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Cartridge Test Cryostats for ALMA Front End

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Abstract

We have developed four cartridge test cryostats for ALMA FE cartridge-type receiver with taking account of reliability and easy operation. It uses a simple, compact and efficient thermal link between a cartridge-type receiver and a plate connected to a 3 stage Gifford-Mcmahon (GM) cryocooler. The cooling time of the cartridge-type receiver is less than 10 hours. With a cartridge loader, a cartridge-type receiver is easily inserted and extracted in a condition that the cryostat is closed.

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1 Introduction

The ALMA requires production of a large number of the state-of-art SIS receivers. To produce and operate several hundred receivers, a concept of modular receiver corresponding to frequency bands is adopted for ALMA [1]. The module called as a cartridge-type receiver is equipped with all components as cooled optics, SIS mixers, IF amplifiers, and LO. Then it works as designed under cooled condition. To realize the modular concept, automatic thermal link has been proposed [2]. A concept of cartridge-type receiver has a clear and compatible interface, and thus the band cartridges can be developed independently by worldwide front end engineers.

NAOJ and universities in Japan planed the Large Millimeter Submillimeter Array (LMSA) [3]. A submillimeter antenna with 10 m diameter was constructed as a prototype one of LMSA [4]. It has been installed at Pampa la Bola (Alt. 4800m) in the northern Chile as one of research activities of LMSA, which is called Atacama Submillimeter Telescope Experiment [5]. For this telescope, an ALMA cartridge-type cryostat with three cartridge bays has developed [6]. To accommodate cartridge-type receivers, we have developed a simple thermal link which makes it possible to plug-in them [7]. We have evaluated with engineering models of Band 3, 8 and 10 cartridges on the site in the northern Chile [8].

To support developments of state-of-art cartridge-type receivers, we have fabricated cartridge test cryostats by modifying the ALMA cartridge-type cryostat. To design it, we counted reliability, short cooling time and easy handling. A cartridge loader is also fabricated for easy handling of cartridge-type receiver.

2 Instrumentation

2.1 Cryostat

The cryostat is designed to be as small as possible for easy handling and short cooling time. A cylindrical cryostat has a dimension of 460 mm diameter and 600 mm height houses a cartridge-type receiver of 170 mm or 140 mm diameter as shown in Figure 1. The cryostat is cooled by a 3 stage GM cryocooler (Sumitomo RDK 3ST). In this cryostat, temperature of 4 K is used for SIS mixers and optical components such as mirrors, feed horns, a local oscillator (LO) coupler, and polarization grids. Low noise amplifiers are cooled on the 12 K stage. Temperature of 80 K is used for radiation shield and cooled LOs.

A cross-section of the cryostat is shown in Figure 2. The sidewall of the vacuum vessel (①) is made of SUS304 with 4 mm thickness. The inner surface of the sidewall is polished to reduce the emissivity. The top and bottom flanges (②, ③) of the vacuum vessel are made of Al6061-T6 to reduce the weight.

The 4 K (⑦) and 12 K (⑥) plates connected to the cold head are made of oxygen free copper (C1050) of 6 mm thickness with gold plated. The 80 K plate (⑤) is made

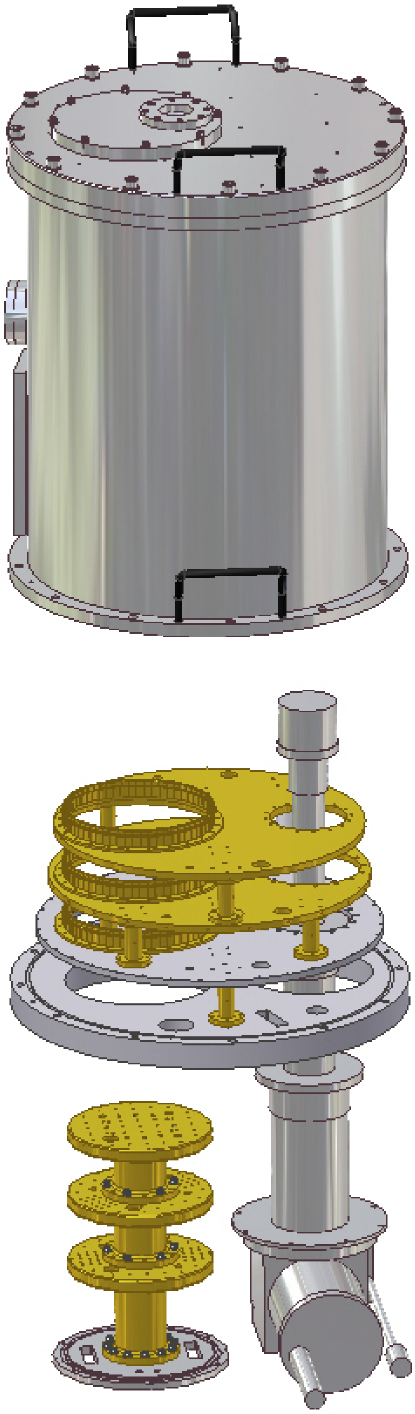

Figure 1: Schematic drawing of the cartridge test cryostat. There are three plates of 4 K, 12 K, and 80 K from up to down.

of Al6061 with 6 mm thickness to reduce the weight. These plates are supported by 3 columns of GFRP with 46 mm in diameter and 2 mm thickness.

The 12 K and 80 K radiation shields (⑪, ⑬) are made of 2 mm thick copper with Ni-plated. No multi-layer insulator is used.

2.2 Cartridge

The interface of the receiver cartridges for the ALMA was proposed by the RAL [2]. A cartridge has 3 disk-like stages, the diameter of which is 169.0 mm at the 4 K stage, 169.5 mm at the 12 K stage, and 170 mm at the 80 K stage. A cartridge proposed by the RAL is supported by the outer shell (closed-type). Although the closed-type cartridge is stronger against gravitational deformation, decomposition of the cartridge is indispensable to assemble receivers.

A column-type cartridge we have developed can be assembled without any decomposition of the cartridge (Figure 3). The support structure is a column of 90 mm in diameter and 4 mm in thickness made of GFRP. To reduce thermal radiation on the structure, the GFRP pipes are gold plated. The outer space of this support structure is used for installation of the equipments such as LNAs.

Because the optics which couples between subreflector and the feed horn is installed on the 4 K stage of the cartridge, the alignment of the 4 K stage is important. The alignment of a cartridge including the 4 K stage is defined by the bottom plate. The 4 K stage is machined after the structure is assembled so that the tilt to the bottom plate is fabricated to be less than 0.6 mrad. The tolerance between the center of the bottom plate and that of the 4 K stage is less than 50 μm. The structure has enough strength for gravitation deformation due to elevation motion of an astronomical telescope and thermal contraction of the plates.

There are two D-type connectors with 37 pins on the bottom plate. There are two ports for waveguide flange or photo connectors on the bottom plate.

2.3 Thermal link

We have developed a simple, small, and efficient thermal link, which is applied at various temperatures ranging from 2 K to 100 K [7]. The concept of automatic thermal link was first proposed by the Rutherford Appleton Laboratory (RAL) for use in ALMA receivers [2]. Their thermal link was made using flexible braids without screws. However, it is slightly large and complicated.

A thermal conduction is achieved with the thermal link which clamps the cartridge with an external force of a metal spring or nylon. The link is composed of a ring-like structure and a clamp as shown in Figure 4. The link is the same for all 3 stages except for the inner diameter. These links can be fabricated at relatively low cost.

The link requires small space with an extra width of 12.5 mm for a cartridge, and this

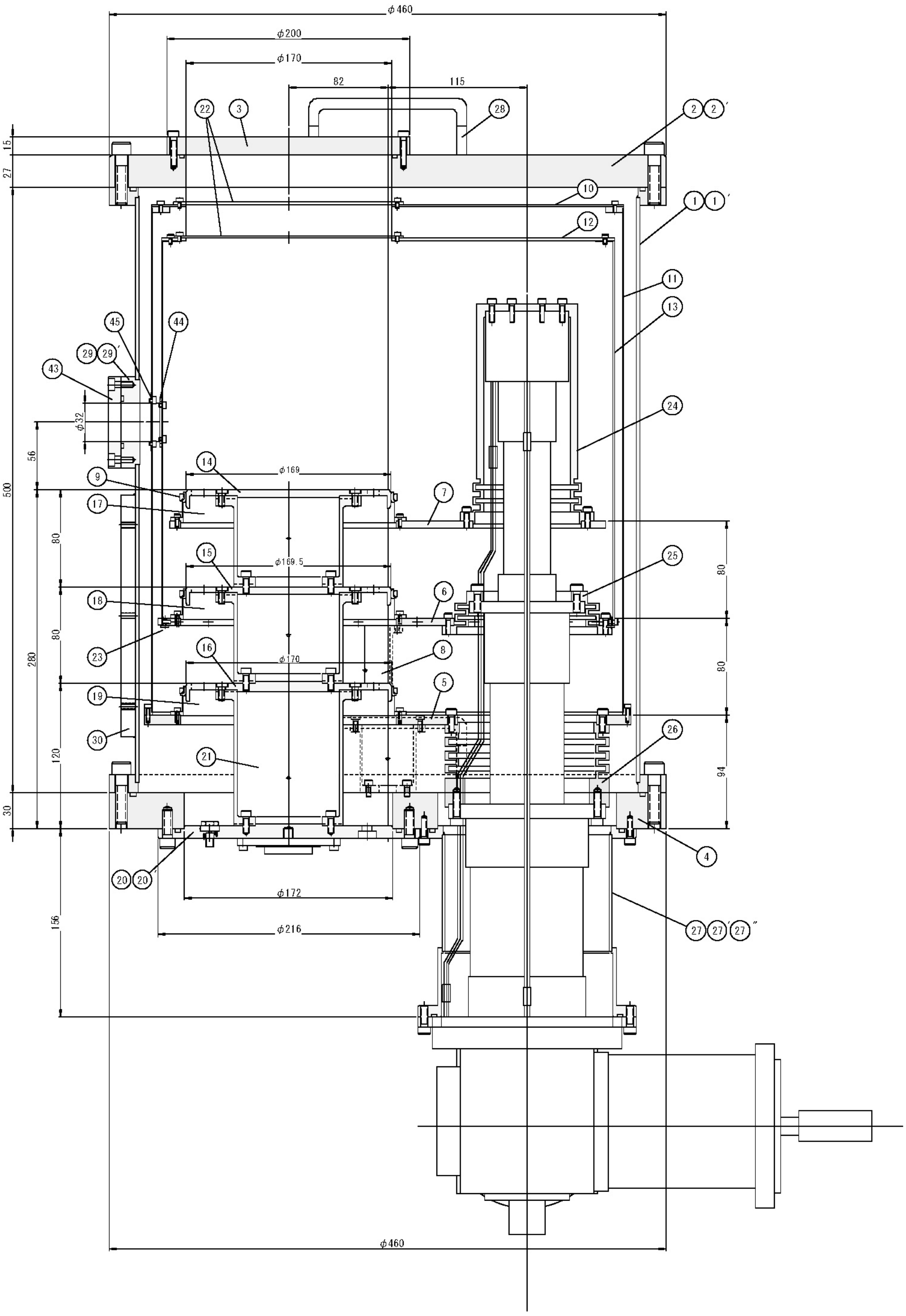

Figure 2: A cross-sectional view of the cartridge-type cryostat. The cryostat is composed of 3 stages, 4 K, 12 K, and 80 K from up to own. The parts number is indicated.

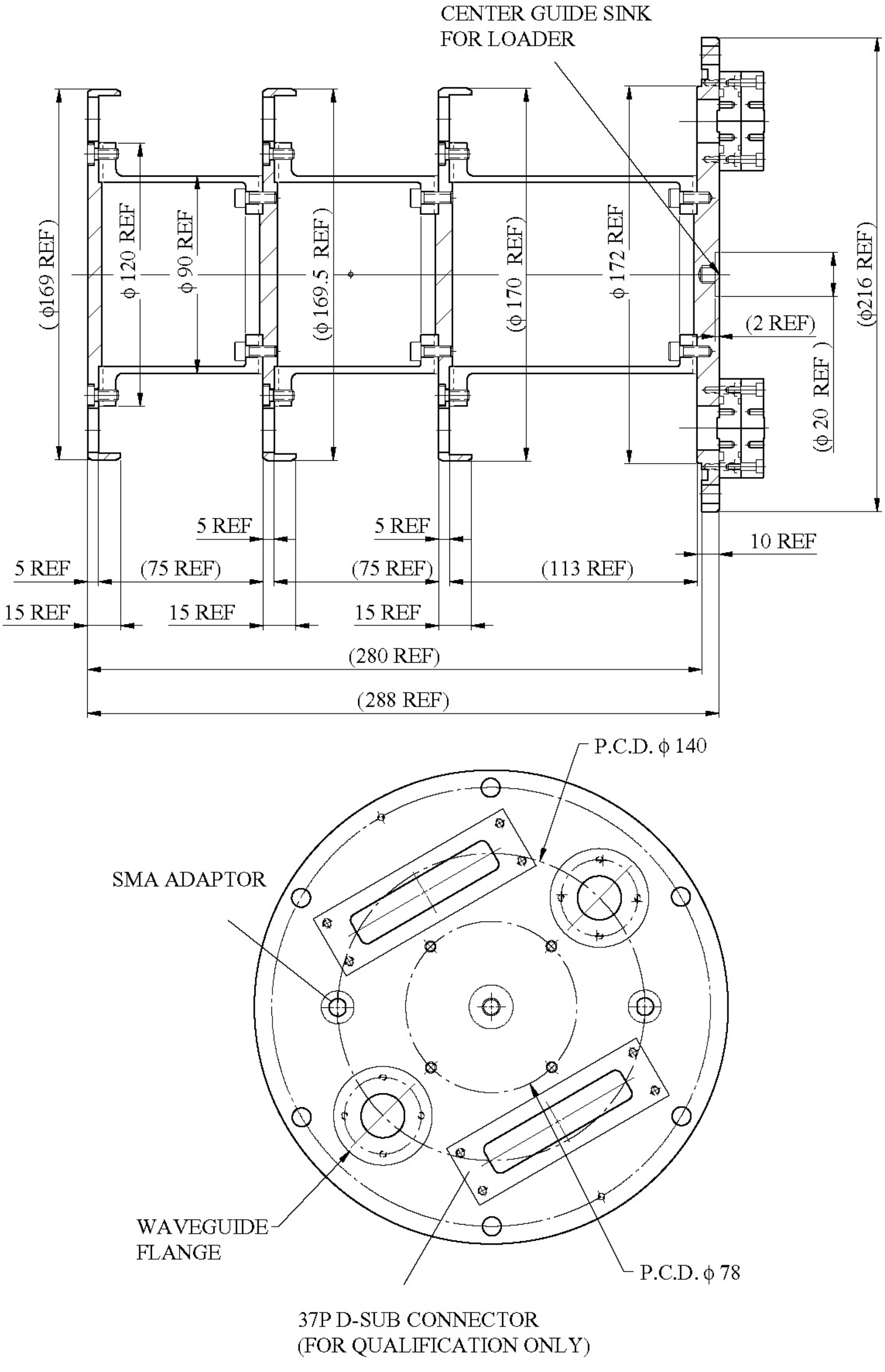

Figure 3: A schematic drawing of the cartridge structure.

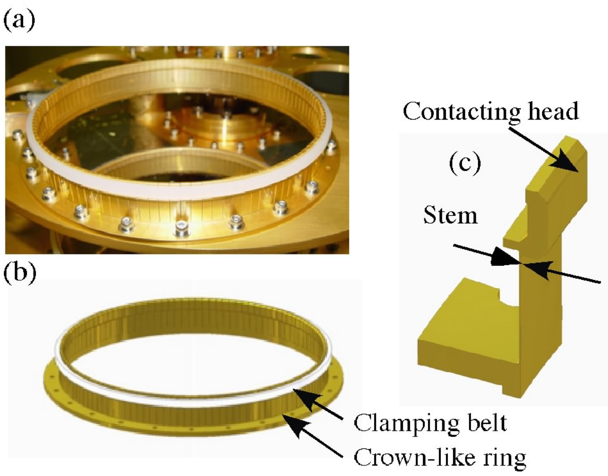

Figure 4: (a) A photograph of the thermal link. (b) Cross-sectional view of the thermal link. The link is composed of a crown-like ring made of oxygen free copper and clamp belt made of nylon. The crown-like rings divided to 120 pieces. (c) Up side view of the thermal link.

thermal link makes the cryostat compact. This link weighs about 250 g. The contacting part of the ring is divided to 120 pieces, like comb. The thin part of the ring is also divided, so that this link is flexible to avoid thermal deformation of the plates.

The clamping part is a metal spring or nylon ring. The thermal shrinkage of the nylon is much larger than that of the copper, and the nylon ring shrinks and ties up the copper ring under the low temperature condition. The nylon is the slightly larger diameter for clamp the inner copper ring. The nylon ring is the same as RAL's link, which enables the link to clamp with ~2000 N at 4 K [2].

2.4 Coldhead interface

To reduce the mechanical vibration of the cartridge, an interface between the coldhead and the 4 K plate has been developed (Figure 5). This flexible part is made of high purity copper cables (99.9999 %), which is fabricated for audio speakerphones. These cables are soldered to OFCu with Ag paste.

The connection between the cryocooler and the 12 K, 80 K plates has bellows-like structure (㉕, ㉖) as shown in Figure 2 to reduce mechanical vibration of the cryocooler.

2.5 Cartridge Loader

A cartridge loader which enables a cartridge insert and extract from the cryostat has developed. It consists 4 poles with ball bearings made by THK Co. to guide the cartridge-type receiver as shown in Figure 6. With this loader, the cartridge is smoothly inserted and extracted in a condition that the cryostat is closed.

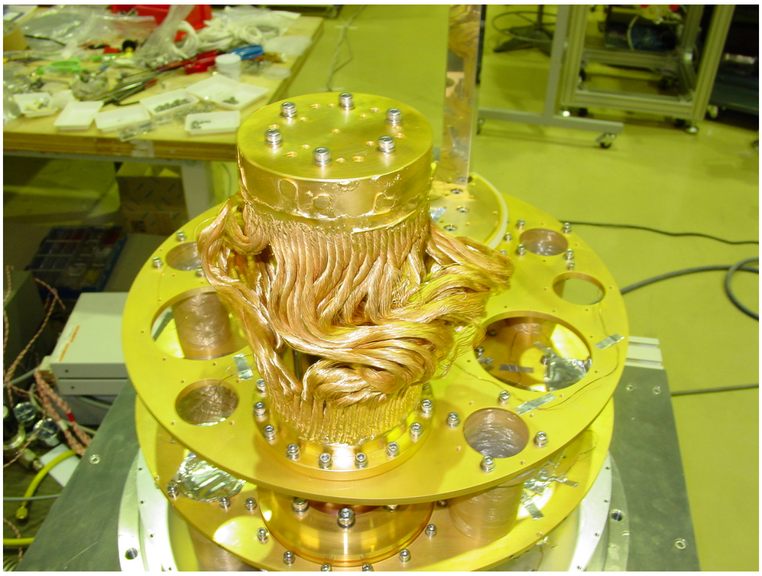

Figure 5: A coldhead interface to reduce the mechanical vibration

2.6 Interface

Vacuum interfaces are provided on the bottom plate as shown in figure 7. There are four ports for evacuation (DN 40 flange), monitor (DN 25 and DN 16 flanges) and ventilation (DN 10 flange).

There are two D-type connectors with 25 pins on the bottom plate. Temp sensors and heaters are cabled from 25 pin D-type connectors. There are two ports for waveguide flange or photo connectors on the bottom plate.

On the top plate, there is an interface plate of 170 m diameter (③). Cartridge developers can modify the position and the size of the vacuum window for their cartridge-type receiver. The IR filters also can be changed with interface plates of 170 mm diameter of the 80 K and 12 K radiation shields (㉒).

There is a window on the sidewall (㉙). This window is used for displacement measurements by a laser or LO injection for submillimeter receivers [6]. This LO window is useful for quasi-optical coupling of conventional LO for bands 8, 9, and 10, which has mechanical tuners.

A frame for this cryostat is constructed with commercial Al rods. The size of the bottom unit is 600 in width, 600 in depth, and 700 mm in height.

2.7 Assembly

The three plates are assembled with a cylinder of 190 mm diameter instead of the cartridge for alignment. Between the parts, Apiezon Greece is used for conduction.

There are positioning holes on the bottom and top vacuum plates for alignment.

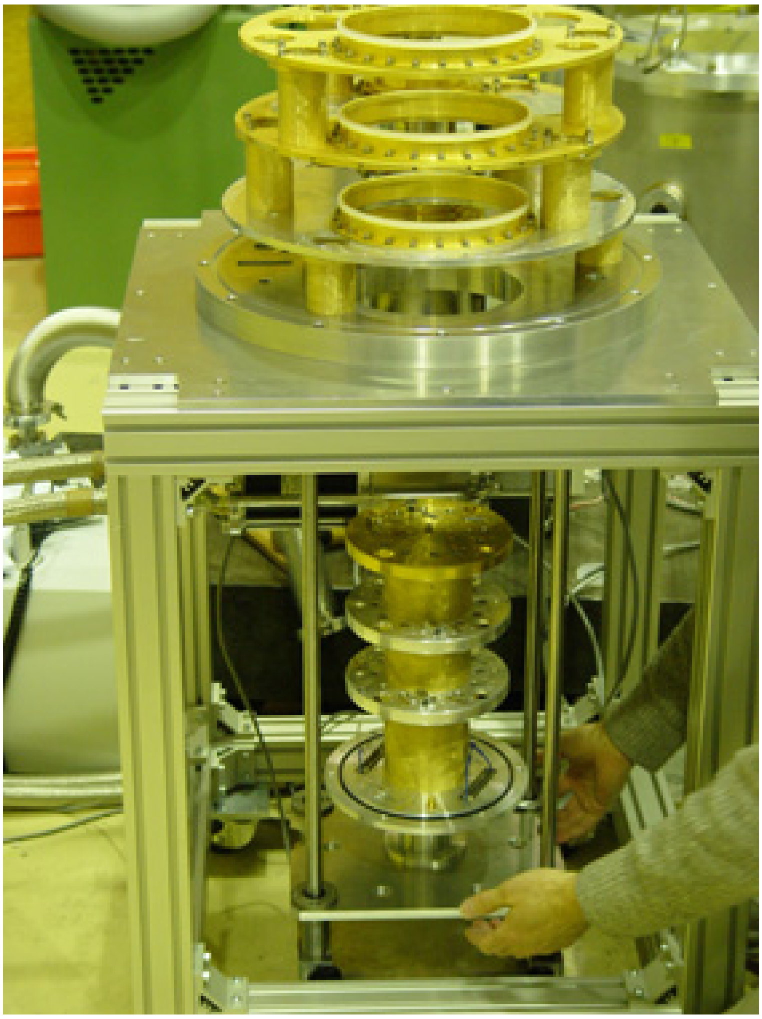

Figure 6: The cartridge loader

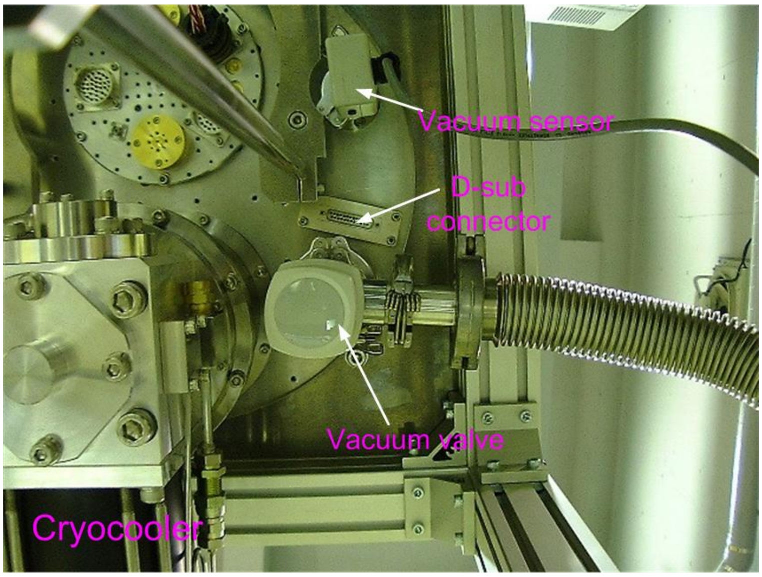

Figure 7: The bottom plate of the cryostat.

2.8 Cryocooler and Compressor

The cryostat is cooled by a 3 stage GM cryocooler (Sumitomo RDK 3ST), which has a cooling power of 0.8 W at 4.2 K, 8 W at 15 K, and 30 W at 80 K. A He pot to reduce temperature ripple at the 4 K coldhead is equipped. This pot is compact, simple, and safe. It reduces temperature ripple of the cold head from 100 mK to 10 mK at 4 K [9].

There are three kinds of compressor for the cryocooler, air cooling type (Sumitomo CSA 71), water cooling type (Sumitomo CSW 71), and outdoor type (Sumitomo CNA 61). The power consumption is around 7.5 kW.

The outdoor-type compressor has been used on the ASTE telescope at Pampa la Bola [8]. The performance is almost same as that at laboratory.

3 Results

3.1 Cooling Time and Temperature

The cooling time of this cryostat is around 10 hours as shown in Figure 8. To evacuate the cryostat, it takes around 1 hour with a small turbo drag pump of TMH 071 Pfeiffer Vacuum GmbH. Temperature at the cartridge without load are tabulated in Table 1.

With heaters, the temperature rises from 4 K to 300 K in 10 hours.

3.2 Thermal conductance of thermal link

The thermal conductance of the thermal-links are reported by Sugimoto et al. [7]. The measued thermal conductances of three stages are tabulated in Table 1. We note that the

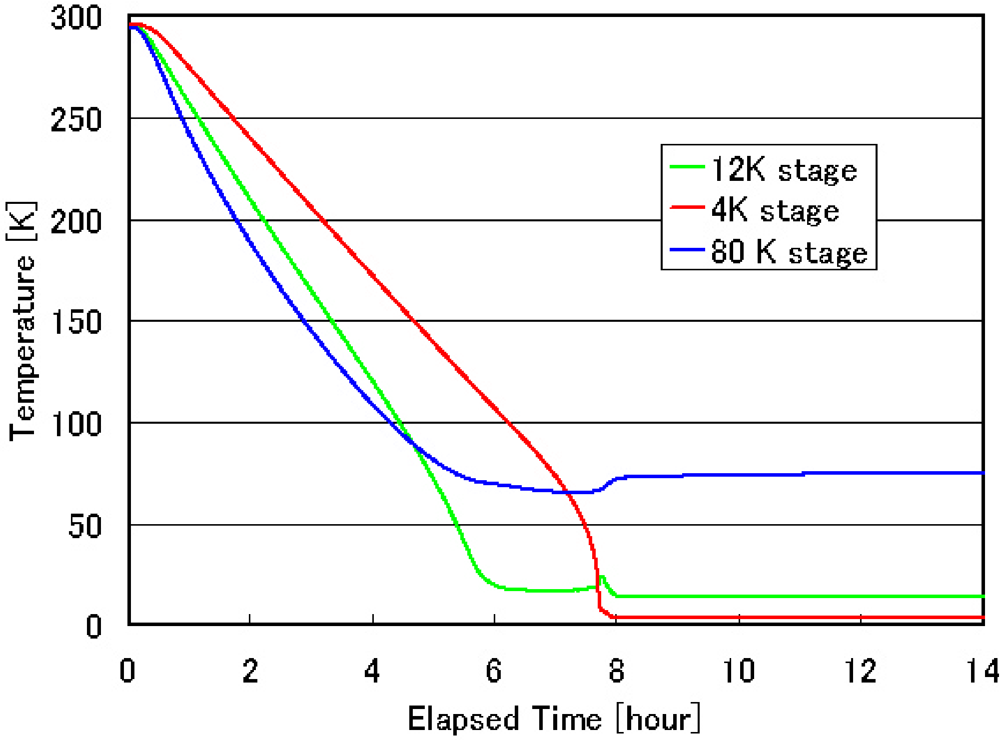

Figure 8: Cooling time of a cartridge-type cryostat.

Table 1: summary of results

	No1		No2		No3		No4
Cartridge diameter	170 mm		170 mm		170 mm		140 mm
Cartridge-type	NAOJ	RAL	NAOJ	RAL	NAOJ	RAL	NAOJ
Temperature	[K]	[K]	[K]	[K]	[K]	[K]	[K]
4K stage	2.91	2.80	2.98	3.18	3.29	3.25	3.06
12K stage	12.33	12.75	10.48	8.82	13.26	12.61	10.87
80K stage	59.08	58.86	53.41	52.19	74.11	73.29	68.36
Conductance	[W/K]	[W/K]	[W/K]	[W/K]	[W/K]	[W/K]	[W/K]
4K stage	1.1	1.0	1.0	4.2	1.0	2.0	2.0
12K stage	2.9	2.3	2.2	1.7	1.6	1.3	1.7
80K stage	5.4	6.5	3.5	8.6	5.2	4.2	4.0
Vibration	[μm]	[μm]	[μm]		[μm]		[μm]
horizontal	$7 \sim 9$		$10 \sim 12$		6		6
Vacuum	[torr]	[torr]	[torr]	[torr]	[torr]	[torr]	[torr]
room temp	4.2×10^{-4}		-	-	8.7×10^{-5}		1.5×10^{-3}
cooled state	-	-	4.5×10^{-7}	-	1.8×10^{-7}		
Cooling time	[hour]	[hour]	[hour]	[hour]	[hour]	[hour]	[hour]
	10	10	10	10	10	10	10

thermal conductances of RAL's cartridges are consistent with that of NAOJ's cartridges.

3.3 Temperature ripple

Temperature ripple associated with cryocooler motions is reduced with a He pot attached on the 3rd stage of the cold head. The ripples at the cartridge, plate and bellows are 4, 7, and 12 mK, respectively (Figures 9, 10). The dependence is related to the distance from the coldhead. If some amount of heat capacitance as optics is put on the 4 K stage, the ripple will be reduced further [9].

3.4 Mechanical vibration

Mechanical vibration with respect to vertical on the 4 K stage of the cartridge was measured with a laser displacement system. The vibration is 3 μm peak-to-peak as shown in Figure 11. The displacement of coldhead of 30 μm peak-to-peak [9] is reduced by order of magnitude. Because the cartridge structure is so strong, the vibration may be due to that of the bottom plate.

Horizontal mechanical vibration on the 4 K stage of the cartridge also was measured as shown in Figure 12 and Table 1. It is larger than the vertical vibration. Vertical vibration of the cryocooler is transformed to horizontal one due to the structure of this cryostat.

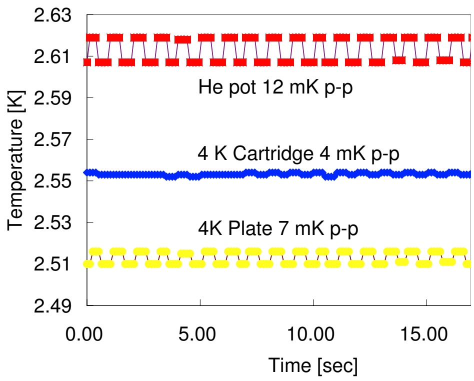

Figure 9: The temperature variation on the 4 K stage and plate in 20 seconds. The ripple is associated with the cold head displacement of 3 stage GM cryocooler.

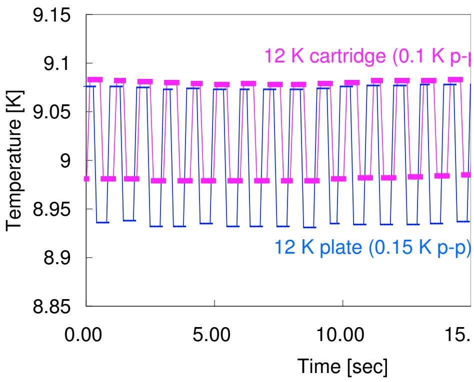

Figure 10: The temperature variation on the 12 K stage and plate in 20 seconds. The ripple is associated with the cold head displacement of 3 stage GM cryocooler.

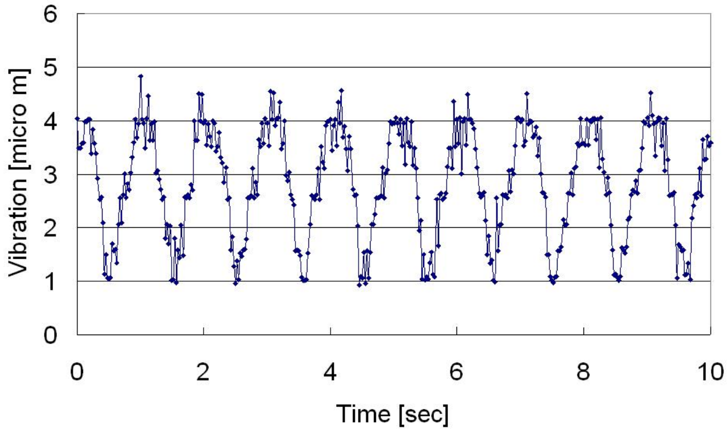

Figure 11: The vertical vibration on the 4 K stage of the cartridge.

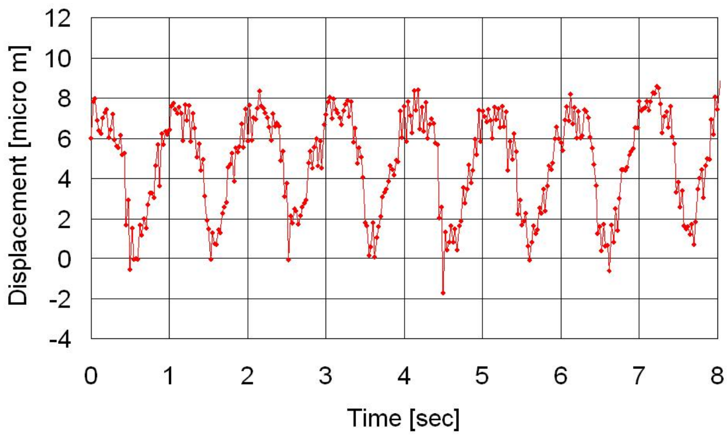

Figure 12: The horizontal vibration on the 4 K stage of the cartridge.

The amplitude of 8μm is reasonably small compared with the submillimeter wavelength ($> 350\mu$m).

4 Conclusion

Design and performance of cartridge test cryostats are presented. We have developed engineering models of Band 10, band 8, and Band 3 cartridges with this cartridge-test cryostat[8]. This cryostat was used for noise measurements of hybrid photonic LO at 500 GHz [10]. The cryostats were reliable over a year. We hope that these cryostats are useful for developing cartridge-type receivers.

Acknowledgements

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