Status of ALMA Band 7 Cartridge Production

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***Abstract*— The Atacama Large Millimeter/Sub-millimeter Array (ALMA) will be composed of at least 65 high-precision antennas. In this framework, IRAM is responsible for the production (component procurement, assembly and test) of 65 production + 8 spare state-of-the-art receivers, covering the 275-373GHz frequency range, called the ALMA Band 7 cartridges.**

Some of the challenging issues that were solved during the design and prototyping of the cartridge, and early experimental results were presented at a previous ISSTT.

The first production cartridge was delivered in Spring 2009. The last receiver (65th) has to be provided to the project before the end of 2012.

Currently, half of the production cartridges have been delivered and accepted by the project.

Every single cartridge has to go through thorough preliminary acceptance tests to make sure that they all meet the specifications imposed by the project. In order to achieve such a level of quality with high delivery rate, some product (PA) and quality (QA) assurance processes had to be put in place and fully automated test setups had to be implemented.

We will briefly describe the cartridge, then the PA/QA processes and present the test setups together with the main performances of the production cartridges delivered so far.

I. Introduction

IRAM is responsible for the design and production of 73 (including spares) integrated front-end modules for Band 7 (275–373 GHz).

When they were laid down in the early 2000's, the technical specifications of the project were pushing the envelope of the then-current state-of-art. The corresponding challenges were successfully overcome during the design phase and reported in several articles (see [1], [2] and [3] references at the end of this article). At present, well into the production phase, the emphasis has shifted to quality assurance and schedule.

With its background in mm-wave radioastronomy and interferometry, IRAM was in a unique position to meet the technical requirements of the design phase. Performing the series production of 73-off state-of art modules, with tight performance and schedule constraints, was a new type of challenge for a medium size scientific institute, and required to set up an adequate workflow organization and test instrumentation. The present paper is a brief account of how this was achieved.

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II. Brief presentation of the Band 7 cartridge

The ALMA front end will consist of a 4-K cryostat with ten plug-in dual polarization receivers called cartridges, covering the frequency range 31 to 950 GHz. A block diagram of the Band 7 cartridge is given in Fig. 1. It includes a cold cartridge assembly (CCA), which was developed and is currently being produced at IRAM, and a warm cartridge assembly (WCA), which is provided to IRAM by the ALMA project for test purposes. An overall view of a production cold cartridge assembly is given in Fig. 2.

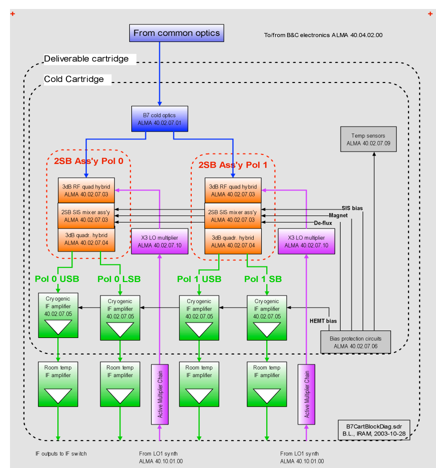

Fig. 1: Band 7 cartridge block diagram.

The cold cartridge assembly consists of three cold stages with operating temperatures of 4K, 15K and 80K and a room temperature baseplate which is the interface between the vacuum and the air. The stages are supported by G10 glass fiber tube spacers. The four plates and G10 tubes constitute the blank cartridge, designed and supplied within the ALMA project by Rutherford Appleton Laboratories (UK).

- The 4 K assembly comprises:
  - The cold optics, consisting of three off-axis elliptical mirrors and a polarization diplexing grid, designed to achieve near-optimum coupling of the two cartridge feedhorns to the telescope within prescribed tolerances;
  - Two dual-sideband (2SB) Superconductor-Insulator-Superconductor (SIS) mixer assemblies, one per polarization, covering the RF band 275-373 GHz. Each 2SB assembly is cascaded with 2x4-8GHz IF low noise amplifiers that provide down converted signals from both upper (USB) and lower sidebands (LSB). These

are thermalized to the 4K stage for improved stability and better noise performance.

- e 15K stage only provides thermal shunts for wiring, IF coaxial cables, and local oscillator (LO) waveguides, as well as mechanical (thermally insulated) support for the HEMT amplifiers.
- The 80K stage has one LO tripler per polarization, to multiply the 94.3-121.3 GHz signal coming from a room temperature oscillator to the 283-365GHz LO band. Wiring thermal shunts are also mounted on this stage.
- The 300K baseplate supports the ESD protection board and the IF, DC and LO feedthroughs.

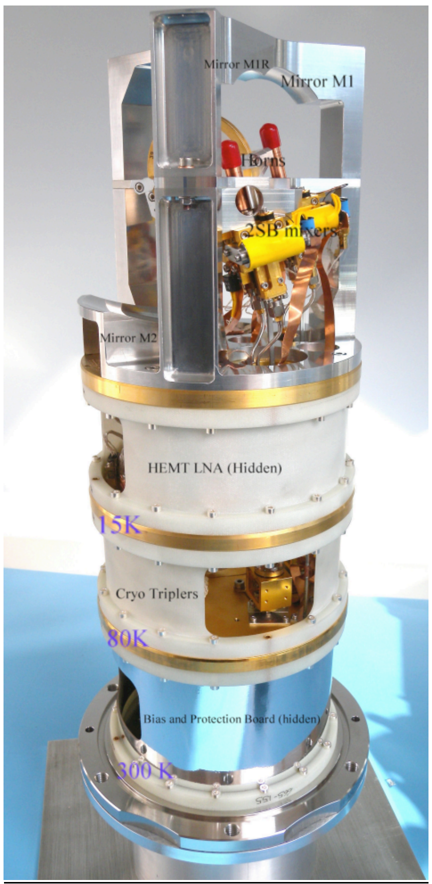

Fig. 2: Complete Production Band 7 Cartridge

III. Cold Cartridge: from Components Procurement to Delivery:

A. Procurement Control

Detailed procurement specification documents were written for the main components of the cold cartridge assembly produced outside IRAM (isolators, semi-rigid coax cable, grid, Low Noise Amplifiers, 4 K optics, wire harnesses, ESD protection board). The suppliers were carefully selected based on their know-how and capability to deliver product quality in due time.

B. Material and Processes Control

Most of the incoming parts are subject to validation tests, following proper test procedures. Most components are identified with serial numbers to allow for traceability through incoming/outcoming items record and traveler writing up.

C. Band 7 Cartridge Assembly

The cartridges are fully assembled and tested at IRAM. Two parallel assembly lines with laminar flow hoods and ESD protective equipment are in place to achieve the high production rate required by the project. The test system is described in the section F below.

D. Validation Tests

After assembly, the cartridges have to undergo time-consuming validation tests on dedicated test setups. This topic is addressed in details in the section III.F below.

E. Cartridge Delivery

Finally, each cartridge is delivered to the project to so called integration centers, together with a batch of documents including bill of material (BOM), shipping inspection checklist, full test report, compliance matrix, configured item data list (CIDL) and electronic data files (configuration / tuning parameters and test data).

TABLE I: Band 7 Cartridge Main Performance Requirements

Property	Required Performance
Mixing scheme	Linearly polarized Sideband Separating Mixer
RF port frequency range	275-373 GHz
LO port frequency range	283-365 GHz
IF bandwidth	4-8 GHz 2SB
SSB receiver noise	<147K over 80% of the RF frequency band <221K at any RF frequency <300K in 370-373GHz extended band
Image band suppression	>-10dB, with allowance: no more than 10% <-10dB no more than 1% <-7dB Globally over all LO settings
Total IF output power integrated over 4-8GHz	-32dBm…-22dBm
IF power variations across 4-8GHz	5dB p-p over any 2GHz window 7dB p-p full band
Large signal gain compression @ 300K input	<5%
Amplitude stability: Allan variance 0.05s…100…300s	4.0E-7, 3.0E-6, respectively
Signal path phase stability	7.1fs over 300s
Aperture efficiency	>80%
Polarization efficiency	99.5% polarization coupling, (equiv<–23dB)
Focus efficiency	>98%
Polarization alignment accuracy	< 2°
Beam squint	1/10 FWHM
Stabilization time from non-operational	< 15 min
Stabilization time from stand by mode	< 1.5 s
Added cartridge mass	< 2.38kg on cold stages
Complete cartridge first eigen-frequency	> 70 Hz

F. Non Conformance Control

When a cartridge does not meet a given specification, a non-conformance (NCR) report and a request for weaver document (RFW) are written for review by the project and keep a record of the discrepancy.

IV. Automated Test Systems

A. Cartridge Technical Requirements

Each band 7 cartridge must meet given electrical and mechanical specifications as of TABLE I following a test plan and dedicated test procedures.

B. Band 7 Cartridge Test System

1) System description

An automated test setup was developed to check in an efficient and timely manner that all of the produced receivers comply with the ALMA specifications (see Fig. 3).

Part of the test system was developed during the pre-production phase (2003-2007) in conjunction with the assembly and delivery of the first eight pre-production cartridges, and test procedures were also refined during the same period.

The first year of the production phase (2008) was dedicated to setting up a second complete cartridge test set that allows for a high rate of cartridge delivery of approximately one every three weeks. A second antenna test range is currently being assembled to further improve the production rate and avoid conflicting needs between the two test setups. The band 7 test system comprises four main parts:

A single-cartridge test cryostat developed by the National Astronomical Observatory of Japan (NAOJ);

A two IF chain test circuit that incorporates 4-8GHz band-pass filters, amplification stages, computer controlled 50MHz bandwidth YIG filters to sample the 4-8 GHz IF band and pin switches that select polarization channel.

A Martin Puplett Interferometer (MPI, Fig. 3 top left and corner and

Fig. 4 right side) to characterize the cartridge in terms of image band rejection. Few linear motors to swap the cold load with hot load and perform Y factor acquisitions. A rotating grid to characterize the cartridge both for the co and the cross polarizations.

A 2D beam scanner (Fig. 3 top left and corner and

Fig. 4, left side) that records signal amplitude and phase in the near field of the cold cartridge assembly optics. The emitter, based on an ALMA YIG type local oscillator source designed by NRAO, is positioned with the E-field vector at 45° position angle so that beam patterns for the two orthogonal polarization channels – performed simultaneously– share a consistent origin in the X-Y plane, thus allowing the verification of the beam squint specification.

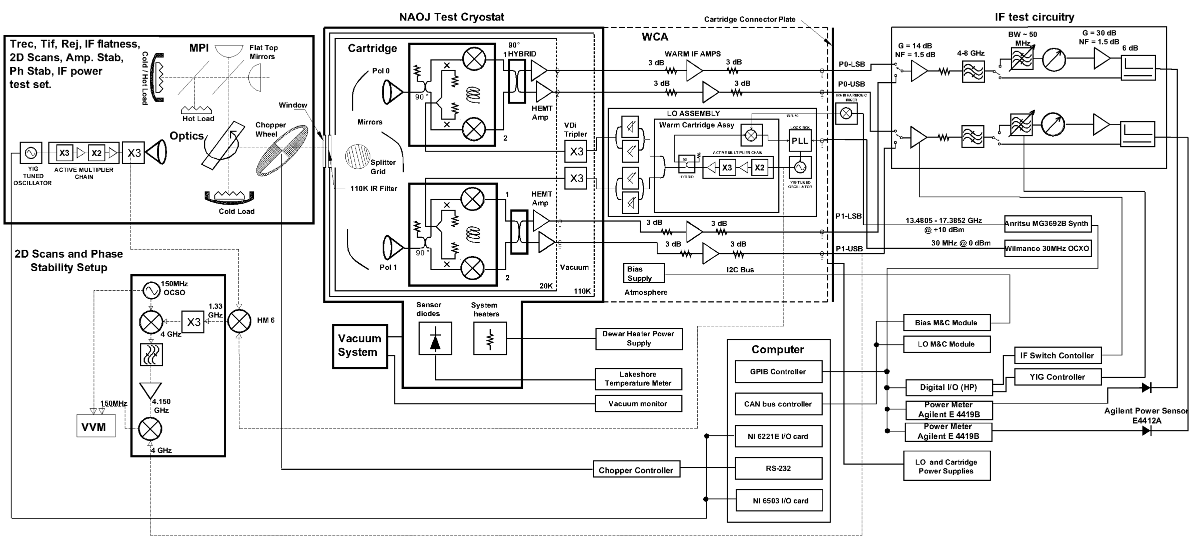

Fig. 3: Band 7 Cartridge Complete Test Setup

The setup involves two monochromatic sources: the local oscillator, and a test signal. The measurement consists of generating a beat note (in the IF band) in two ways: in the mixer, and in an alternate path, generating a reference signal. The relative amplitude and phase of the two beat notes is measured in a commercial vector voltmeter (VVM hereinafter)

This equipment is used to characterize the receiver beam pattern and pointing characteristics of the cartridge (Co-polarization, Cross-polarization, Aperture Efficiency, FWHM, Beam Squint) as well as receiver phase stability at a one second sampling rate. Far field response is derived in post processing by a succession of FFT calculations using a MATLAB-based spreadsheet. Labview based monitor and control software to operate the cartridge test setup bias and control equipment.

1) Monitor and Control Software Design.

All cartridges tests are fully automated and are based on Labview Software platform. Manual intervention is only required to change from one test type (e.g. noise temperature characterization) to another (e.g. image band suppression). Tests that use to take between half a day and one day during the early days of the project are now performed in less than half an hour. Some of the performances like IF signal amplitude stability are verified during night time, when the laboratory temperature is more stable.

The communication between the warm and cold cartridge with the computer is realized through a Monitor and Control unit, an electronic bias module with CAN interface, and a Labview dedicated software first developed at NRAO. The software was then upgraded at IRAM to allow both full and semi-automation.

Integrated noise temperature measurements over 4-8 GHz are automatically performed at 22 LO frequencies ranging from 283GHz to 365 GHz in 4 GHz steps. The same applies to narrow band (40-50 MHz bandwidth over 4-8 GHz IF bandpass) noise temperature measurements from which the cartridge IF signal flatness across the 4 GHz band pass and in a 2GHz sliding window is derived.

Image band suppression test is itself performed at only five LO frequencies across the IF band of both sidebands.

For all these measurements, the Labview software uses mixer bias voltages and currents look up table created as a result of noise temperature optimization tests. Routines were also developed to refine the optimization if needed.

These mixer bias settings are then subsequently used to fully characterize the receiver as per test plan. The tuning parameters are finally provided to the project under tuning and configuration parameters csv file form.

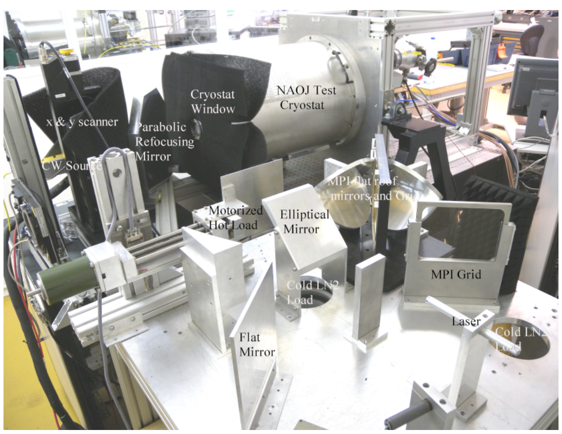

Fig. 4: ALMA Band 7 Cartridge Test Set for Noise Temperature, Image band suppression and beam scanner test set

V. Band 7 Cartridge Main Performances

At the time of writing, 36 cartridges have been assembled, tested and accepted by the project. All of them are meeting the full set of specifications and some of the test results are shown in this section.

A. *Noise temperature*

The Fig. 5 below shows the integrated noise temperature over 4-8 GHz bandpass test results for 36 production cartridges. One can see that the specification is met with comfortable margin.

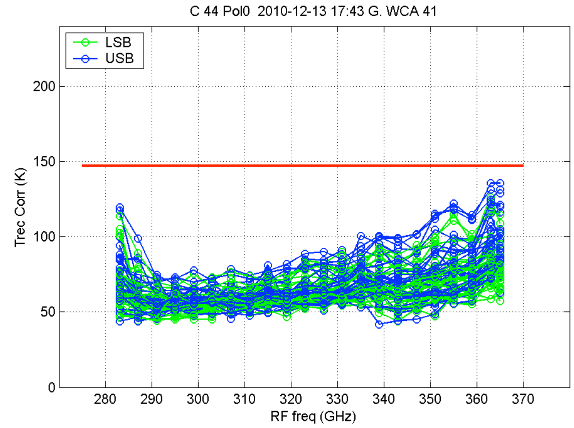

Fig. 5: Total Power Receiver Noise Temperature for 35 production cartridges

B. *Image band suppression*

The Fig. 6 below shows the image band suppression test results for 38 production cartridges. Again, the specification is met.

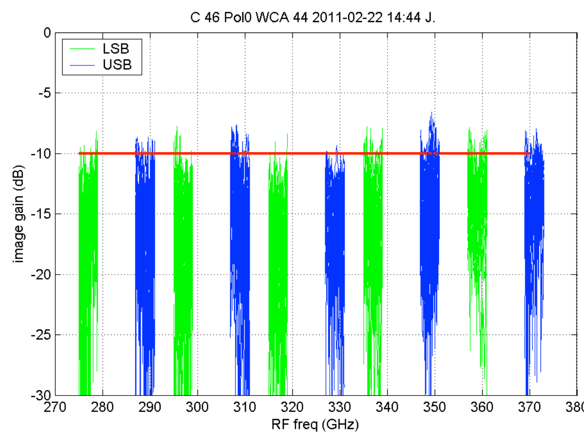

Fig. 6: Pol 0 Image Band Suppression for 38 cartridges

VI. Conclusion

A more industrially minded way of assembling and testing receivers on a larger scale than usually practiced in research institutes has been put in place at IRAM. More than half of the band 7 receivers needed for the Atacama Large Millimeter Array have been produced in a couple of years that meet stringent specifications and deadlines. This has been made possible by the implementation of PA/QA processes and to a large extent, to the automation of the test sets.

References

[1] S. Claude, "Sideband Separating SIS Mixer for ALMA Band 7, 275-370 GHz", March 2001, ALMA Memo #357.

[2] D. Maier et al, "The ALMA Band 7 Mixer", *in 16th International Symposium on Space Terahertz Technology,* May 2005, pp. 428-431.

[3] S. Mahieu et al, "The Band 7 Cartridge (275-373 GHz) for ALMA", *in 16th International Symposium on Space Terahertz Technology,* May 2005, pp.99-104.