# Wide Band Cryogenic IF Amplifiers for ALMA and Herschel Receivers

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## 1. INTRODUCTION

This work describes the design, construction and measured results of the cryogenic IF amplifiers developed for band 7 (275-370 GHz) receivers of ALMA (Atacama Large Millimeter Array) built by IRAM. The present approach for this channel is to use 2SB (sideband-separating) mixers. In that case, the bandwidth allocated for each individual sideband and polarization will be 4 GHz. The design and the results obtained are compared with those from the amplifiers built for the instrument HIFI (Heterodyne Instrument for the Far Infrared) of Herschel Space Mission[1]. In both cases, the required band is from 4 to 8 GHz. There is no need to integrate the amplifier with the mixer, since a cryogenic isolator has been developed for that band and it is commercially available.

## 2. DESIGN

Both amplifiers use a high quality **InP HEMT** device in the first stage to obtain the ultimate noise performance. The subsequent stages also employ InP transistors to overcome the severe power dissipation requirements of the two projects: HIFI mission lifetime is limited by the amount of liquid He, and in ALMA dewars the thermal load is important due to the great number of channels. ALMA amplifiers are made of three stages to obtain more gain and to overcome the noise of the next uncooled amplifier in the IF chain, while HIFI amplifiers were built with only two stages. The disadvantages of using InP HEMTs against commercial GaAs devices are their sensitivity to ESD, their larger gain fluctuations and the difficulties in its procurement.

The amplifier designed for ALMA (fig. 2) is smaller and lighter than the one of Herschel (fig. 1), although it has one stage more. Three stages give more degrees of freedom and made possible a new design of the interstage networks, which allows reducing the overall length while keeping the gain flat. In addition, an extra cavity in the bottom of the Herschel amplifier was suppressed. The cavity was introduced to have the possibility of adding a filter for rejection of interference in the bias cables.

| | HIFI DMs | ALMA PROTOTYPE |
|---|---|---|
| **Dimensions** | 58 × 32 × 15 mm | 46 × 29 × 9 mm |
| **Weight** | 65 g | 31 g |
| **Transistors** | 1$^{st}$ = TRW IREL1<br>2$^{nd}$ = TRW IREL1 | 1$^{st}$ = TRW CRYO4<br>2$^{nd}$ & 3$^{rd}$ = ETH run1 |
| **Technology** | Hybrid microstrip, soft substrates | |
| **Construction** | Gold plated aluminium | |
| **RF connectors** | SMA O-ribbon junction | SMA sliding pin |
| **Bias connector** | ITT-Cannon MDM | |

**Table 1:** *Design features of HIFI DMs and ALMA prototypes*

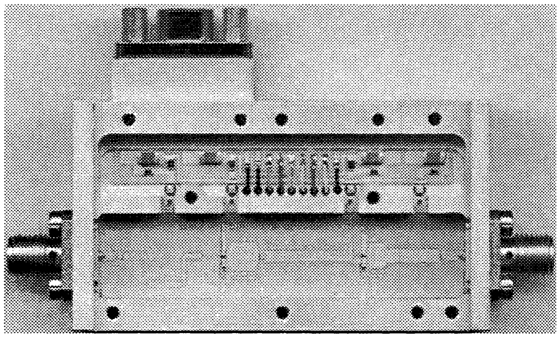

**Figure 1:** *2-stages 4-8 GHz HIFI cryogenic LNA Development Model (DM) YCF 6.*

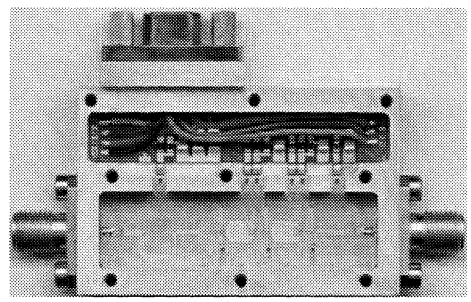

**Figure 2:** *3-stages 4-8 GHz cryogenic LNA prototype for ALMA band 7.*

**Reliability** was a concern in the construction of the amplifiers for Herschel. The lessons learned in the process of space qualification have been applied to the design of the ALMA amplifiers. Herschel amplifiers have been tested for thermal cycling, vibration, radiation, ESD and EMC. Power connectors were carefully selected, and the junction of SMA connectors to the circuit was identified as a critical point. The junction was implemented using the O-ribbon technique to avoid any stress in thermal cycles. The ESD damage level of the HEMT devices was measured, and the bias circuit was designed with a combination of charge and voltage divider to reduce the sensitivity to a level of ~38000 V at the power connector, which can be considered safe for manipulation with standard ESD precautions. EMC measurements were performed on the Herschel amplifiers in the range from 1 MHz to 18 GHz and were found acceptable. It was identified that the weakest point was due to radiation picked up by bias cables, in particular at frequencies below 2 GHz. Special attention was paid in both amplifiers to obtain unconditional stability (no oscillation under any passive loading condition).

## 3. RESULTS

Table 2 shows the performance of HIFI and ALMA amplifiers. Noise and gain curves, measured in our 350 cold attenuator system are presented in figs. 3 and 4. The noise results are comparable, at the level of 3.6 K (NF=0.05 dB). Notice the improvement in gain flatness and output return losses in ALMA prototype, and the 11 dB higher gain, because of the extra stage and a perfected design.

The measurements were taken without **input isolator**. PAMTECH developed the cryo-isolator CTH-1365 K10 for the 4-8 GHz band. The performance of a number of units of

| PARAM. @15 K, 4-8 GHZ | YCF 6 DMS AVERAGE | YCA 1003 PROTOT. |
|---|---|---|
| **Average Noise Temperature** | 3.6 K | 3.6 K |
| **Average Gain** | 27.1 ±1.1 dB | 38.0 ±0.5 dB |
| **Worst Output reflection** | < -13 dB | < -16 dB |
| **Norm. Gain Fluctuations. @ 1 Hz** | $9.4 \cdot 10\text{-}5\ Hz^{-1/2}$ | $6.2 \cdot 10^{-5}\ Hz^{-1/2}$ |
| **Total power dissipation** | 4 mW | 9 mW |

**Table 2:** *Comparison of the performance of HIFI (average) and ALMA amplifiers.*

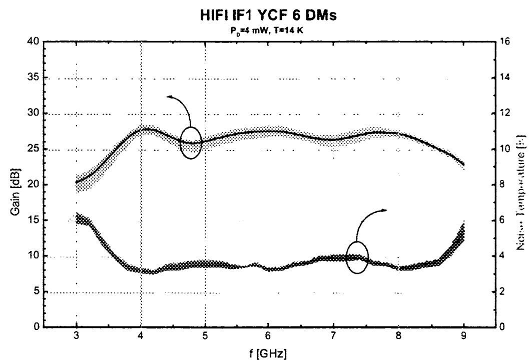


**Figure 3:** *Noise and gain plots of all DMs built for HIFI. The colored bands represent the dispersion.*

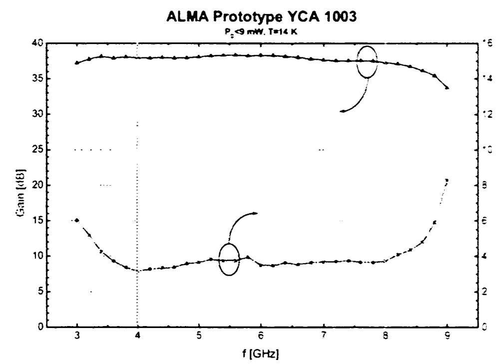


**Figure 4:** *Noise and gain plots of prototype YCA 1003 for ALMA (see features in tables).*

this type has been measured in our labs at 15 K. Typical insertion loss (worst case in the band) is 0.5 dB, which result in an estimated noise increment for an isolator-amplifier unit of 1.3 K. Typical input and output reflection and isolation are higher than 15 dB.

A series of measurements of the ALMA amplifier **gain fluctuations** were taken to evaluate the dependence with the bias point (see fig. 5). This parameter can become a key issue in these projects, where large bandwidths and very low noise temperatures are needed. It depends mainly on the transistors and we have seen a great dispersion in the results of different devices. Therefore, apart from device selection, bias optimization appears as the only procedure to reduce the fluctuations. We have found a remarkable dependence of the gain fluctuations with the drain voltage of the transistor, especially at low drain currents. Above 0.5 volts the fluctuations are rather constant, while below the variation is steep. There is no direct link between power dissipation and fluctuations: the fluctuations increase with drain voltage and decrease with drain current. The optimum bias point for gain fluctuations is not related with the optimum bias for noise measurements and is more critical. It is important to notice that small changes in bias, which may not affect significantly the noise temperature, may lead to great variations in gain fluctuations.

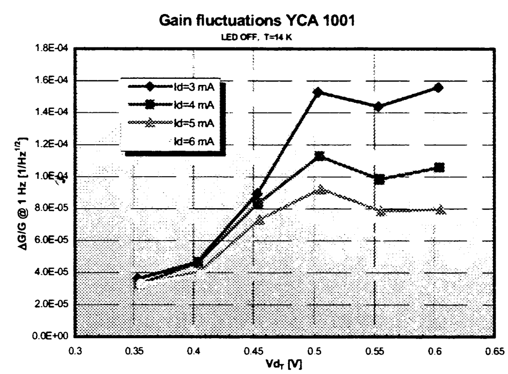


**Figure 5:** *Measurements of the gain fluctuations of an ALMA prototype amplifier at different bias of the 1st stage. TRW IREL1 transistor is used in the 1st stage and ETH run1 in the 2nd and 3rd stages. The parameter used to characterize the fluctuations is the spectral density of the normalized gain at 1 Hz. The data is obtained averaging several spectra of the time domain data taken at 6 GHz with a HP8510C VNA.*

[1] This work is funded in part by by the Spanish MCyT under projects DGES/AYA2000-927, ESP2001-4519-PE and ESP2002-01693, and European FEDER funds. It is described in detail in *I. López-Fernández, J. D. Gallego, C. Diez, A. Barcia, J. Martín-Pintado, "Wide band, ultra low noise cryogenic InP HEMT amplifiers for the Herschel mission radiometers", Millimeter and Submillimeter Detectors for Astronomy, Proc. SPIE Vol. 4855, pp. 489-500, 2003* (available at **http://www.oan.es/cay/tech/SPIE2002_paper.pdf**).