NASA Electronic Parts and Packaging Program

Evaluation of Silicon-On-Insulator HTOP-01 Operational Amplifier for Wide Temperature Operation

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Scope of Work

Electronics capable of operation under extreme temperatures are required in many of NASA space exploration missions. Aerospace and military applications, as well as some terrestrial industries constitute environments where electronic systems are anticipated to be exposed to extreme temperatures and wide-range thermal swings. Electronics that are able to withstand and operate efficiently in such harsh environments would simplify, if not eliminate, traditional thermal control elements and their associated structures for proper ambient operation. As a result, overall system mass would be reduced, design would be simplified, and reliability would be improved. Electronic parts that are built utilizing silicon-on-insulator (SOI) technology are known to offer better radiation-tolerance compared to their conventional silicon counterparts, provide faster switching, and consume less power. They also exhibit reduced leakage current and, thus, they are often tailored for high temperature operation. These attributes make SOI-based devices suitable for use in harsh environments where extreme temperatures and wide thermal swings are anticipated. A new operational amplifier, based on silicon-on-insulator technology and geared for high temperature well-logging applications, was recently introduced by Honeywell Corporation. This HTOP-01 dual precision operational amplifier is a low power device, operates on a single supply, and has an internal oscillator and an external clocking option [1]. It is rated for operation from -55 °C to +225 °C with a maximum output current capability of 50 mA. The amplifier chip is designed as a 14-pin, hermetically-sealed device in a ceramic package. Table I shows some of the device manufacturer’s specifications.

Table I. Specifications of HTOP-01 operational amplifier [1].

Parameter (Unit)	Value
Supply Voltage (V)	4.5 to 5
Supply Current (mA)	5
Output Current (mA)	20 to 50
Bandwidth (MHz)	2
Slew Rate (V/µs)	1.5
Temperature Range (°C)	-55 to +225
Package	DIL-14 ceramic
Part #	22028324-006
Lot #	28324-1C29

An amplifier circuit was constructed in an inverting unity gain configuration utilizing the HTOP-01 chip and a few passive components. Due to single supply operation of this amplifier, a dc offset voltage was fed into the non-inverting pin to allow for a full swing of the output signal. The circuit was evaluated in the temperature range between -190 °C and +200 °C in terms of signal gain, phase shift, and supply current. These properties were recorded at selected test temperatures in the frequency range of 1 kHz to 5 MHz. At each test temperature, the device was allowed to soak for 15 minutes before any measurements were made. Extreme-temperature re-start capability, i.e. power switched on while the device was at extreme temperatures, was also investigated. In addition, the effects of thermal cycling were determined using a wide-range operating temperature swing. The circuit was exposed to a total of 10 cycles between -190 °C and +200 °C at a temperature rate of 10 °C/minute. Following the thermal cycling, circuit measurements were then performed at +22, -190, and +200 °C.

Temperature Effects

The gain of the amplifier circuit at various test temperatures before thermal cycling is shown in Figure 1 over the frequency range of 1 kHz to 5 MHz. It can be seen that the gain of the amplifier was not affected by the test temperature until the test frequency of about 200 kHz was reached. Beyond that frequency, the gain exhibited some temperature dependency as reflected in changes in its magnitude and roll-off frequency. For example, while the roll-off frequency (-3 dB) was at about 1 MHz at room temperature, it increased slightly with increase in temperature, reaching about 1.5 MHz at the high temperature of +200 °C. Conversely, when exposed to low temperatures, the drop in the gain was more profound as seen in Figure 1. While the roll-off frequency decreased to about 700 kHz at -100 °C, it further decreased to reach about 350 kHz at the extreme cryogenic temperature of -190 °C. Although the circuit was tested at ten different test temperatures between -190 °C and +200 °C, only data obtained for five temperatures are reported as the omitted data (0, -50, -150, +50, and +150 °C) followed the same trend depicted in Figure 1. In terms of temperature, therefore, the amplifier circuit operated well in the temperature range between -190 °C and +200 °C; however, bandwidth did show a decrease with decreasing temperatures.

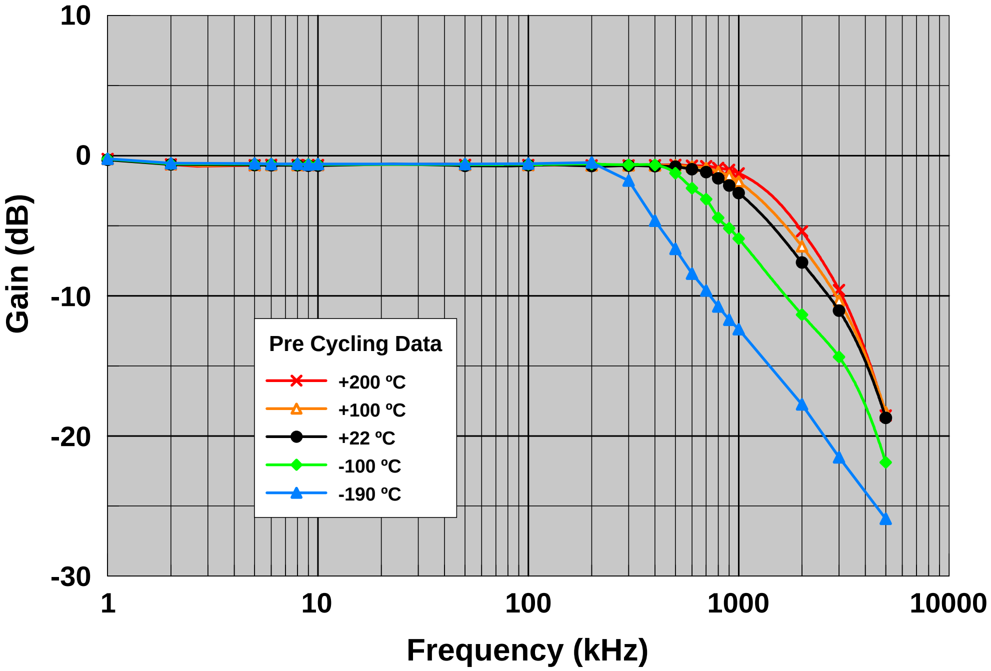


Figure 1. Gain versus frequency at various temperatures prior to thermal cycling.

Figure 2 depicts the phase shift of the amplifier as a function of temperature and frequency. Similar to the gain characteristics, at 200 kHz the phase began to change, most notably at the cryogenic test temperature of -190 °C.

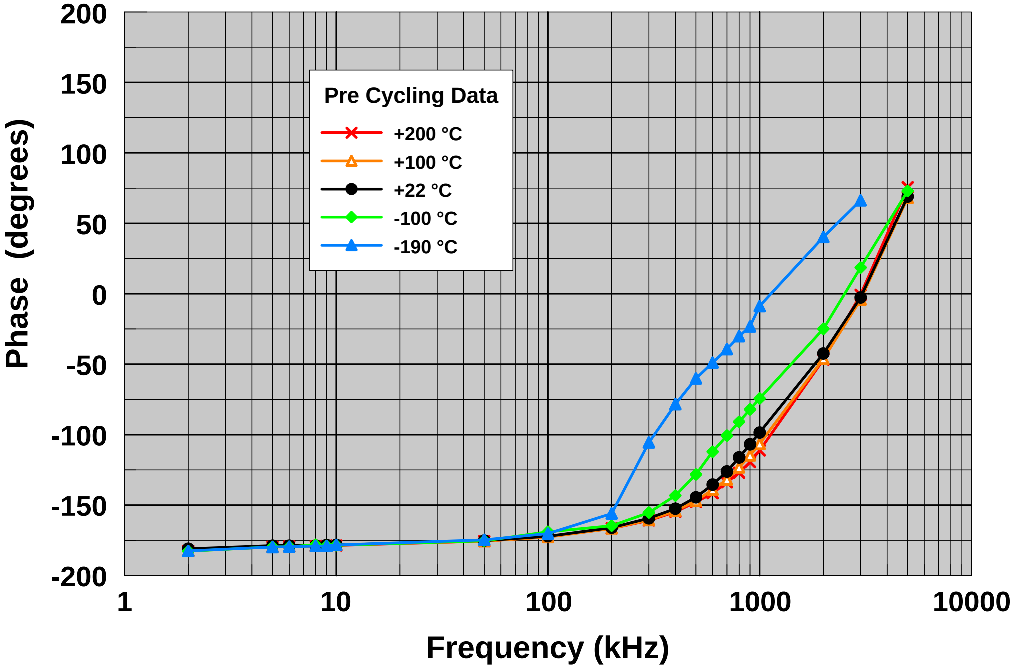


Figure 2. Phase shift versus frequency at various temperatures prior to thermal cycling.

The supply current of the circuit exhibited modest change with temperature as depicted in Figure 3. It can be seen that the amplifier supply current dropped from its room temperature value with decrease in test temperature, and it increased with increase in temperature. This variation in the supply current amounted from 1.55 mA at -190 °C to 3.85 mA at +200 °C. Although this change in the supply current amounted to more than a factor of two, its magnitude, nonetheless, remained within the specified level.

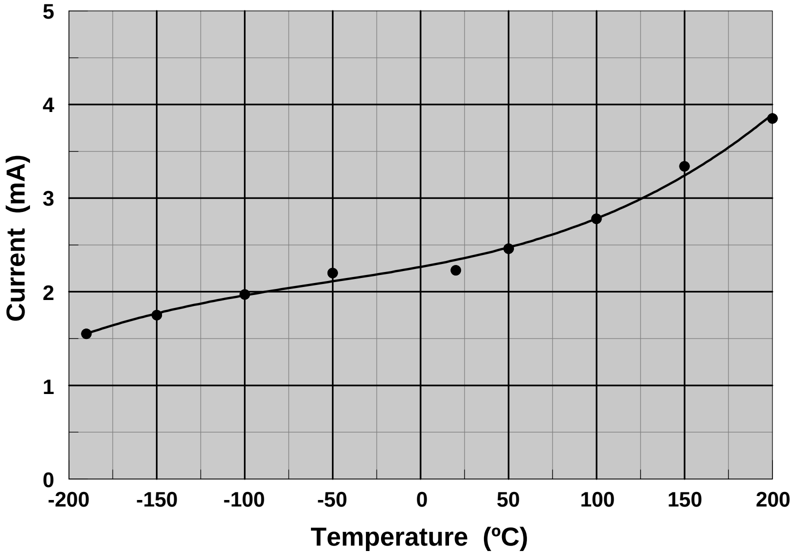


Figure 3. Circuit supply current as a function of temperature prior to thermal cycling.

Re-start Operation at Extreme Temperatures

Re-start capability of the HTOP-01 amplifier was investigated at both -190 °C and at +200 °C by allowing the circuit to soak at each of these temperatures for at least 20 minutes without the application of supply voltage or input signal. Power was then applied, and measurements were taken on the output characteristics. The amplifier circuit was able to successfully re-restart at either of the two extreme temperatures, and the results obtained were similar to those obtained earlier at the respective temperatures.

Effects of Thermal Cycling

The effects of wide-swing thermal cycling were investigated by subjecting the HTOP-01 device to a total of 10 cycles between -190 °C and +200 °C at a temperature change rate of 10 °C/minute. The amplifier gain obtained after the thermal cycling is shown in Figure 4 as a function of frequency at the selected test temperatures of +22, +200, and -190 °C. It can be seen that these results were very similar to those obtained prior to cycling as depicted in Figure 1, and thus, it can be concluded that the thermal cycling had no effect on the amplifier's gain. Similarly, the phase shift of the amplifier did not undergo much change with cycling, as shown in Figure 5. In addition to maintaining its electrical performance with cycling, the operational amplifier chip did not suffer any deterioration or damage in its packaging due to the limited thermal cycling.

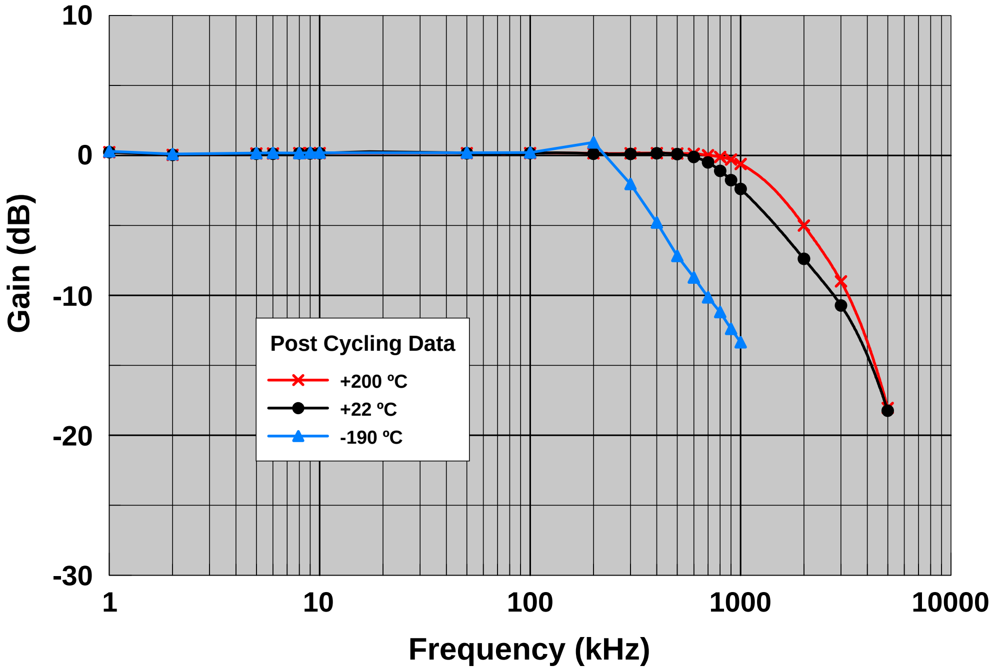


Figure 4. Gain versus frequency at various temperatures after thermal cycling.

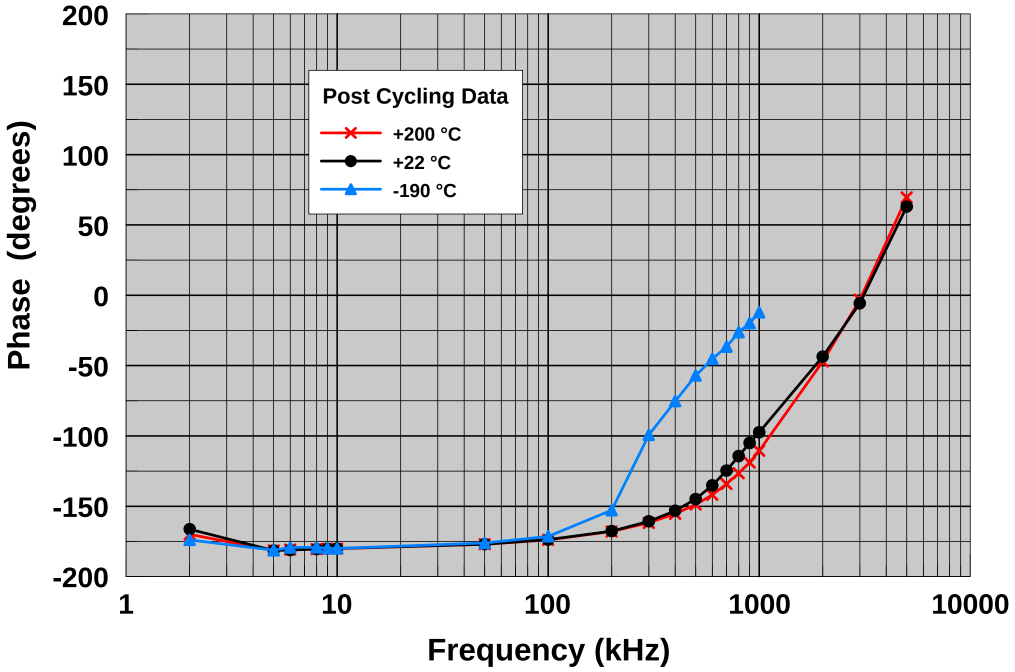


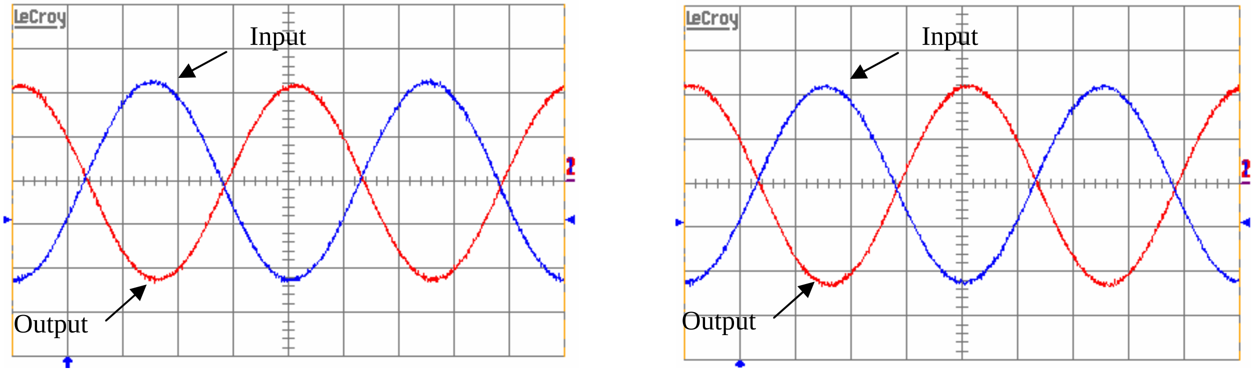
Figure 5. Phase shift versus frequency at various temperatures after thermal cycling.

The amplifier supply current was also recorded at various test frequencies and temperatures after thermal cycling. A comparison of these values obtained at the test temperatures of +22, +200, and -190 °C for pre- and post-cycling conditions are shown in Table II. The data reported are those obtained at 500 kHz frequency. Again, no major changes occurred in the supply current, at any given temperature, as a result of the thermal cycling.

Table II. Supply current at various temperatures for pre- and post-cycling conditions.

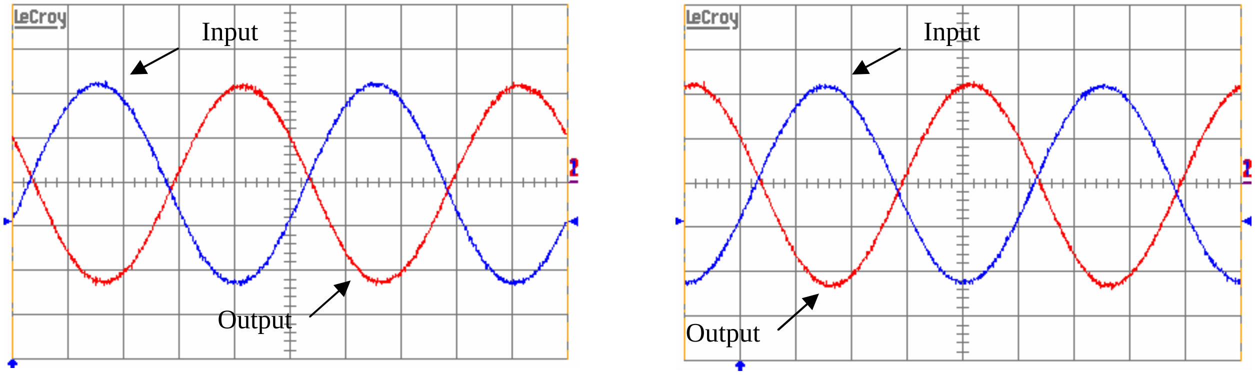
	Supply Current (mA)	
Temperature (°C)	**Pre-cycling**	**Post-cycling**
+200	3.85	3.72
+22	2.23	2.27
-190	1.55	1.54

Waveforms of the input and the output signals of the amplifier were captured at 22, -190, and +200 °C prior to and after the thermal cycling. These waveforms are depicted in Figures 6, 7, and 8 at the test frequency of 100 kHz, 500 kHz, and 1 MHz, respectively. Once again, these figures indicate that while the amplifier chip seemed to function properly at high temperatures, it underwent a drop in its gain at the test temperature of -190 °C only at very high frequencies, i.e. 500 kHz and beyond. In fact, the amplifier seemed to operate in a saturation mode as witnessed by clipping of the output signal under these conditions, and it occurred before as well as after subjecting it to the ten thermal cycles. The data presented in Figures 6 through 8 indicate, therefore, that this limited thermal cycling activity performed on the circuit had no influence on its operational characteristics.



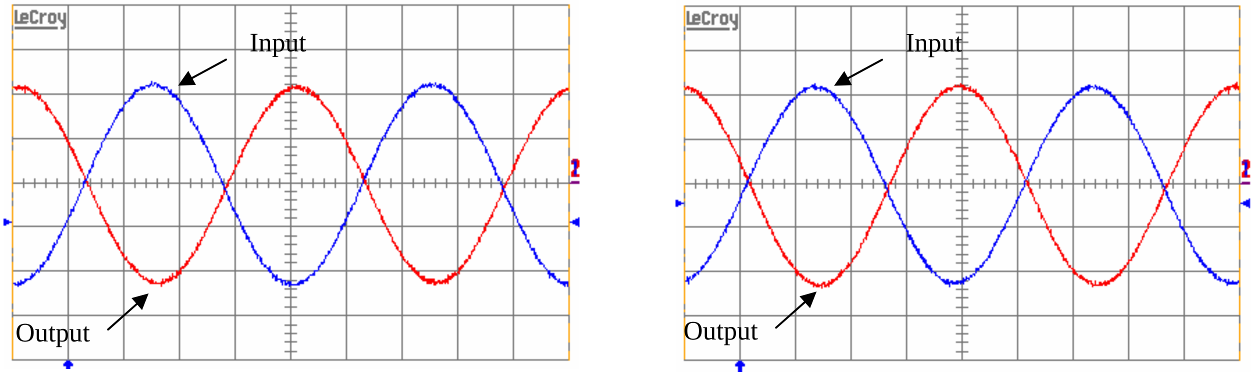
Pre 22 °C

Post 22 °C



Pre -190 °C

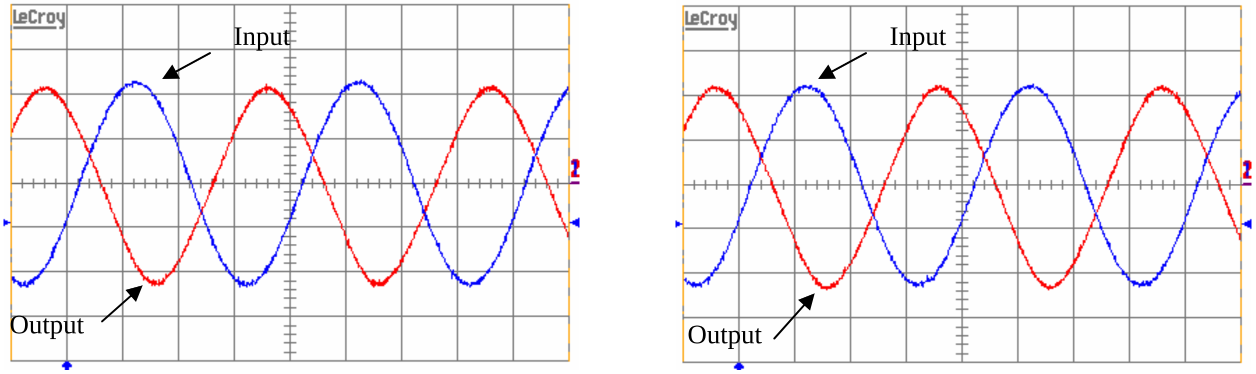
Post -190 °C



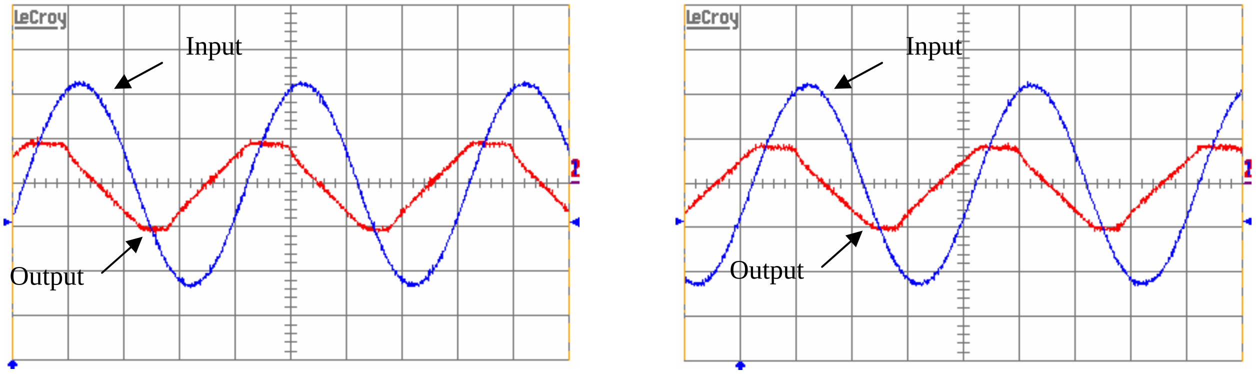
Pre +200 °C

Post +200 °C

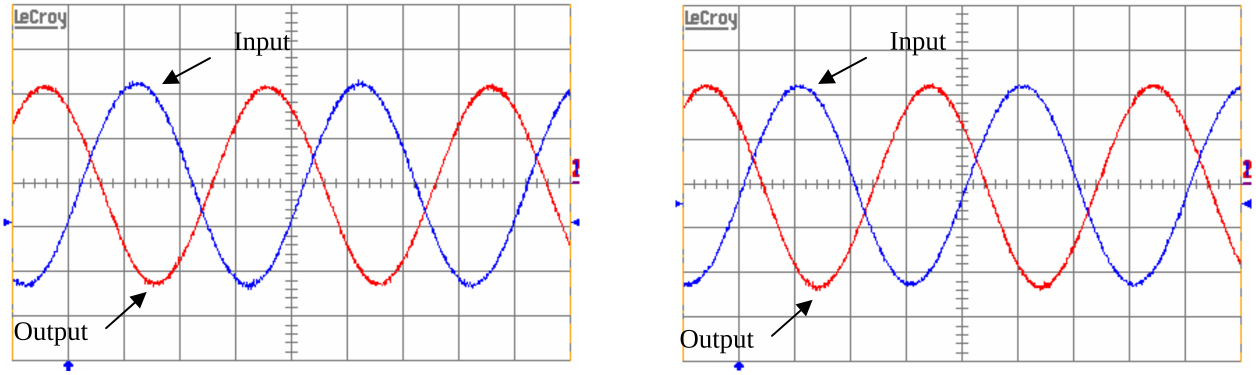
Fig 6. Input (blue) & output (red) waveforms at various temperatures at 100 kHz for pre- and post-cycling conditions. (Scale - Vertical: 200mV/div; Horizontal: 2μs/div).



Pre 22 °C Post 22 °C

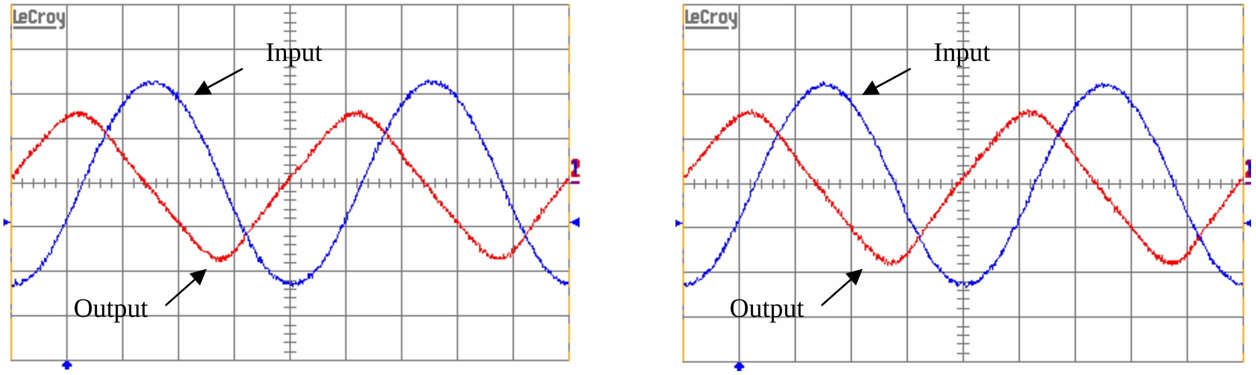


Pre -190 °C Post -190 °C



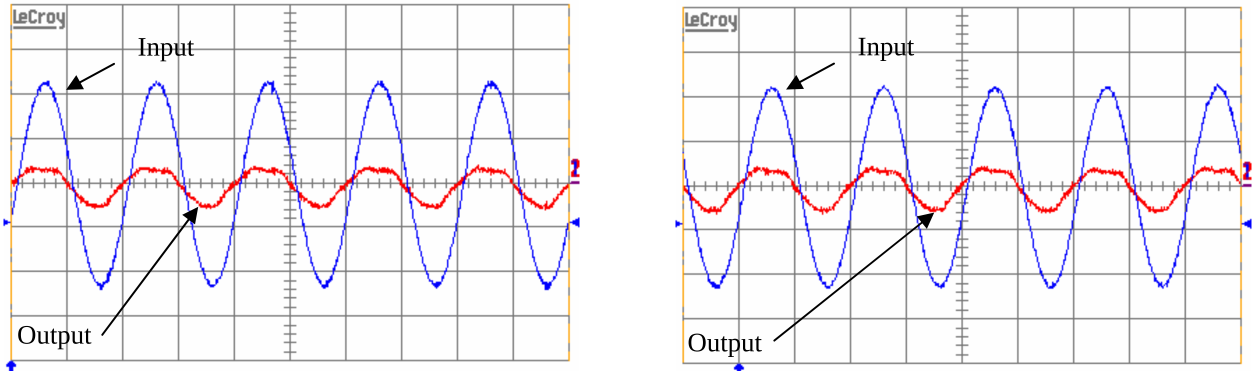
Pre +200 °C Post +200 °C

Fig 7. Input (blue) & output (red) waveforms at various temperatures at 500 kHz for pre- and post-cycling conditions. (Scale - Vertical: 200mV/div; Horizontal: 0.5μs/div).



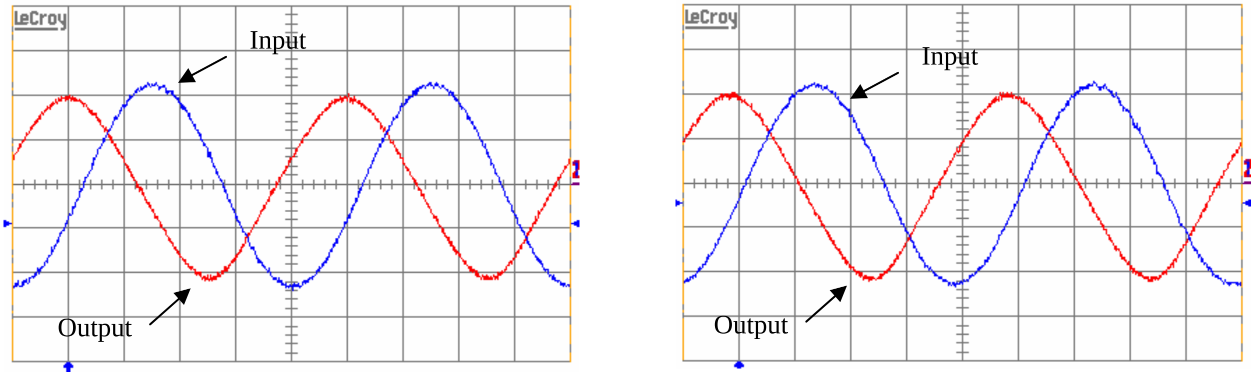
Pre 22 °C

Post 22 °C



Pre -190 °C

Post -190 °C



Pre +200 °C

Post +200 °C

Fig 8. Input (blue) & output (red) waveforms at 1 MHz for pre- and post-cycling conditions.
(Scale - Vertical: 200mV/div for all; Horizontal: 0.2μs/div for 22 and +200 °C, and 0.5μs/div for -190 °C).

Conclusions

A new silicon-on-insulator operational amplifier was evaluated for potential use in space exploration missions under extreme temperature environments. This Honeywell HTOP-01 device is a low power, precision operational amplifier with very low input offset voltage and drift over specified operating temperature between -55 °C and +225 °C. A unity gain inverting circuit was constructed utilizing the HTOP-01 chip and a few passive components. The circuit was evaluated in the temperature range from -190 °C to +200 °C in terms of signal gain and phase shift, and supply current. Re-restart capability at the extreme temperatures of -190 °C and +200 °C was also investigated. In addition, the effects of thermal cycling under a wide temperature range on the operation of this high performance amplifier were determined. The results from this work indicate that this silicon-on-insulator amplifier chip maintained, in general, very good operation throughout the test temperature range. At -190 °C and at high frequencies (> 400 kHz), however, the amplifier began to exhibit reduction in its gain. The limited thermal cycling had no effect on the performance of the amplifier, and the circuit was able to re-start at both -190 °C and +200 °C. In addition, no physical degradation or packaging damage was introduced due to either extreme temperature exposure or thermal cycling. These preliminary results suggest that this silicon-on-insulator operational amplifier can be used over a wide temperature range, but its gain-bandwidth product would be reduced at high frequencies under very low temperature exposure.

References

1. Honeywell International Inc., “High Temperature Dual Precision Operational Amplifier HTOP-01,” Data Sheet, Form #900334, January 2008.

Acknowledgments

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