter Array. This receiver will use a low-noise amplifier which is specified to have 5 times the quantum limit (~10 K). Here we present the first efforts and results towards reaching that goal.

Keywords: Q Band, LNA, HEMT

1. INTRODUCTION

The Atacama Large Millimeter Array (ALMA) is the largest radio astronomical array ever constructed. Every one of its constituent antennas will cover the spectroscopic window allowed by the atmospheric transmission at the construction site with ten different bands. Despite being declared as of top scientific priority, the receiver for Band 1 (31-45 GHz) was not selected for the first phase of construction. Therefore, Universidad de Chile has started a program to develop a prototype receiver for this band [1]. The need for low noise, high stability receivers implies the use of state-of-the-art technologies to reach the best possible performance. In this report we present work on the development of a low noise amplifier.

2. RECEIVER AND AMPLIFIER SPECIFICATIONS

In brief, the receiver we are proposing to build is structured in the following way. The RF signal coming from the secondary is coupled with the horn via a lens. The signal is then divided in its polarization components in an orthomode transducer. Each polarization signal is amplified in two consecutive low noise amplifiers (LNA). Finally, the amplified signals are filtered to suppress the lower sideband and mixed in separate Schottky diodes [1]. The specifications that the receiver has to comply were established by the ALMA committee, and are summarized in Table 1.

Table 1 Receiver specifications for Band 1 of ALMA

Parameter	Value
RF frequency	31 – 45 GHz
Total noise temperature (80% band)	17 K
Total noise temperature (100% band)	28 K

Preliminary calculations indicate that the optical focusing system of the receiver will have a contribution of around 7 K above the noise temperature of the receiver. This contribution is mainly originated at the lens. Several alternatives have been considered for redesigning the focusing system and reduce the noise contribution to the receiver [2]. However, even in the best of configuration, an improvement of no more than 2 K is expected. If we take the contribution of the optical system to the total noise temperature of the receiver to be 7 K, the specifications for ALMA Band 1 requires that the LNA must have a noise of 10 K over 80% of the band and a relaxed specification of 21K over 100% of the band (Figure 1).

Other specifications arise from the architecture of the receiver. The first of them is that the gain should in the range of 30 to 35 dB to allow the following stages of down-conversion to be at ambient temperature. The second specification concerns the input return loss (S_{11}) which should be lower than −10 dB over the complete band, to avoid the use of

*pmena@ing.uchile.cl; phone +56 2 978 4888; fax +56 2 695 3881; http://www.cec.uchile.cl/~raig

cryogenic isolators between the orthomode transducer and the LNA. Finally the output return loss (S_{22}) is required to be lower than -5 dB.

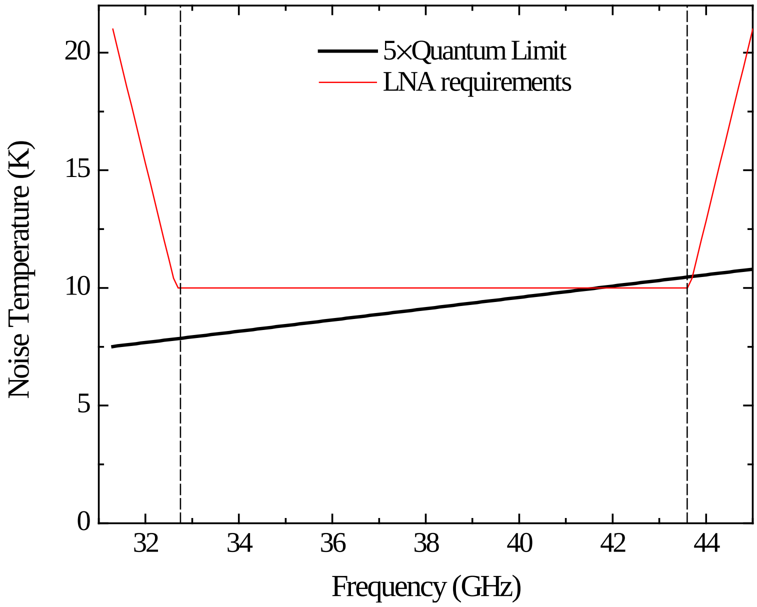

Figure 1 Required noise performance for a Band-1 low-noise amplifier (thin red line). This requirement means that the LNA should achieve 5 times the quantum limit (thick black line) over a bandwidth of 36% of the center frequency. The current state of the art for HEMT-based LNAs is 5 times the quantum limit over a bandwidth of only 20%.

3. HYBRID VERSUS INTEGRATED AMPLIFIERS

As we see in Figure 1 the noise specification over the LNA means that the amplifier to be used should have a noise of 5 times the quantum limit over a bandwidth of 36%. The best noise performance reported up to now for the Ka and Q bands is 5 times the quantum limit over a bandwidth of 20 % by the usage of hybrid amplifiers [3]. It has to be noted, moreover, that in the case of ALMA a batch production of amplifiers is required (64 receivers with two polarizations each). This fact limits the time that can be used on tuning each amplifier to reach the best possible noise performance.

There are two technology candidates for the LNAs to be placed in an ALMA Band-1 receiver. The first is the use of hybrid technology (also known as MIC). In this technology the amplifier is built using discrete transistors connected by bond wires. This technique allows to tune each amplifier, e.g. by slightly modifying the bonding lengths, as to reach the best possible noise temperature. Several amplifiers for the Ka and Q Band have been reported using transistors from well know foundries as NGST and HRL [3][4][5]. The cryogenic noise of these kinds of LNAs is in the range from 5 to 7 times the quantum limit.

The second alternative is the use of Microwave Monolithic Integrated Circuit (MMIC) technology. In this case the amplifier is completely built over the same substrate with the active devices. This procedure allows, in principle, the fabrication of thousands of amplifiers with similar performance in a short period of time. The fabrication of a series of LNAs then becomes easier, as only one chip has to be mounted and bonded. The time in assembling a MMIC LNA is several times lower than for a hybrid amplifier [6] at the penalty of noise which is around 30% higher than a MIC amplifier [6]. The noise of a MMIC chip with current InP technology is expected to be 15 - 18K at Band 1 frequencies [6][8]. Probably the noise will increase by 1 or 2 K when the MMIC is packaged.

During the last years GaAs m-HEMT technology has proved to be a good alternative. Good results have been demonstrated by IAF [9] and OMMIC [10] at ambient temperature. Possible applications of this technology to cryogenic applications and particularly to radio astronomy are currently being studied.

4. DEVELOPMENT AT UNIVERSIDAD DE CHILE

4.1 RF amplifier based on commercial MMIC

For amplification we have decided to use LNA's based on high electron-mobility transistors. In a first attempt to test our packaging capabilities, we have integrated a commercial MMIC amplifier [11] into a split block (Figure 2). For the waveguide-to-microstrip transitions we have selected a radial antenna [11] that was optimized using HFSS [13].

Figure 2 Commercial chip packaged in a split block.

The measured S-parameters, at ambient temperature, are presented in Figure 3. The selected MMIC has a balanced configuration allowing an excellent input and output return loss of around -10dB over the complete Q band. The gain, on the other hand, is between 15 and 20 dB over the entire Band-1 frequency range. These results are in close agreement with the chip specifications which evidences the good quality of the packaging.

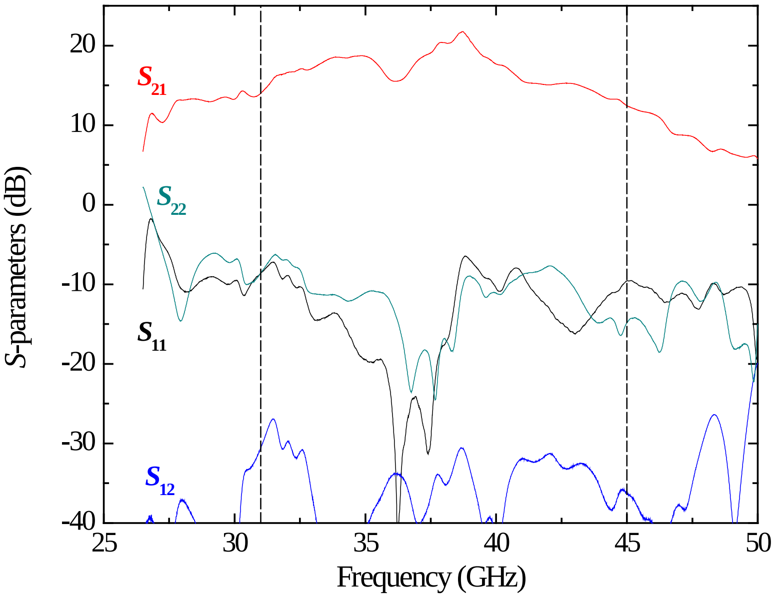

Figure 3 Measured *S*-parameters of the packaged LNA based on a commercial MMIC. The vertical dashed lines represent the Band-1 frequency range.

4.2 RF amplifier based on single transistors

A LNA based on commercial GaAs p-HEMT transistors from UMS [14] has also been designed. The idea is to test the cryogenic performance of these devices and their possible use in radio astronomy. The first design consists of a four-stage amplifier with a gain of 30 dB and noise of 2 dB (170 K) at ambient temperature. In the design the effect of the radial antennas was included in the input matching network in order to optimize more realistically the noise of the LNA.

The simulation results for this amplifier are shown in Figure 4. The gain is around 30 dB over the complete band, with gain flatness of 4 dB. The input return loss (S_{11}) is lower than –5 dB with a typical value –10 dB. The output return loss is –8 dB. The noise figure of this amplifier is expected to be between 170 K and 180 K (2 dB). This LNA is going to be built and tested during 2010. In a second design iteration we would like to improve these results by redesigning the first stage of the amplifier with the inclusion of a low-noise InP transistor with a noise as low as 10 K at the Q Band. Since the noise is dominated by the first stage we expect to have a LNA with 12 to 13 K of noise.

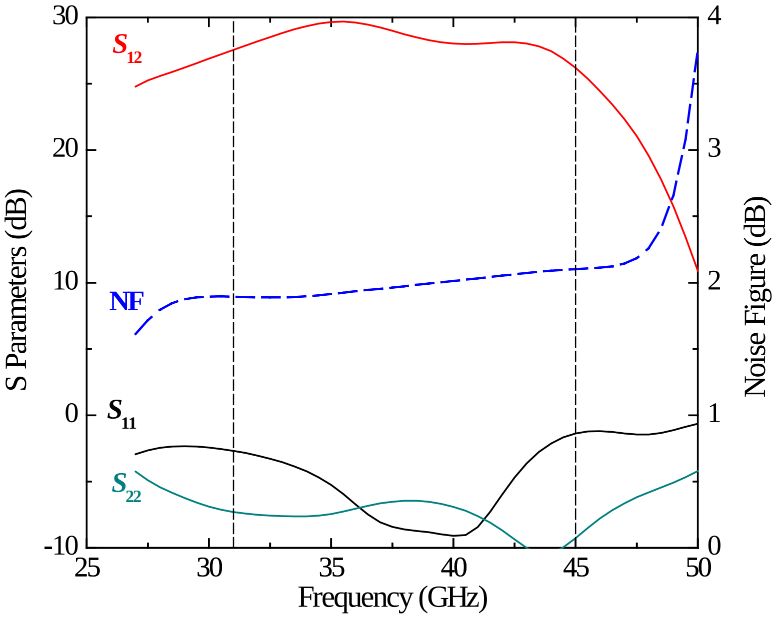

Figure 4 Simulated results, at ambient temperature, of a discrete amplifier using GaAs p-HEMT transistors. The main features of the LNA are gain around 30 dB over the complete band, gain flatness of 4 dB, S_{11} lower than –5 dB over the complete band (but typically at –10 dB), S_{22} around –10 dB, and noise between 170 K and 180 K (2 dB). The vertical dashed lines represent the Band-1 frequency range.

5. CONCLUSIONS AND FUTURE WORK

Here we have presented our first efforts towards the construction of a low-noise amplifier able to comply with the requirements of Band-1 of ALMA. A review of the current state of the art in amplifier construction has also been presented. Our next step is to build an amplifier based on hybrid technology and evaluate its possibilities for being included in future ALMA Band-1 receivers.

ACKNOWLEDGEMENTS

We would like to thanks the LNA Group at University of Manchester for their help in the development of this project. This work received support from the Center of Excellence in Astrophysics and Associated Technologies (PBF 06) and from the ALMA-CONICYT Fund for the Development of Chilean Astronomy (Projects 31080003 and 31080004).

REFERENCES

[1] N. Reyes, P. Zorzi, C. Jarufe, P. Altamirano, F. P. Mena, J. Pizarro, L. Bronfman, J. May, C. Granet and E. Michael, “Construction of a Heterodyne Receiver for Band 1 of ALMA,” Proc. ISSTT’10, P6.2 (2010).

[2] P. Zorzi, D. Henke, S. Claude, F.P. Mena, L. Bronfman and J. May, “Revisiting the ALMA Band 1 optics design,” Proc. ISSTT’10, P5-6 (2010).

[3] B. Aja, E. Artal, L. De La Fuente, J.P Pascual, A. Mediavilla, N. Roddis, D. Kettle, W.F. Winder, L. Pradell and P. de Paco, “Very low noise differential radiometer at 30 Ghz for the Planck LFI”, IEEE Transactions on microwave and techniques 53(6), 2050-2062 (2005).

[4] S. Padin, J. K. Cartwright, M. C. Shepherd, J. K. Yamasaki, & W. L. Holzapfel. “The Cosmic Background Imager Cosmic Background Imager", Publications of the Astronomical Society of the Pacific 114, 1234-1240 (2002).

[5] M.W. Pospieszalski, E.J. Wollack, N. Bailey, D. Thacker, J. Webber, L. D. Nguyen, M. Le and M. Lui, "Design and performance of wideband, low-noise, millimeter-wave amplifiers for Microwave Anisotropy Probe radiometers" Microwave Symposium Digest IEEE MTT-S International 1, 25-28 (2000).

[6] C. Lawrence, T. Gaier, and M. Seiffert, “Millimeter-wave MMIC cameras and the QUIET experiment,” Proc. SPIE 5498, 220-231 (2004).

[7] P. Kangaslahti, T. Gaier, M. Seiffert, S. Weinreb, D. Harding, D. Dawson, M. Soria, C. Lawrence, B. Hooberman and A. Miller, “Planar Polarimetry Receivers for Large Imaging Arrays at Q-band,” Microwave Symposium Digest IEEE MTT-S International, 89-92 (2006).

[8] Y.L. Tang, N. Wadefalk, M.A. Morgan and S. Weinreb, “Full Ka-band high performance InP MMIC LNA module”, IEEE Microwave Symposium Digest, 81-84 (2006).

[9] A. Tessmann, “220-GHz Metamorphic HEMT Amplifier MMICs for High-Resolution Imaging Applications”, IEEE Journal of solid state circuits 40, 2070-2076 (2005)

[10] D. Smith, G. Dambrine, J.C. Orlhac, “Industrial MHEMT Technologies for 80–220GHz Applications”. Proc. 3rd European Microwave Integrated Circuits Conference, 214 - 217 (2008).

[11] GaAs HEMT MMIC low noise amplifier (HMC-ALH376), Hitite, 2008.

[12] J. W. Kooi, G. Chattopadhyay, S. Withington, F. Rice, J. Zmuidzinas, C.Walker, and G. Yassin “A full-height waveguide to thin film microstrip transition with exceptional RF bandwidth and coupling eficiency", Int. J. Infrared Millimeter Waves 24(3) 261-284 (2003).

[13] High Frequency Structure Simulator, Ansoft.

[14] United Monolithic Semiconductor, http:\\www.ums.com.