Cryogenic Evaluation of an Advanced DC/DC Converter Module For Deep Space Applications

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Background

Electronic circuitry and power systems designed for deep space applications and outer planetary exploration are required to operate reliably and efficiently under extreme temperature conditions. This requirement is dictated by the fact that the operational environments associated with some of the space missions would encompass temperatures as low as -183 °C. The development and utilization of electronics capable of low temperature operation would not only fulfill the advanced technology requirements, but also would contribute to improving circuit performance, increasing system efficiency, and reducing development and launch costs. These benefits are generally achieved by the improved intrinsic properties of some of the electronic materials at low temperature, reduced device losses, and the elimination of heating elements used in conventional systems at low temperatures.

The Low Temperature Electronics Group at NASA Glenn Research Center (GRC) is currently performing investigation on the effects of cryogenic temperature and thermal cycling on electronic devices and circuits. These activities are pursued in collaboration with other NASA Centers and Jet Propulsion Laboratories (JPL) in support of the NASA Electronic Parts and Packaging (NEPP) Program. DC/DC converters are widely used in space power systems in the areas of power management, conditioning, and control. In this work, the performance of an advanced commercial DC/DC converter was investigated under low temperature. The converter module was investigated in terms of its output voltage regulation, efficiency, and ripple characteristics. These properties, which were determined in the temperature range of -140 °C to 20 °C, were obtained at various load levels and at different input voltages. Some of the experimental data obtained are presented in this summary. More detailed information is presented in a NASA internal white paper [1], and the full report will be posted on the NEPP Web site.

Experimental Investigation

The investigated commercial-off-the-shelf modular DC/DC converter has a power rating of 10 W with an input voltage range of 16 V to 40 V and an output voltage of 3.3 V, and is space qualified in terms of radiation tolerance. Its operating temperature range is specified between -65 °C to 70 °C. The converter module was investigated in terms of its output voltage regulation, efficiency, and ripple characteristics. These properties were determined in the temperature range of -140 °C to 20 °C. At a given temperature, these properties were obtained at various input voltages and at different load levels from no-load to full-load conditions. The tests were performed as a function of temperature using an environmental chamber cooled by liquid nitrogen. A temperature rate of change of 10 °C/min. was used throughout this work. The modular converter was tested at the following temperatures: 20, 0, -20, -40, -60, -80, -100, -120, and -140 °C. At every test temperature, the test article was allowed to soak for a period of 30 minutes before any measurements were made. After the last measurement was taken at the lowest temperature, the converter was allowed to stabilize to room temperature, and then the measurements were repeated at room temperature.

The output voltage and efficiency of the converter at various load levels is shown in Figure 1 as a function of temperature. These parameters are obtained utilizing an input voltage of 24 V. The converter exhibited good voltage regulation with temperature down to -100 °C. This trend was maintained regardless of the load level to which the converter was subjected. Below -100 °C, however, the converter started to display inconsistent behavior in its voltage regulation. At any given test temperature, the efficiency increased as the load was increased. At temperatures below -100 °C, the efficiency was at minimum as the converter exhibited some loss in output regulation.

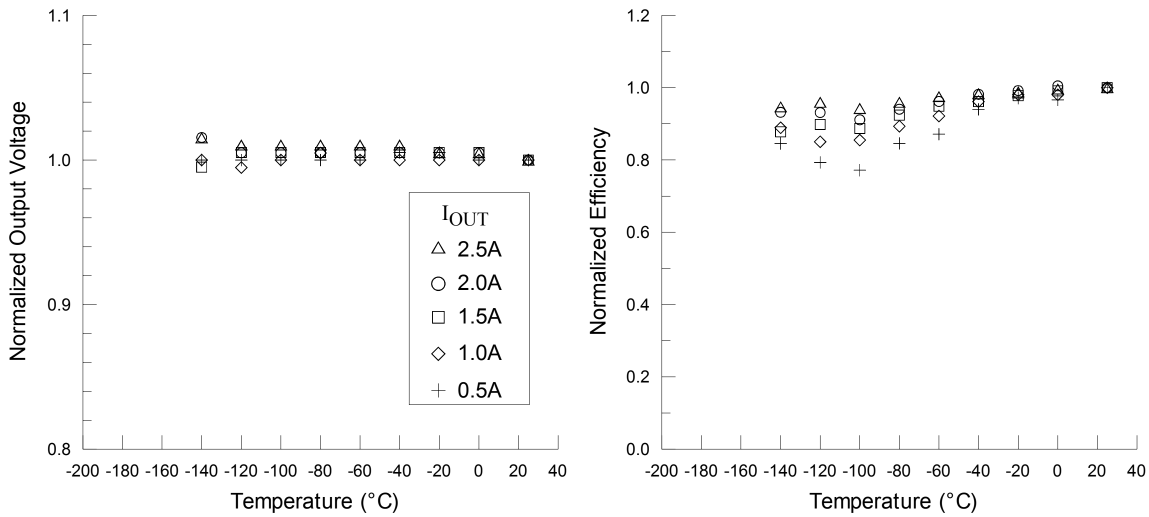

Figure 1. Output voltage and efficiency versus temperature at various loads (input voltage = 24 V).

The converter displayed the same behavior in its voltage regulation and efficiency with an applied input voltage of 40 volts, as shown in Figure 2. Once again, the efficiency, at a given test temperature, had the highest value when the maximum loading level was applied to the converter. At temperatures below -140 °C, regardless of the input voltage level, the converter exhibited complete loss in output regulation. This trend, however, reversed when the test temperature was brought above -140 °C.

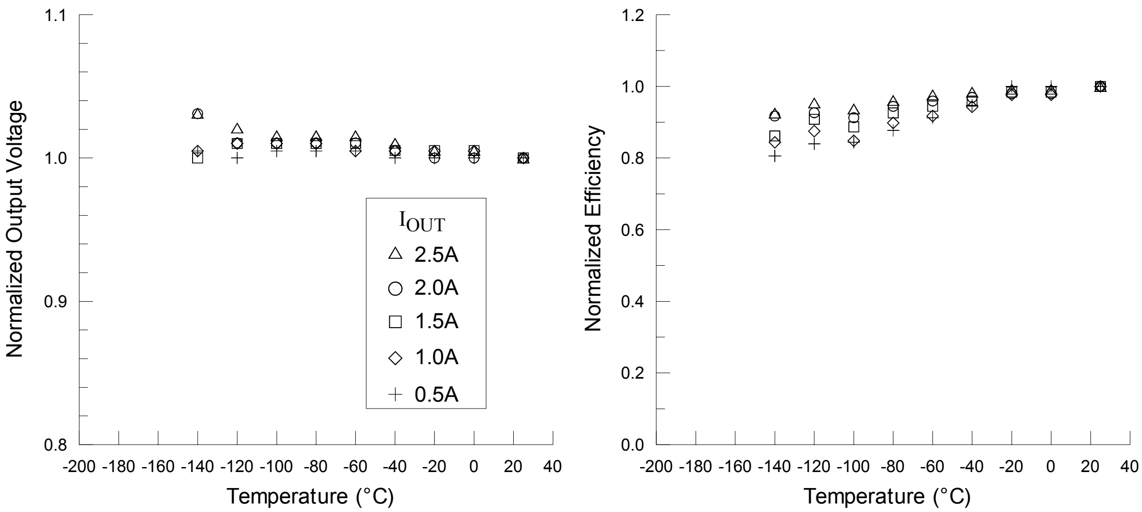

Figure 2. Output voltage and efficiency versus temperature at various loads (input voltage = 40 V).

Waveforms of the converter output voltage and current ripple, and the input current ripple at room temperature (25 °C) and at a low temperature (-100 C) are shown in Figures 3 and 4 for light load and heavy load, respectively. Theses waveforms were obtained using an input voltage of 16 V. No effect of temperature can be observed as no significant variations occurred in either the frequency or the amplitude of the investigated properties.

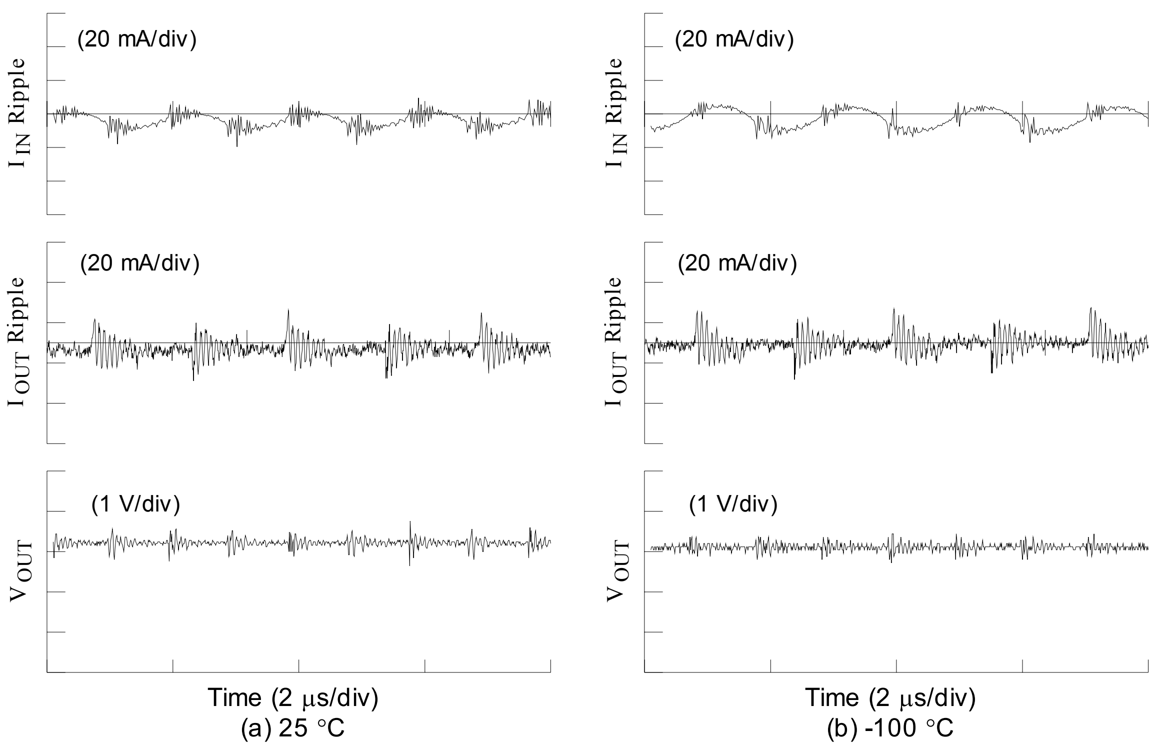

Figure 3. The converter ripple characteristics at low input voltage (16 V) and under light load (1.0 A) at two temperatures.

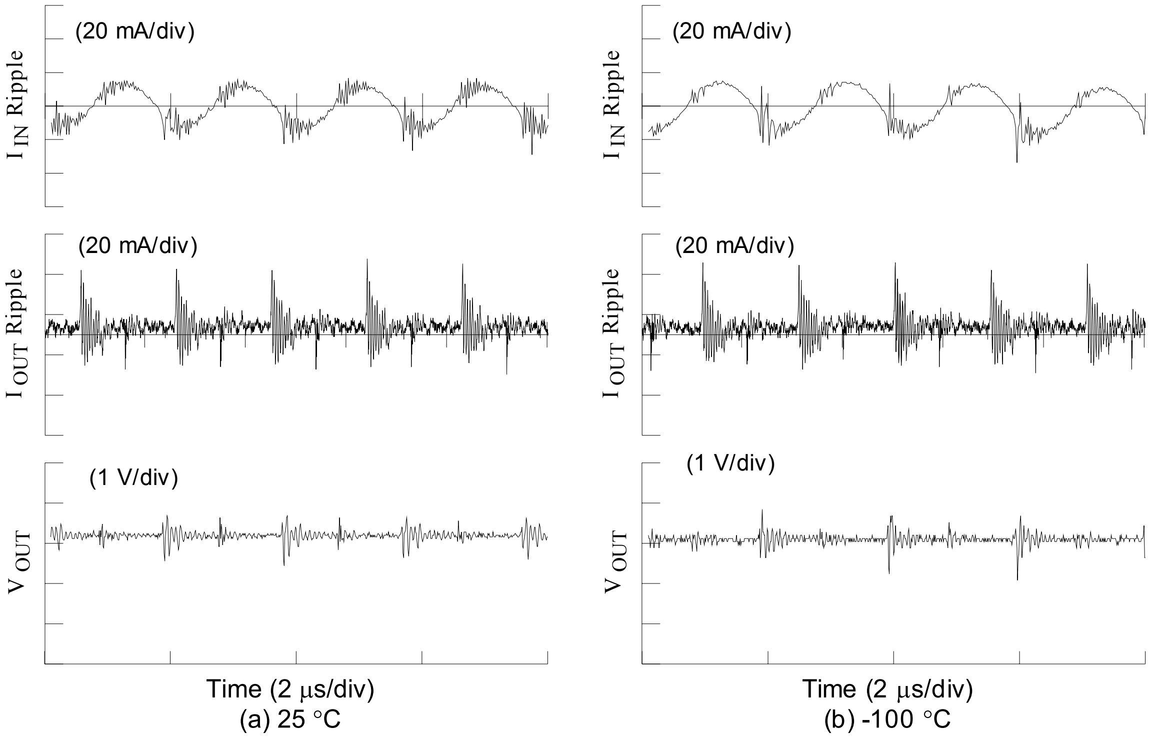

Figure 4. The converter ripple characteristics at low input voltage (16 V) and under heavy load (2.5 A) at two temperatures.

Conclusion

An advanced radiation-hardened DC/DC converter was characterized in terms of its performance as a function of temperature in the range of -140 °C to 20 °C. The converter was evaluated with respect to its steady state output voltage regulation, efficiency, output voltage ripple, input current ripple, and output current ripple at various input voltage levels and loads. In general, this converter displayed good performance in regulation, efficiency, and dynamic characteristics with temperature down to -100 C. Some instability was observed as the temperature was decreased further. More testing under long-term thermal exposure is needed to fully characterize this converter for potential application in low temperature environments.

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References

[1]. "Cryogenic Evaluation of an Advanced DC/DC Converter Module for Deep Space Applications," internal NASA white paper.