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Performance Evaluation of Isolated Gate Driver, ADuM4121, Under Exposure to Extreme Temperature

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Scope

Electronics designed for use in space missions are expected to be exposed to harsh environmental conditions, including radiation and extreme temperatures. Severe thermal swings are also encountered depending on planetary environment, orbital orientation, and mission duration. Most commercial-off-the-shelf (COTS) devices are not designed to function under such extreme conditions and very little data exist on their performance outside their specified range of operation. In this work, the performance of an isolated gate driver for controlling power-level transistors, including gallium nitride (GaN) and silicon carbide (SiC) devices, was evaluated under extreme temperatures and thermal cycling. The investigations were carried out to assess performance for potential use of this device in space exploration missions under extreme temperature conditions.

Test Procedure

The device investigated in this work is comprised of a high voltage, isolated gate driver with an internal clamp to minimize Miller capacitance-induced turn on [1]. The ADuM4121ARIZ is a 2A single channel driver that utilizes monolithic transformer technology for galvanic isolation between the input and the output. The device features under-voltage lockout and is rated for operation in the temperature range of -40°C to +125°C [1]. Table I shows some of the device manufacturer's specifications. The operation of the gate driver was investigated over a wide temperature regime that extended beyond its specified range. The driver chip was characterized in terms of its output signal, turn-on (t_{DLH}) and turn-off (t_{DHL}) propagation delay times, output's rise (t_R) and fall times (t_F), and supply current. These parametric evaluations were performed at different frequency and supply voltage levels. Propagation switching delay parameters are shown in Figure 1 [1]. The operational characteristics of the drive circuit were obtained, using a 3.0 V, square-wave logic input at various frequencies (1 kHz, 10 kHz, 50 kHz, 100 kHz, 500 kHz, and 1 MHz). These tests, which were carried out over the test temperature range between -190 °C and +140°C using a liquid nitrogen-cooled environmental chamber, utilized supply voltage of 10, 15, or 20 Volts. A temperature rate of change of 10 °C per minute was used, and a soak time of at least 20 minutes was allowed at every test temperature. Restart capability at extreme temperatures, i.e. power switched on while the device was soaking at the test temperature of either +140°C or -190°C, was also investigated. In addition, the effects of limited thermal cycling on the operation of the driver were determined by exposing it to 100 cycles between -190°C and +140°C at a temperature rate of 20°C/minute. Following cycling, circuit measurements were then performed at the test temperatures of +20, -190, and +140°C. Figure 2 shows the gate driver chip along with bypass capacitors mounted on a circuit board that was placed inside the environmental chamber during the tests.

Table I. Specifications of ADuM4121ARIZ Gate Driver [1]

Parameter	**Symbol**	
Supply Input Voltage (V)	V_{DD1}	2.5 - 6.5
High Side Input Voltage (V)	V_{DD2}	4.5 - 35
V_{DD1} Input Current (mA)	I_{DD1}	3.6
V_{DD2} Input Current (mA), quiescent	I_{DD2}	2.3 – 2.7
Output Current, max (A)	I_O	2.3
Operating Temperature (°C)	T(oper)	-40 to +125
Turn-on Propagation Delay (ns)	t_{DLH}	22 - 42
Turn-off Propagation Delay (ns)	t_{DHL}	30 - 53
Output Rise Time (ns)	t_R	11 - 26
Output Fall Time (ns)	t_F	11 - 26
Part #		ADuM4121ARIZ
Package		Wide-body, 8-lead SOIC
Lot Code		1843

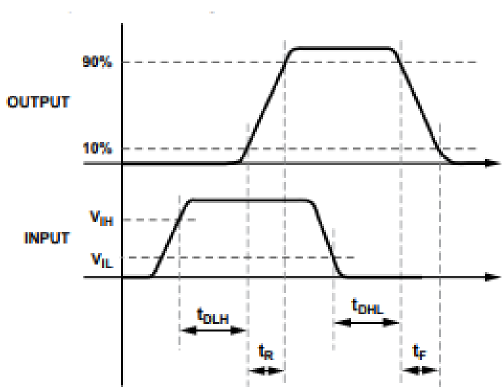


Figure 1. Propagation Delay Parameters [1]

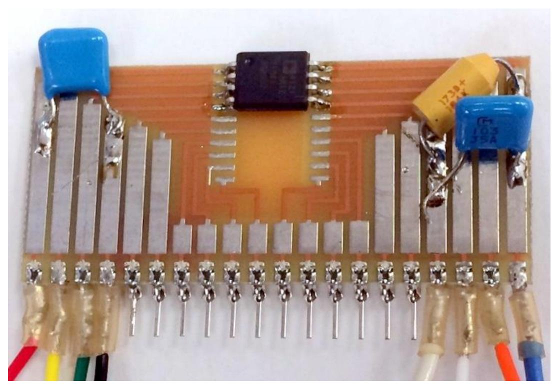


Figure 2. ADuM4121 Gate Driver Chip with Capacitors Mounted on Test Board

Test Results

Two gate drivers were examined in this investigation. The results revealed similar trends in their performance with temperature. Therefore, data pertaining to only one device is presented.

Temperature Effects

Waveforms of the ADuM4121ARIZ input, output, and clamp signal recorded at 10 kHz frequency and a 15 V supply at room temperature are shown in Figure 3. The operation of the circuit was examined, as mentioned earlier, over a wide temperature range where signal waveforms, amongst other parameters, were obtained at the test points of +140, +125, +100, +50, +20, 0, -25, -50, -75, -100, -150, -175, and -190°C. While the circuit survived the extreme temperature exposure, its operation underwent mild irregularities at the test frequencies of 1 kHz and at 1 MHz. The anomalies observed at the low frequency consisted of fluctuations in the supply current I_{DD1} only when a supply voltage of 10 V was applied. However, upon increasing the test frequency or using a higher supply voltage, e.g. 15 or 20V at 1 kHz, I_{DD1} regained its stability. The other variance experienced by the chip was a significant increase in the high voltage supply current I_{DD2} at the highest test frequency of 1MHz. The increase in the latter was more pronounced at cryogenic temperatures. Other than these fluctuations, no major changes were registered in the shape or magnitude of the chip's output and clamp signals throughout the range of -190 °C to +140 °C. For illustrative purposes, only waveforms obtained at room temperature and at the extreme temperatures of -190 °C and +140 °C are reported and shown in Figures 3-5, respectively. These signals were obtained at the test conditions of 15 V supply and 10 kHz frequency.

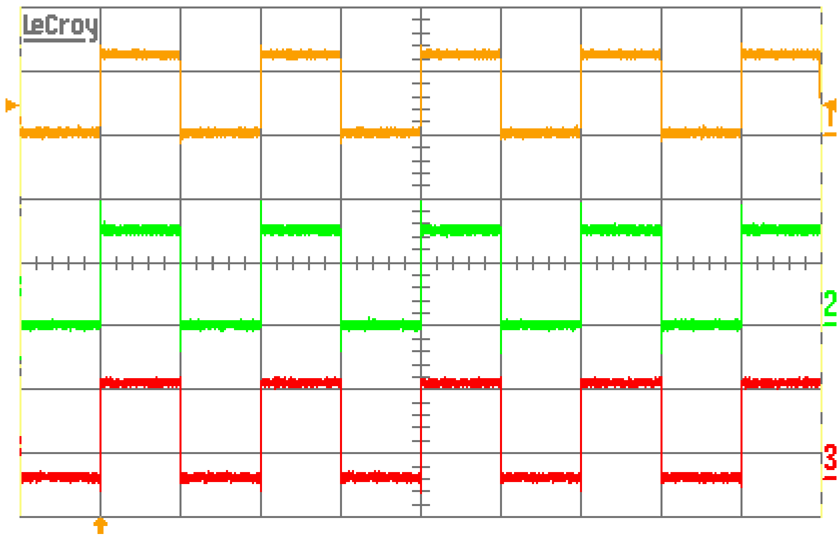


Figure 3. Input (Trace 1), Output (Trace 2), and Clamp (Trace 3) Signals at +20°C (Scale: Vertical 5V/div (1), 10V/div (2 &3); Horizontal 50µs/div)

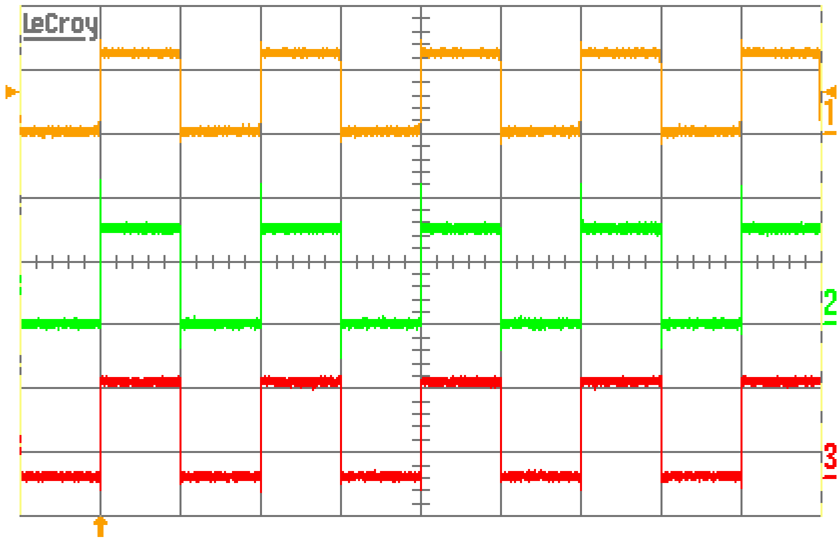


Figure 4. Input (Trace 1), Output (Trace 2), and Clamp (Trace 3) Signals at -190°C

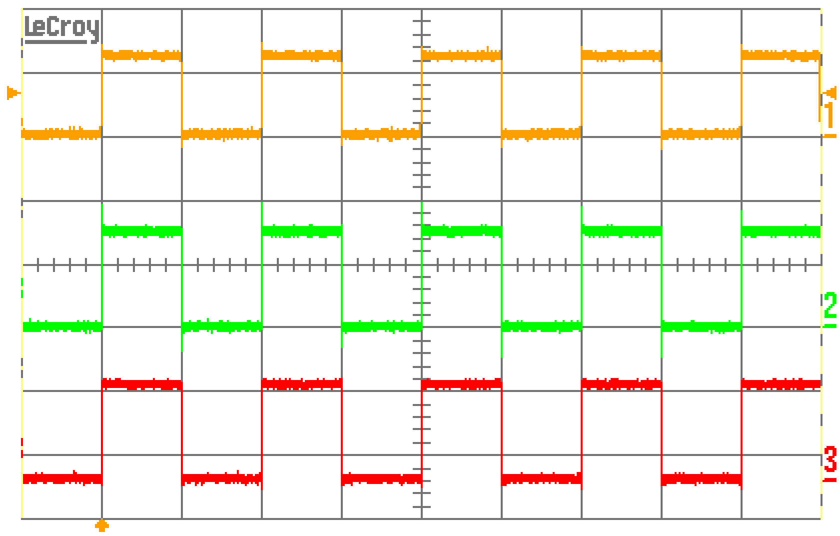


Figure 5. Input (Trace 1), Output (Trace 2), and Clamp (Trace 3) Signals at +140°C

Figure 6 shows the turn-on (t_{DLH}) and turn-off (t_{DHL}) propagation delay times of the gate driver as a function of temperature. A similar trend was observed in these attributes with a change in temperature as they exhibited a gradual decrease as the test conditions varied from +140°C to -190°C. This decrease was trivial, however, at cryogenic temperatures.

The rise and fall times of the output signal of the gate driver are shown in Figure 7 as a function of temperature. Both parameters experienced insignificant changes with variation in the test temperature.

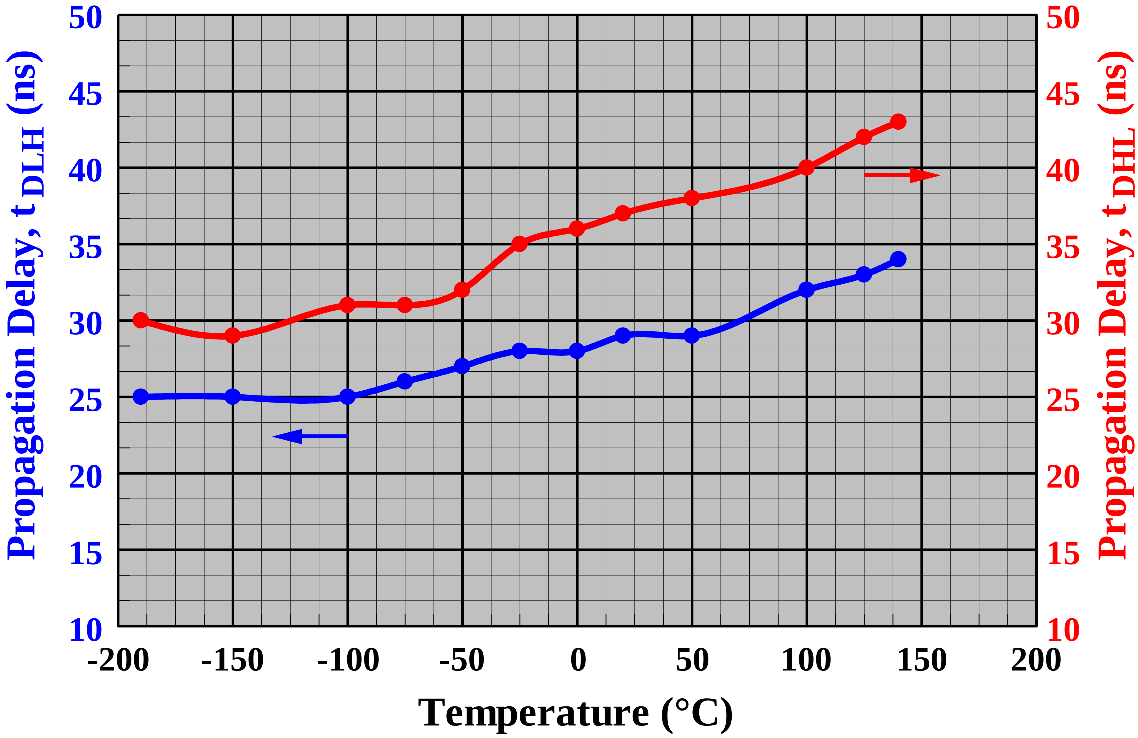


Figure 6. Turn-on and Turn-off Propagation Delays as a Function of Temperature

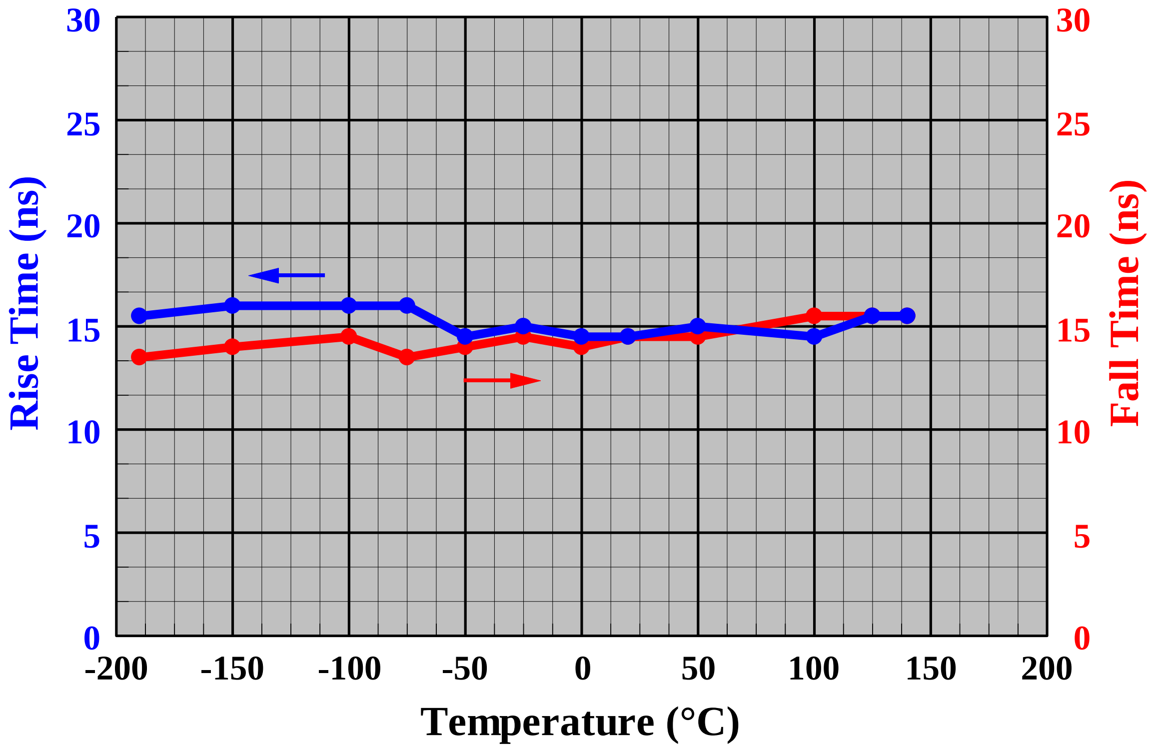


Figure 7. Rise and Fall Times of Gate Drive Output Signal versus Temperature

The supply current of the ADuM4121ARIZ gate driver did not show much dependency on either the test frequency or the supply voltage. It did, however, experience an increase in its magnitude with increase in test temperature, as shown in Figure 8. For example, the current almost doubled its value when the temperature varied from -190°C to +140°C.

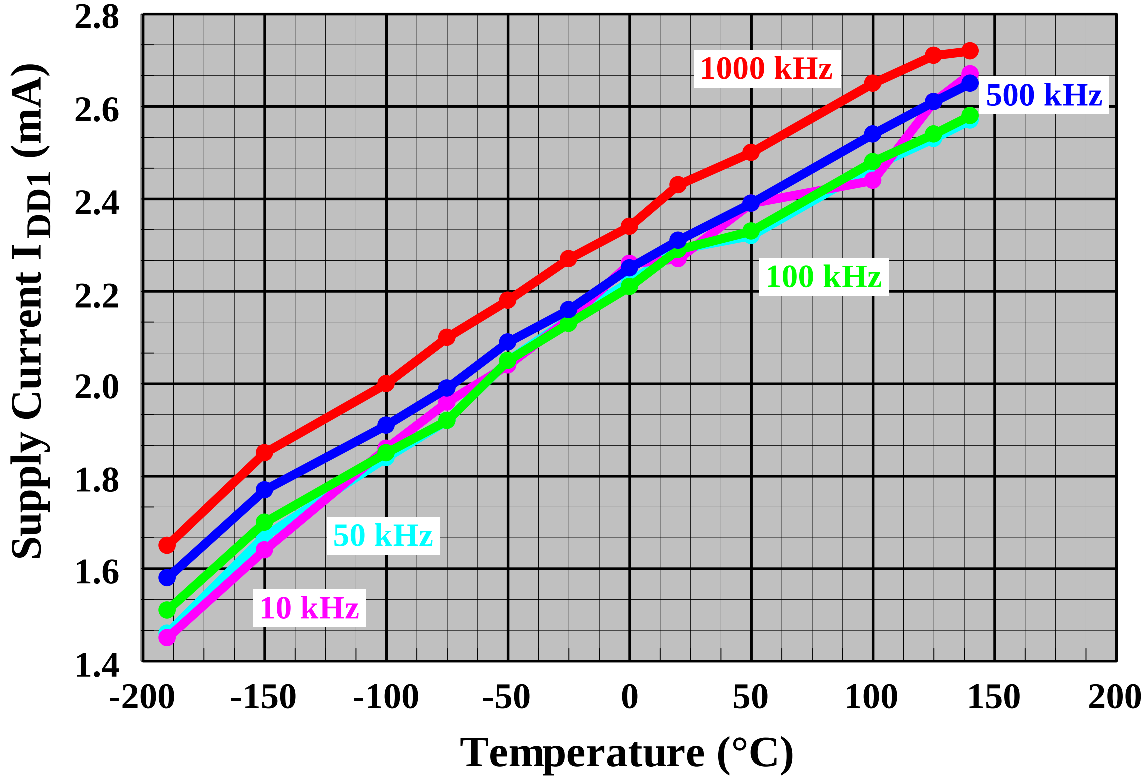


Figure 8. Supply Current versus Test Temperature at Various Frequencies

Restart at Extreme Temperatures

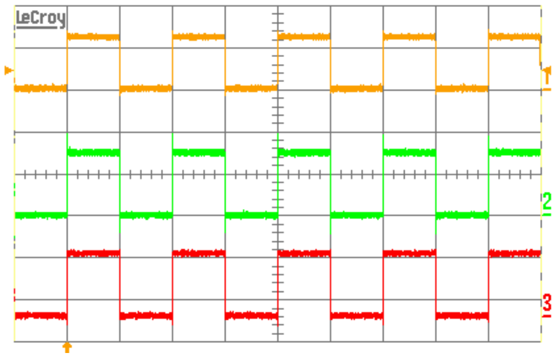
Restart capability of the ADuM4121ARIZ gate driver chip at extreme temperatures was also investigated by allowing the device to soak for at least 30 minutes at each of the test temperatures of -190 °C and +140 °C without electrical bias. Power was then applied to the circuit and measurements were taken on the output characteristics. The driver chip 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

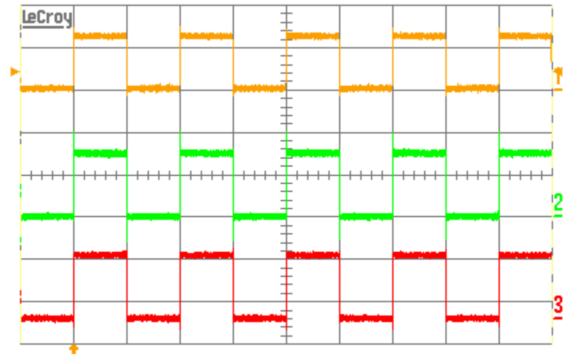
The effects of thermal cycling under a wide temperature range on the operation of the ADuM4121ARIZ gate driver chip were investigated by subjecting it to 100 cycles between -190°C and +140°C at a temperature rate of 20 °C/minute. A dwell time of 15 minutes was applied at the extreme temperatures. Following cycling, measurements of the investigated parameters were taken again as a function of temperature. A comparison of the gate driver’s input, output, and clamp signals at the selected test temperatures of +20ºC, -190ºC, and +140°C for pre- and post-cycling conditions are shown in Figure 9. Again, these waveforms were recorded at a 10 kHz frequency using a 15 V supply voltage. It can be clearly seen that the post-cycling signal waveforms at any given test temperature were the same as those obtained prior to cycling. Similarly, no significant changes were registered between the pre- and post-cycling values of the circuit's propagation delay times, rise and fall times, and the supply current, as depicted in Table II at the selected three test temperatures. The data listed in Table II pertain to selected test conditions of 15 V supply and an input frequency of 10 kHz. Based on this preliminary investigation, it can be concluded that the extreme temperature exposure as well as thermal cycling did not induce much change in the behavior of this gate driver integrated circuit chip. This thermal cycling also appeared to have no effect on the structural integrity of this device as no structural deterioration or packaging damage was observed.

Table II. Pre- and Post-cycling Propagation Delays, Switching Times, and Supply Current at 15 V Supply Voltage and 10 kHz Input Frequency.

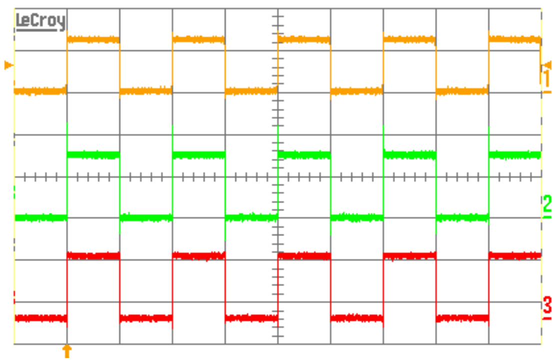
	Turn-on Propagation Delay, t_{DLH} (ns)		**Turn-off Propagation Delay, t_{DHL} (ns)**		**Rise Time, t_r (ns)**		**Fall Time t_f (ns)**		**Supply Current (mA)**	
T (°C)	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
+20	29	28	37	36	14.0	14.50	14.5	14.0	2.27	2.30
-190	25	25	30	30	15.5	17.5	13.5	15.5	1.45	1.50
+140	34	33	43	43	15.5	15.5	15.5	16.0	2.67	2.66



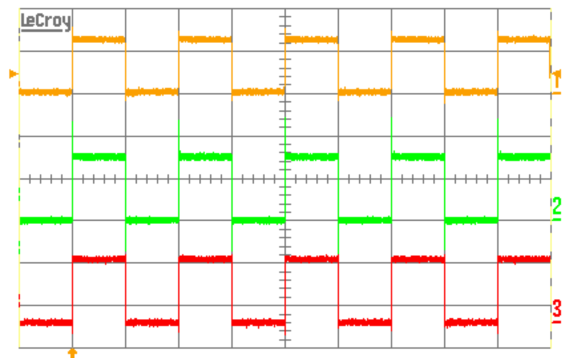
Pre-cycling @ 20 °C



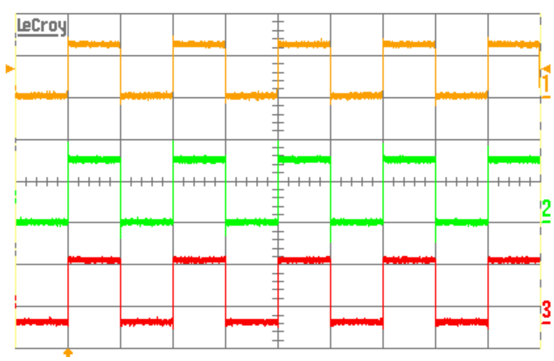
Post-cycling @ 20 °C



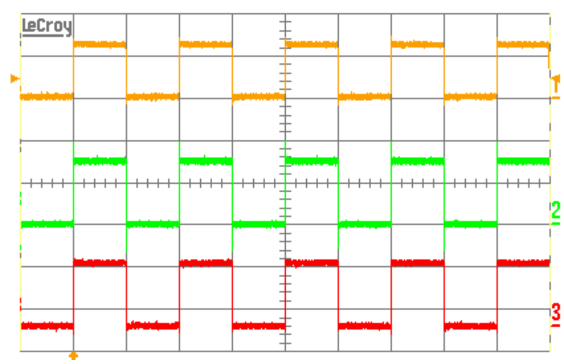
Pre-cycling @ -190 °C



Post-cycling -190 °C



Pre-cycling @ +140 °C



Post-cycling @ +140 °C

Figure 9. Pre- and Post-cycling Waveforms of Input (Trace 1), Output (Trace 2), and Clamp (Trace 3) Signals of ADuM4121ARIZ Isolated Gate Driver at Selected Temperatures. (Scale: Vertical 5V/div (1), 10V/div (2 &3); Horizontal 50µs/div)

Conclusions

The performance of an isolated gate driver for controlling power-level transistors, including gallium nitride (GaN) and silicon carbide (SiC) devices, was evaluated under extreme temperatures and thermal cycling to determine suitability for use in space exploration missions. The high voltage gate driver, ADuM4121ARIZ, utilizes built-in monolithic transformer technology for galvanic isolation and has an internal clamp to minimize Miller capacitance-induced turn on. Experimental work was performed to determine viability of the driver, which is rated for operation between -40°C and +125°C, for use beyond its recommended temperature limits. Performance assessment included output and switching characteristics and restart capability at extreme temperature and thermal cycling. While the circuit survived the extreme temperature exposure, its operation underwent mild irregularities at 1 kHz and at 1 MHz. The anomaly observed at the low frequency consisted of fluctuations in the supply current only when 10V supply voltage was applied. However, upon increasing the test frequency or using a higher supply voltage, the current regained its stability. The other variance experienced by the chip was a significant increase in the high voltage supply current at the highest test frequency of 1MHz, most notably at cryogenic temperatures. Despite these fluctuations, no major changes were registered in the shape or magnitude of the chip's output and clamp signals throughout the range of -190°C to +140°C. Thermal cycling also had no effect on performance, and the gate driver chips were able to restart successfully at each of the extreme temperatures of -190°C and +140°C. The plastic packaging of these parts was also not affected by either the extreme temperature exposure or the thermal cycling. Although these preliminary results show promise to use the ADuM4121 gate driver in temperature zones beyond its specified range, more comprehensive testing is warranted to fully assess its behavior and reliability for use in the harsh environment of space.

References

[1]. Analog Devices, Inc., "High Voltage, Isolated Gate Driver with Internal Miller Clamp, 2A Output - ADuM4121/ADuM4121-1 Datasheet," Publication D14967-0-10/16(0), Rev. 0. https://www.analog.com/media/en/technical-documentation/data-sheets/ADuM4121_4121-1.pdf

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