# Testing of a High-Capacity Pulse Tube Cryocooler System for Space Applications

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## ABSTRACT

Creare is developing high-reliability, long-life cryocooler control electronics for Stirling and pulse-tube cryocoolers. These electronics are derived from our low-cost cryocooler control electronics that were developed and qualified for tactical space missions. The new electronics offer increased reliability and enhanced features that are tailored for the strategic space marketplace. Air Liquide's LPTC pulse-tube cryocooler is an ideal cryocooler for mating with our new electronics. The LPTC has been developed for high-reliability space missions and provides up to 7 W of refrigeration at 80 K with 160 W of AC power. Air Liquide Advanced Technologies and Creare have collaborated on an initial demonstration of the LPTC cryocooler couple with prototype electronics. This paper reviews the initial test results.

## INTRODUCTION

Since 1991 Creare has been developing electronics to drive multiple types of cryocoolers, including turboBrayton, Stirling, pulse tube, and JouleThomson varieties. Starting in 2017 we started development of a family of cryocooler electronics designed around nominal 100 W input power Stirling and Pulse Tube cryocoolers aimed at radiation tolerant, lowcost space missions where commercial electronics are not suitable, but budgetary requirements do not support the cost and increase SWAP of a fully radiation-hardened electronics. The first product developed in this family was the MCCETS (Figure 1), developed on NASA Contract 80NSSC18C0059 [1]. This unit is intended to support a wide range of Stirling and pulse-tube reciprocating cryocoolers for NASA's Class C/D missions.

We matured the MCCETS through a spiral development program with two spirals to reach the flight prototype. The Spiral 1 unit achieved a Test Readiness Level (TRL) of 5 in April 2019. This unit demonstrated the most critical functions of the MCCETS though testing with multiple cryocoolers including the Thales LPT9510. The TRL 5 prototype demonstrated 96% conversion efficiency when driving a Thales LPT9510 at 35 W per channel. The MCCETS Spiral 1 unit uses several parts (processor, MOSFETs, and power supplies) that are not suitable for flight from a quality perspective but have the same form, fit, and function as the corresponding flight part. Spiral 2 utilizes all flight quality components. This approach was taken to reduce lead time for parts and overall development time. The Spiral 2 architecture, shown in Figure 2, and prior to the current effort had been successfully used to drive a range of cryocoolers, including the Thales LPT-9510, the AIM SF070, and the

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**Figure 1.** The MCCETS is a single board assembly designed to fit on a side of a 1U CubeSat.

Sunpower DS1.5, DS2.1, and DS-Mini cryocoolers. We are currently working on versions of these electronics that support higher power levels and enhanced functionality, and are suitable for longer duration missions with high reliability.

**Table 1.** Summary of MCCE TS specifications.

| | |
|---|---|
| Input Voltage | 28 VDC nominal, 22 VDC–36 VDC unregulated. 11 VDC–40 VDC input possible with inclusion of Input Ripple Filter |
| EMI | MILSTD461, optional input ripple filter for CE101/CE-102 ripple reduction. |
| Max AC Output Current | 4 $A_{RMS}$ (2 channels @ 2 $A_{RMS}$ per channel) |
| Max AC Output Power | 80–100 W (2 channels @ 40–50 W per channel at 28 VDC input voltage) depending on cryocooler impedance |
| CCE Thermal Management | Conductive cooling |
| Size (including chassis) | 5.2 in. x 4.8 in. x 2.0 in. w/o ripple filter |
| Mass (including chassis) | 800 grams w/o ripple filter and standard packing |
| Operating Temperature Range | -40ºC to 71ºC |
| Radiation Hardness (TID) | Min TID: 30 kRad (Si) |
| Radiation Hardness (SEL) | Min SEL threshold ($LET_{th}$): 40 $MeVcm^2/mg$ |
| Reliability (MILHDBK217) | 96% for twoyear mission with standard BOM. Potential for improved reliability with BOM upgrades. |
| Active Vibration Control | Optional with inclusion of radiation-tolerant charge amplifier |
| Command and Control | RS422 |
| Motor Launch Lock | Optional |
| Programming | Hardware Description Language (HDL) firmware |
| Temperature Sensors | 2 kΩ PRT or comparable sensors |
| Control Temperature Range | 50 K to 200 K |
| Temperature Control | +/ 0.1 K |
| Temperature Accuracy | +/ 1 K from 70 K to 150 K |

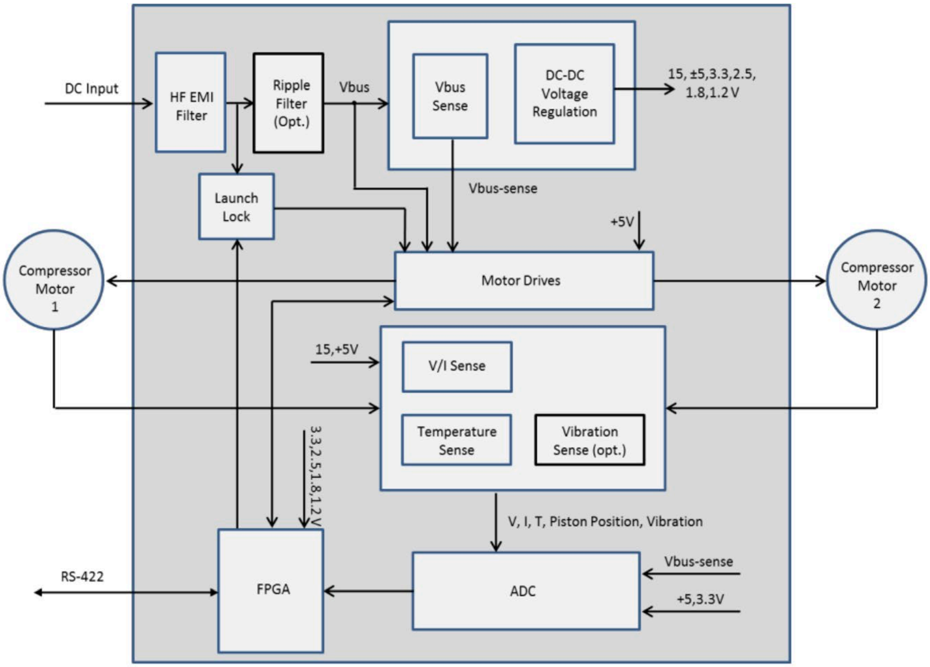

**Figure 2.** The MCCE-TS Drive Architecture.

## CRYOCOOLER

The Air Liquide LPTC (Large Pulse Tube Cryocooler) is a 160 W input space-rated pulse tube cryocooler aimed at 50–80 K applications such as focal plane arrays and other infrared instrumentation. The cryocooler, shown in Figure 3, is designed to provide cryogenic cooling between 3 W at 50 K and 7 W at 80 K while minimizing exported vibrations. The LPTC couples a high-performance dual-opposed compressor licensed from Thales Cryogenics B.V. with a coaxial pulse tube expander assembly, yielding a compact, high-reliability system.

The goal of this experimental effort was to demonstrate the ability of Creare's MCCE technology to successfully drive the Air Liquide LPTC cryocooler, and to characterize the overall performance of the combined system.

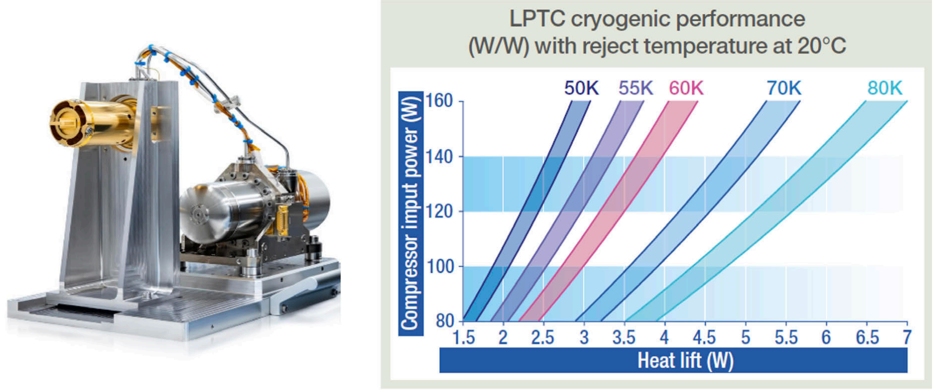

**Figure 3.** The Air Liquide LPTC Cryocooler

## MCCE-TS MODIFICATIONS

The MCCE-TS was originally developed to support coolers with input waveforms up to 28 $V_p$ at 25–150 Hz, and 50 W per channel, supporting either single-ended or dual-opposed compressor configurations. To enable the existing MCCE-TS prototype to drive the LPTC, only two minor modifications were required: (1) separating the voltage input to the MCCE into two inputs that drive the internal electronics and the H-bridge, allowing larger input voltages to be used with the H-bridge, and (2) providing external excitation to the CX-1080 Cernox sensor integrated into the LPTC cold finger.

## TEST CHAMBER

For cryocooler testing, the LPTC is installed in a test chamber built by Air Liquide that provides an integrated cryostat including cold tip sensor measurement (via Cernox sensor), and an integrated 5 W electric power resistor heater, contained within a high vacuum enclosure (Figure 4).

Monitoring equipment includes a Yokogawa WT-230 for measuring MCCE input and output powers; a cryogenic temperature monitor for monitoring the cold tip temperature; and GW Instek GDM 8341 digital multimeters to measure cold tip thermal load powers.

## TESTING OVERVIEW

Demonstration of the MCCE-TS and LPTC involves functional testing with a demonstrated cooldown, load characterization, and temperature setpoint stability testing.

### Cooldown

A typical cooldown curve for the LPTC while operating at maximum drive voltage is shown in Figure 5. The cooldown was performed with no additional thermal load on the cold tip. A circulating

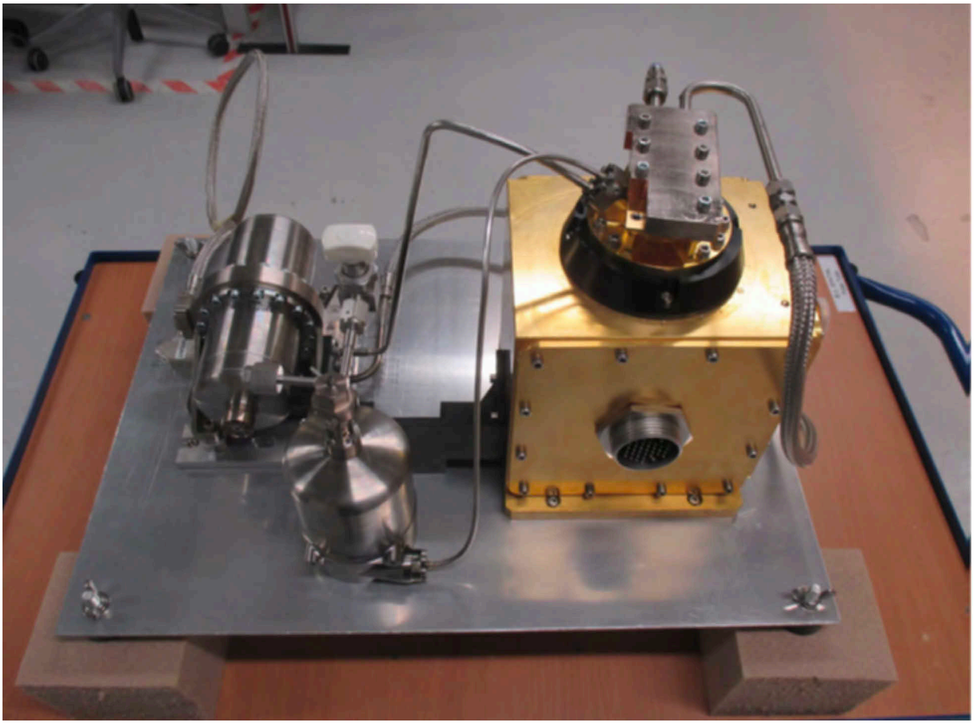

**Figure 4.** The LPTC Installed in the Cryostat. The cryostat is a double-chambered vacuum vessel designed to minimize heat leak.

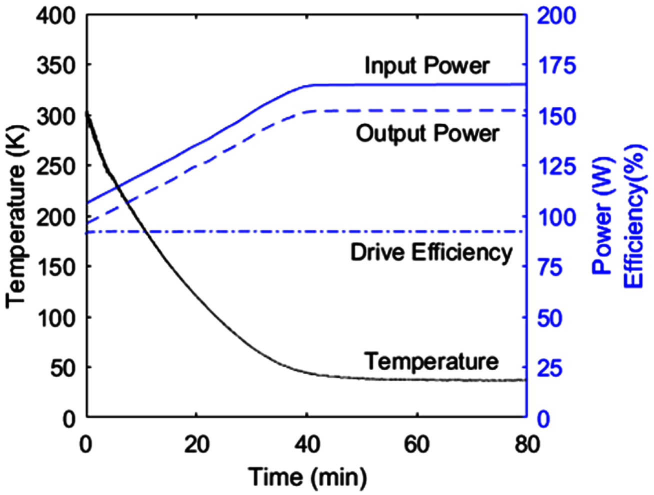

**Figure 5.** Cooldown of the LPTC Cold Head with No Thermal Load.

chiller maintains the expander heat rejection temperature to 35°C. The thermal load on the cryocooler is solely due to heat leak into the cryostat and the thermal capacity of the cold head.

Under these conditions, the LPTC cools from 300 K to 40 K in approximately 40 minutes. The input power increases as the cold head temperature cools down to accommodate the increased thermal lift of the cooler. At the minimum load temperature of 40K, the cryocooler electronics consume 160 W with an efficiency of 92 %.

## Load Characterization

Figure 6 shows the steady state operating conditions for the LPTC paired with the MCCE-TS drive electronics at various cold tip thermal loads. The total load on the cryocooler is a combination of heat leak into the cryostat and a resistive heater mounted on the cold head. The resistive heater load (x-axis) is characterized by a 3-wire power measurement. The LPTC is operating at the maximum drive voltage fir these tests.

Under no load conditions, the LPTC requires approximately 160 W to maintain 40 K at the cold head. As the load heater power increases, the system establishes a new equilibrium by increasing

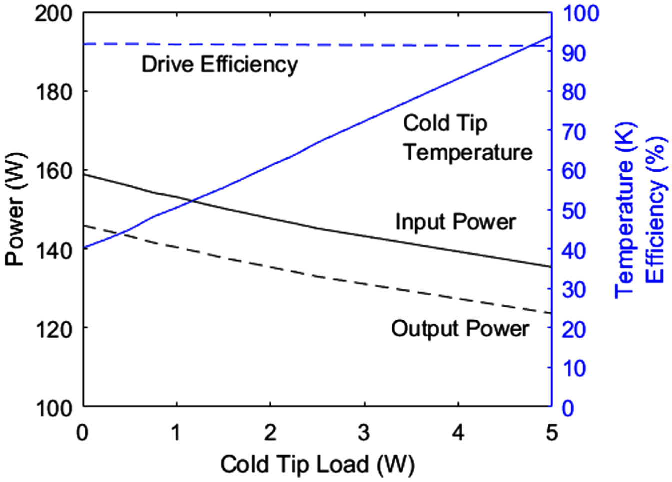

**Figure 6.** Steady State Performance of the LPTC with MCCE-TS Operating at Maximum Drive Voltage.

the cold head temperature and raising the Carnot efficiency of the system. As a result, the overall power consumption decreases with load heater power. This behavior is also seen on the cool down curves as the cold head temperature decreases (Figure 5). For all loads evaluated, the efficiency remains constant at 92%.

## SETPOINT STABILITY

The MCCE-TS drive electronics include a proportional-integral (PI) controller for automated set point regulation via a host system. The ability to control at a given setpoint depends on the cold tip thermal load and the cryocooler cooling capacity at the target setpoint for the maximum and minimum allowable drive voltages.

The MCCE-TS measures the cold tip temperature via a resistance temperature detector (RTD) with common choices being platinum resistance thermometers (PRT) or Cernox sensors in the 1 to 10 kOhm range. For this test, a calibrated Cernox sensor was installed on the LPTC cold head.

Figure 7 shows the temporal response to set point changes from 90 to 150 K in 20 K intervals. In all cases, the cryocooler is operating with a fixed bus voltage with a 4 W resistive thermal load on the cold head. Testing indicates setpoint accuracy and stability is within one bit of resolution on the temperature measurement circuit (+/-0.01K in the tested configuration). The PI controller achieves this level of accuracy in a lab setting as it continually adjusts the drive voltage to achieve the target temperature. For specific applications, the MCCE can be customized for other resistive temperature detector as mission requirements dictate.

## OPPORTUNITIES FOR IMPROVEMENT

The test results reported herein demonstrate the basic performance of the LTPC driven by the MCCE-TS drive electronics.

Heat leakage. Although the double chambered cryostat is designed to minimize heat leak to the cold head, uncharacterized parasitic thermal loads remain. The data presented in this paper neglect the additional thermal loads imposed by heat leakage.

Unoptimized drive frequency. The LPTC performs best when operating at the resonant drive frequency of the compressor. In this testing, the MCCE-TS drive electronics were configured to drive the LPTC at the nominal drive frequency provided by Air Liquide. Further improvements are possible by optimizing the drive frequency for the specific unit under test.

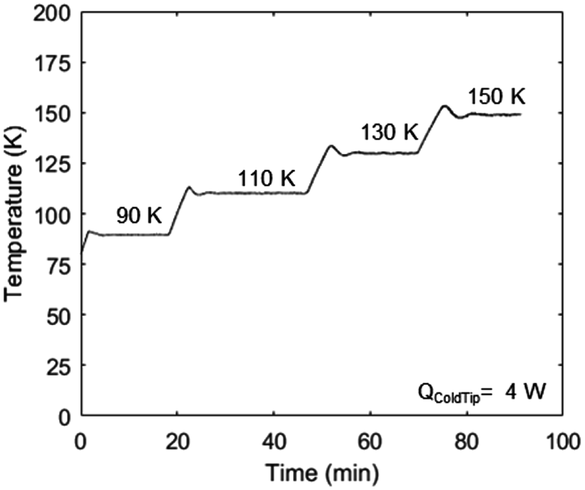

**Figure 7.** Setpoint control and stability with 4 W of heat added to the cold head by a resistive heating element.

## CONCLUSIONS AND NEXT STEPS

The initial testing of the Creare MCCE technology with Air Liquide's LPTC is complete. Performance of the cryocooler and cryocooler control electronics were consistent with expectations. Ongoing work includes optimization of drive frequency and testing of active vibration cancelation to mitigate the effects of cryocooler vibration on critical instruments.

## ACKNOWEDGEMENT

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## REFERENCE

1. Pilvelait, B., Cameron, C., Kaszeta, R., Zagarola, M, Martin, M., Hudson, N, Kirkconnell, C., "Linear Cryocooler Electronics for Tactical Space Missions," *Cryocoolers 21*, ICC Press, Boulder, CO (2021), pp. 379-385.