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- TECHNOLOGY DEVELOPMENT -

Cryogenic Test Readiness Report

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1 Change Record

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A	07/04/2017	6,7	Completed
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B	15/05/2017	5	RID #5-AGO

2 Applicable and reference Documents

2.1 Applicable documents

AD-1.	ESO / INAF contract	Collaboration Agreement No. 64776/15/69626/HNE	14/03/2016
AD-2.	SOW	FEND-40.02.02.00-0023-B-SOW	22/02/2016
AD-3.	B2+3 Warm Test Interface Control Document	iALMA-TEC-ICD-IAB-001 Rev. H	14/01/2016

2.2 Reference documents

REF1.	B23 Cartridge Prototype Final Report	iALMA-TEC-TRP-IAB-008-A	31/03/2017
REF2.	B23 Passive Component Final Report	iALMA-TEC-TRP-OAA-005-A	31/03/2017
REF3.	B23 Cartridge Prototype Manufacturing Report	iALMA-TEC-TRP-IAB-010-A	31/03/2017
REF4.	B23 Cartridge Prototype Performance Cold Test Report	iALMA-TEC-TRP-IAB-007-A	31/03/2017
REF5.	iALMA Cryofacility dry-run report	iALMA-TEC-TRP-IAB-004-A	10/10/2016
REF6.	iALMA NAOJ Cryofacility Dry Run Report	iALMA-TEC-TRP-IAB-006-A	10/01/2017
REF7.	IASF-BO copper strap thermal conductance test report	iALMA-TEC-TRP-IAB-009-A	25/01/2017



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4 Introduction and Scope

A cryostat, developed by NAOJ, reproducing the ALMA cryostat interfaces has been provided to the CryoWaves Lab in order to perform preliminary integration and cryogenic test of the Band 2+3 cartridge prototype.

This document describes the setup of the cryogenic test environment and integration of the auxiliary equipment used to test the cartridge.

The goal of the activity has been to verify that operating cryogenic environment condition would have been compatible with the nominal operating condition of the prototype cartridge, i.e.:

- Pressure at cooldown start $< 10^{-4}$ mBar
- 1st stage temperature < 110 K
- 2nd stage temperature < 20 K

The preliminary runs have also allowed to estimate the main transient times during cooldown and warmup processes and their optimization.

5 Cryogenic test equipment

The drawings of the ALMA test cryostat, as received by ESO, are reported in Annex A. To be compatible with the ALMA Band 2+3 cartridge, modified the filters and window/lens adapter flanges, i.e. the flanges interfacing the cryostat shields with the filters and lens holders. The drawings of the adapter flange drawings are reported in Annex C of the iALMA-TEC-TRP-IAB-010 Manufacturing Report (Ref 3). For convenience the drawings of the adapters are also shown in Figure 1, Figure 2, and Figure 3.

The 15K filter is made by Gorotex material, while the 110K filter is made of Molded PTFE. Details of the filters and lens are reported in AD-3 and relative drawings. Lenses (one for INAF horn and the other for UdC horn) have been designed by NAOJ and manufactured by UdC made of HPDE.

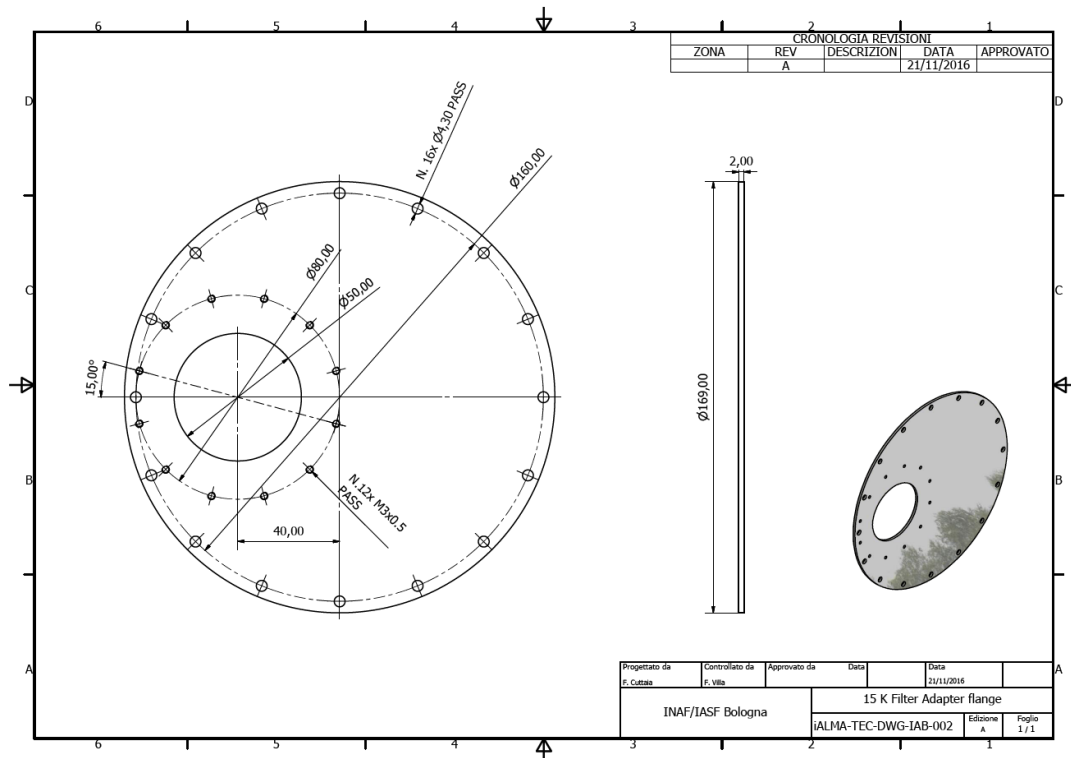


Figure 1.15K filter adapter flange

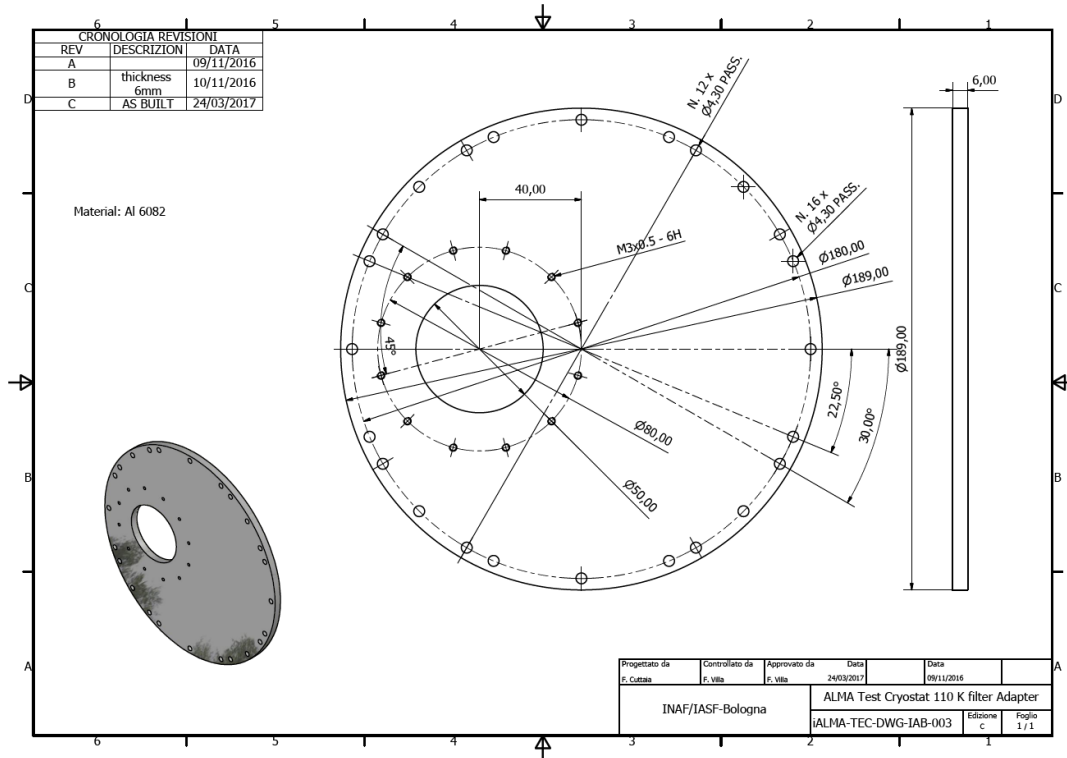


Figure 2. 110K Filter Adapter Flange

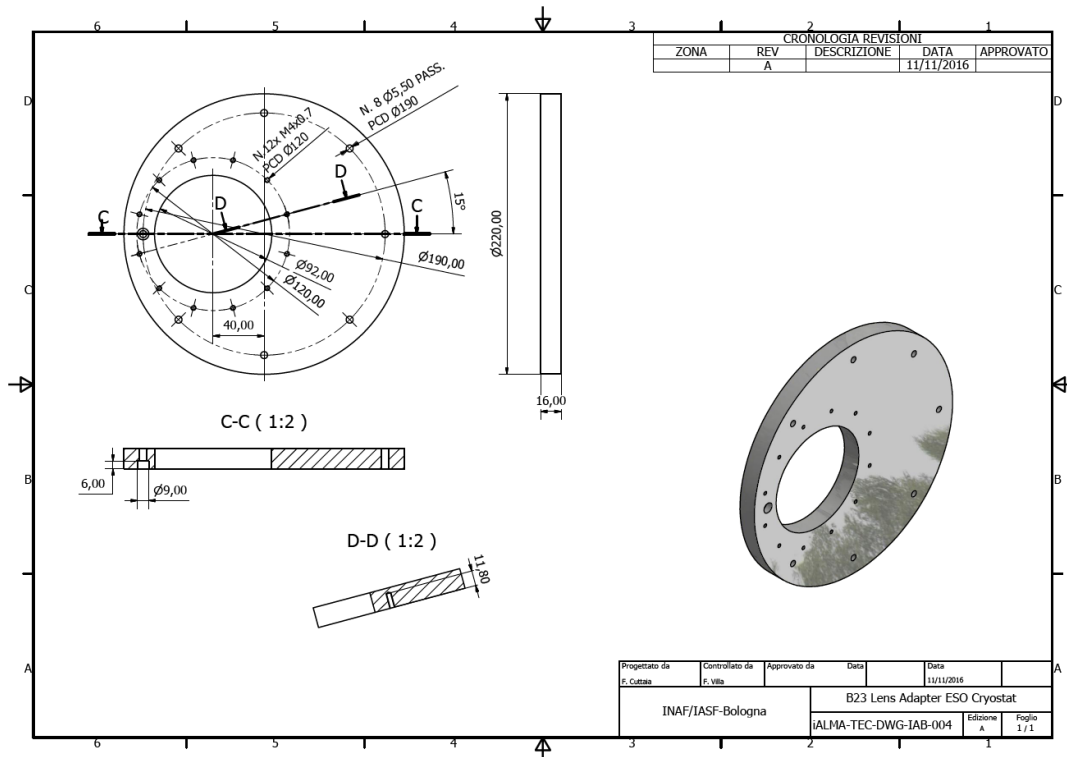


Figure 3. Lens Adapter Flange

Early preparatory activity has started with the check of additional instrumentation and equipment needed to integrate what provided with the cryostat and the following verification of availability at CryoWaves Lab.

Instrumentation delivered with the cryostat consisted of:

- a 3-stage 4K cooler cold head, model RDK-3ST-R2 by Sumitomo Heavy Industries;
- a set of four temperature sensors (LakeShore Cryotronics, model DT670) mounted on the main temperature stages of the cryostat, one sensor each for the 100 K and 20 K stage and two sensors for the 4K stage, one on the mounting flange of the cartridge and one on the cold head of the cooler; all the sensors internal wiring was setup up to a connector (Type SubD-25 pin), mounted on the bottom cryostat shell;
- a set of three resistances, mounted on each of the three temperature stages of the cryostat, connected, through dedicated wires routing, to a connector (Type SubD-25 pin), mounted on the bottom cryostat shell;
- a temperature monitor (LakeShore Cryotronics, model 218) for reading temperature sensors
- an outer connecting cable, compatible with the 25 pin connector of the temperature monitor;
- a Granville-Philips micro-ion vacuum gauge to monitor cryostat pressure.

In order to make such setup operating, CryoWaves Lab was then asked to provide with:

- a) a vacuum bench able to let the cryostat internal pressure drop down a level suitable for cooling down;
- b) a Helium compressor and piping system compatible with the delivered cooler cold head;
- c) a bias supply for the vacuum gauge.

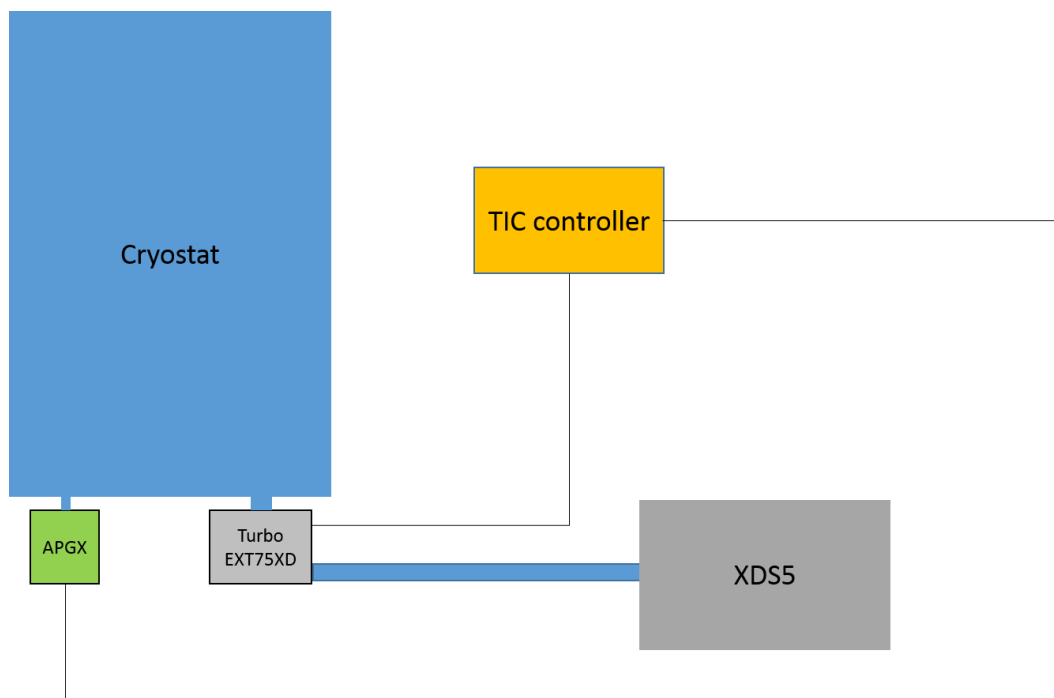
Correspondingly, the setup was equipped with:

- a) a scroll pump and a turbo-molecular pump by Edwards Vacuum, model XDS5 and EXT75DX, respectively, together with the related Turbo Instrument Controller;
- b) a Sumitomo Heavy Industries compressor, model F50-H and related pipes, compatible with RDK cold heads, which was earlier purchased to be used in the dedicated ALMA Band 2+3 project cryogenic chamber (REF5);
- c) an Agilent DC power supply, model E3631A.

In order to improve the capabilities of the test setup, the cryostat was also equipped with

- d) a pirani gauge APG by Edwards Vacuum, read by the same instrument used for controlling turbo pump system; this was useful since the pre-installed vacuum gauge could start monitoring pressure only from about 10^{-2} Torr down;
- e) a LakeShore Cryotronics temperature controller, model 340 with additional board 3468, which allowed us to both monitor the four temperature sensors (we actually did not use the temperature monitor provided with the cryostat) and to actively operate two of the three resistors, in order to support a faster warmup; the whole temperature monitoring and control is driven through a dedicated PC program, earlier developed in LabView to be used in the operation of the dedicated ALMA Band 2+3 project cryogenic chamber (REF5);

The resulting scheme of the vacuum bench connection and monitoring is shown in the figure below.



6 Test environment performance

Once assembled the whole instrumentation setup, the verification of the cryostat performance involved a set of dry runs during the month of November 2016.

A first dry run was performed by cooling the dummy cartridge contained in the cryostat when it was delivered to the CryoWaves Lab. It just consisted of the cold plates interfaced to the different temperature stage flanges of the cryostat, linked through small insulating supports (Figure 4).



Figure 4 The dummy cartridge (left panel) which was integrated in the cryostat (middle and right panels) at its delivery to IASF Bologna and was cooled down during the first dry run

A second dry run was performed in order to test the cooling of the Band 5 cartridge interfaces, adapted to the Band 2+3 receiver (Figure 5). The details of such set of dry runs are reported in the REF6. Here we summarize the relevant performance reached with respect to what needed for the optimal B2+3 cold testing and listed in Section 4.

An additional run was performed on mid December, with a pre-integrated receiver chain (see REF3 and REF6), to verify the cryogenic chamber performance in a configuration more representative of the nominal.

6.1 Vacuum performance

The vacuum procedure consists of a preliminary pumping by the scroll pump and the following activation of the turbo pump as the pressure drops down below 10^{-1} mBar. The cooler is then switched on when the pressure of the chamber has reached about 10^{-4} mBar.

In both the dry runs the value of the pressure needed to start pumping by the turbo was reached in less than two hours of scroll pump activity. The

pressure then dropped down below 10^{-4} mBar in less than 1 hour of turbo pump operation.

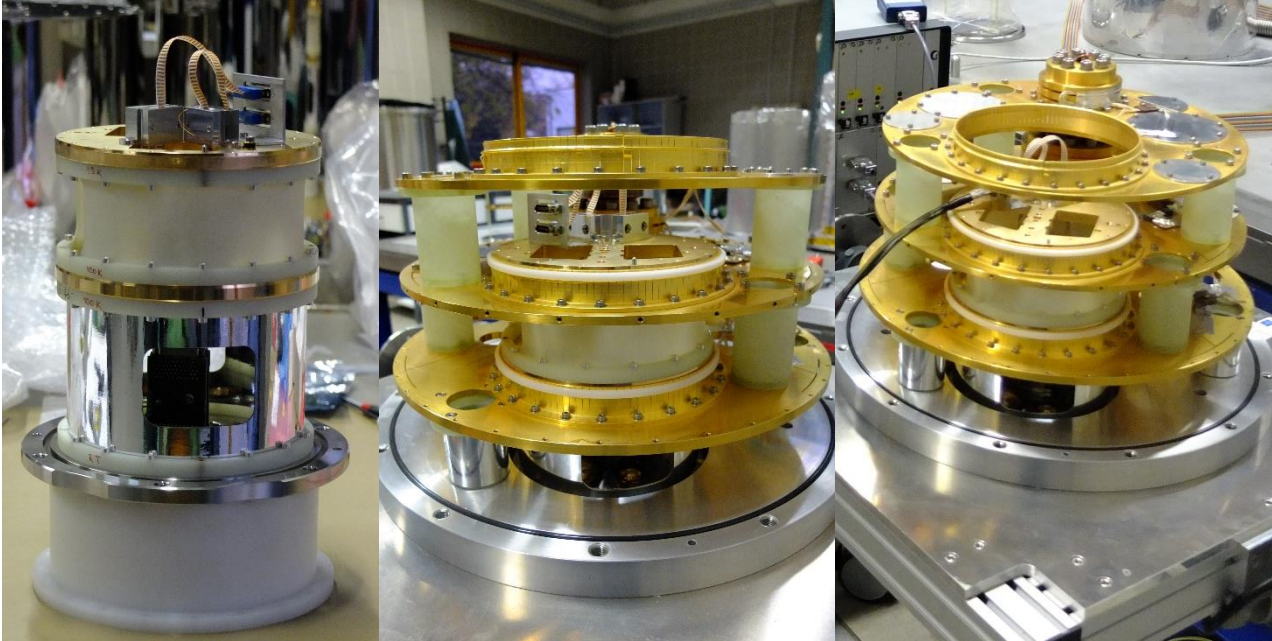


Figure 5 The Band 5 cartridge body (left panel) adapted to support Band 2+3 receiver prototype. In the middle and right panels it is evident that it exploits just the 100 K and 20 K cryostat temperature stages, while the 4 K flange aperture is left open and will allow the integration of the front end (horn, OMT and LNAs) of the receiver during the final tests.

6.2 Cooldown and heatup phases

The Band 2+3 cartridge prototype reference temperature stages went down below 110 K and 20 K, respectively, after less than 10 hours from the cooler switch on. Figure 6 shows the final cooldown of the Band 5 cartridge body run. For a better view of the following figures below, we also report in the Table 1 the correspondence between sensor labelling and the temperature measured.

Id	Sensor type	Location
A	DT670	100K flange
B	DT670	20K flange
C	DT670	4K flange
D	DT670	4K cold head

Table 1 The table reports the readout channel Id, the type of the sensors and the position inside the chamber.

Even though the desired low temperature limits are reached quite quickly the steady operating temperatures require an additional time to be spent cooling, as reported in the Table 2.

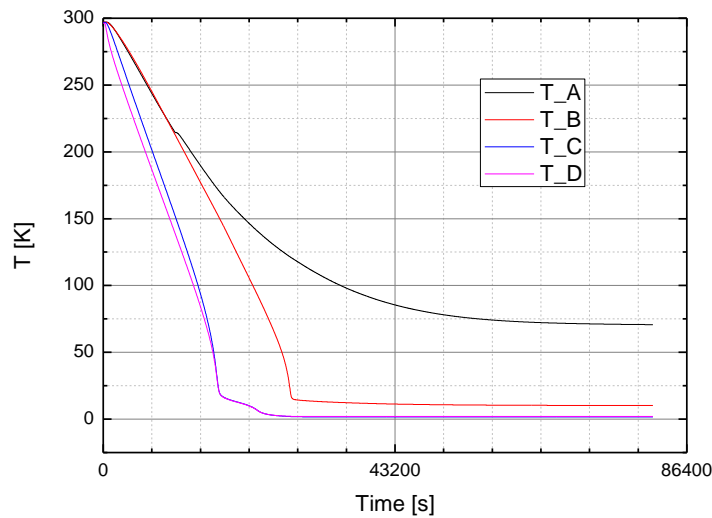


Figure 6 The overall behaviour of the different temperature stages during the second cycle of the second dry run cooldown of the NAOJ cryostat.

During the dry runs different scenarios were tested for the warmup phase.

At the end of the first dry run, the system was left to freely evolve once the cooler was switched off (Figure 7, left); this led to a warmup time (which we have defined as the time between the cooler switch off and the time when all the sensors inside the chamber measure a temperature higher than 280 K) of about 4 days. During the second dry run, with the Band5 cartridge body, the heating of the chamber was supported by supplying smoothly increasing power to the heaters located on the 4 K and 20 K flanges (from 0.25 W to 1.66 W and from 0.22 W to 2.2 W, respectively) during the first six hours after the cooler switch off (Figure 7, right). In this case the warmup time was reduced to less than 3.5 days.

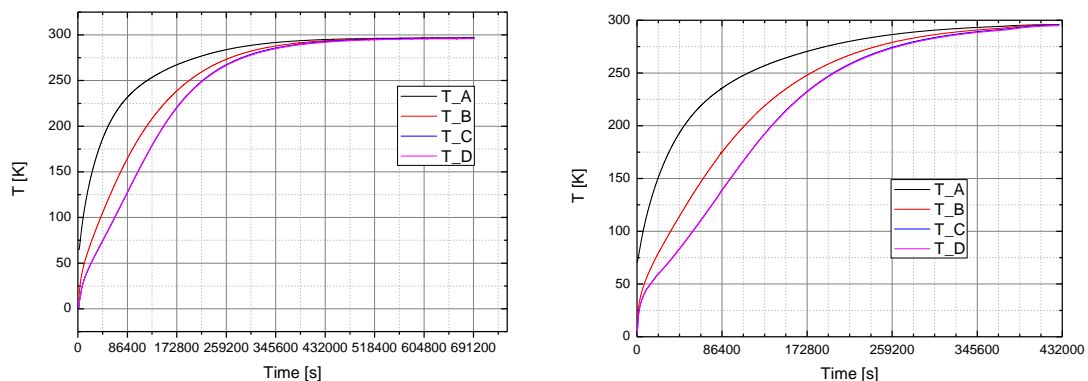


Figure 7 The overall behaviour of the different temperature stages during the dummy cartridge (left) warmup, with no active procedure applied to speed up the process, and Band5 cartridge body (right) warmup, when, during the first part, the heaters were activated in the coldest stages.

The second dry run cooldown and warmup timescales are summarized in the table below where also the steady state low temperatures reached are reported.

Id	Steady low T [K]	Cooldown Time (hours)	Warmup Time (hours)
TA	70.7	22.4	59.9
TB	10.2	21.75	73.3
TC	1.73	8.5	78.6
TD	2.0	8.3	79.5

Table 2 The table reports the readout channel Id, the steady state average low temperature reached, the time spent to reach such temperature, the time spent to reach 280 K, once the cooler is switched off.

In order to provide a more flexible and quicker thermal cycling, in particular for the warmup phase which demonstrated the less time efficient, at the end of the receivers testing runs, the heaters on the coldest, 4 K and 20 K, stages were fully exploited and kept active (0.75 W and 11 W, respectively) up to the time the corresponding plate reached a temperature of 240 K. Figure 8 shows the warmup curve of the December run, with JPL LNAs receiver, which was the first performed with this final procedure; the warmup time is strongly reduced up to about 1.5 days.

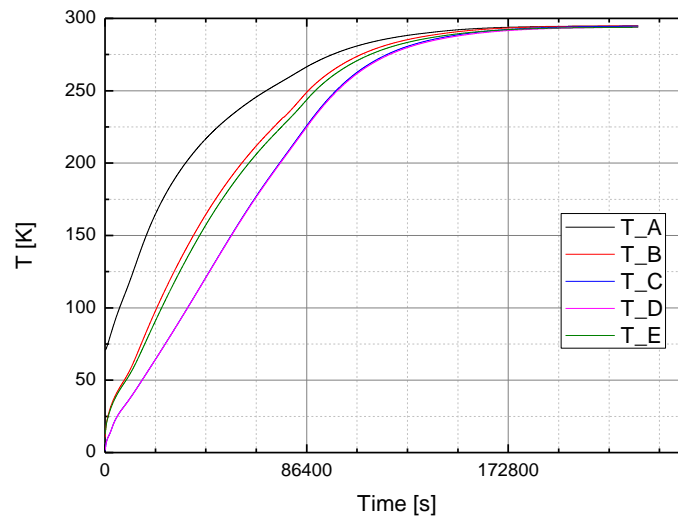


Figure 8 The overall behaviour of the different temperature stages during the warm up phase of the first run with the whole cartridge preliminary setup (JPL LNAs). This phase was shorter than previous runs because the heaters were active for most of the time. An additional sensor, T_E, was also used to monitor the amplifier assembly temperature.

6.3 Low temperature steady state

As mentioned above the temperature stages relevant to the Band2+3 tests are the 100K and the 20K interfaces and the temperature range reached during the dry run are far below the maximum limit requested for an optimal test environment. In this section we summarize further details of the

steady state low temperature data, which have been evaluated during the dry test.

As far as the temperature stability regards, we could evaluate, during the final phase of the second dry run cooldown (Figure 9), a preliminary estimation of the 20 K stage average temperature and standard deviation, for a period of about three hours, as 10.273 ± 0.017 K, while the peak-to-peak variation is 65 mK. For the 100K stage, the estimation, taken from a shorter data set of about 20 minutes, was 73.078 ± 0.003 K, with a peak-to-peak variation of 12 mK.

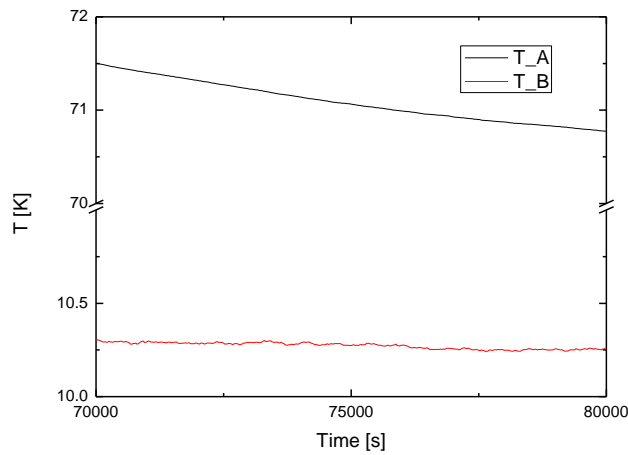


Figure 9 During the last phase of cooldown the 20 K stage has reached its steady state low temperature, while the 100 K flange is still drifting.

Finally, a quick verification of the heat lift of the 20 K stage of the cooler was performed by supplying power through the corresponding resistance heater. Two main steps were induced in this stage by providing 100 mW and 475 mW, which resulted in a temperature increase of 70 mK and 265 mK, respectively (Figure 10).

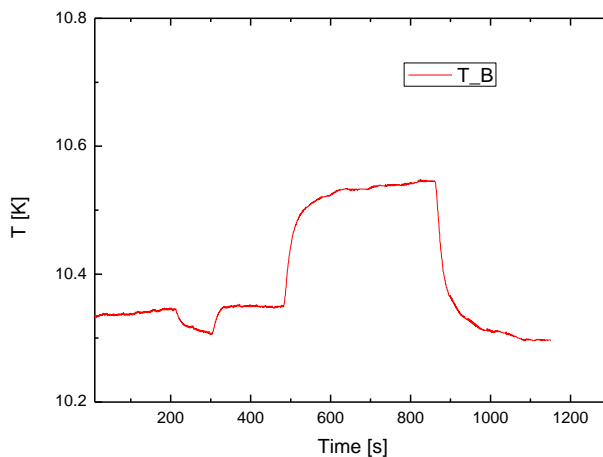


Figure 10 Temperature curve of the 20 K cooler stage during the head load curve test.

Such results confirm that the cryostat would keep compliant performance in terms of reference temperature also in presence of the receivers to be tested, typically showing a power dissipation of few tens of mW.

Actually, during the test with the JPL LNAs assembly, the 20 K plate reached a low temperature of less than 10 K (Figure 11), while a sensor mounted on the cartridge interface close to the LNAs measured a temperature of about 12.4 K.

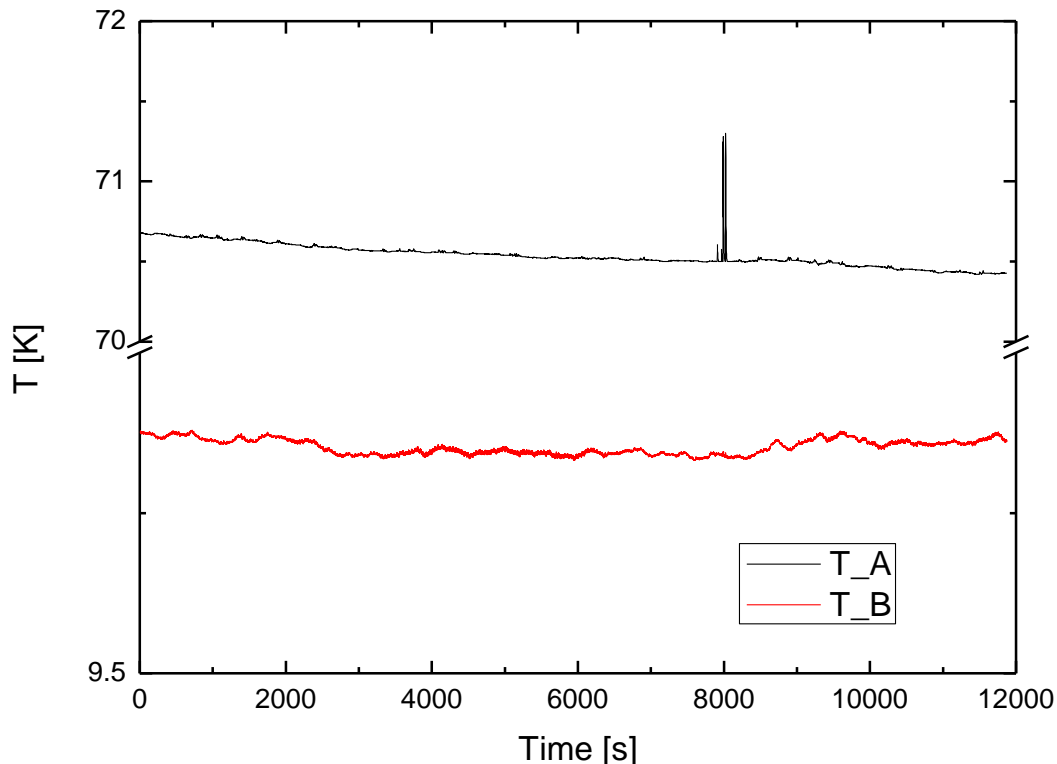


Figure 11 Temperature curve of the 100 K and 20 K stage during the steady state of the preliminary cartridge (JPL LNAs) test run.

7 Conclusions

A set of dry runs of the cryostat, received by ESO and integrated with CryoWaves Lab equipment and instrumentation, have been run in order to verify functionality and characterize cryogenic performance of such environment, expected to host cold test of the Band2+3 receiver prototype.

Such dry runs have demonstrated cryogenic chamber performance compatible with the cartridge cold test.

One criticality found has been a series of failures of the temperature acquisition and control computer, which has been then substituted with a backup PC, running successfully all over the cartridge cold test campaign.