IPN Progress Report 214 • August 15, 2018

1-K Cryogenic System for Optical Communication Receivers on Tipping Telescopes

Michael Britcliffe,* Theodore Hanson,* and Erik Pereira†

ABSTRACT — The superconducting receivers planned for Deep Space Network (DSN) optical communications require a cryogenic system to cool the detector to 1 K. Some implementations require the detector to tilt with the telescope main reflector. The cryostats currently used are not designed to tip. The article describes a system that will provide cooling at 1 K in a tipping installation for as long as 12 hours with a regeneration time of slightly more than an hour.

I. Introduction

The superconducting nanowire detectors being developed for Deep Space Network (DSN) optical communication systems require that the detector be maintained near 1 K with a maximum allowable temperature of 1.3 K. Any low-cost prime-focus telescope, including the hybrid radio frequency (RF)/optical receiver being developed in the advanced engineering program requires that the detector be mounted on the tipping structure [1].

Providing cooling below 2.5 K is challenging. Typically it is done a laboratory setting with elaborate multi-stage systems that are impractical for telescope operation. The systems used for detector development combine pulse tube cryostats and sorption stages that use gravity to separate high-density helium from the ambient temperature fluid, making it difficult to implement in a tipping environment such as a DSN telescope. To overcome this limitation, a system was designed using a Gifford McMahon (GM) 4-K cryostat coupled with the addition of a 1-K sorption stage that operates from vertical to horizontal orientations.

* Retired, formerly Communications Ground Systems Section

† Communications Ground System Section

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

II. GM Cryostat

The cryostat used in this system is an SHI Cryogenics RDK-415D two-stage GM system. It provides two stages of cooling: 1.5 W of cooling at 4.2 K and 40 W at 40 K. The cryostat is the same cryostat as the one used in the DSN dual-X and X/X/Ka-band systems that have been in operation for more than 15 years. They operate in any physical orientation and have proven to be very reliable in DSN operation. The system is available with both air-cooled and water-cooled compressors, and it can be used with the DSN cryo-control systems to provide unattended operation.

III. 1-K Sorption Stage

The 1-K sorption cryostat is an additional stage added to the unit to decrease the operating temperature further from 4.2 K to the 1 K needed for the optical detector to function. Chase Research Cryogenics provided the 1-K sorption stage used in this system. The system is hermetic and has no moving parts or valves. Thus, it requires no maintenance. The system is not a steady-state flow system such as a GM or Joule-Thomson cycle but a regenerative system. It consists of a carbon-filled pump that adsorbs helium gas when it is cooled and releases the helium when it is warmed. A gas-gap heat switch allows the pump to be connected or disconnected from the GM stage. An electrical heater provides heat to the pump. The cold stage is the volume where the helium condenses. Figure 1 shows the operating cycle of the 1-K sorption stage operating with the GM cryostat.

The GM cryostat cools the system to approximately 4 K. During the compression stage, the heat switch is opened, a small current is connected to the heater on the pump, and the pump is then heated to approximately 50 K. Gravity separates the colder fluid, which flows down into the cold stage filling it with 4-K liquid. During the adsorption stage the heat switch is closed, which cools the carbon in the pump, reducing the pressure of the helium. This causes the helium in the cold stage to boil and lowers its temperature to 1 K. A small fraction of the helium remains in the 1-K stage and is used to absorb heat from the detector at constant temperature until it is depleted. At this point, the cold stage warms, and the compression/adsorption phase repeats.

The process is straightforward and easily automated. In this system the pump heating was done with a timer.

- Pump on 25 minutes
- Dwell 15 minutes
- Switch on and run
- Regenerate for 72 minutes (1.2 hours)

The regeneration process is dependent on gravity to separate liquid helium. Regeneration was tested at various elevation angles. The system will regenerate at angles as low as 20 deg and still provide the 720-minute (12-hour) run time specified in Section V.

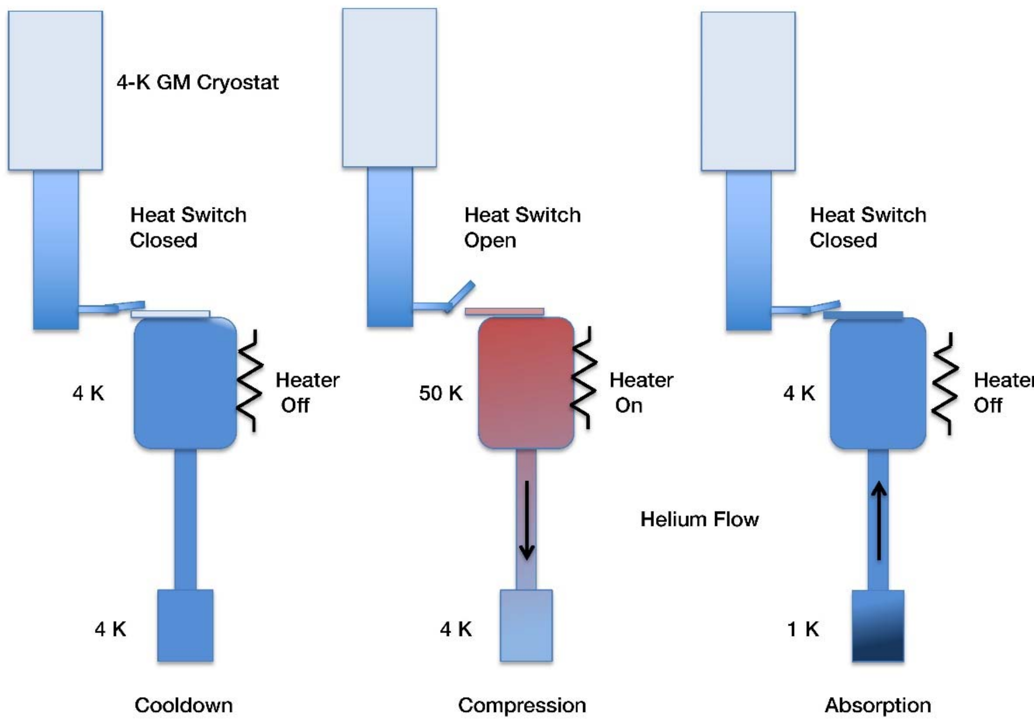

Figure 1. Cartoon showing 1-K cryostat operating cycle working with 4-K GM cryostat.

IV. Cryostat Design

The GM cryostat, vacuum housing, and hardware are spare DSN X-band high electron mobility transistor (X-HEMT) parts. Although the final design might differ from this configuration, it is suitable to demonstrate a capability that can be scaled to accommodate typical reasonable receiver designs. The sorption stage and radiation shields were designed around this hardware with minimal changes to that standard 4-K RF cryostat. A light path was added to the 1-K stage using a sapphire window on the vacuum housing. Provisions for infrared (IR) filters were added to the radiation shields.

Figure 2 shows the cryostat with the vacuum housing and radiation shields removed.

V. Run Time

The amount of time the cryostat will maintain temperature is a function of the applied load. The higher the load the faster the liquid helium in the cold stage will evaporate. Table 1 shows the run time as a function of applied load. The detector systems currently in operation require 1 mW of cooling. This prototype system demonstrated a run time of 720 minutes (12 hours) with a 1-mW load. The regeneration process was done at 20 deg elevation to simulate a worst-case condition as optical communication missions are planned with a 20-deg minimum elevation angle. This run time is adequate for any planned DSN optical communication pass. Figure 3 shows the operating temperature during the regeneration and run phase (regeneration starts at time zero).

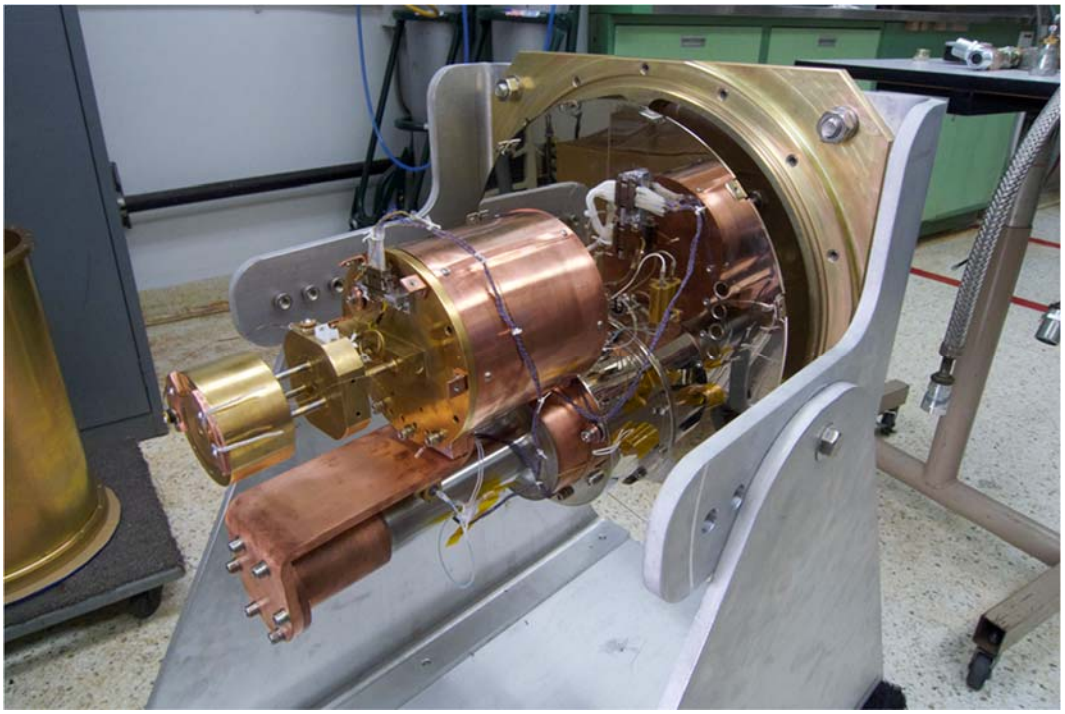

Figure 2. Cryostat with vacuum housing and shield removed.

Table 1. Run time with various loads at 90-deg elevation.

Load (mW)	Run time (hours)	Temperature (K)
1	12	1.00
2	7	1.06
10	1.5	1.25

VI. Physical Orientation

The operation of the GM cryostat is virtually unaffected by gravity. No information was available on the effect of orientation of the sorption stage. To quantify any possible orientation effects, a gimbal was constructed that allowed the cryostat to be operated over elevation angles of ± 90 deg. The prototype configuration results in a cryostat run time that is unaffected by gravity. Figure 4 shows the cryostat on the gimbal. Figure 5 shows a plot of the temperature stability during a simulation of antenna motion. The cryostat was tilted from 90-deg elevation to zero and back to 90 deg with less than a 1-mK variation.

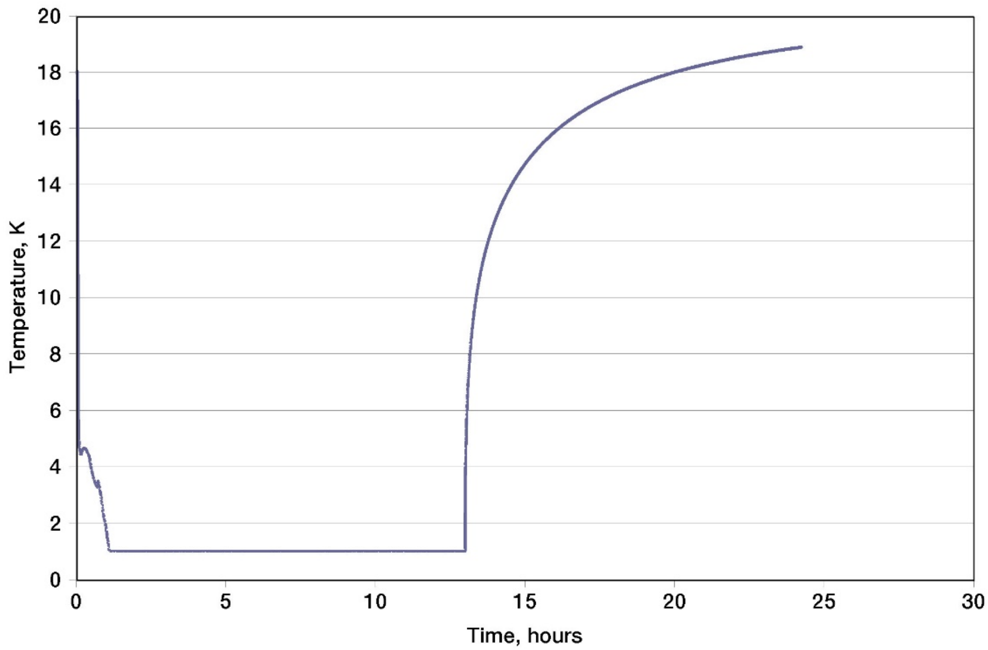

Figure 3. Operating temperature with cryostat operating at 20 deg elevation.

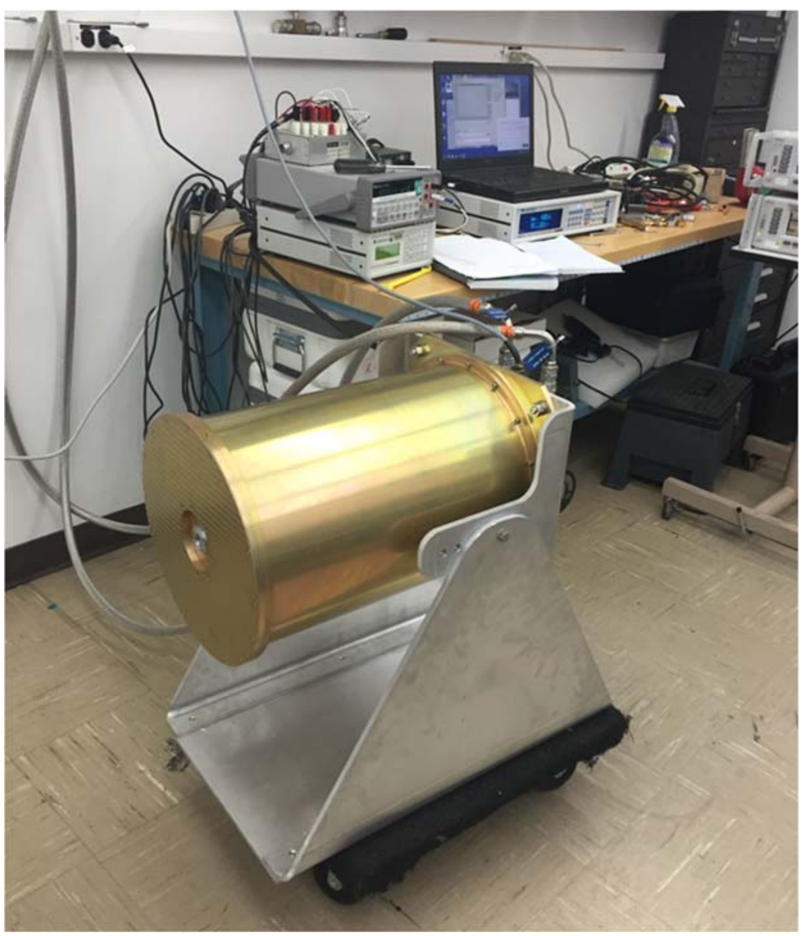

Figure 4. Cryostat on tilt-test gimbal.

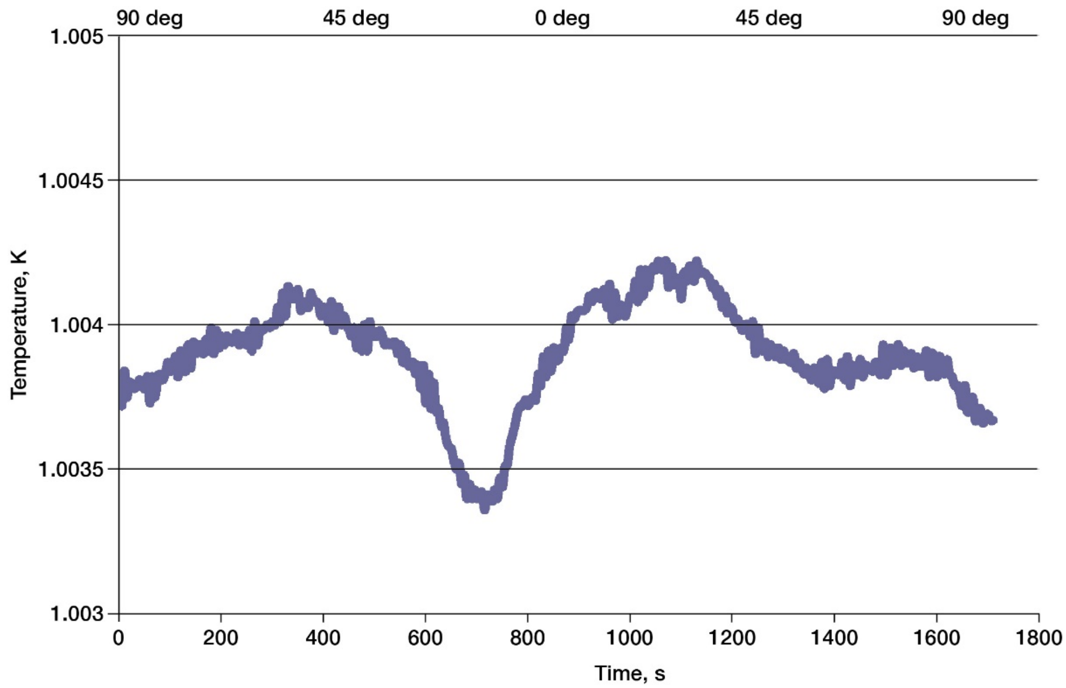

Figure 5. Temperature variation during 90–0–90 deg tilt test.

VII. Conclusions and Recommendations

The operation of the GM cryostat is virtually unaffected by gravity. No information was available on the effect of orientation of the sorption stage. To quantify any possible orientation effects, a gimbal was constructed that allowed the cryostat to be operated over elevation angles of ± 90 deg. The prototype configuration results in a cryostat run time that is unaffected by gravity. Figure 4 shows the cryostat on the gimbal. Figure 5 shows a plot of the temperature stability during a simulation of antenna motion. The cryostat was tilted from 90-deg elevation to zero and back to 90 deg with less than a 1-mK variation.

Reference

[1] D. Hoppe, J. Charles, S. Piazzolla, F. Amoozegar, M. Britcliffe, and H. Hemmati, "Integrated RF/Optical Ground Station Technology Challenges," The Interplanetary Network Progress Report, vol. 42-181, Jet Propulsion Laboratory, Pasadena, California, pp. 1–38, May 15, 2010. http://ipnpr.jpl.nasa.gov/progress_report/42-181/181B.pdf

Acronyms

DSN	Deep Space Network
GM	Gifford McMahon (cryostat)
IR	infrared
Ka-band	26.5–40 MHz
RF	radio frequency
X-band	8–12 GHz

CL#18-3245