

NASA Electronic Parts & Packaging (NEPP) Program

Performance of the Micropower Voltage Reference ADR3430 Under Extreme Temperatures

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Scope of Work

Electronic systems designed for use in space exploration systems are expected to be exposed to harsh temperatures. For example, operation at cryogenic temperatures is 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. Similarly, rovers and landers on the lunar surface, and deep space probes intended for the exploration of Venus are expected to encounter high temperature extremes. Electronics capable of operation under extreme temperatures would not only meet the requirements of future space-based systems, but would also contribute to enhancing efficiency and improving reliability of these systems through the elimination of the thermal control elements that present electronics need for proper operation under the harsh environment of space.

In this work, the performance of a micropower, high accuracy voltage reference was evaluated over a wide temperature range. The Analog Devices ADR3430 chip uses a patented voltage reference architecture to achieve high accuracy, low temperature coefficient, and low noise in a CMOS process [1]. The device combines two voltages of opposite temperature coefficients to create an output voltage that is almost independent of ambient temperature. It is rated for the industrial temperature range of -40 °C to +125 °C, and is ideal for use in low power precision data acquisition systems and in battery-powered devices. Table 1 shows some of the manufacturer’s device specifications.

Table I. Specifications of the ADR3430 voltage reference [1].

Parameter (Unit)	ADR3430ARZ-R7
Input Voltage, V_{in} (V)	3.2 to 5.5
Output Voltage, V_{out} (V)	3.0000
Temperature Coefficient, TCV_{OUT} (ppm/°C)	2.5
Quiescent Supply Current, I_S (μA)	85
Maximum Output Current, I_{out} (mA)	-3 to +10
Temperature Range, T (°C)	-40 to +125
Package	Plastic 6-Lead SOT-23
Lot #	0947

The voltage reference chip was examined for operation over a wide temperature range to determine its functionality at temperatures beyond its specified operating limits. The low temperature test was restricted to -100 °C because the output began to exhibit instability at that point (as discussed later), while the upper test temperature was confined to +140 °C; a value that exceeded the part’s high temperature operating limit but fell short of the absolute maximum

junction/storage rated temperature of +150 °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 five different load levels between -3 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 soaking the test circuit for 20 minutes without bias, followed then by applying power to the device and recording its output voltage and power supply current data. To determine the effects of thermal cycling on its performance, the device was exposed to a total of 12 cycles between -70 °C and +140 °C at a rate of change of 10 °C/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, -70, and +140 °C. Figure 1 shows the test circuit populated with the ADR3430 device with a parallel-combination of 0.1 μF NP0 ceramic and 1.0 μF solid tantalum capacitors as input bypass, and another 0.1 μF NP0 ceramic capacitor connected at the output.



Figure 1. Circuit board populated with ADR3430 chip, input-bypass and output capacitors.

Results and Discussion

Output Voltage

Figure 2 shows the output voltage of the reference chip at no load as a function of applied input voltage for various test temperatures between -100 °C and +140 °C. At any given temperature, the voltage reference was able to produce a stable, steady output regardless of varying the magnitude of the input voltage. For example, the output voltage of the regulator maintained a steady value of about 3.000 V throughout the test temperature range between -70 °C and +140 °C. At the extreme cryogenic temperature of -100 °C, the output also maintained a constant value but at a slightly increased level of 3.007 V. Figure 3 shows this impact of subjecting the voltage reference to -100 °C on its output level, again under no load conditions. This was also the case when the voltage reference was loaded provided that the load didn't exceed 5 mA. At loads above 5 mA or at sink current of -3 mA, however, the output of the device exhibited instability when tested at -100 °C. This instability was found to disappear as the test temperature was raised to -75 °C. This was confirmed by performing several test runs around the -75 °C point. Thus, it was deemed that the lower operable temperature limit, for both no-load and full-

load conditions, to be $-70\text{ }^{\circ}\text{C}$ and all subsequent low temperature testing was confined to this point.

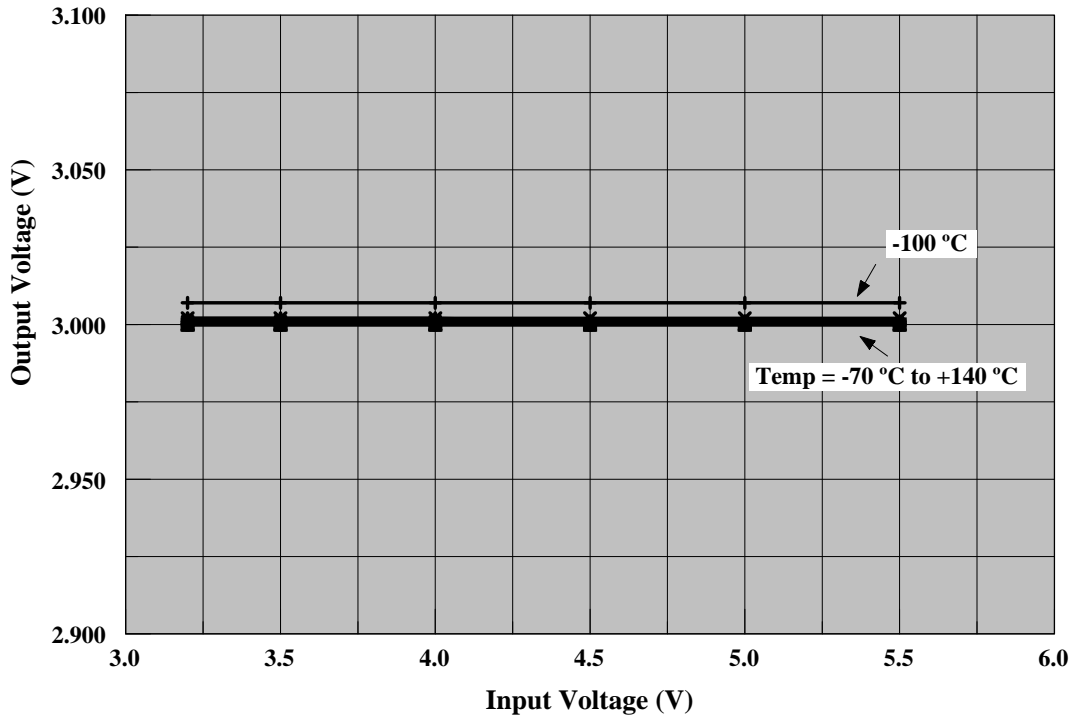


Figure 2. Output of voltage reference versus input voltage at various temperatures.

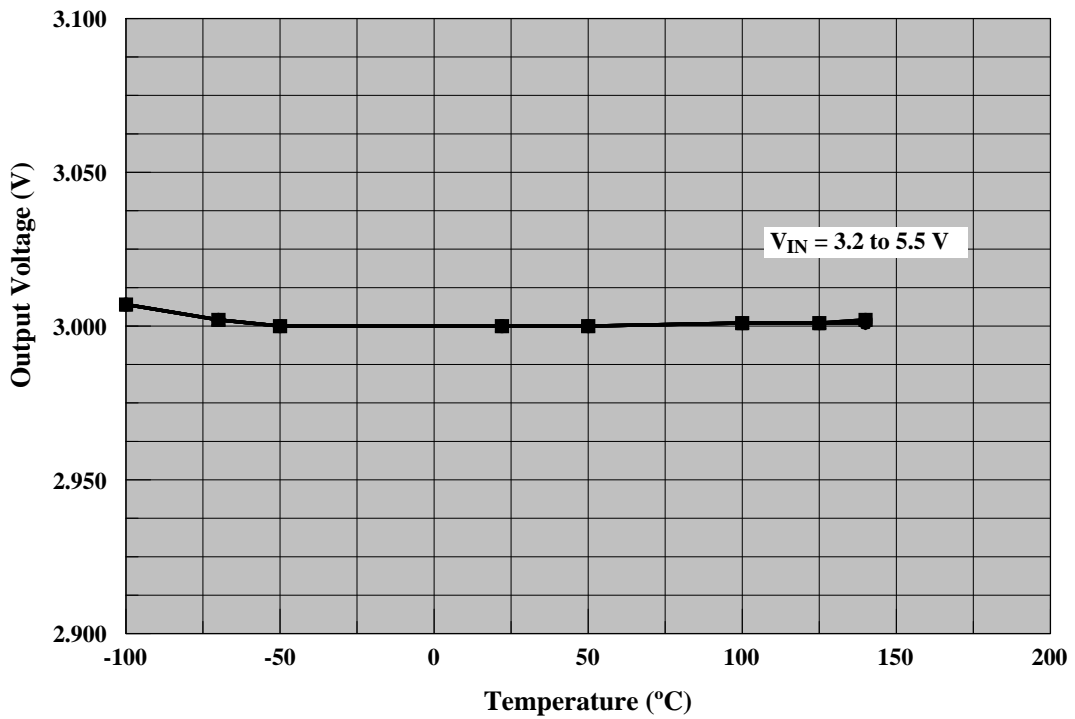


Figure 3. Voltage reference output voltage as a function of temperature at different inputs.
Supply Current

The supply current of the voltage reference under no load is shown in Figure 4 as a function of temperature. At room temperature, the supply (quiescent) current of this voltage reference attained a value of about 0.06 mA. This property displayed an almost linear dependency on temperature. As indicated in Figure 4, the supply current increased as temperature was increased and vice versa. This variation was small though as the current varied from 0.04 mA at -100 °C to reach a level of 0.08 mA at +140 °C. This trend in the supply current variation with test temperature was the same irrespective of the input voltage used, as seen in Figure 4.

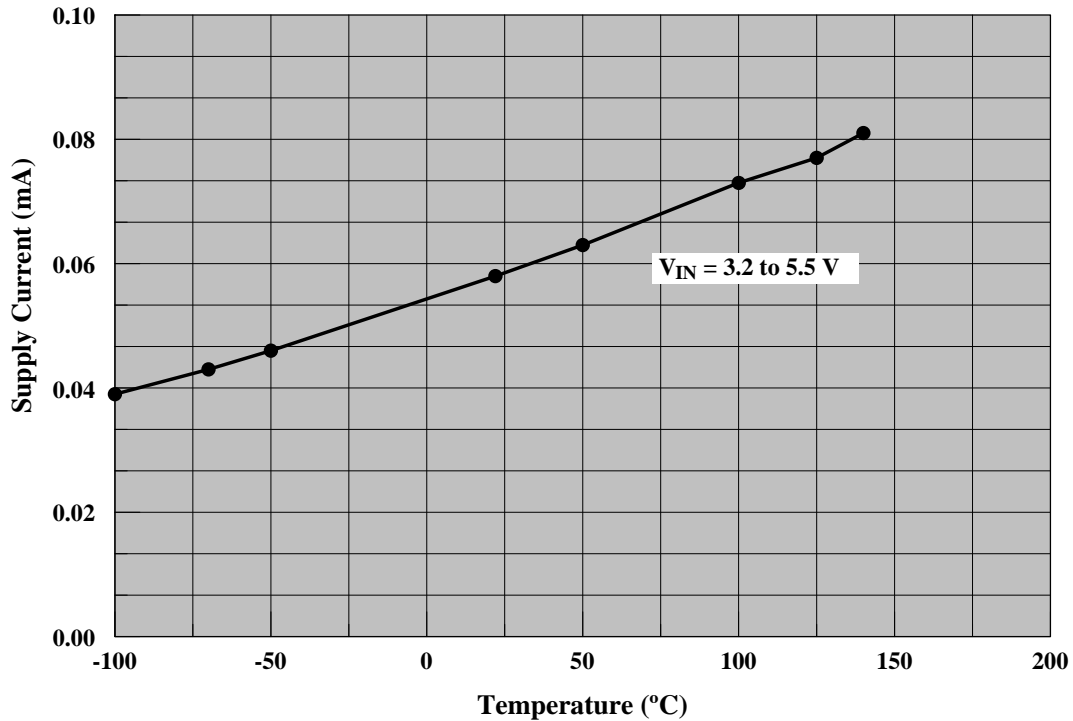


Figure 4. Supply current of voltage reference versus temperature.

Line Regulation

Line regulation characteristics of the ADR3430 voltage reference were determined at load current levels of -3, 0, 5, 7, and 10 mA. These characteristics were obtained over the test temperature range of -70 °C to +140 °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:

Ambient Temperature: The voltage reference displayed excellent line regulation at all load levels.

Cryogenic Temperature: At -70 °C, the voltage reference replicated the performance obtained at room temperature by displaying excellent output stability irrespective of the applied load. At -100 °C, however, stability in the output was maintained only when

loads in the range of 0 to 5 mA were applied, as discussed earlier. At higher load levels, stability is lost as the reference acted erratically and its output fluctuated dramatically especially at output currents between 7 and 10 mA.

High Temperature: With the exception of the applied input being at 3.2 V, the reference voltage device exhibited superior performance at high temperatures and at all load levels, as shown in Figure 5. When an input of 3.2 V was used, the output of the reference seemed to slightly drop from the nominal value of 3.0 V; particularly at the highest load level of 10 mA, as depicted in Figure 5. It is important to note that the specified input voltage range for operation of this device is from 3.2 V to 5.5 V at 25 °C and when high temperature are encountered, the applied minimum voltage of 3.2 V might not be sufficient to ensure proper biasing of the internal circuitry of the reference. Thus, it may be appropriate not to stress this effect at 3.2 V, but instead, highlight the excellent line regulation obtained at high temperatures at the other inputs.

Load Regulation

The variation in the output voltage of the ADR3430 reference device as a function of load current at the various test temperatures is depicted in Figure 6. This data was obtained using an input voltage of 3.5 V. It can be seen that the reference voltage displayed superb performance in terms of load regulation at any temperature in the test range from -70 °C to 140 °C. Such was not the case though at the test temperature of -100 °C where the output voltage dropped when either a low input voltage of 3.2 V was used or a heavy load of 10 mA was applied. This observation is consistent with that reported earlier about the instability in the output of the reference voltage occurring under certain conditions at -100 °C. Variation in the input voltage had no effect on load regulation in the test domain of -70 °C to +140 °C, as illustrated in Figure 7 using 5-V input as an example.

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 -70 °C and +140 °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 either temperature and the results obtained were the same as those attained earlier for both temperatures.

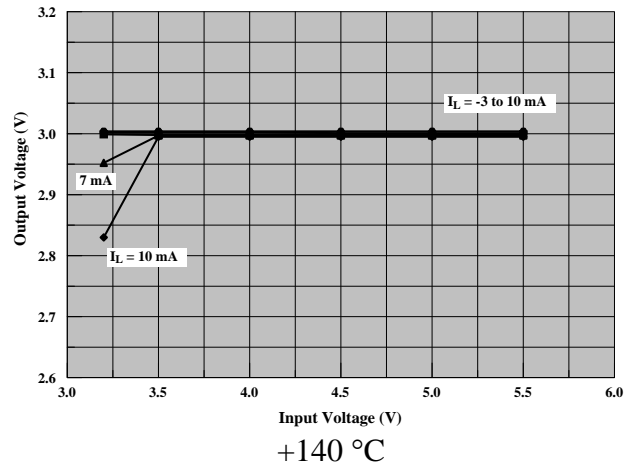
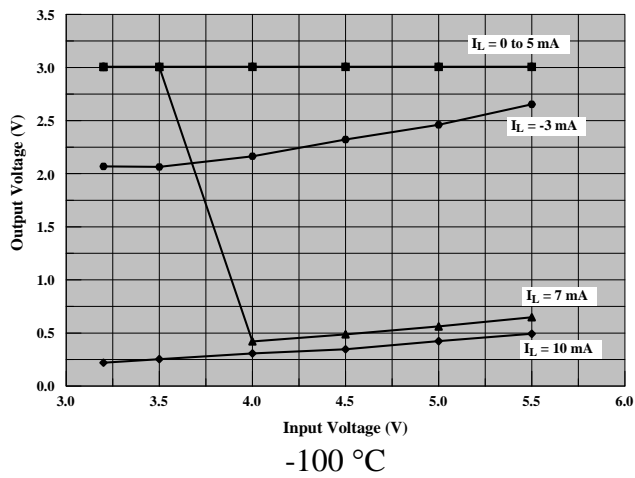
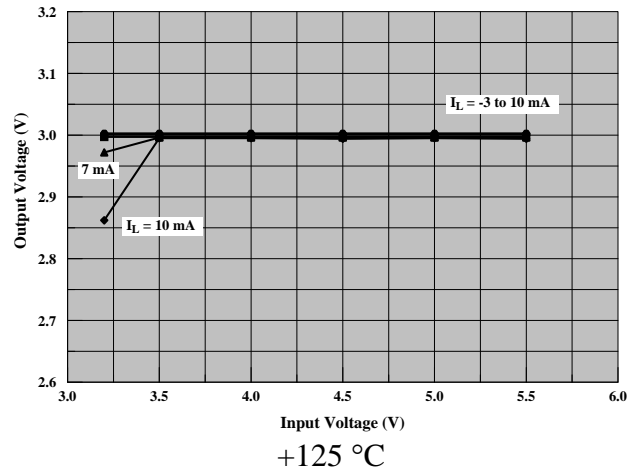
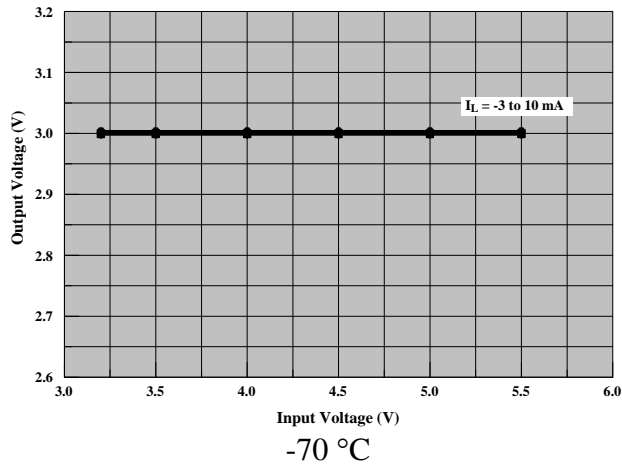
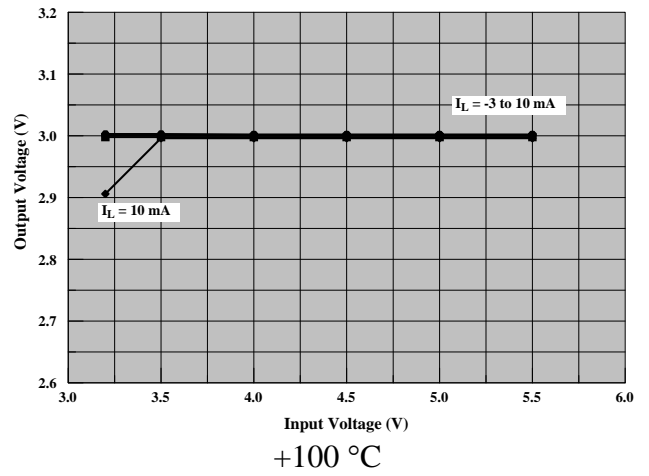
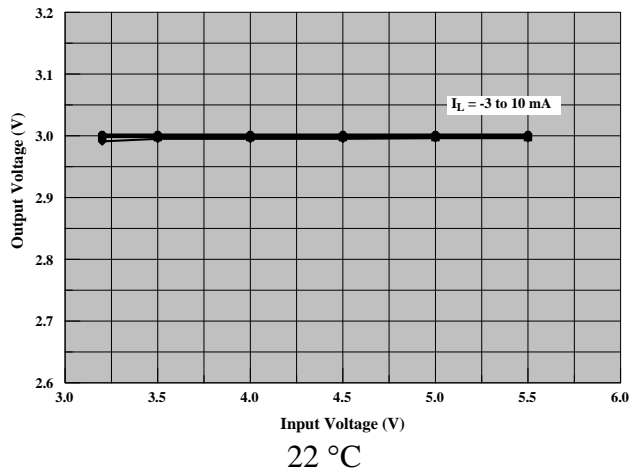


Figure 5. Line regulation of the voltage reference at various test temperatures.

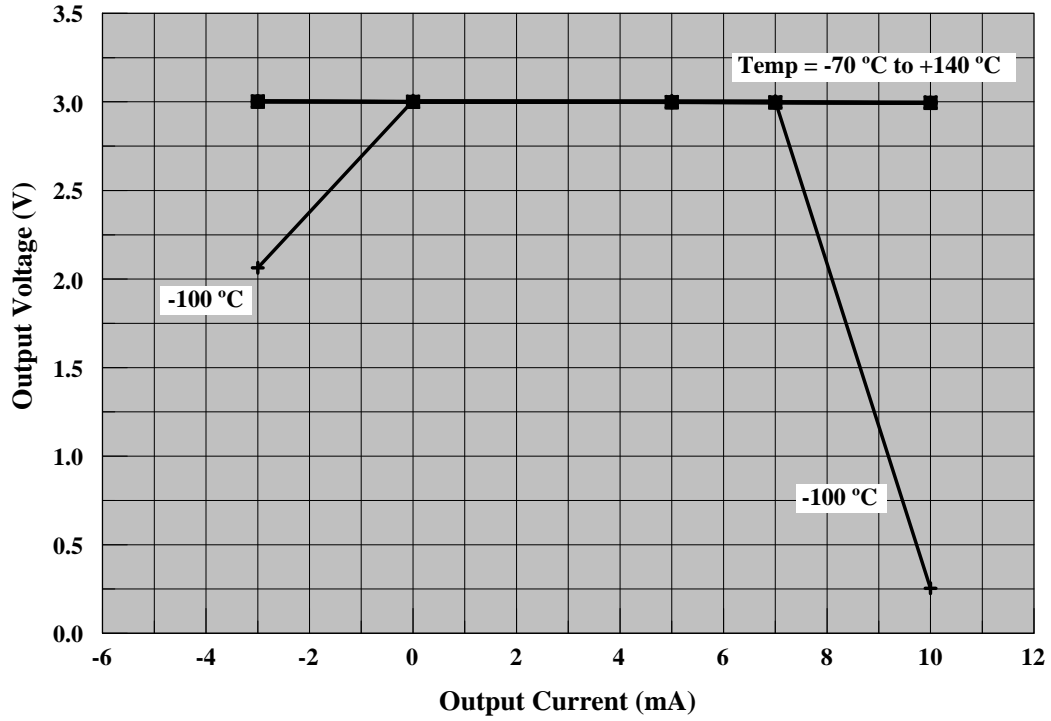


Figure 6. Load regulation of the voltage reference at various temperatures with $V_{IN} = 3.5$ V.

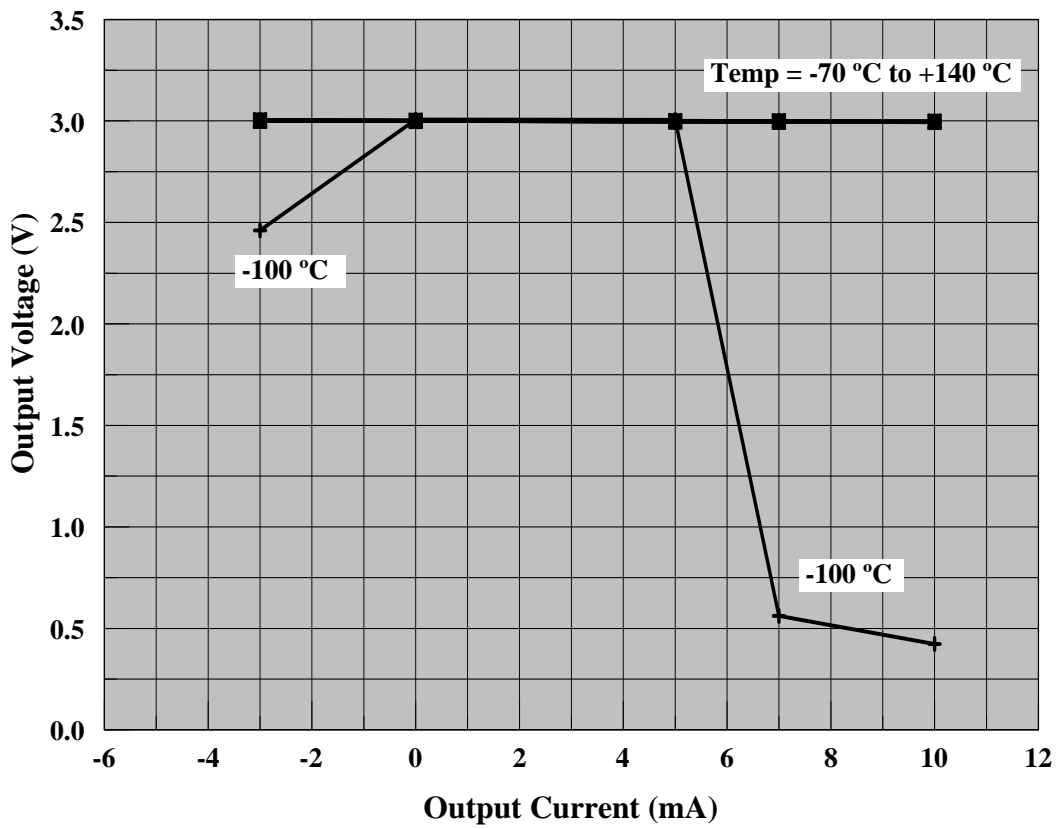


Figure 7. Load regulation of the voltage reference at various temperatures with $V_{IN} = 5$ V.

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 $-70\text{ }^{\circ}\text{C}$ and $+140\text{ }^{\circ}\text{C}$ 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 reference output were then taken as a function of input voltage at various temperatures. A comparison of this voltage recorded at the selected test temperatures of -70 , $+22$, and $+140\text{ }^{\circ}\text{C}$ for pre- and post-cycling conditions are shown in Figure 8 for various load levels. While there was no effect of cycling on the reference device under no load, the magnitude of its output seemed to slightly change, however, with application of load. Upon sinking current of -3 mA , for example, the output increased from 3.000 V to about 3.033 V , regardless of either the test temperature or the applied input voltage. On the other hand, the output of the reference decreased in current-source mode; with the decrease being more profound with increasing load as shown in Figure 8. Such a trend, which was observed after cycling, was consistent at all test temperatures. At 5 mA load for instance, the output of the reference decreased to 2.944 V while it reached a value of about 2.890 V when the load was increased further to 10 mA . These cycling-induced changes were permanent in nature as similar results were obtained when room temperature-measurements were performed at 150 hours after completion of the cycling activity. In the testing the device was subjected to temperatures as low as $-100\text{ }^{\circ}\text{C}$ and as high as $+140\text{ }^{\circ}\text{C}$. These temperatures were outside its specified operating temperature range of $-40\text{ }^{\circ}\text{C}$ to $+125\text{ }^{\circ}\text{C}$. It is very likely that the exposure to high temperature is responsible for these changes via alteration in the biasing conditions or trimming accuracy internal to the chip. In addition, past experience with similar and other devices demonstrated that functional changes exhibited by some electronic components under exposure to cryogenic temperatures were only temporary as full recovery occurred when the devices were heated up (usually to specified operating temperatures). Note well that in past experiments some components worked very well at cryogenic temperatures and were not affected by limited thermal cycling. As far as device packaging is concerned, the thermal cycling appeared to have no effect on the voltage reference chip as no structural deterioration or packaging damage was observed.

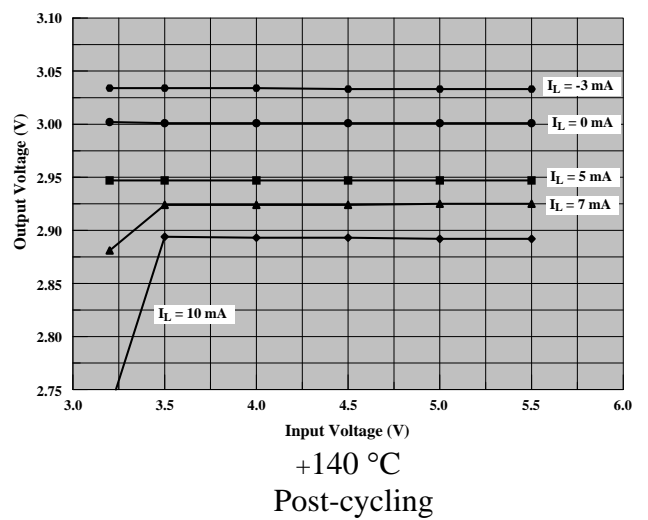
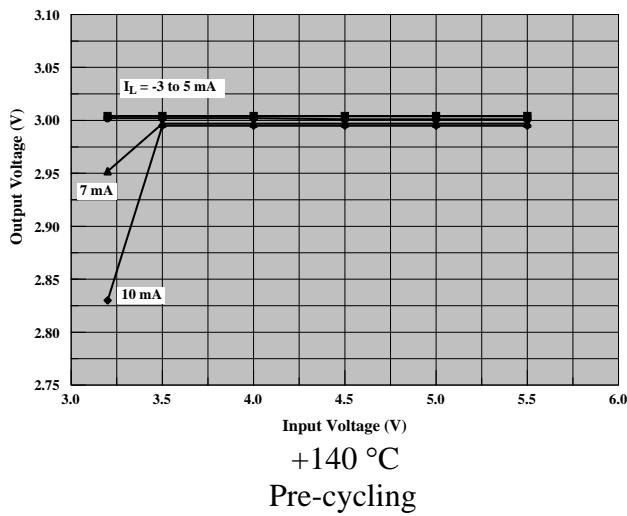
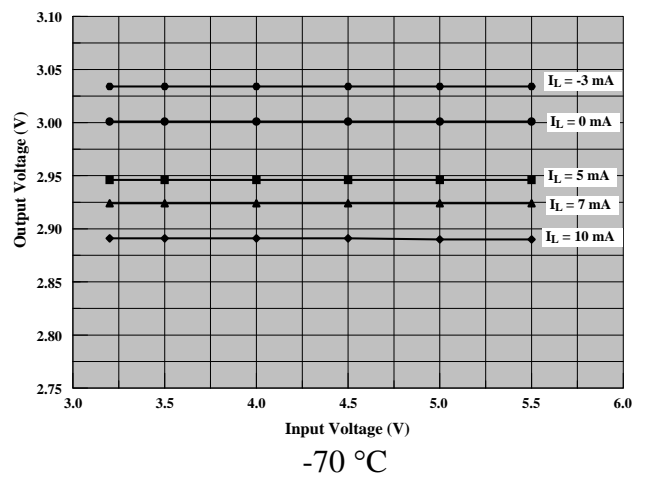
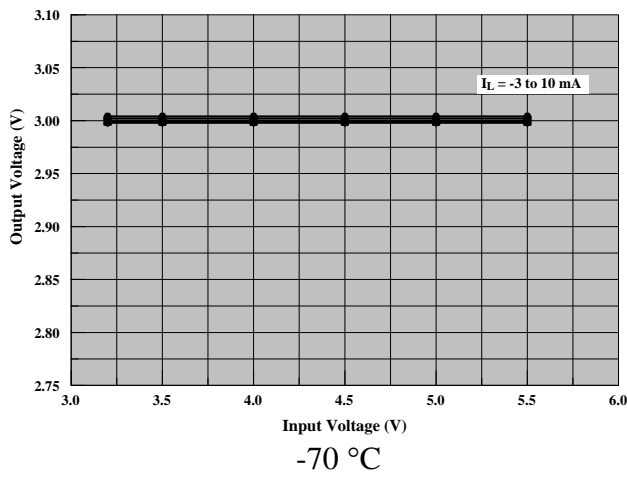
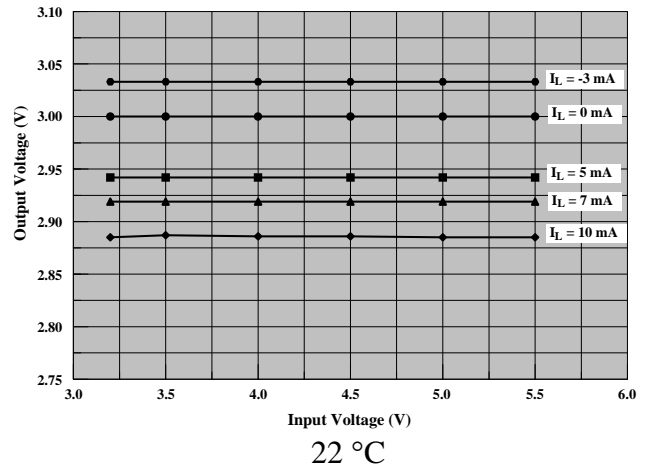
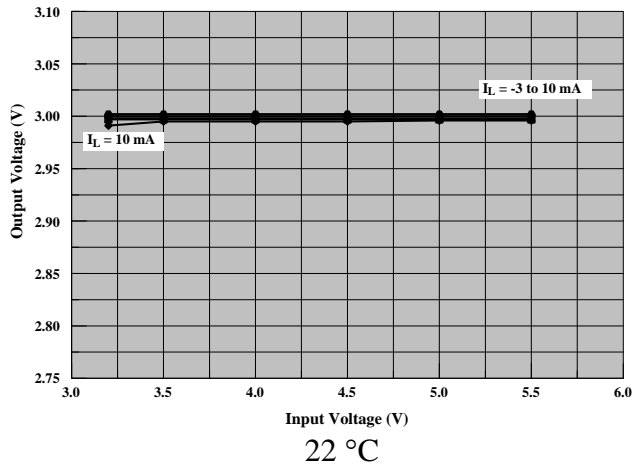


Figure 8. Comparison of voltage reference output versus input voltage at selected temperatures.

Conclusions

The performance of a micropower, high accuracy voltage reference chip was evaluated over a wide temperature range. The reference device, Analog Devices ADR3430, combine two voltages of opposite temperature coefficients to create an output voltage that is almost independent of ambient temperature. It is rated for the industrial temperature range of $-40\text{ }^{\circ}\text{C}$ to $+125\text{ }^{\circ}\text{C}$, and is ideal for use in low power precision data acquisition systems and in battery-powered devices. The device was investigated for potential operation under temperatures outside its specified range. The output of the voltage reference and its supply current were obtained as a function of temperature between $-100\text{ }^{\circ}\text{C}$ and $+140\text{ }^{\circ}\text{C}$. Line and load regulation characteristics were also established at five 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 by maintaining a steady value of about 3.000 V throughout the test temperature range between $-70\text{ }^{\circ}\text{C}$ and $+140\text{ }^{\circ}\text{C}$. At the extreme cryogenic temperature of $-100\text{ }^{\circ}\text{C}$, the output also maintained a constant value but at a slightly increased level of 3.007 V provided that the load was kept between 0 and 5 mA . At loads above 5 mA or at sink current of -3 mA , however, the output of the device exhibited instability when tested at this temperature. This instability was found to disappear as the test temperature was raised to $-75\text{ }^{\circ}\text{C}$. The quiescent supply current of the voltage reference varied slightly, in almost a linear fashion, with temperature but remained close to its specified value. In terms of line regulation, the device exhibited excellent stability between $-70\text{ }^{\circ}\text{C}$ and $+140\text{ }^{\circ}\text{C}$ at all load levels when an input voltage above 3.2 V was used. The reference chip also displayed outstanding performance in terms of load regulation at any temperature in the test range from $-70\text{ }^{\circ}\text{C}$ to $140\text{ }^{\circ}\text{C}$. At $-100\text{ }^{\circ}\text{C}$, the output voltage dropped in value when either a low input voltage of 3.2 V was used or a heavy load of 10 mA was applied. While the device was able to restart at either of the extreme temperatures of $-70\text{ }^{\circ}\text{C}$ and $+140\text{ }^{\circ}\text{C}$, the limited thermal cycling did influence its characteristics; particularly under heavy loads but without impacting its packaging. The changes in the performance of the device due to cycling are believed due to the elevated temperature exposure. Thus, while the operation of the device could be extended to temperature as low as $-70\text{ }^{\circ}\text{C}$, its high temperature operation should be limited to the specified upper limit boundary of $+125\text{ }^{\circ}\text{C}$. Additional testing would help in corroborating these results.

References

1. Analog Devices ADR3430, "Micropower, High Accuracy Voltage Reference," Datasheet Rev. B, 2010. www.analog.com

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