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Low Temperature Performance of High Power Density DC/DC Converter Modules

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ABSTRACT

In this paper, two second-generation high power density DC/DC converter modules have been evaluated at low operating temperatures. The power rating of one converter (Module 1) was specified at 150 W with an input voltage range of 36-75 V and output voltage of 12 V. The other converter (Module 2) was specified at 100 W with the same input voltage range and an output voltage of 3.3 V. The converter modules were evaluated in terms of their performance as a function of operating temperature in the range of 25 °C to -140 °C. The experimental procedures along with the experimental data obtained are presented and discussed in this paper.

INTRODUCTION

Presently, spacecraft operating in the cold environment of deep space carry on-board a large number of radioisotope heating units to maintain an operating temperature for the electronics of approximately 25 °C. To reduce system development and launch costs, improve reliability and lifetime, and increase energy densities, electronic components and systems capable of low-temperature operation will be required for many future space missions. These improvements will require proper system and circuit design, component selection and the development of components better suited for operation at extremely low temperatures. At the NASA Glenn Research Center, the Low Temperature Electronics Program focuses on research and development of "low temperature" electrical components and systems suitable for deep space mission.

Past and present activities of the Low Temperature Electronics Program have included characterization and evaluation of components such as semiconductor switching devices, integrated circuits, resistors, magnetic components, and capacitors [1-3]. In addition, low temperature device development activities have been conducted primarily in the area of semiconductor switching devices through Phase I Small Business Innovation Research Grants. The program has also been extensively involved in investigating DC/DC converters for low temperature space missions.

In addition to deep space applications, low temperature electronics have potential uses in terrestrial applications that include magnetic levitation transportation systems, medical diagnostics, cryogenic instrumentation, and super-conducting magnetic energy storage systems.

ADVANCES IN DC/DC CONVERTERS

Recently, there has been a great progress in the design of DC/DC converters with high power density. Converters that operate at power densities of 50% or more greater than the available standard conventional converter designs have been developed. This increase in power density is achieved using new designs, advanced devices and components, and packaging techniques. Today's leading edge DC/DC converter modules use synchronous rectifiers with multi-layer thick film hybrid packaging. This provides more usable output power without the use of a heat sink than do the conventional DC/DC converters that use Schottky diode with a heat sink and thick-film single-layer packaging. The first generation of DC/DC converter modules has a typical power rating of 10-15 W. The second-generation of DC/DC converters has a power rating of about 100-150 W with packaging and thermal management that provide high power density with small temperature gradients. Extensive use of silicon integration resulted in about one third the part count of a first generation converter.

LOW TEMPERATURE POWER CONVERTERS

Most aerospace power management systems are DC-based, and they require DC/DC power converters that operate with different inputs and outputs at various power levels. However, most of the existing DC/DC converter systems are specified to operate at low temperatures between -40 °C and -55 °C.

The Low Temperature Electronics Program has gone through a number of stages in building, testing and evaluating DC/DC converters for potential low temperature missions. During the first stage, a number of DC/DC converters were designed or modified to operate from room temperature to -196 °C using commercially available discrete components such as CMOS-type devices and MOSFET switches. These converters had output power in the range of 5 W to 1 kW and switching frequencies of 50 kHz to 200 kHz. Pulse-width modulation technique was implemented in most of these systems with open as well as closed-loop control. The topologies included buck, boost, multi-resonant, push-pull and full-bridge configuration [5-9].

The second stage followed the recent advancement in design and manufacturing of low power DC/DC converter modules. Several commercial-off-the-shelf (COTS) DC/DC converters have been characterized in terms of their performance as a function of temperature in the range of 20 °C to - 180 °C. These converters ranged in electrical power from 8 W to 13 W, input voltage from 9 V to 75 V and an output voltage of 3.3 V. Test results showed that they operated as expected within the manufacturer's specified temperature range, but at low temperature results varied. For some converters performance degraded rapidly, with others, reasonably good performance was seen down to temperatures between -80 °C and -100 °C. For temperatures below -100 °C, performance was either out of range, erratic, or non-existent for most of the converters [10-12].

The third evaluation stage is presented in this paper. Two of the second-generation high power density DC/DC converter modules have been evaluated at low temperature. The converters had power rating of 100 W and 150 W, input voltage range of 36V to 75 V and output voltages of 3.3 V to 12 V, respectively. The converters were evaluated in terms of their performance as a function of temperature in the range of 25 °C to -140 °C. The experimental procedure along with the experimental data obtained are presented and discussed.

EXPERIMENTAL PROCEDURE

The steady-state performances of the DC/DC converters were characterized as a function of temperature from 25 °C to –140 °C in terms of output voltage and efficiency. In addition, output voltage ripple, input current ripple and output current ripple waveforms were obtained. At a given temperature, these properties were obtained at various input voltages and at different load levels: from light-load to full-load conditions. The tests were performed as a function of temperature using a environmental chamber cooled by liquid nitrogen. A temperature rate of change of 10 °C/min was used throughout this work. At every test temperature, the module under test was allowed to soak at that temperature for a period of 30 minutes before any measurements were made. After the last measurement was taken at the lowest temperature, the converters were allowed to stabilize to room temperature and then the measurements were repeated at room temperature to determine the effect of low temperature exposure on the converters.

RESULTS AND DISCUSSIONS

Figure 1 shows the output voltage and efficiency of Module 1, normalized to their respective room temperature values, at different load currents and as a function of temperature. The output voltage and efficiency were normalized to compensate for the voltage drop and power loss resulting from long wires connecting the module, inside the chamber, to the equipment and measuring instruments outside the chamber.

At a given load current, the normalized output voltage (Figure 1a) maintains a steady value from room temperature down to -120 °C. The effect of temperature on the efficiency of Module 1 (Figure 1b) under different load conditions showed that, in general, the normalized efficiency drops as the temperature is lowered with temperature having the least effect on the heavy load condition. Figure 1 represents data taken at a nominal input voltage of 49V. Additional, sets of data were taken with input voltages of 36V, 62V and 75V. The data obtained at these input voltages is very similar to that shown in Figure 1.

Figure 2 shows the output voltage and efficiency of Module 2, measured at different loads, input voltage and as a function of temperature. Similar to Module 1, the output voltage and efficiency were normalized to their values at room temperature. In Figure 2a, the normalized output voltage maintains a steady value from room temperature down to -20 °C. For temperatures below -20 °C the normalized output voltage increased with heavy loads values being higher than light load values. This effect was observed only at the lower input voltage of 36 V. In Figure 2c, for an input voltage of 48 V, the normalized output voltage remained constant, similar to that of Module 1.

The effect of temperature on the efficiency of Module 2 under different input voltage and load conditions is shown in Figures 2b and 2d. Opposite to that of Module 1, the normalized efficiency increases as the temperature is lowered. The effect of temperature is greater with the heavy load condition than that of the light load. This effect is greater at the lower input voltage (Figure 2b) than at the higher input voltage (Figure 2d). Additional, sets of data were taken with input voltages of 60V and 72V. The data obtained at these input voltages is very similar to that obtained at 48V input (Figures 2c and 2d).

Figures 3 and 4 show the waveforms of the output voltage ripple, the output current ripple and the input current ripple at room temperature (25 °C) and at a low temperature (-100 °C) for Module 1, respectively. The corresponding ripple in output voltage, input and output current increases with decreasing temperature. Also, instabilities in the input current are observed with the heavy load conditions being more prominent.

Figures 5 and 6 show the waveforms of the output voltage ripple and the input current ripple at room temperature (25 °C) and at the low temperature (-80 °C) for Module 2, for light load and heavy load conditions. The output voltage ripple changes slightly between room temperature and the low temperature, with very high spikes occurring during heavy loading conditions. Opposite to Module 1, the input current ripple at room temperature is higher than that of the low temperature (i.e. the ripple decreases with decreasing temperature). The output current was not recorded because the data under heavy loading could not be taken due to the need of high current probe. Similar to Module 1, instabilities in the input current are observed with the heavy load conditions being more prominent.

CONCLUSIONS

Two commercially available DC/DC converters were characterized in terms of their performance as a function of temperature in the range of 25 °C to -140 °C. The converters were evaluated with respect to their output voltage regulation, efficiency, output voltage ripple, input current ripple and output current ripple in response to environmental temperature. The two converters generally displayed somehow similar behavior with change in temperature. The intensity of any occurring changes, however, varied with the converter type and the test temperature. This work represents only a preliminary investigation into the steady-state effects of low temperature on these two second-generation high power density DC/DC converter modules. To fully characterize their performance at low temperature, further testing and analysis is required.

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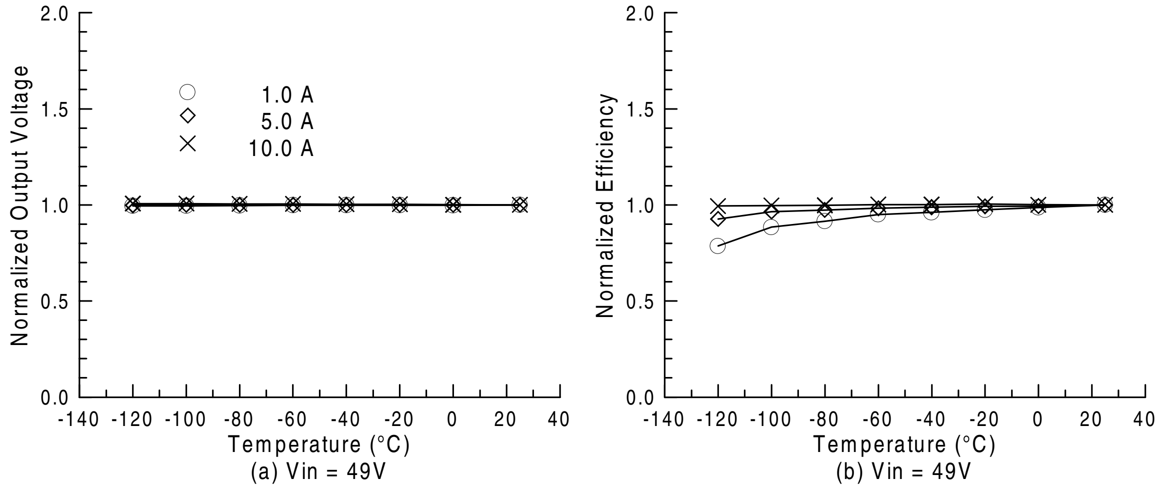


Figure 1. Normalized output voltage and efficiency versus temperature at various load currents for Module#1.

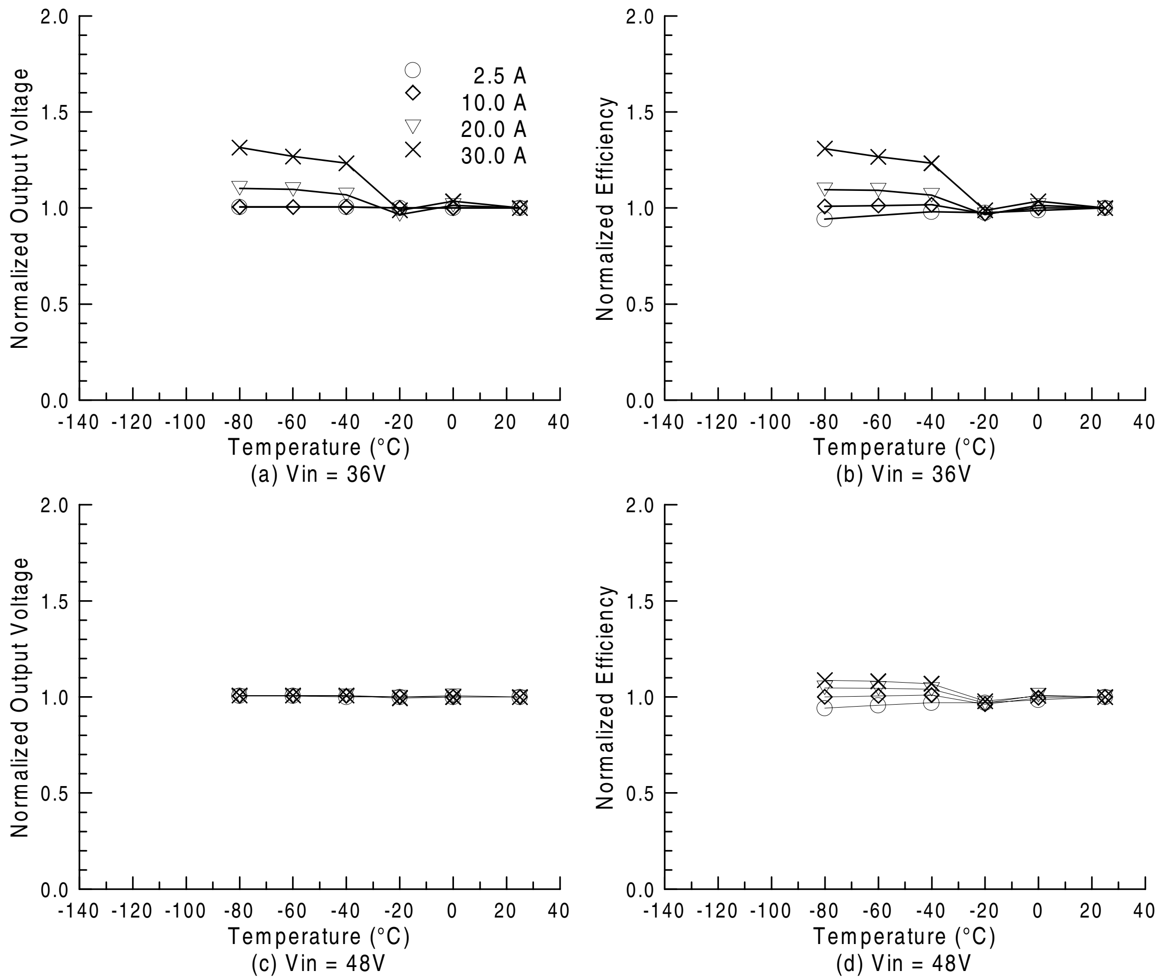
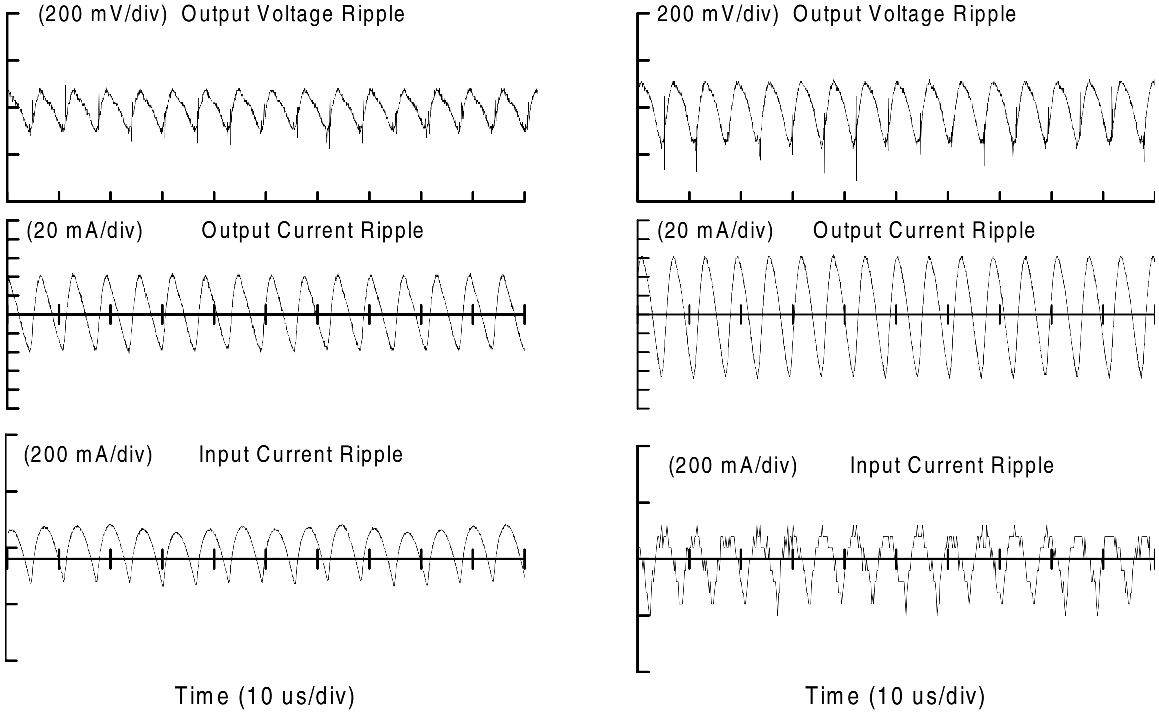
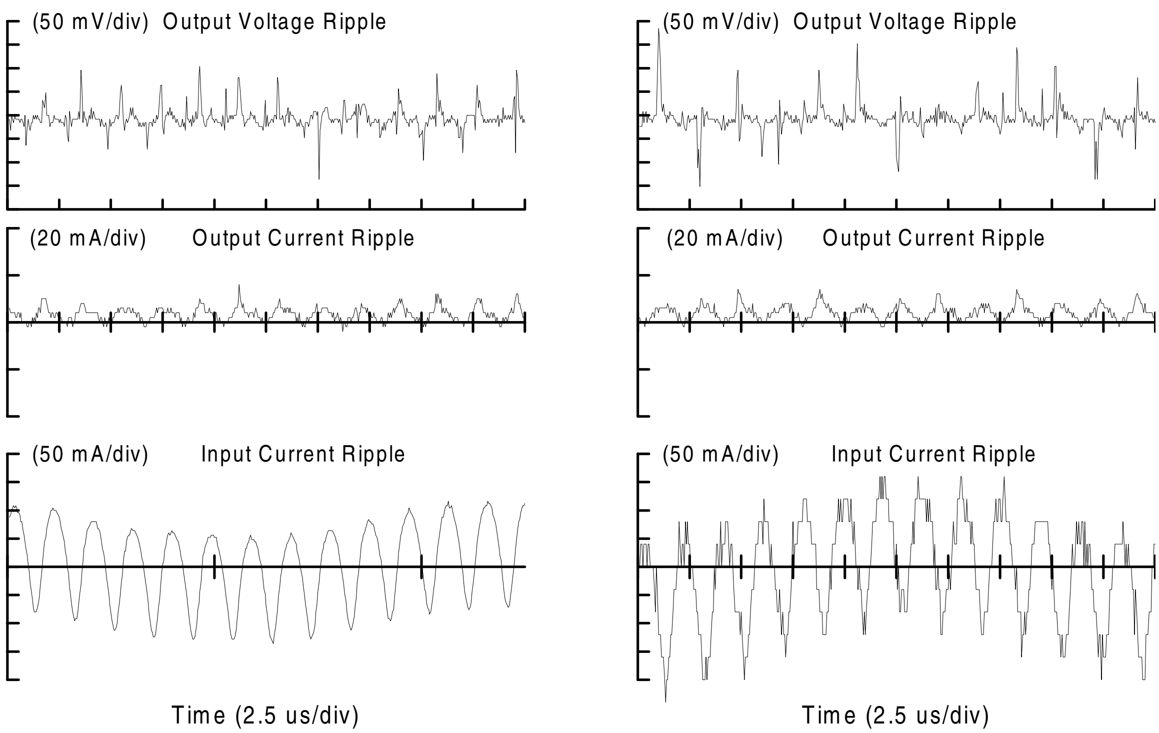


Figure 2. Normalized output voltage and efficiency versus temperature at various load currents for Module #2.



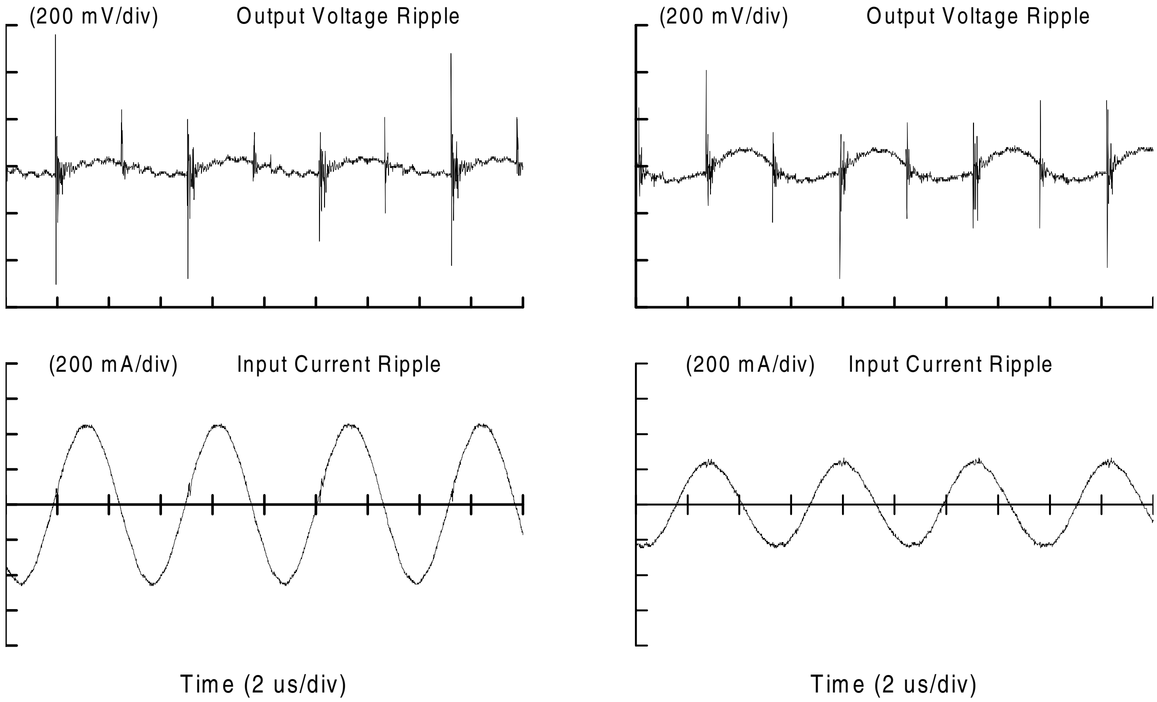
(a) Temperature = 25°C (b) Temperature = -100°C

Figure 3. Module #1 operation with 49V input and under light load condition (1.0A).



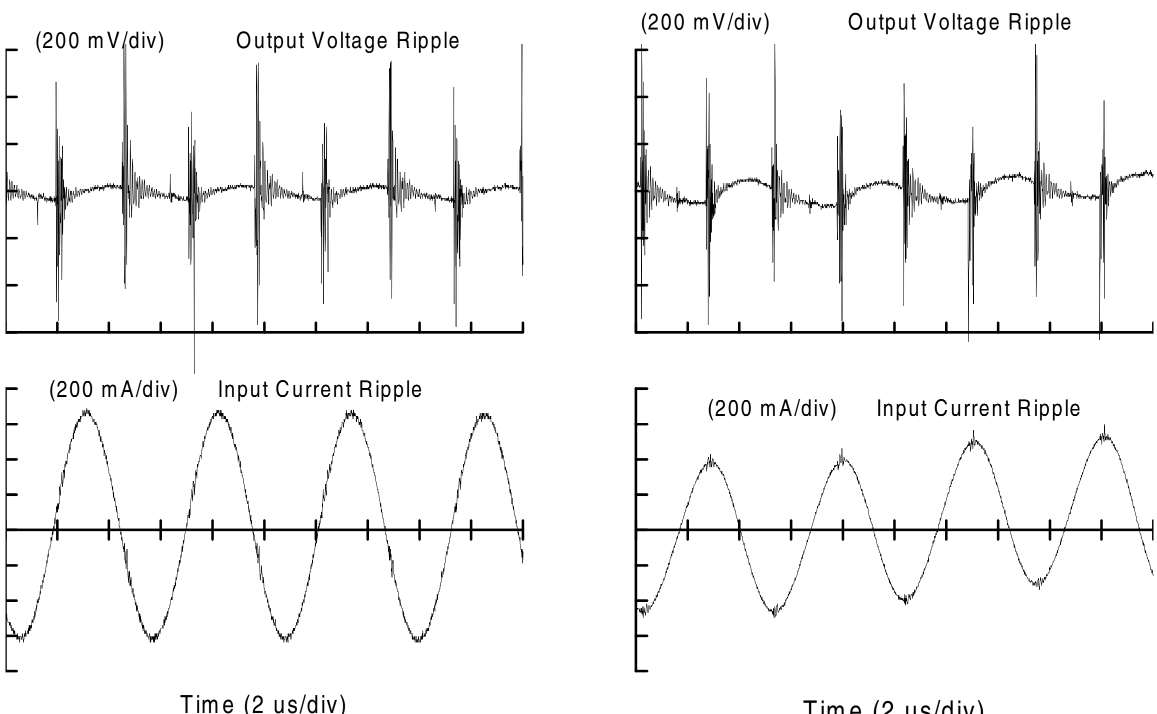
(a) Temperature = 25°C (b) Temperature = -100°C

Figure 4. Module #1 operation with 49V input and under heavy load condition (12.5A).



(a) Temperature = 20°C (a) Temperature = -80°C

Figure 5. Module #2 operation with 48V input and under light load (5.0A).



(a) Temperature = 20°C (a) Temperature = -80°C

Figure 6. Module #2 operation with 48V input and under heavy load (30A).

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