Specifying Cryocooler Electronics for Space Based Missions

Kerry Frohling

Iris Technology Corporation
Irvine, CA 92614

ABSTRACT

Specifying cryocooler electronics (CCE) for space-based missions is often a perplexing exercise for system integrators. In this presentation, Iris Technology will explain the basic architecture of space based CCEs and how to decide which features are necessary to drive the selected cryocooler in the mission environment. The configuration of the CCE will be defined by the cryocooler, the spacecraft bus and the flight environment. Primary considerations are the power bus interface, the data interface, the sensors being used, and the form power required by the cryocooler. In addition to selecting the performance requirements of the CCE, specifying the class of parts acceptable for the mission may have a significant effect on the cost and delivery schedule for the CCE.

INTRODUCTION

Iris Technology has a long history of designing and developing cryocooler control electronics (CCEs). Customers frequently come to Iris with an idea of what CCE they need for their mission. Sometimes these ideas are incorrect or incomplete; this can lead to modifications or redesigns which result in schedule delays and increased costs. Everyone would prefer a previously qualified CCE, but this is not always a practical solution. In order to help customers understand the subtleties of the options for CCE definition, this paper will provide an overview of criteria which can impact CCE configuration.

CRYOCOOLER CONTROL ELECTRONICS DEFINITION

Overview

Space-based CCEs generally convert DC power (typically 28 VDC) to an AC power waveform tuned to a frequency that properly drives a cryocooler. The output power is either selected by the operator or determined by the CCE to maintain a specified temperature at the cold tip. Some CCEs have other features such as vibration control or output synchronization. A block diagram for a generalized CCE is shown in Figure 1.

Cryocooler Specification

The most important item to specify when defining a CCE is the cryocooler. Figure 2 shows several examples of cryocooler configurations that can be driven by Iris Technology CCEs. Iris

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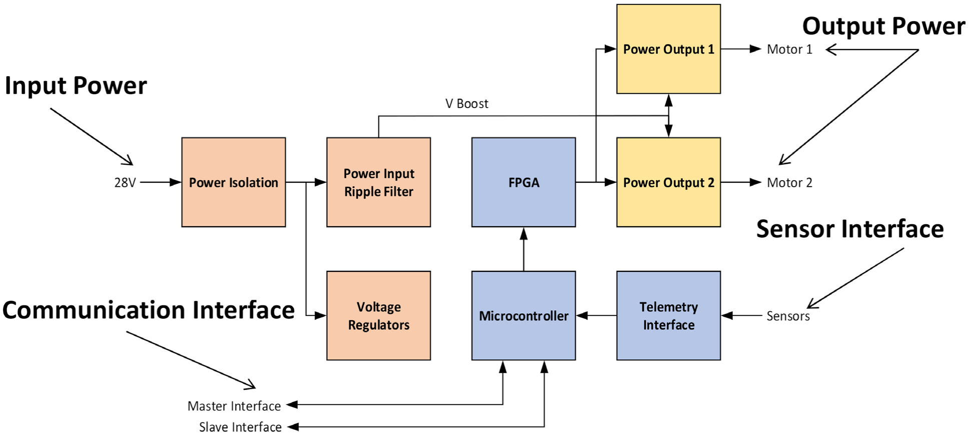


Figure 1. Example of the Elements of a Cryocooler Control Electronic Block Diagrams.

Technology has delivered CCEs to drive single piston cryocoolers, dual piston cryocoolers and rotary cryocoolers.

In addition to specifying the cryocooler make and model, it is important to review the manufacturers data to understand how much input power the cryocooler requires to drive to the desired operating temperature, how much power is required to maintain the desired temperature, and how much excess power needs to be reserved to allow for modification to the initial operating targets.

To define the CCE parameters correctly the characteristics of the motor(s) being driven must be provided. A key parameter for piston motors is the coil impedance. Knowing the coil impedance and the target power levels allows the determination of the maximum output voltage and maximum output current requirements of the CCE.

Input Power Requirements

The total DC power that must be available to the CCE at its input depends on several factors. These factors are the maximum required output power, the system power reserve, the CCE efficiency and the power source overhead (if required). Note that the maximum required output power could be driven by the power required to reach the desired temperature or the power required to maintain the desired temperature. The required input power is defined by the following equation.

$$Input\ Power = \frac{Output\ Power + Reserve}{CCE\ Efficiency} + Overhead \tag{1}$$

Figure 2. This figure shows examples of various configurations of cryocoolers that can be driven by Iris Technology CCEs. Shown are an AIM SX-030 single piston cryocooler, a Thales LPT9310 dual piston cryocooler and a Ricor K508 rotary cryocooler.

Where:

- *Input Power* is the maximum power required from the power source.
- *Output Power* is the maximum power required by the cryocooler to achieve mission goals.
- *Reserve* is the excess power reserved by the system integrator to accommodate changes in mission parameters.
- *CCE Efficiency* is the efficiency of the CCE at the output power level. The efficiency includes the effect of tare power.
- *Overhead* is any power margin required by the power source to avoid tripping.

When discussing input power, it is important to determine if an Input Ripple-current Filter (IRF) is required. Input ripple current is induced current conducted back onto the source power by a CCE when producing an AC power waveform. This current ripple will occur at twice the cryocooler drive frequency. An input ripple filter (IRF) may be required if:

- The input power is tied to other devices that cannot handle input current disturbances
- The power supply cannot handle input current disturbances produced by the CCE
- EMI/EMC requirements cannot be met without ripple reduction

When considering an IRF, in-rush current requirements must be defined. Inrush current generally increases with the addition of an IRF as bulk capacitance is used in its implementation. Note that the addition of an IRF has a negative impact on size, weight, and CCE efficiency.

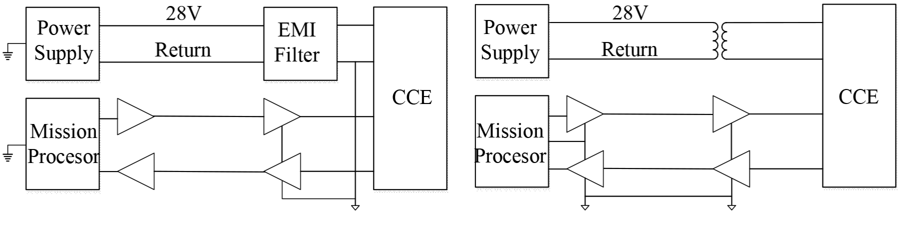
Another input power factor to be considered is whether the input power is isolated or power referenced, examples are shown in Figure 3. Non-isolated design assumes that the input power return is referenced to chassis ground. Isolated power does not need a common reference; however, communication with the CCE is complicated as an independent reference needs to be established to allow communication signals. Note that isolated power systems have a significant negative impact on CCE size, weight, and efficiency.

Communication Interface

The standard communication interface for Iris Technology CCEs is a serial RS-422 interface. Iris has implemented other physical layer serial interfaces on request such as LVDS, CAN bus, Ethernet and Spacewire. Changing the physical layer interface does not affect the underlying communication protocol or register mapping. Over the years, the Iris CCE communication definitions have remained relatively unchanged with the exception of including enhanced features.

Output Power Requirements

In previous sections, we have discussed specifying output power. This section will wrap up the discussion. First, we need to determine how much power needs to be input to the cryocooler to



Non-isolated (power referenced) **Isolated power**

Figure 3. This figure shows examples of Non-isolated (power referenced) and Isolated power inputs.

achieve and maintain the desired heat lift at the operating reject temperature, with the system heat load. Another thing to consider is how fast the desired temperature needs to be reached. The faster the temperature needs to be reached; the more power will be required. This will define the excess power requirement for temperature drive down. Remember that power out of the CCE is not the same as power into the CCE (efficiency, tare, etc.)

Iris has an algorithm that limits output power based on cold tip temperature. Since many cryocoolers cannot take as much power at higher temperatures, this algorithm can protect the cryocooler while providing the maximum possible power to the cryocooler.

Temperature Sensor Selection

Temperature sensors are used to allow the CCE to operate in a temperature control mode. In this mode the CCE provide the appropriate power to keep the cold tip at a selected temperature. Temperature sensors are generally excited by a fixed current provided by the CCE. The current required is dependent on the selected temperature sensor and in some cases the selected operating temperature. Iris CCEs work with a wide variety of temperature sensors including Platinum Resistance Thermometers (PRT), Silicon Diode Temperature Sensors, and Cernox Cryogenic Temperature Sensors. Several factors must be considered to provide optimal performance. Among these is maximum impedance seen on resistive temperature sensors over the temperature range of interest. This is used to optimize the circuit gain for temperature sensitivity. Iris Technology CCEs use a 4-wire Kelvin connection for temperature sensor connections; 2 wires for excitation current, 2 wires for voltage measurement. This connection type separates current and voltage, minimizing wire losses in voltage measurements.

Active Vibration Cancelation

Some CCEs contain the ability to reduce vibration exported from the cryocooler. Note that only vibration in the axis of piston motion can be directly affected. CCEs that can reduce vibration must drive either a dual piston compressor or a single piston compressor with a balancer motor. In addition, there must be a vibration measurement device.

Iris Technology CCEs reduce vibration using the Iris Active Vibration Cancellation (patent pending) algorithm. Typically, the CCE is paired with a piezo-electric accelerometer to measure vibration, but any device that can produce a representative vibration signal will work.

A word of caution about using balancer motors. Balancer motor characteristics usually have vastly different characteristics than compressor motors, and need to be well understood when defining the CCE attributes.

EEE Parts Selection

Parts definition is the most common reason for schedule delay when defining a CCE. Space grade electrical, electronic and electromechanical (EEE) parts have notoriously long lead times. Normally, finalizing the Bill of Materials (BOM) for electronic components is among the first tasks that get priority on a CCE development. This allows early ordering of flight parts to minimize schedule delays in assembly.

In process changes to electronics parts BOM can result in significant schedule delays. Early definition of flight part class, electronic parts screening requirements, environmental requirements, flight duration and radiation environment can also help prevent BOM changes and schedule delays.

Environmental Tests

The number of environmental requirements validated through formal testing can make a substantial difference in CCE cost and schedule. Different customers have different environmental requirements; however, they generally fall into a few classes. Thermal cycle testing, which is used to prove the CCE operates and survives over specified thermal extremes and provide workmanship validation. EMI/EMC testing which is generally performed against selected methods from either

MIL-STD-461 or SMC-S-008 to assure that the CCE will not interfere with or be affected by other equipment meeting the same requirements. Shock and vibration testing which is used to assure the CCE will survive the launch environment and provide workmanship validation. And finally, Thermal Vacuum testing, which verifies CCE performance in a “space like” environment.

The particular requirements of each of the environmental tests can drive cost and especially schedule. For instance, depending on the number of cycles, the soak durations, and operational versus non-operation cycles, a thermal vacuum test can take weeks.

Analyses

Some requirements are validated by analysis rather than test. There are a number of analyses that are commonly requested by our customers such as worst case circuit analysis (WCCA), electronics parts stress analysis (EPSA), reliability analysis (via MIL-HDBK-217 or other method), failure mode and effects analysis (FMEA), Failure mode, effects, and criticality analysis (FMECA), radiation and single event effects (SEE) analysis, thermal analysis, fatigue analysis, shock analysis and vibration analysis. Not all of these analyses have been performed against all of our base designs.

Analyses tend not to be huge schedule drivers, as long as they are defined up front, but can have serious cost effects if there is not any original material to use as a basis.

CONCLUSIONS

In this paper, we presented key parameters that need to be defined to provide the most cost and schedule effective CCE solution. Among these parameters are:

- Cryocooler definition
- Input power characteristics
- Input ripple filter requirements
- Power isolation requirements
- Output power characteristics
- Active vibration cancellation
- Communication interface definition
- Temperature sensor definition
- EEE Parts requirements including screening requirements
- Test and analysis requirements

Early definition of the parameters in this list can help provide a smooth transition from product definition to product delivery ensuring optimal cost and schedule performance.