**National Aeronautics and Space Administration**

# Operation of Ultrafast, Low-Side MOSFET Driver, IXD609, Over Wide Temperature Range

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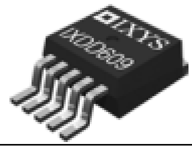
## Scope

Electrical power and control systems designed for use in planetary exploration missions and deep space probes require electronics that are capable of efficient and reliable operation under extreme temperature conditions. In addition, space-based infrared satellites, all-electric ships, jet engines, electromagnetic launchers, magnetic levitation transport systems, and power facilities are also typical examples where system electronics are expected to be exposed to harsh temperatures and to operate under severe thermal swings. 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 ultrafast gate driver for controlling power-level transistors 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 an ultrafast, single-channel gate driver capable of driving N-channel enhancement MOSFETs in low-side switching applications. The IXYS IXD609, is CMOS-input compatible, immune to latch-up, and capable of 9A source or sink current with a wide input voltage range from 4.5 V to 35 V [1]. The device features proprietary circuitry rendering it resilient to cross-conduction and current shoot-through, and is ideal for high frequency and high power applications with an operating 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 ($t_{D1}$) and turn-off ($t_{D2}$) 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. A diagram of the timing characteristics is shown in Figure 1 [1]. The operational characteristics of the drive circuit were obtained, using a 3.5 V, square-wave 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 4, 6, 8, 12, 14, 16, and 18 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 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 IXD609 gate driver [1].

| Parameter | Symbol |   |
|---|---|---|
| Supply Voltage (V) | $V_{DD}$ | 4.5 - 35 |
| Input Voltage (V) | $V_{IN}$ | -5 - +35 |
| Start-up Current (mA) | $I_{DD}$ | 0.15 - 2.5 |
| Source/Sink Current, max (A) | $I_O$ | 9.0 |
| Operating Temperature (°C) | T(oper) | -40 to +125 |
| Turn-on Propagation Delay (ns) | $t_{D1}$ | 40 - 60 |
| Turn-off Propagation Delay (ns) | $t_{D2}$ | 42 - 60 |
| Output Rise Time (ns) | $t_R$ | 22 -35 |
| Output Fall Time (ns) | $t_F$ | 15 - 25 |
| Part # | | IXDN609SI |
| Package | | 8-Pin SOIC |
| Lot Code | | G00765 |

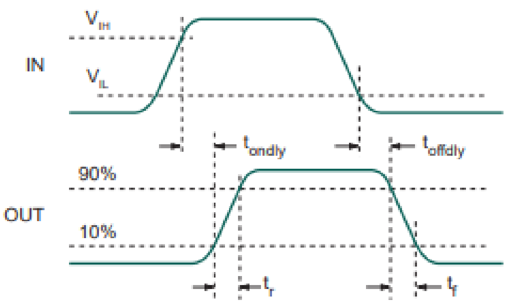



Figure 1. Timing diagram of input/output signals [1].

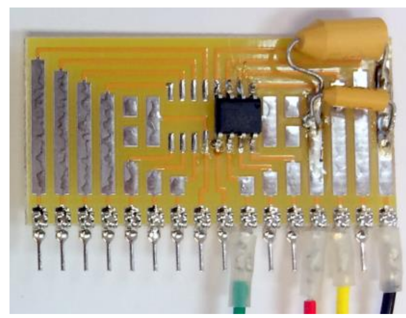


Figure 2. IXD609 gate driver chip with capacitors mounted on test board.

**Test Results**

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

*Temperature Effects*

Waveforms of the IXD609 output signal along with the input signal recorded at 10 kHz frequency and a 12 V supply at room temperature are shown in Figure 3. The operation of the circuit was examined, as mentioned previously, 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. The circuit maintained proper operation and no major change was observed in the shape or magnitude of its output as the test temperature was changed throughout the range of -190 °C to +140 °C. For illustrative purposes, only waveforms obtained at the extreme temperatures of -190 °C and +140 °C are reported, as shown in Figures 4 and 5, respectively.

Figure 6 shows the turn-on ($t_{D1}$) and turn-off ($t_{D2}$) 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 less dominant, though, at cryogenic temperatures.

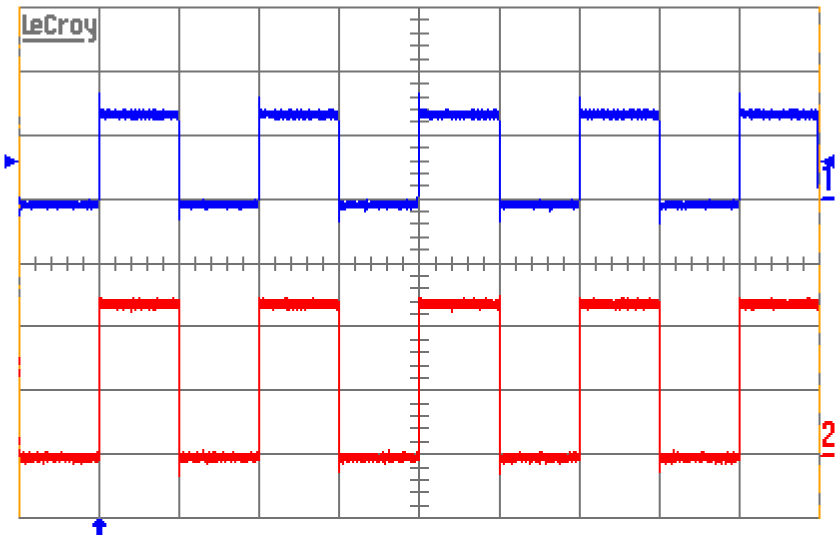



Figure 3. Input (trace 1) and output (trace 2) signals at +20°C.
(Scale: Vertical 5V/div; Horizontal 50µs/div)

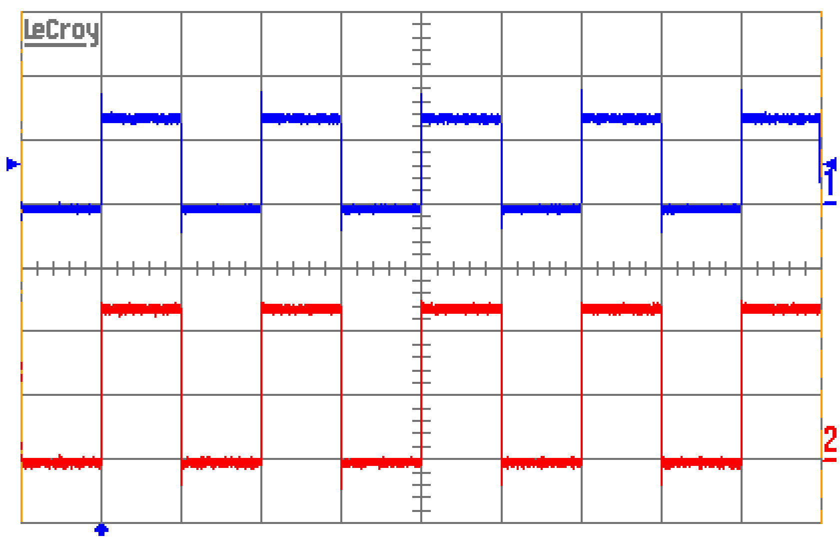



Figure 4. Input (trace 1) and output (trace 2) signals at -190°C.

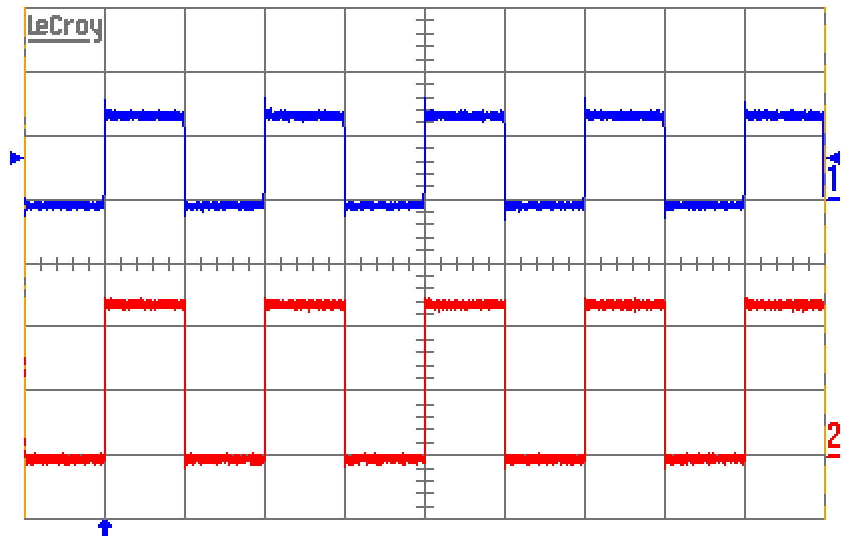



Figure 5. Input (trace 1) and output (trace 2) signals at +140°C.

The rise and fall times of the output signal of the gate driver are shown in Figure 7 as a function of temperature. Similar to the propagation delays, the rise and fall times of the gate driver seemed to be influenced more, albeit trivial, at high temperatures. The slight increase in the rise time with temperature was more evident than its counterpart.

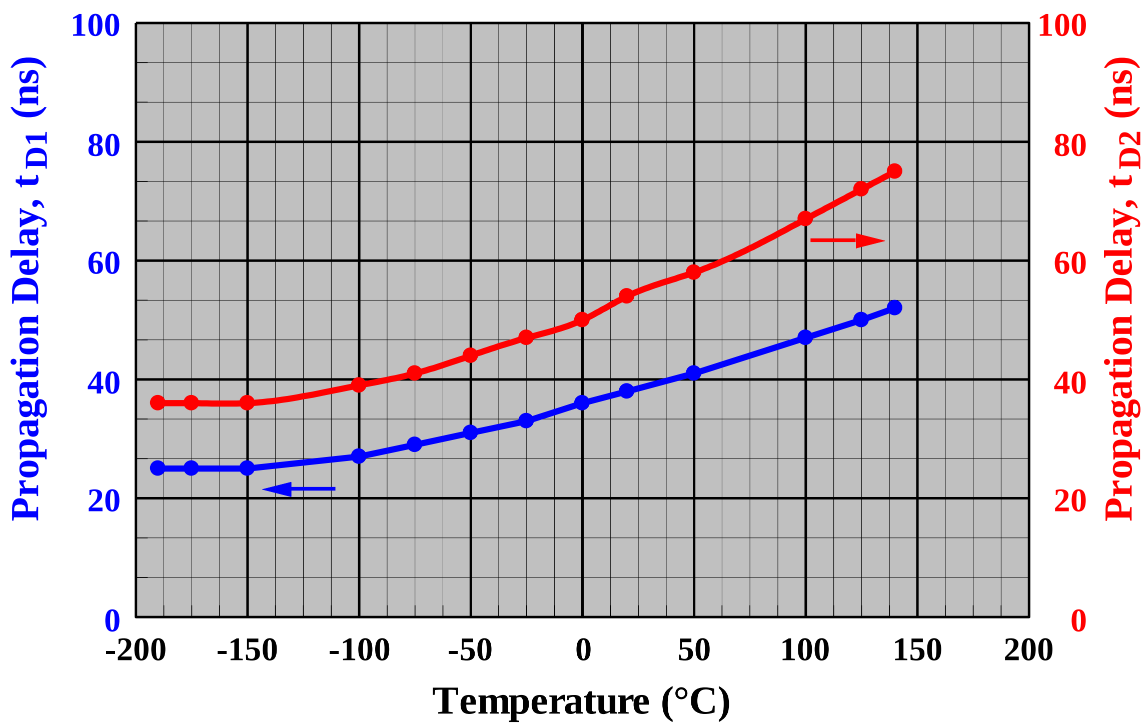



Figure 6. Turn-on and turn-off propagation delays as a function of temperature.

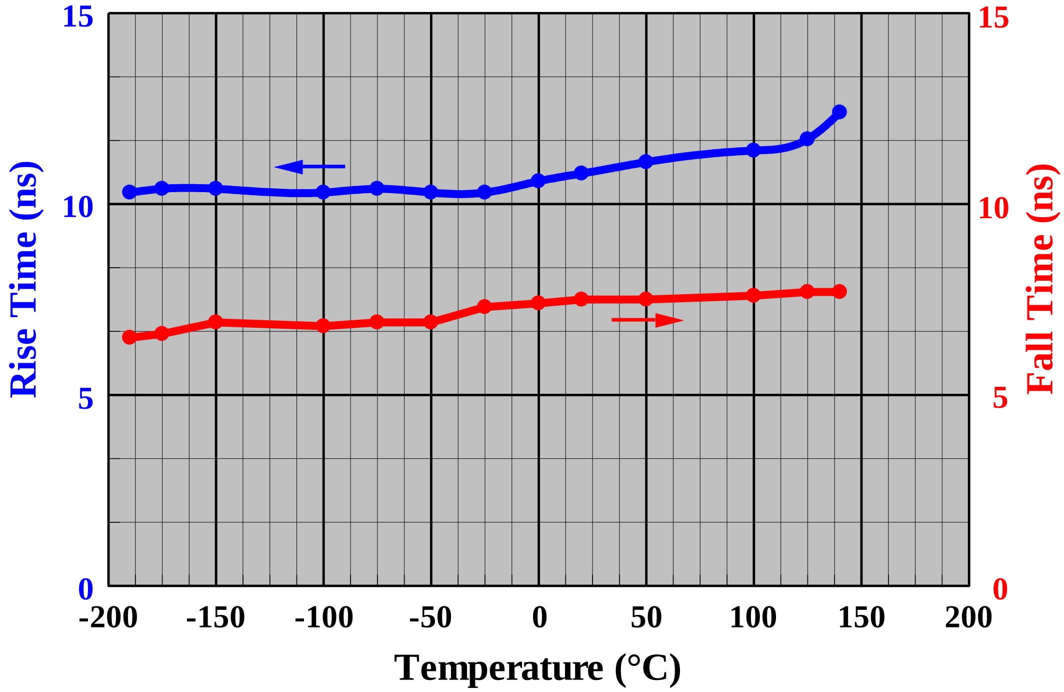



Figure 7. Rise and fall times of gate drive output signal versus temperature.

The effect of temperature on the supply current of the IXD609 gate driver was dependent on the test frequency. As depicted in Figure 8, while the supply current remained unchanged at low frequencies, it exhibited an increase with temperature at high frequencies. This increase, which is evident at the test frequencies of 500 and 1000 kHz, is more profound at the higher test temperatures.

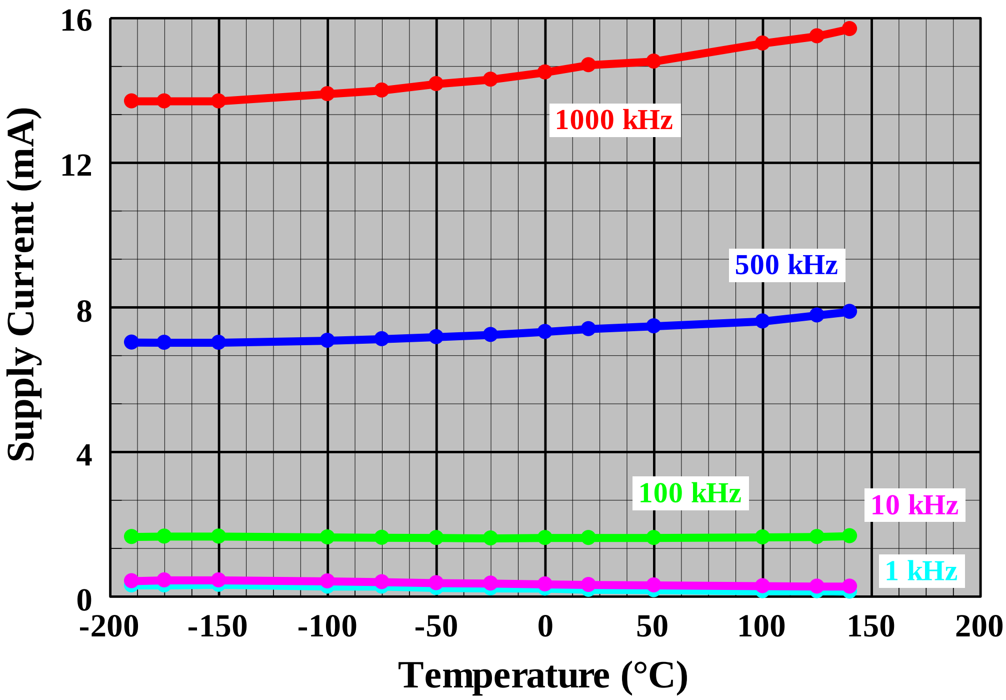



Figure 8. Supply current versus test temperature at various frequencies.

*Restart at Extreme Temperatures*

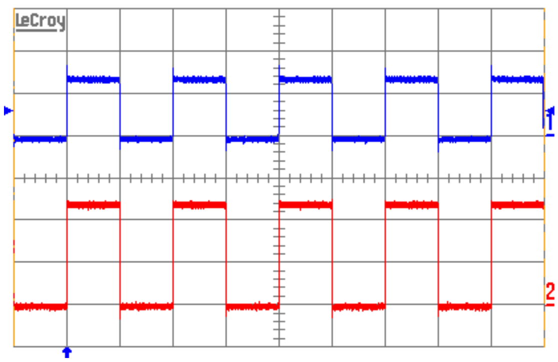
Restart capability of the IXD609 gate driver chip at extreme temperatures was also investigated by allowing the device to soak for at least 30 minutes at each of the test temperatures of -190 °C and +140 °C without electrical bias. Power was then applied to the circuit and measurements were taken on 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*

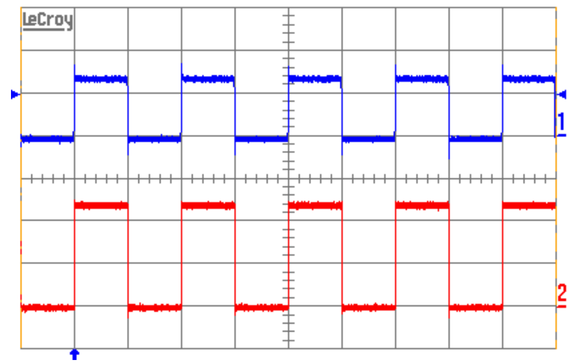
The effects of thermal cycling under a wide temperature range on the operation of the IXD609 gate driver chip were investigated by subjecting it to 100 cycles between -190 °C and +140 °C at a temperature rate of 20 °C/minute. A dwell time of 15 minutes was applied at the extreme temperatures. Following cycling, measurements of the investigated parameters were taken again as a function of temperature. A comparison of the gate driver's input and output signals at the selected test temperatures of +20 ºC, -190 ºC, 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 12 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 12 V supply and an input frequency of 100 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- & post-cycling propagation delays, switching times, & supply current under 12 V supply voltage and 100 kHz input frequency.

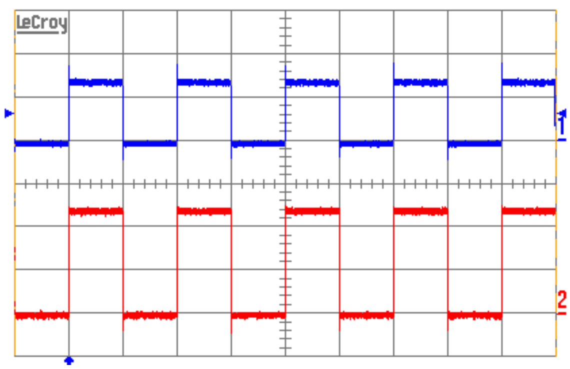
| | **Turn-on Propagation Delay, $t_{D1}$ (ns)** | | **Turn-off Propagation Delay, $t_{D2}$ (ns)** | | **Rise Time, $t_r$ (ns)** | | **Fall Time $t_f$ (ns)** | | **Supply Current (mA)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **T (°C)** | Prior | Post | Prior | Post | Prior | Post | Prior | Post | Prior | Post |
| +20 | 38.00 | 38.00 | 54.00 | 54.00 | 10.80 | 10.80 | 7.50 | 7.40 | 1.34 | 1.33 |
| -190 | 25.00 | 25.00 | 36.00 | 36.00 | 10.30 | 10.20 | 6.50 | 6.60 | 1.33 | 1.34 |
| +140 | 52.00 | 51.00 | 75.00 | 76.00 | 12.40 | 12.60 | 7.70 | 7.80 | 1.41 | 1.42 |



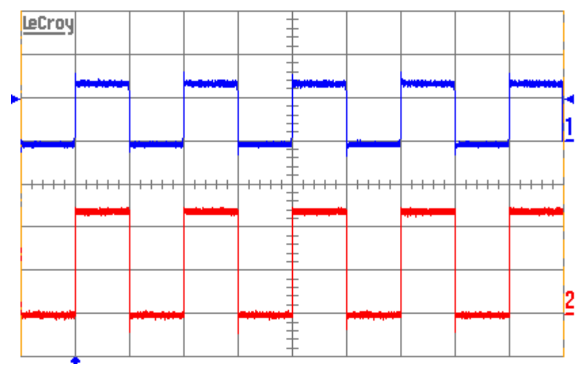

Pre-cycling @ 20 °C



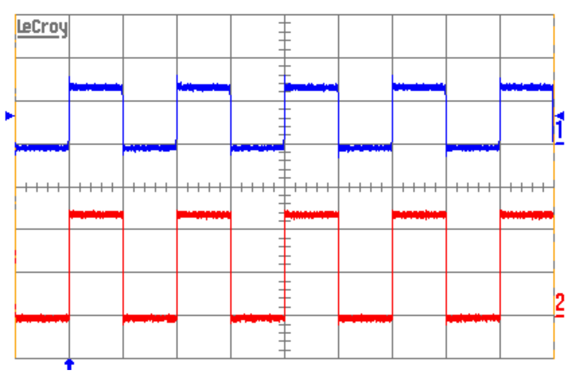

Post-cycling @ 20 °C



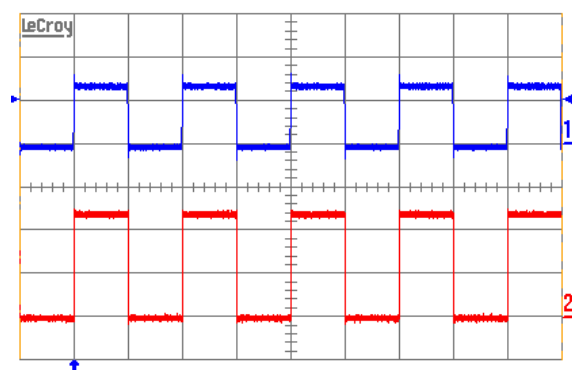

Pre-cycling @ -190 °C




Post-cycling -190 °C




Pre-cycling @ +140 °C




Post-cycling @ +140 °C

Figure 9. Pre- & post-cycling waveforms of input (trace 1) and output (trace 2) signals of IXD609 gate driver at selected temperatures with 12 V supply and 10 kHz input.

## Conclusions

An ultrafast, single-channel, gate driver capable of driving N-channel enhancement MOSFETs in low-side switching applications, IXYS IXD609, was investigated for potential operation at temperatures beyond the recommended limits of -40 °C to +125 °C by evaluating its performance under exposure to extreme temperatures and to thermal cycling. Restart capability at the extreme cryogenic and hot temperatures were also investigated. The gate driver was able to maintain good operation throughout the entire test regime between -190 °C and +140 °C, a broader temperature range than specified, without undergoing any major changes in its output signal and switching characteristics. Thermal cycling performed on these devices also had no effect on performance, and the gate driver chips were able to successfully restart at each of the extreme temperatures of -190 °C and +140 °C. The plastic packaging of the parts was also not affected by either the extreme temperature exposure or the thermal cycling. Although these preliminary results indicated the capability of this IXD609 gate driver to be possibly utilized in temperature zones that extended beyond its specified range without major impact on performance, further and more comprehensive tests are required to better assess the reliability and to determine the applicability of these devices for extended use in the harsh environments of space.

## References

[1]. IXYS Integrated Circuits Division, "IXD_609 9-Ampere Low-Side Ultrafast MOSFET Drivers," Publication DS-IXD_609-R09, 10/25/2017. http://www.ixysic.com/home/pdfs.nsf/www/IXD_609.pdf/$file/IXD_609.pdf

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