

**Performance of High Temperature Operational Amplifier,
Type LM2904WH, Under Extreme Temperatures**

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Scope of Work

Operation of electronic parts and circuits under extreme temperatures is anticipated in NASA space exploration missions as well as terrestrial applications. Exposure of electronics to extreme temperatures and wide-range thermal swings greatly affects their performance via induced changes in the semiconductor material properties, packaging and interconnects, or due to incompatibility issues between interfaces that result from thermal expansion/contraction mismatch. Electronics that are designed to withstand operation and perform efficiently in extreme temperatures would mitigate risks for failure due to thermal stresses and, therefore, improve system reliability. In addition, they contribute to reducing system size and weight, simplifying its design, and reducing development cost through the elimination of otherwise required thermal control elements for proper ambient operation. A large DC voltage gain (100 dB) operational amplifier with a maximum junction temperature of 150 °C was recently introduced by STMicroelectronics [1]. This LM2904WH chip comes in a plastic package and is designed specifically for automotive and industrial control systems. It operates from a single power supply over a wide range of voltages, and it consists of two independent, high gain, internally frequency compensated operational amplifiers. Table I shows some of the device manufacturer's specifications.

Table I. Specifications of LM2904WH operational amplifier [1].

Parameter (Unit)	Value
Supply Voltage (V)	3 to 30
Supply Current (mA)	0.7 to 1.2
Output Current (mA)	20
Bandwidth (MHz)	1.1
Slew Rate (V/ μ s)	0.6
Temperature Range (°C)	-40 to +150
Package	SO-8 plastic
Part #	2904WHDT
Lot #	9341

An amplifier circuit configured in a unity gain, inverting configuration was constructed utilizing the LM2904WH 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 -195 °C and +190 °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 10 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. A total of three amplification circuits were constructed using three separate LM2904WH chips. All three circuits performed similarly with temperature and, therefore, data pertaining to only one of them is presented.

Temperature Effects

The gain of the amplifier circuit at various test temperatures in the frequency range of 1 kHz to 10 MHz is shown in Figure 1. At any given temperature, the amplifier did not experience any significant change in its gain as the frequency was varied from DC to about 100 kHz. Beyond that frequency, however, the gain displayed some dependency on the test temperature; in particular at the extreme levels. For example, while the amplifier retained its unity gain up to the test frequency of 300 kHz within the temperature range of $-100\text{ }^{\circ}\text{C}$ to $+150\text{ }^{\circ}\text{C}$, the gain started to exhibit a decrease in its magnitude outside this temperature range as soon as the test frequency exceeded 100 kHz. In addition, while the roll-off frequency (-3 dB gain) at the intermediate test temperatures occurred in the vicinity of 5 kHz, it decreased to 2 kHz and 1.5 kHz at the test temperature of $+190\text{ }^{\circ}\text{C}$ and $-150\text{ }^{\circ}\text{C}$, respectively, as shown in Figure 1. At very high frequencies, i.e. above 2 MHz, the gain became unappreciable. It is important to note that although the test temperature ranged between $-195\text{ }^{\circ}\text{C}$ and $+190\text{ }^{\circ}\text{C}$, data obtained at cryogenic temperatures were reported only to $-150\text{ }^{\circ}\text{C}$. At lower temperatures, the amplifier circuit maintained operation, however, the output began to display instability in both magnitude and wave shape. Waveforms of the input and the output signals of the amplifier captured at 22, $+190$, and $-155\text{ }^{\circ}\text{C}$ at the selected frequencies of 100 kHz and 500 kHz are shown in Figure 2.

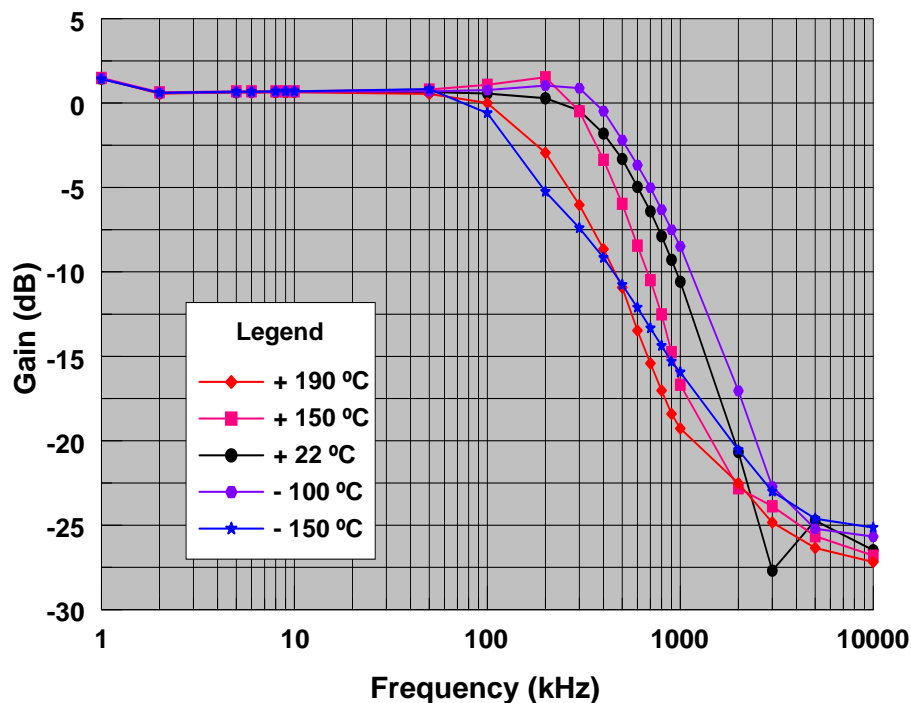
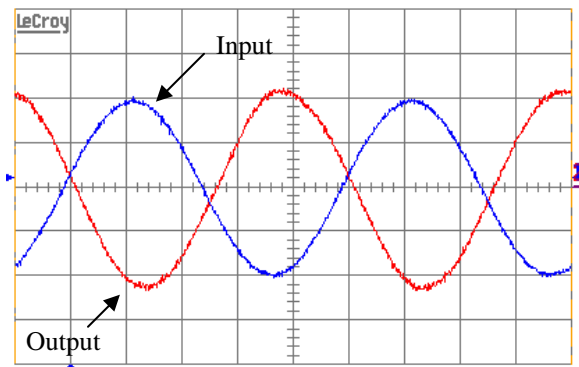
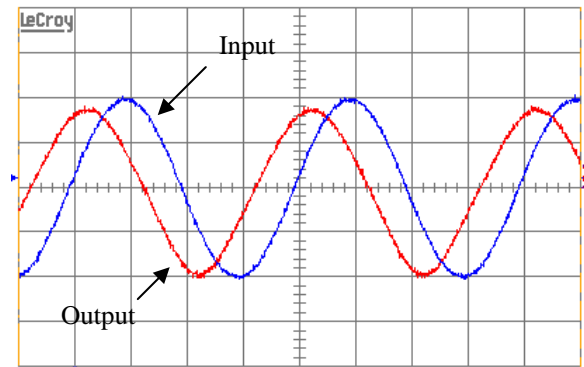


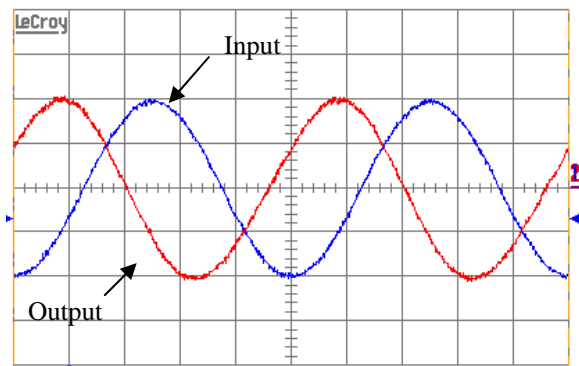
Figure 1. Gain versus frequency at various temperatures



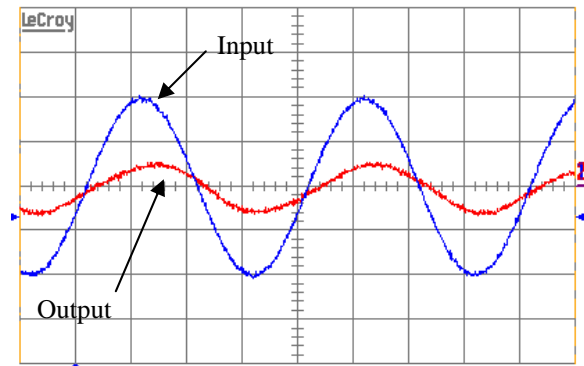
Temp: 22 °C, Freq: 100 kHz
(Vert: 100mV/div; Horiz: 2 μ s/div)



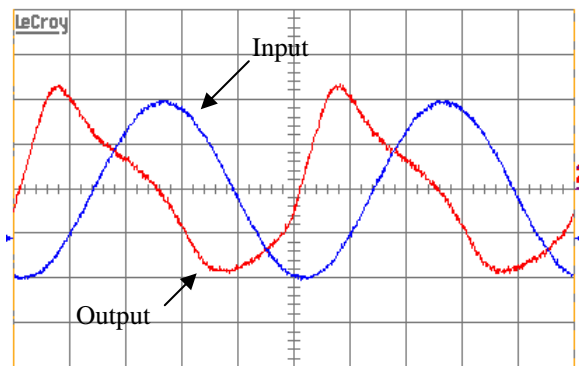
Temp: 22 °C, Freq: 500 kHz
(Vert: 100mV/div; Horiz: 0.5 μ s/div)



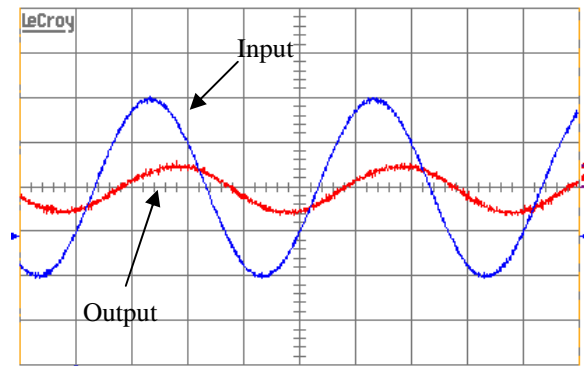
Temp: +190 °C, Freq: 100 kHz
(Vert: 100mV/div; Horiz: 2 μ s/div)



Temp: +190 °C, Freq: 500 kHz
(Vert: 100mV/div; Horiz: 0.5 μ s/div)



Temp: -155 °C, Freq: 100 kHz
(Vert: 100mV/div; Horiz: 2 μ s/div)



Temp: -155 °C, Freq: 500 kHz
(Vert: 100mV/div; Horiz: 0.5 μ s/div)

Fig 2. Input and output waveforms of LM2904WH amplifier at 22, +190, and -155 °C for test frequency of 100 kHz and 500 kHz

Figure 3 depicts the phase between the input and the output signals of the amplifier as a function of temperature and frequency. Similar to the gain characteristics, changes in the phase began to appear at about 100 kHz, most notably at the extreme cryogenic and high temperatures.

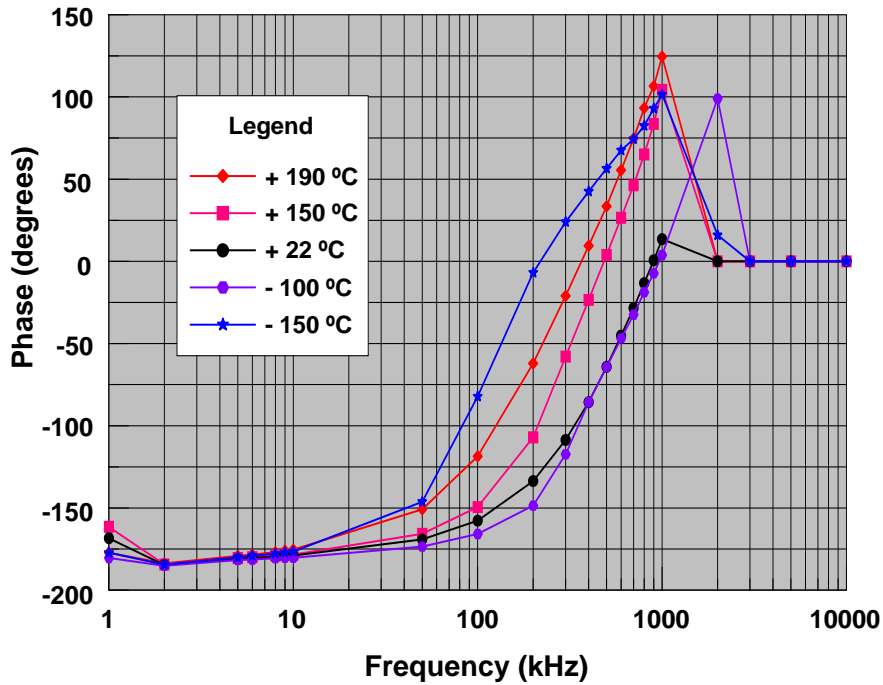


Figure 3. Phase versus frequency at various temperatures

The supply current of the circuit exhibited modest change with temperature as depicted in Figure 4. It can be seen that the amplifier supply current underwent a decrease as the test temperature approached either extreme; i.e. hot or cold. This variation in the supply current was insignificant and remained within the device specified level.

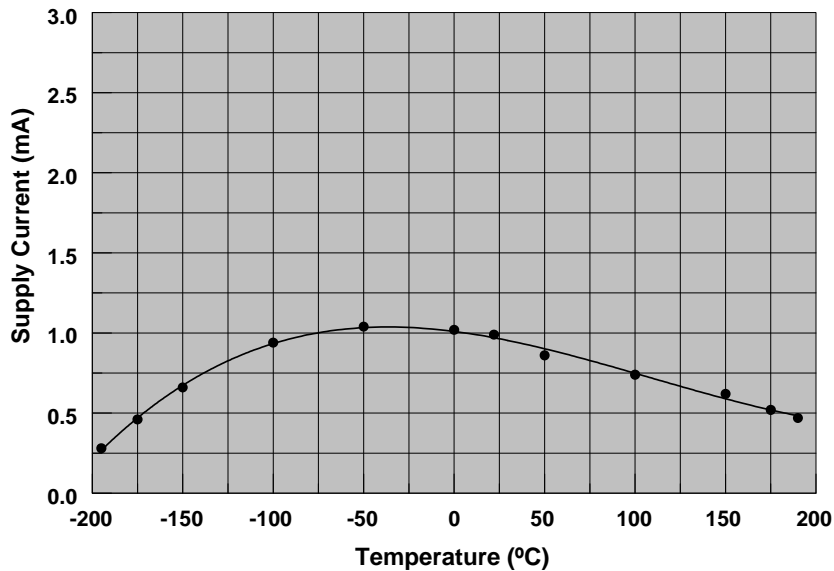


Figure 4. Circuit supply current as a function of temperature

Re-start Operation at Extreme Temperatures

Re-start capability of the LM2904WH amplifier was investigated at both -150 °C and at +190 °C by allowing the circuit to soak at these temperatures without the application of supply voltage or input signal. Hibernation time with no power at each of these extreme temperatures was 2 hours. 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.

Conclusions

A large DC voltage gain (100 dB) operational amplifier with a maximum junction temperature of 150 °C was evaluated at extreme temperatures beyond its specified operating range of -40 °C to +150 °C. This LM2904WH chip, which comes in a plastic package designed for automotive and industrial control systems, was evaluated in a unity gain inverting circuit configuration in the temperature range from -195 °C to +190 °C in terms of signal gain and phase shift, and supply current. Re-restart capability at extreme hot and cold temperatures was also investigated. The results from this work indicate that this silicon amplifier chip maintained, in general, very good operation in temperature range of +190 °C to about -150 °C. As the test temperature was decreased further, however, the amplifier began to exhibit some instability in its output characteristics. Nevertheless, this amplifier demonstrated satisfactorily in an extended temperature range that exceeded its rating, and the chip was able to re-start at both -150 °C and at +190 °C after being soaked for at least two hours at either extreme temperature. In addition, no physical degradation or packaging damage was introduced due to either extreme temperature exposure. These preliminary results suggest that this operational amplifier may have the potential for use over a wide temperature range in space exploration missions but its performance and reliability under long term temperature exposure need to be established through additional and more comprehensive testing.

References

1. STMicroelectronics Inc., “LM2904WH Low Power Dual Operational Amplifier” Data Sheet, Rev 6, April 2008.

Acknowledgments

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