Micro-Sized Cryocooler Controllers for Space

Kerry Frohling

Iris Technology Corporation
Irvine, CA 92614

ABSTRACT

The explosion in SmallSat and CubeSat deployments has led to a need for miniaturized cooling solutions for sensors that require cooling. Since there are limited opportunities for miniaturization in the thermal mechanical unit (TMU) portion of the cryocooling system, much of the pressure to reduce size falls on the cryocooler control electronics (CCE). In the world of digital electronics, continuous size reduction is the expected norm. However, in the world of power electronics this is not the case. The number of components and their variety is greatly limited when selecting space grade electronics, typically resulting in designs that make space grade electronic solutions much larger than an equivalent circuit made of commercial grade electronics.

One way to reduce the size of the power components is to switch at a higher speed. The current generation CCE devices built by Iris Technology utilize MOSFET power transistors to perform power conversion. The characteristics of the power MOSFETs limit the switch rate to something on the order of 100 kHz, thus driving the energy storage requirements of the capacitors and inductors. If we could switch faster, we reduce the required energy storage and thus the size of the inductors and capacitors.

One solution to the switching frequency problem is the use of Gallium Nitride (GaN) FETs which can be switched on the order of 1 MHz. GaN FETs are inherently radiation tolerant, and recently GaN FETs have become available with space-grade packaging. The space-grade packaging is available with an integral radiation hardened high/low side driver. This integrated part provides further size reduction to the electronics design.

Recently, high performance space grade microcontrollers have become available. These parts offer another integration opportunity, as the FPGA and ADC functions can be combined into a single smaller chip. Space grade GaN FETs when combined with the space grade microcontrollers provide an opportunity for significant reduction in the volume required for the CCE portion of a cryocooler system.

INTRODUCTION

The current generation CCE devices built by Iris Technology utilize MOSFET power transistors to perform power conversion. The characteristics of the power MOSFETs limit the switching rate to something on the order of 100 kHz, thus driving the energy storage
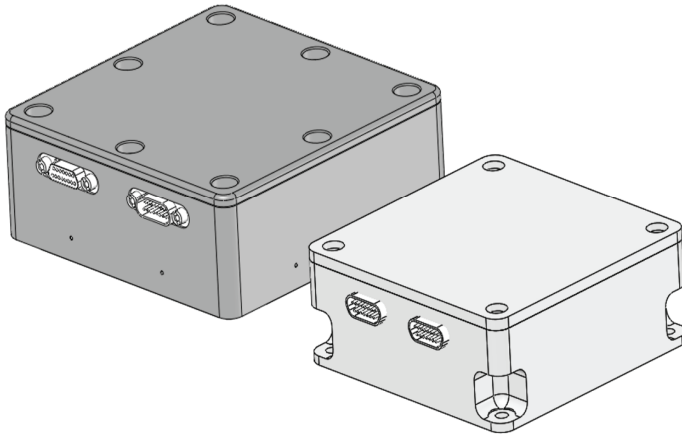
Figure 1. This image presents a size comparison of mLCCE (dark gray) and μLCCE (light gray). The mLCCE is 288 cubic centimeters and the μLCCE is 195 cubic centimeters.

requirements of the capacitors and inductors. Switching at faster rates would reduce the required energy storage and thus the size of the inductors and capacitors. One solution to the switching frequency problem is the use of Gallium Nitride (GaN) FETs which can be switched on the order of 1 MHz. GaN FETs are inherently radiation tolerant, and recently GaN FETs have become available with space grade packaging. The space grade packaging is available with an integral radiation hardened high/low side gate driver. This integrated part provides further size reduction to the electronics design. Additionally, higher performance space grade microcontrollers have recently become available. These parts offer another integration opportunity, as the FPGA and ADC functions can be combined into a single smaller chip. Space grade GaN FETs when combined with the space grade microcontrollers provide an opportunity for significant reduction in the volume required for the CCE portion of a cryocooler system.

SIZE REDUCTION TARGETS

Space electronics, due to the limited number and larger size of components available for space use, are usually much larger than an equivalent commercial grade circuit solution. This paper explores the possibilities for size reduction of the current Iris Technology miniature Low Cost Control Electronics (mLCCE), shown in Fig. 1. Three primary areas for size reduction will be examined: (1) Power Conversion circuits, (2) System Processing circuits, and (3) Signal Sensing circuits. Each of these areas will be discussed in detail in the following sections.

POWER CONVERSION CIRCUITS

The power conversion circuits shown in Fig. 2 are an area that provides potential for significant size reduction. This will be accomplished by changing the conversion circuitry from a MOSFET-based architecture to a GaN FET based architecture. Generally, GaN devices have a smaller size for a given on resistance and breakdown voltage [1]. However, the first generation space grade GaN FETs and drivers currently available do not by themselves provide significant size reduction compared to existing MOSFETs and their drivers. The size reductions are primarily achieved in the passive components (inductors, capacitors and resistors). Recall that
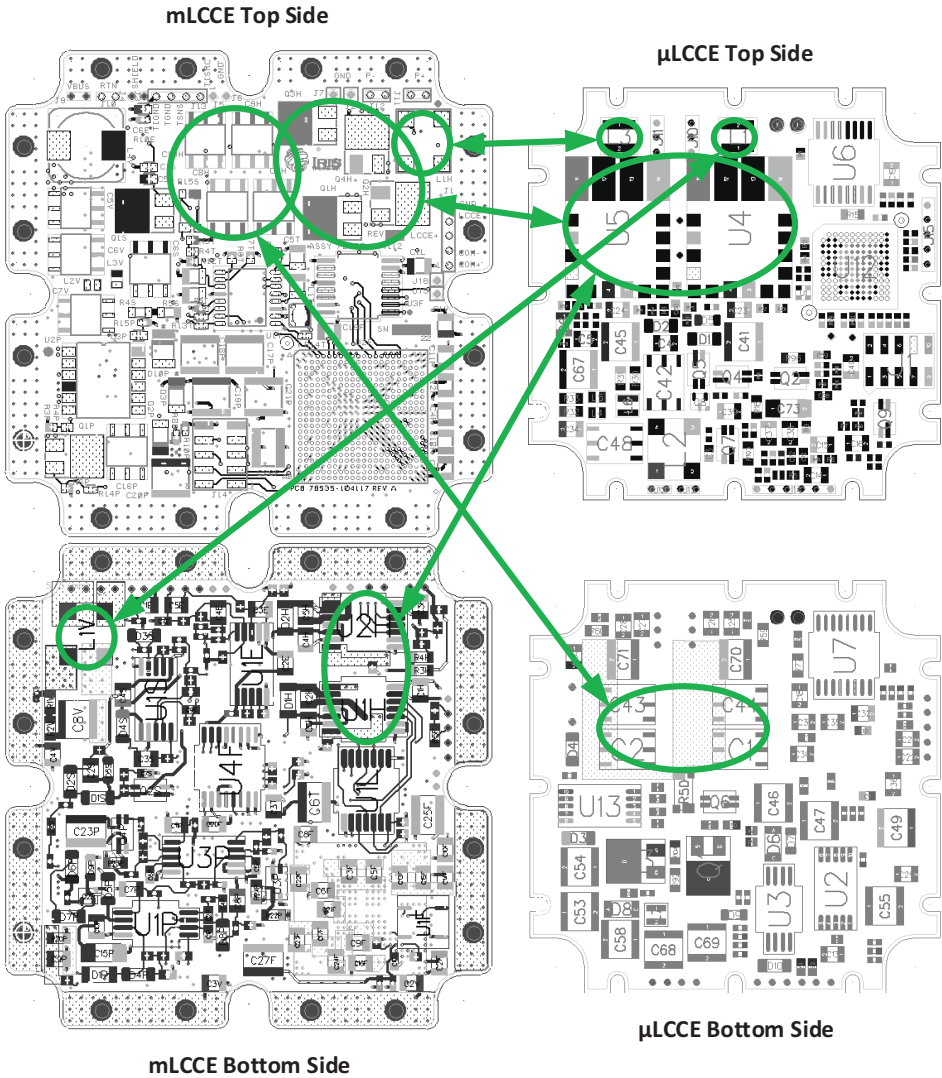
Figure 2. Comparison of Power Conversion Circuits in the mLCCE and the μLCCE showing the transition from a MOSFET design to a GaN FET based design. Four MOSFETs are shown in the upper right hand corner of top side of the mLCCE and the GaN FETs are in integrated half-bridge modules shown in the upper left hand side of the top side of the μLCCE. The MOSFET drivers are shown in the upper right hand corner of bottom side of the mLCCE and the GaN FET drivers are in integrated half-bridge modules shown in the upper left hand side of the top side of the μLCCE. The rest of the highlighted components are capacitors and inductors.

we are increasing the system switching speed from 100 kHz to 1 MHz. Since the switching rate is increased by a factor of 10, the energy needed to be maintained per switching period is reduced by a factor of 10. This means that inductor and capacitor values can be reduced by a factor of roughly 10. Since the size of capacitors and inductors scales with the value and power
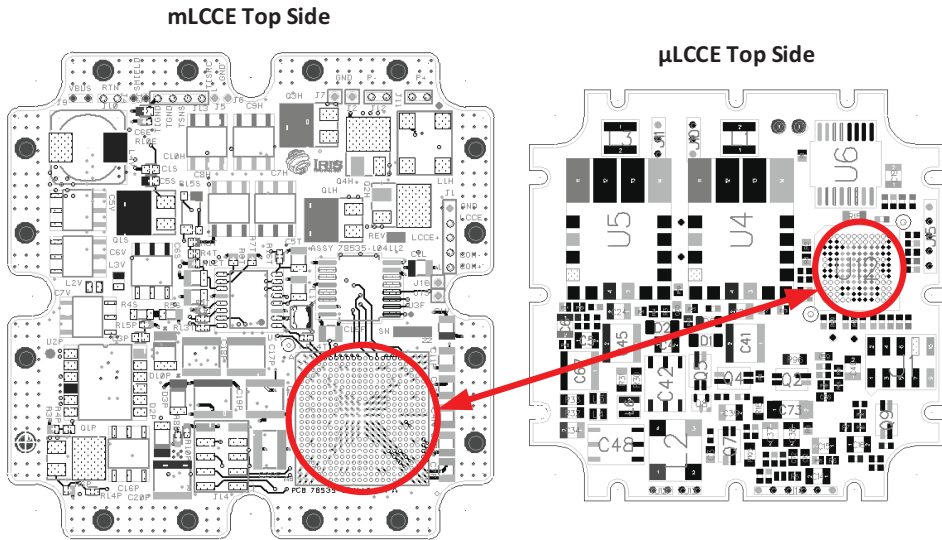
mLCCE Top Side

μLCCE Top Side

Figure 3. Comparison of System Processing Circuits in the mLCCE and the μLCCE showing the transition from a FPGA based design to a microcontroller based design. The FPGA is shown in the lower right hand corner of top side of the mLCCE and the microcontroller shown in the upper right hand side of the top side of the μLCCE.

handling capability of the component, the size of the passive components required to support the GaN FET design are going to be much smaller than those required for an equivalent MOSFET design [2].

SYSTEM PROCESSING CIRCUITS

As shown in Fig. 3, the current generation mLCCE uses a space grade FPGA to perform the processing required to control the system output power. The output power is either defined by the system user via command messages or defined by the CCE processing based on a measured temperature versus a desired temperature set point. For the next generation design, the FPGA is replaced by a space grade microcontroller. The microcontroller Iris Technology has selected for the next generation CCE is smaller than the FPGA used on the mLCCE thus requiring less circuit board real estate. It also uses less quiescent power. The microcontroller has a 32-bit ARM Cortex core. This provides a rich instruction set which allows for additional features that would not be possible in an FPGA based processing architecture. The microcontroller also has built-in peripherals used to replace current external components as well as providing opportunity to add features not previously achievable.

SIGNAL SENSING CIRCUITS

The mLCCE senses input, output, and internal voltages, and external temperature using a discrete analog to digital converter (ADC) as noted in Fig 4. The microcontroller selected for the next generation CCE has a built-in ADC, which removes the need for the external ADC and some of the signal conditioning circuitry. The microcontroller also has a precision current source which can be used in the Kelvin connection the CCE provides to the temperature sensor.
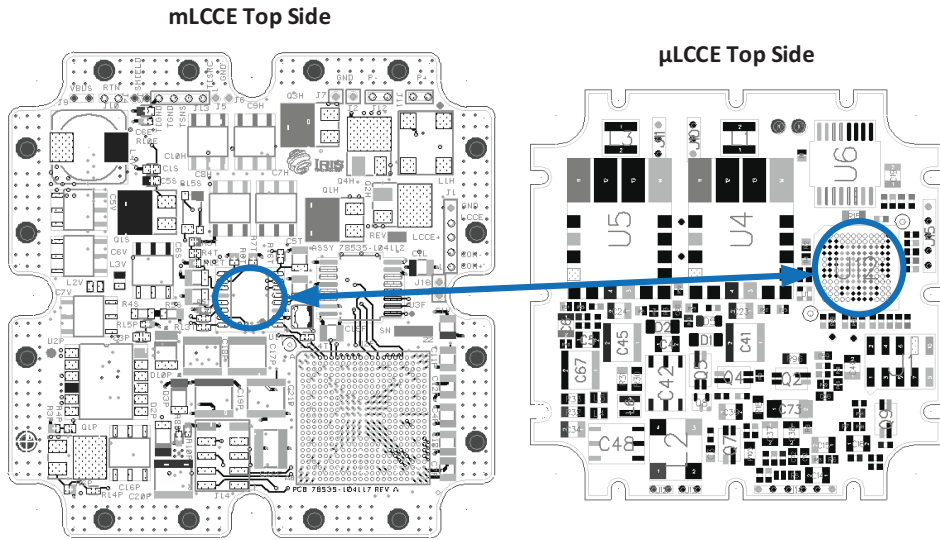
mLCCE Top Side

μLCCE Top Side

Figure 4. Comparison of Signal Sensing Circuits in the mLCCE and the μLCCE showing the transition from a discrete ADC design to an embedded ADC design. The discrete ADC is shown in the center of top side of the mLCCE and the embedded ADC is part of the microcontroller shown in the upper right hand side of the top side of the μLCCE.

In addition, the microcontroller provides digital to analog converters and comparators that could be used to provide additional features that were not previously possible.

DESIGN GOALS AND STATUS

The goal of the next generation CCE effort is a size reduction of 30% compared to the existing mLCCE using space grade components. The design that has been developed shows a 28% reduction in board area and a 32% reduction in unit volume.

CONCLUSIONS

In this paper we have shown a smaller next generation space grade cryocooler controller that is facilitated by the use of recently available space grade GaN FETs and microcontrollers. The new architecture also provides the opportunity for additional features, not previously possible. These newly available space grade components help to partially mitigate the large size and lack of variety in components available for space flight applications.

ACKNOWLEDGMENTS

REFERENCES

1. Lidow, A., Strydom, J., De Rooij, M. and Yanping, M., "GaN Transistors for Efficient Power Conversion," Power Conversion Publications, El Segundo (2012), pp. 1-2.

2. Keeping, S., "Design Trade-offs when Selecting a High-Frequency Switching Regulator," DigiKey TechZone article (2015).