

## Characterization of Low Noise, Precision Voltage Reference REF5025-HT under Extreme Temperatures

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### Scope of Work

Operation of electronics under cryogenic conditions are anticipated in space missions such as polar craters of the moon (-223 °C), James Webb Space Telescope (-236 °C), Mars (-140 °C), Europa (-223 °C), Titan (-178 °C), and other deep space probes away from the sun. To accommodate for proper operation under such conditions, present on-board electronics usually rely on thermal management systems such as radioisotope thermoelectric generators (RTG) for providing adequate environment. Electronics capable of operation at cryogenic temperatures will, thus, eliminate the need for the thermal control elements and this, in turn, will enhance the efficiency of space systems, improve their reliability, and simplify their overall design.

In this work, the performance of a low noise, very low drift, precision voltage reference was evaluated under a wide temperature range. The Texas Instruments' REF5025-HT chip is capable of both sinking and sourcing current, and is robust to line and load variation [1]. The device is rated for -55 °C to +210 °C operation and is ideal for use in down-hole drilling and other high temperature applications. It is capable of operation under a wide input voltage range, and its output can be adjusted by modification of the internal bandgap via an external trim pin. Table 1 shows some of the manufacturer's device specifications [1].

Table I. Specifications of the REF5025-HT voltage reference [1].

Parameter (Unit)	REF5025-HTSHKJ
Input Voltage, $V_{in}$ (V)	3.25 to 18
Output Voltage, $V_{out}$ (V)	2.5
Output Voltage Accuracy (%)	0 to 0.14
Quiescent Supply Current, $I_S$ (mA)	1.2
Maximum Output Current, $I_{out}$ (mA)	$\pm 7$
Temperature Range, T (°C)	-55 to +210
Package	Ceramic DFP-F8
Lot #	A03BNA11

The voltage reference chip was examined for operation between -190 °C and +210 °C. The device was evaluated in terms of its output voltage and supply current at different input voltage levels as a function of temperature. Line regulation was also established for seven different load levels between -7 mA (sinking) and 10 mA (sourcing) over the test temperature range. The effect of temperature on load regulation of the voltage reference was also determined. In addition, restart operation capability of the chip under extreme temperatures was investigated by

first soaking the device for a period of 20 minutes at either extreme  $-190\text{ }^{\circ}\text{C}$  or  $+210\text{ }^{\circ}\text{C}$  with power off, followed then by applying power to the device and recording its output voltage and supply current data. To determine the effects of thermal cycling on its performance, the voltage reference chip was exposed to a total of 12 cycles between  $-190\text{ }^{\circ}\text{C}$  and  $+210\text{ }^{\circ}\text{C}$  at a rate of change of  $10\text{ }^{\circ}\text{C}/\text{min}$ , and a soak time of at 20 minutes at the extreme temperatures. Following the thermal cycling, another set of measurements were then performed at the test temperatures of  $+22$ ,  $-190$ , and  $+210\text{ }^{\circ}\text{C}$ . Figure 1 shows the circuit board populated with the REF5025-HT device with a couple of bypass NP0 ceramic capacitors.

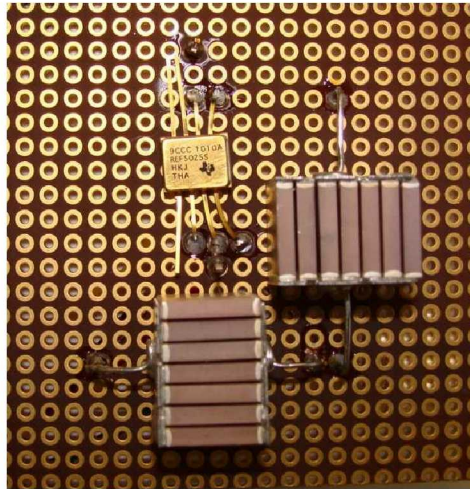


Figure 1. Test circuit board populated with REF5025-HT chip and bypass capacitors.

## Results and Discussion

### *Output Voltage*

The output voltage of the reference chip at no load as a function of applied input voltage is shown in Figure 2 for various test temperatures between  $-190\text{ }^{\circ}\text{C}$  and  $+210\text{ }^{\circ}\text{C}$ . It can be seen that the output voltage of the regulator maintained a steady value of about  $2.5\text{ V}$  at any test temperature in the range between  $-50\text{ }^{\circ}\text{C}$  and  $+200\text{ }^{\circ}\text{C}$ . Outside this temperature envelope, however, the output voltage exhibited a decline in its value that was dependent on the test temperature. That is, while the output voltage dropped slightly at the extreme temperatures of  $-190\text{ }^{\circ}\text{C}$  ( $2.32\text{ V}$ ) and  $+210\text{ }^{\circ}\text{C}$  ( $2.43\text{ V}$ ), it experienced more decrease in the intermediate test temperatures of  $-100\text{ }^{\circ}\text{C}$  and  $-150\text{ }^{\circ}\text{C}$  where output levels of  $2.03\text{ V}$  and  $1.90\text{ V}$  were obtained. Figure 3 shows that, for any input voltage between  $3.25\text{ V}$  and  $18\text{ V}$  under no load conditions, changes in the output voltage with temperature appeared to be independent of the input voltage being supplied to the device.

### *Supply Current*

The supply current of the voltage reference under no load is shown in Figure 4 as a function of temperature and at various input voltages. The variations in the supply current with change in temperature were not large. For example, while the current hovered around  $1.8\text{ mA}$  for test temperatures between  $+25\text{ }^{\circ}\text{C}$  and  $+150\text{ }^{\circ}\text{C}$ , it experienced a gradual drop as temperature was decreased below room temperature; reaching a level of about  $0.17\text{ mA}$  at  $-190\text{ }^{\circ}\text{C}$ . Similarly, the

current began to decrease when the test temperature was increased above 150 °C, but the trend reversed direction above +200°C. These changes, as stated earlier, were not significant as the supply current only changed from 1.81 mA to about 1.36 mA when temperature increased from +150 °C to +210 °C. The changes in the supply current are close to those of the manufacturer’s specified quiescent current between 0.8 and 1.5 mA. Variation in the input voltage level of the voltage reference had no impact on its supply current.

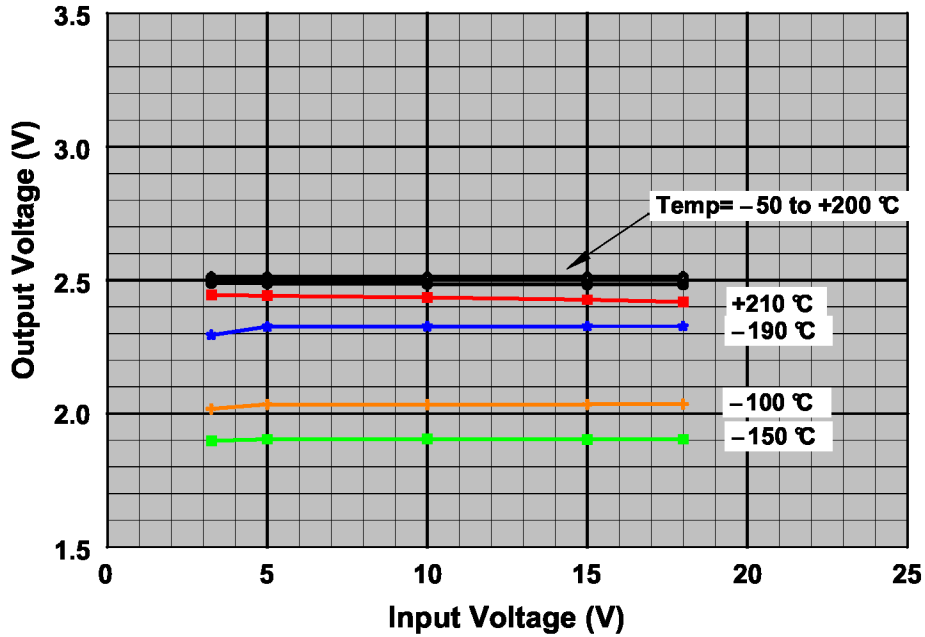


Figure 2. Output of voltage reference versus input voltage at various temperatures.

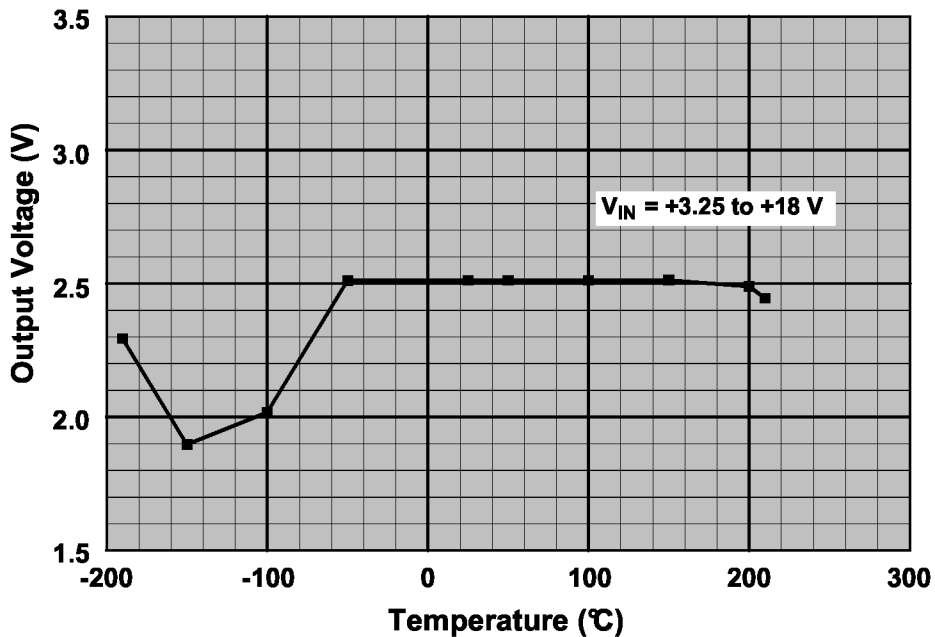


Figure 3. Voltage reference output voltage as a function of temperature at different inputs.

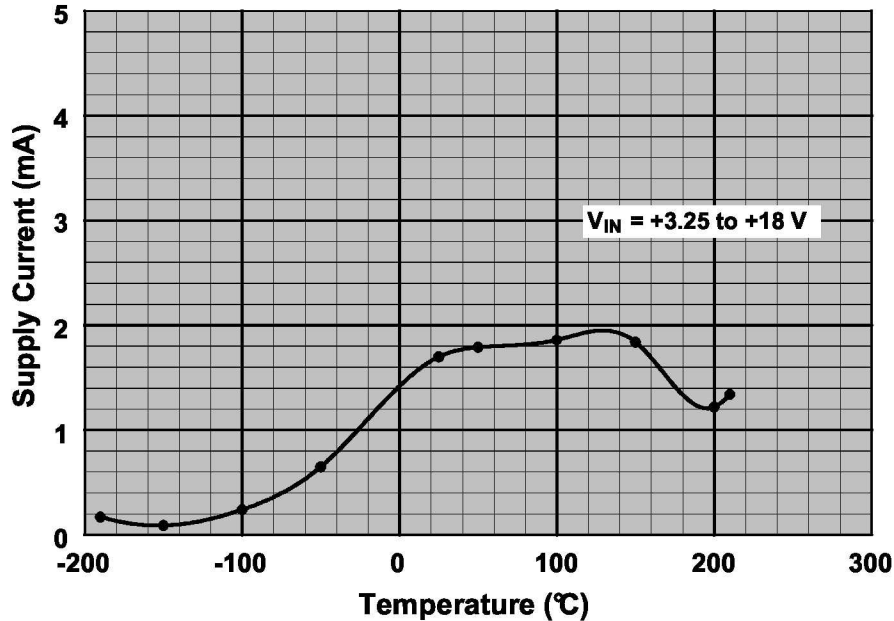


Figure 4. Supply current of voltage reference versus temperature.

### *Line Regulation*

Line regulation characteristics of the REF5025-HT voltage reference were determined at load current levels of -7, -5, 0, 5, 7, and 10 mA. These characteristics were obtained over the test temperature range of -190 °C to +210 °C. The dependence of the voltage reference output on its input voltage at these load currents is depicted in Figure 5 at selected test temperatures. The following observations can be deduced from this data:

The voltage reference displayed excellent line regulation at any given input voltage and load current levels throughout the test temperature range from -50 °C to +150 °C.

At -100 °C, the voltage reference maintained its line regulation only at the 10 mA load level. At the load levels of 0, -5, or -7 mA, the output of the voltage reference held a steady but reduced value of about 2.03 V. For sourcing current between 5 and 7 mA, the output voltage was influenced by the applied input voltage. At 5 mA load, the output of the voltage reference maintained the nominal value of 2.51 V at any input voltage except at the lowest level of 3.25 V where the output voltage dropped to about 2.02 V. Similar behavior was observed at 7 mA with the exception that the minimum input voltage to maintain good line regulation was 10 V.

Under exposure to the high test temperatures of +200 °C, the output of the voltage reference exhibited a slight and gradual decrease with increase in input level for all load levels except at 10 mA. At this current level, the voltage reference began to lose regulation at input level below 5 V or above 15 V, as shown in Figure 5. Similar behavior is exhibited by the voltage reference at 0, -5, or -7 mA load when tested at +210 °C, but under the other load current conditions, in particular 10 mA, the loss in regulation became more severe, as illustrated in Figure 5 depicting the +210 °C condition (Note the change in scale for this figure).

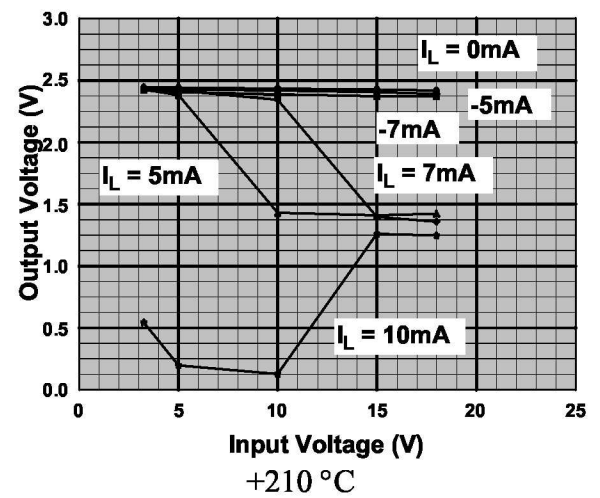
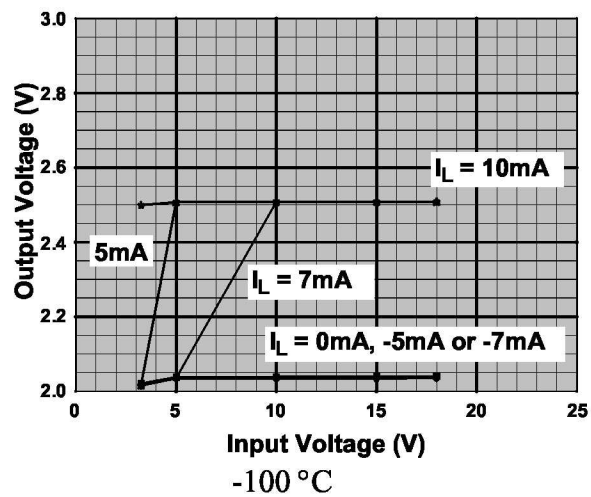
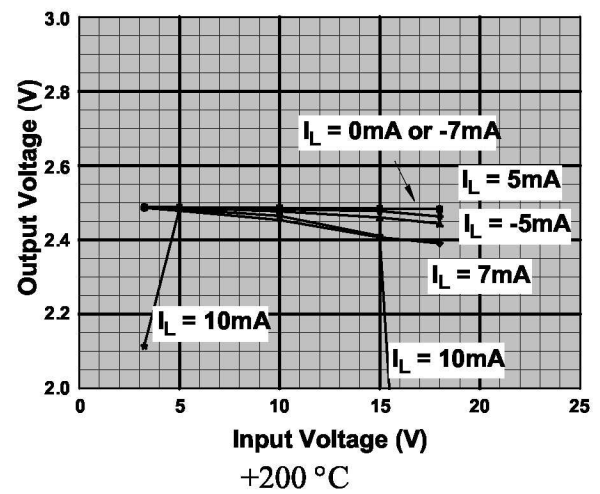
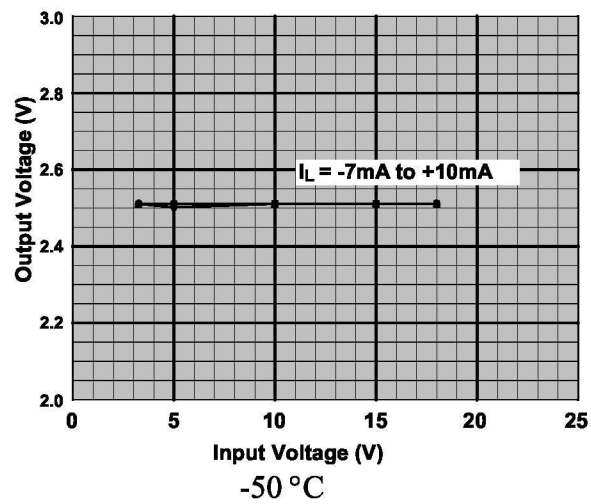
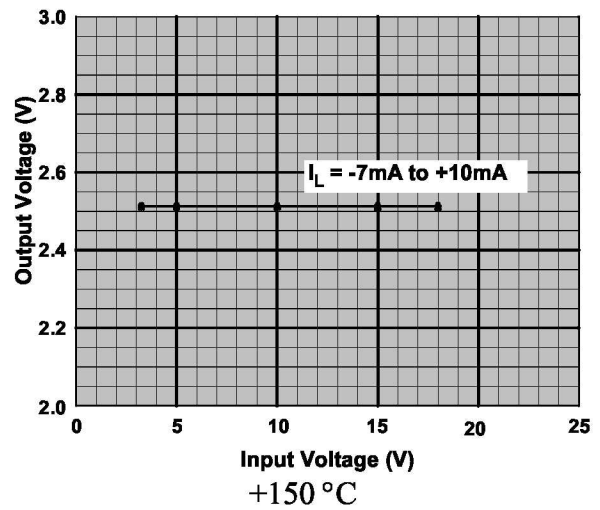
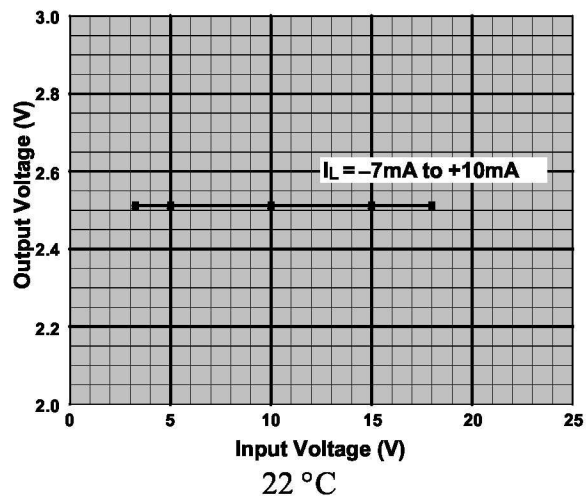


Figure 5. Line regulation of the voltage reference at various test temperatures.

### Load Regulation

The variation in the output voltage of the REF5025-HT voltage reference device as a function of load current at the various test temperatures is depicted in Figure 6. The voltage reference exhibited good load regulation in the temperature range of  $-50\text{ }^{\circ}\text{C}$  to  $+200\text{ }^{\circ}\text{C}$  as its output did not change significantly from the nominal value of about 2.51 V. At the extreme test temperatures of  $-100\text{ }^{\circ}\text{C}$  and  $+210\text{ }^{\circ}\text{C}$ , however, the device experienced some changes in its output. At  $210\text{ }^{\circ}\text{C}$ , for example, the output voltage ranged from 2.44 V to 2.40 V for all load levels except at 10 mA where it appreciably dropped to about 0.2 V. When the voltage reference was exposed to the cryogenic test temperature of  $-100\text{ }^{\circ}\text{C}$ , its output held a steady value of 2.03 V while the device was not loaded or it was sinking current of  $-5$  or  $-7$  mA. Under source-current conditions, though, the output switched to the normal 2.51 V level under loads of 5 or 10 mA, but relapsed back to 2.03 V under a 7 mA load, as shown in Figure 5. Although it might be thought that the internal heat generated by the device when loaded tends, in general, to lessen the impact of the cold temperature on its operation, the peculiar behavior at 7 mA condition is not fully understood, or could have been due to some experimental error.

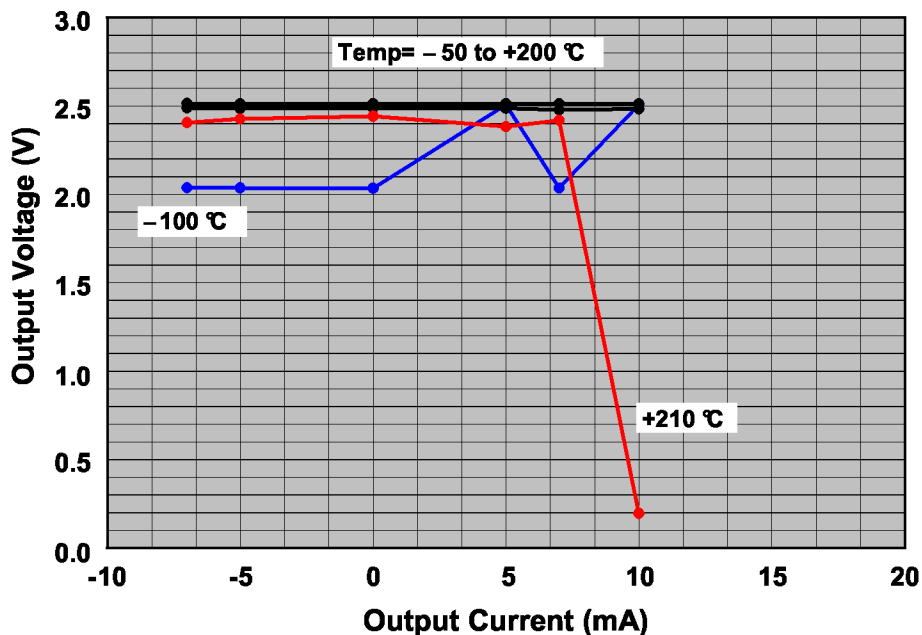


Figure 6. Load regulation of the voltage reference at various temperatures ( $V_{\text{IN}}=5\text{V}$ ).

### Restart at Extreme Temperatures

Restart capability of the voltage reference at extreme temperatures was investigated by allowing it to soak for at least 20 minutes at each of the test temperatures of  $-190\text{ }^{\circ}\text{C}$  and  $+210\text{ }^{\circ}\text{C}$  without electrical bias. Power was then applied to the reference circuit, and measurements were taken on the output characteristics. The circuit was able to successfully restart at both extreme temperatures and the results obtained were the same as those attained earlier for both temperatures.

### Effects of Thermal Cycling

The effects of thermal cycling on the operation of the voltage reference circuit were investigated by subjecting it to a total of 12 cycles between  $-190\text{ }^{\circ}\text{C}$  and  $+210\text{ }^{\circ}\text{C}$  at a rate of  $10\text{ }^{\circ}\text{C}/\text{minute}$ . A dwell time of 20 minutes was applied at the extreme temperatures. Measurements of the voltage reference output were then taken as a function of input voltage at various temperatures. A comparison of the output voltage recorded at the selected test temperatures of  $+25$ ,  $-190$ , and  $+210\text{ }^{\circ}\text{C}$  for pre- and post-cycling conditions are shown in Figure 7. It can be clearly seen that the post-cycling output level at any given test temperature were the same as those obtained prior to cycling. Similar data was obtained for the circuit's supply current. Therefore, it can be concluded that this limited thermal cycling did not induce much change in the characteristics of the circuit. The thermal cycling also appeared to have no effect on the structural integrity of the voltage reference chip as no structural deterioration or packaging damage was observed.

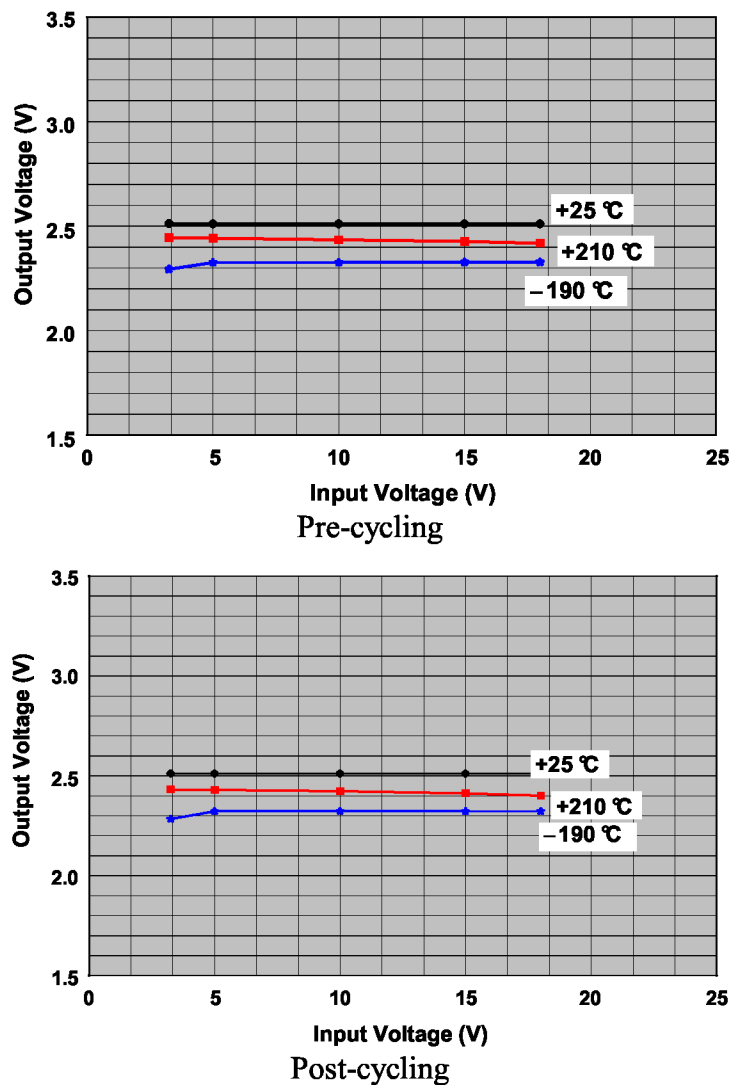


Figure 7. Comparison of voltage reference output versus input voltage at selected temperatures.

## **Conclusions**

The performance of Texas Instruments' precision voltage reference REF5025-HT was assessed under extreme temperatures. This low noise, 2.5 V output chip is suitable for use in high temperature down-hole drilling applications, but no data existed on its performance at cryogenic temperatures. The device was characterized in terms of output voltage and supply current at different input voltage levels as a function of temperature between +210 °C and -190 °C. Line and load regulation characteristics were also established at six load levels and at different temperatures. Restart capability at extreme temperatures and the effects of thermal cycling, covering the test temperature range, on its operation and stability were also investigated. Under no load condition, the voltage reference chip exhibited good stability in its output over the temperature range of -50 °C to +200 °C. Outside that temperature range, output voltage did change as temperature was changed. For example, at the extreme temperatures of +210 °C and -190 °C, the output level dropped to 2.43 V and 2.32 V, respectively as compared to the nominal value of 2.5 V. At cryogenic test temperatures of -100 °C and -150 °C the output voltage dropped by about 20%. The quiescent supply current of the voltage reference varied slightly with temperature but remained close to its specified value. In terms of line regulation, the device exhibited excellent stability between -50 °C and +150 °C over the entire input voltage range and load levels. At the other test temperatures, however, while line regulation became poor at cryogenic temperatures of -100 °C and below, it suffered slight degradation at the extreme high temperature but only at the high load level of 10 mA. The voltage reference also exhibited very good load regulation with temperature down to -100°C, but its output dropped sharply at +210 °C only at the heavy load of 10 mA. The semiconductor chip was able restart at the extreme temperatures of -190 °C and +210 °C, and the limited thermal cycling did not influence its characteristics and had no impact on its packaging as no structural or physical damage was observed.

## **References**

1. Texas Instruments REF5025-HT, "Low Noise, Very Low Drift, Precision Voltage Reference," Datasheet SBOS502B, Rev. May 2010.

## **Acknowledgments**

This work was performed at the NASA Glenn Research Center under GESS-2 Contract # NNC06BA07B. Funding was provided from the NASA Electronic Parts and Packaging (NEPP) Program Task "Reliability of SiGe, SOI, and Advanced Mixed Signal Devices for Cryogenic Power Electronics".