# Low Temperature Space-Borne Power Electronics and Semiconductor Devices

V.J. Kapoor, C.H. Melkonian and T.A. Miller
Nanotechnology Research Center, MS #309
The University of Toledo, Toledo, OH 43606

J.E. Dickman and R.L. Patterson
Electro Physics Branch, Power Technology Division
NASA-Glenn Research Center, Cleveland, OH 44135

## INTRODUCTION

Missions charted for deep space have utilized radio-isotope heater units (RHUs) to keep craft ambient temperatures warm enough, near room temperature (300K), to ensure proper operation of traditionally available, 'off-the-shelf,' electronic systems. Deep space missions have also relied on plutonium-based power units to run systems in regions remote enough that utilization of solar radiation for power would have required very large solar cell collection arrays. Elimination of nuclear power sources from space probes will alleviate environmental concerns, but will necessitate dependence on radically new power electronics, which can operate highly efficiently at temperatures down to and below 40K. Deep-space ambient temperatures, near and beyond Pluto, can go down to ~40K.

Real concerns exist regarding the ability of currently available electronics to undergo hibernation and subsequent cold restart. Therefore, development of electronic devices and circuits, which can function over the range of 300°K to below 77°K, offers great advantages for future space missions.[1-5]

A power electronic system in space applications would require dc-dc converters, control circuits for the converter, adequate power supplies for the control circuit derived from the input dc power, proper isolation between input and output, and a filter-conditioning circuit for the output. Therefore, dc-dc power converters and control devices with silicon and compound semiconductor devices (GaAs) were fabricated and compared for low temperature space-borne power electronics.

## EXPERIMENT AND RESULTS

A power converter in our investigation was a direct current to direct current (dc-dc) converter. Four reliable and efficient power converters were designed, fabricated, and tested to function from room temperatures (300°K) down to liquid nitrogen temperatures (77°K). During the design process of the low temperature dc-dc converter, close attention must be made in the selection of the components used for operation of electronics at low temperatures.[3]

First, a step-up power dc-dc converter with a LM 2587 5A Flyback Simple Switcher was built with bipolar transistors. Second, a Buck type dc-dc converter with a MOSFET based LM 2560 chip was designed and built. Third a CMOS based buck type dc-dc converter was built using a TC35C25CPE CMOS chip and IRF224N power MOSFET's. Fourth a GaAs based MESFET dc-dc power converter circuit was designed and built.

The results of our investigation indicated that the biopolar dc-dc converter stopped working below 120K with an efficiency of 60% at 120K, the MOS dc-dc converter stopped working below 90K with efficiency of 70% at 120K. As the temperature got colder, the switching wave form of the biopolar dc-dc converter became distorted at 200K while the MOS dc-dc converter became distorted at 100K, the efficiency of CMOS converter was around 79%.

It was constant from 300K to 77K as well as the output voltage of the converter was constant. Comparison of biopolar, MOSFET and CMOS based converter showed that CMOS worked the most reliable among the three. CMOS dc-dc converter proved to be able to cold start. The GaAs MESFET dc-dc converter was for buck type with superior performance up to 77K with 15% improvement in efficiency at 77K compared to room temperature.

As a result of this research, a reliable and efficient dc-dc converter was designed, fabricated, and tested to function from room temperature (300°K) down to liquid nitrogen temperatures (77°K). It was determined that there was no change in the waveforms of the CMOS converter and efficiency actually increased 1% at low temperatures. Furthermore, this CMOS converter proved to cold start after 24 hours of sitting in a dewar filled with liquid nitrogen. The CMOS converter also used specific capacitors, resistors, and magnetics that perform well in low temperatures.

The CMOS dc-dc converter was able to provide excellent output regulation from room temperature to 77°K. The performance of the dc-dc converter was verified by measuring the output regulation, efficiency, switching behavior and control circuitry from changing the load, the input voltage and the operating temperature conditions. The potential for commercial application of this technology is excellent, especially the saving due to improvement in efficiency outweighs the additional costs of cryogenic cooling.

Research supported by NASA grant.

## REFERENCES

(1) C.H. Melkonian, "Indium Gallium Arsenide/Indium Phosphide MISFETs for Cryogenic DC Switching Applications," M.S. Thesis, The University of Toledo, May 1999
(2) D. Bernardon, "Theortical Investigation of Semiconductor – Buck Converter for Low Temperature Applications," M.S. Thesis, The University of Toledo, December 1998
(3) T.A. Miller, "Power Converter for Low Temperature Electronics," M.S. Thesis, The University of Toledo, October 1998
(4) B. Ray, S.S. Gerber, R.L. Patterson, and I.T. Myers, "Low-Temperature Operation of a Buck DC/DC Converter," Proc., IEEE-APEC, March 1995
(5) S.S. Gerber, R.L. Patterson, B. Ray, and C. Stell, "Performance of a Spacecraft dc-dc Converter Breadboard Modified for Low Temperature Operation," IEEE and ASME 31st InterSociety Energy Conversion Eng. Conf., August 1996