Application of Commercial Electronics in the Motors and Actuator systems for Mars Surface Missions

Mohammad M. Mojarradi¹, R. Scott Cozy¹, Yuan Chen¹, Mathew Johnson¹, Elizabeth A. Kolawa¹, Michael Johnson¹, Thomas Mccarthy¹, Greg C Levanas¹, Benjamin Blalock², Gary Burke¹, Linda Del Castillo¹, Andrew A. Shapiro¹
¹Jet Propulsion Laboratory. ²University of Tennessee

Introduction

Commercial-off-the-shelf electronic components (COTS) offer a very low cost and attractive solution for construction of electronic systems for Mars missions, including the actuator electronic systems for the Mars Rovers. One issue with using COTS lies in the difference between their specified operating temperature range (-55°C to 125°C for military components) and the temperatures observed at the surface of Mars (-120°C to 20°C). To compensate for the difference between these temperatures, most of the electronics are placed in a central Warm-Electronics-Box or (WEB). In some cases, such as the distributed control system for the actuators, the electronic assemblies that will have to be placed on or near the motors are outside of the central WEB. The COTS parts used for the distributed control of actuators will have to be capable of operating at the very cold temperatures on Mars.

The list of COTS used for the control of actuators encompasses discrete transistors, digital gates, FPGA’s, mixed signal circuits, and analog CMOS amplifiers. Since there is no published performance data from COTS manufacturers for the colder temperature range of Mars, an experimental search will have to be used to identify COTS that are capable of functioning at -120°C. The experimental search consists of two steps. First, a short functional/non functional test at -120°C is used to identify and narrow down the number of candidate COTS that can work at very cold temperatures. Following this test, a longer, more extensive characterization of the parts that passed the short test is performed to determine the operating margins and estimate the thermal cycle life capability for the COTS parts. Finally, the operating margins of the COTS parts are published as a set of specifications.

This paper summarizes the testing and characterization results performed down to -120°C on a group of COTS identified. Further reliability and performance study of temperature cycling impacts on the COTS will follow.

Experimental Details

A group of COTS have been identified, tested and characterized under a wide range of temperature, from 27°C to -175°C. All the electronic devices under testing were kept in the cryogenic chamber with thermal couples attached on the device package to ensure accurate testing temperature monitoring. Functional testing and parametric measurements were done on each device when the cryogenic chamber temperature was stabilized.

Hex inverter, DC-DC converter, analog-digital converter, operational amplifier and power-up microprocessor reset circuit were the first group of devices to be tested.

1. Hex inverter

A commercial hex inverter was tested in the temperature range of 27°C to -120°C. Figure 1(a), (b) and (c) show the waveform of the hex inverter at temperature of 27°C, -55°C and -
120°C, respectively. There is no indication of functional failure for this hex inverter.

The 5-Watt DC-DC converter was functioning down to -160°C, shown in Figure 2(a). For the 15-Watt DC-DC converter, Figure 2(b) indicates that it stopped working at slightly colder than -120°C. However, the 15-Watt DC-DC converter came back to life around -96°C and resumed normal operation.

3. Analog-digital converter

The analog-digital converter chosen for the study is a monolithic, single-supply, 12-bit commercial device with specified operating temperature from -40°C to 85°C.

The 12-bit accuracy was maintained in the device specified temperature range. It yielded 11-
bit resolution down to -80°C and 10-bit resolution down to -160°C. After cold soaking for 5 minutes at -160°C, the internal reference voltage Vref stayed steady and output had 1.2% error, shown in Figure 3(b) as a function of temperature.

Figure 3(a). Internal reference voltage Vref as a function of temperature for the ADC.

Figure 3(b). Error percentage as a function of temperature for the ADC.

4. Operational amplifier

The operational amplifier is a commercial qual input and output op amp. Shown in Figure 4(a) and (b), there was no significant performance change for the operational amplifier during functional testing ranging from 27°C to -165°C.

Figure 4(a). Operational amplifier at 27°C.

Figure 4(b). Operational amplifier at -165°C.

5. Power-up microprocessor reset circuit

The power-up microprocessor reset circuit tested in this study is a radiation hardened device with specified operating temperature between -55°C and 125°C. It monitors the power supply voltage during power-up and interface with control units to ensure proper device operation by sending a reset pulse to the microprocessor when the supply reaches a nominal operating voltage.

In Figure 5(a), channel 1 and 2 are power supply voltage Vcc and reset, respectively. The figure shows that reset was still functioning under -175°C when power supply voltage Vcc reached the specified nominal voltage.
Figure 5(a). Reset (channel 2) functioned when power supply voltage Vcc (channel 1) reached at the specified nominal voltage.

The power-up microprocessor reset circuit also includes a watchdog circuit that verifies proper reset has occurred. Figure 5(b) and (c) show the Watchdog Input (WDI) timing under 0°C and -175°C, respectively. Time to reset is the delay between the reset (channel 3) and time when the clock goes low (channel 4). It was measured as 1.4 second at 0°C compared to 4.8 second at -175°C. This indicates that the circuit was still functioning, but the time to reset became longer at lower temperature. Figure 5(d) shows the time to reset as a function of temperature, which exhibits a nearly exponential increase of the time to reset below -100°C.

The other two input pins on the power-up microprocessor reset circuit are the threshold detector input (PFI) pin and the manual reset (MR) input pin. The threshold detect pin may be used to monitor a power fall or low battery condition, or for monitoring other voltage supply levels. The PFI stayed high at -175°C, indicating that threshold detector malfunction at the temperature, shown in Figure 5(e). The manual reset input (MR) was found to be functioning at -175°C with a longer reset pulse.
Figure 5(e). PFI (channel 4) stayed high.

Summary

A group of COTS have been identified, tested and characterized under a wide range of temperature, from 27°C to -175°C. Hex inverter, DC-DC converter, analog-digital converter, operational amplifier and power-up microprocessor reset circuit were the first group of devices to be tested. The detailed performance and reliability characterization is an on-going effort and the results will be available in the near future.

Acknowledgments

This work was carried out at Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References