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Performance Evaluation of an Automotive-Grade, High-Speed Gate Driver for SiC FETs, Type UCC27531, Over a Wide Temperature Range

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Scope

Silicon carbide (SiC) devices are becoming more readily available and are finding a wide spread use as replacement for conventional silicon parts in many electronic applications. Advancement in the manufacturing process by maximizing yield and reducing defects at the wafer level, as well as the low on-resistance of the SiC wide-bandgap materials allows the development of a new generation of transistor devices that handles higher power levels with faster switching and with much reduced losses [1]. In addition, they are more tolerant to high temperature and are capable of high frequency operation; resulting in reducing system weight, saving board space, and conserving power. In this work, the performance of an automotive-grade high-speed gate driver with potential use in controlling SiC FETs (field-Effect Transistors) in converters or motor control applications 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 single-channel, high-speed gate driver capable of driving power switches by up to 2.5A source and 5-A sink peak current. The Texas Instruments UCC27531, an AEC-Q100 qualified for automotive applications, single gate driver features the industry's fastest propagation delays of less than 15ns. The ultra-low propagation delays in the gate driver help automotive systems efficiently switch power electronics at high frequencies to maintain a small footprint and reduce overall vehicle weight [2]. The device has a wide input voltage from 10V to 35V providing flexibility to drive emerging SiC FETs [3], and is offered in a standard SOT-23 package with an operating temperature range of -40 °C to +140 °C. 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, output's rise (t_R) and fall times (t_F), turn-on (t_{D1}) and turn-off (t_{D2}) propagation delay times, and supply current. Diagram of the timing characteristics is shown in Figure 1. The supply current was recorded under no-load and as well as using a capacitive load of 2.5nF. The operational characteristics of the drive circuit were obtained, using a 5V, 100 kHz input and a supply voltage of 18V, over the test temperature range between -194 °C and +145 °C using a liquid nitrogen-cooled environmental chamber. 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 +145 or -194 °C, was also investigated. In addition, the effects of limited thermal cycling on the operation of the driver were determined by exposing it to a total of 12 cycles between -194 °C and +145 °C at a temperature rate of 10 °C/minute. Following cycling, circuit measurements were then performed at the test temperatures of +23, -194, and +145°C using a soak time of at least 30 minutes at these test temperatures. Figure 2 shows the gate driver chip mounted on a circuit board along with ceramic and tantalum decoupling capacitors.

Table I. Specifications of UCC27531 gate driver chip [3].

Parameter	**Symbol**	
Supply Voltage (V)	V_{DD}	10 to 32
Input Voltage (V)	IN	-5 to 25
Start-up Current (mA)	I_{DD}	0.2
Source/Sink Current (A)	I_O	2.5/5.0
Operating Temperature (°C)	T(oper)	-40 to +140
Turn-on Propagation Delay (ns)	t_{D1}	17
Turn-off Propagation Delay (ns)	t_{D2}	17
Output Rise Time (ns)	t_R	15
Output Fall Time (ns)	t_F	7
Part #		UCC27531DBVR
Package		SOT23-6
Lot Number		42779442

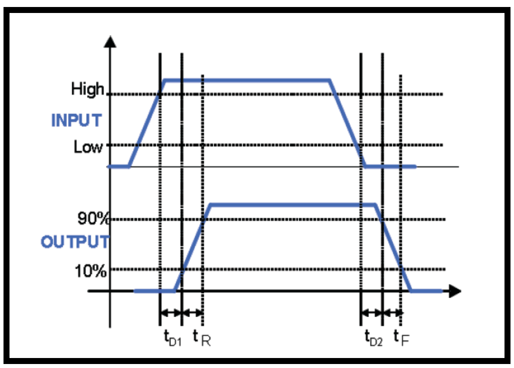


Figure 1. Timing diagram of input/output signals.

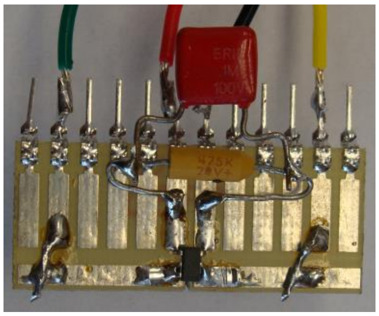


Figure 2. UCC27531 Gate driver chip and capacitors mounted on test board.

Test Results

Temperature Effects

Waveforms of the UCC27531 output signal along with the input signal recorded at room temperature are shown in Figure 3. The operation of the circuit was examined, as mentioned earlier, over a wide temperature range and signal waveforms were also obtained at the test points of +145, +140, +100, +50, +23, 0, -20, -40, -60, -80, -100, -120, -140, -160, -180, and -194 °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 -194 °C to +145 °C. For illustrative purposes, therefore, only waveforms obtained at the extreme temperatures of -194 °C and +145 °C are also presented here as shown in Figures 4 and 5, respectively.

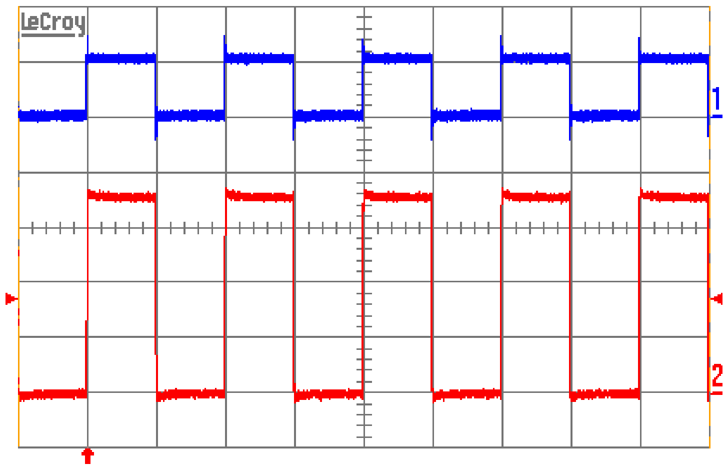


Figure 3. Input (trace 1) and output (trace 2) signals at +23°C.
(Scale: Vertical 5V/div; Horizontal 5µs/div)

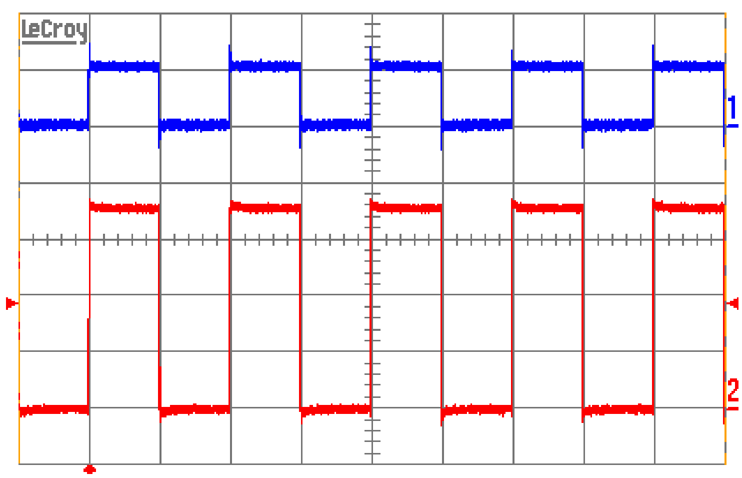


Figure 4. Input (trace 1) and output (trace 2) signals at -194°C.
(Scale: Vertical 5V/div; Horizontal 5µs/div)

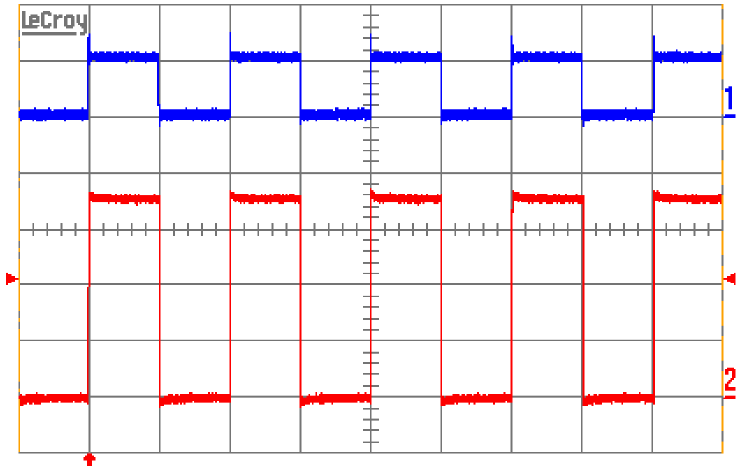


Figure 5. Input (trace 1) and output (trace 2) signals at +145°C.
(Scale: Vertical 5V/div; Horizontal 5μs/div)

Figure 6 shows the turn-on and turn-off 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 but slight increase as the test conditions varied from cryogenic to high temperature. This increase, for either delay time, amounted to about three fold as temperature was raised from -194 °C to + 145 °C.

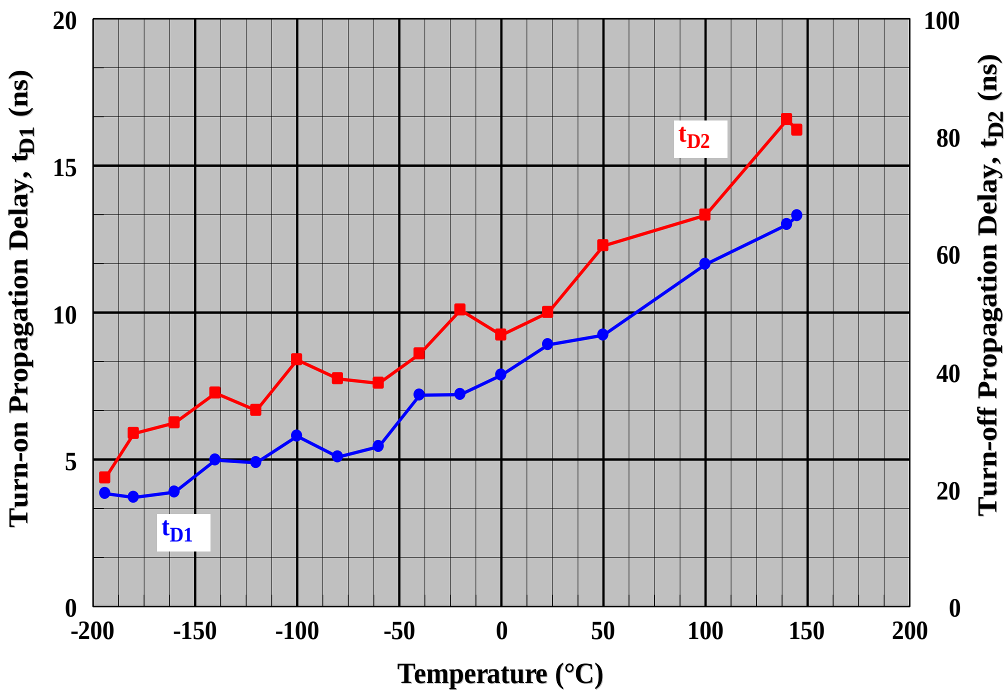


Figure 6. Turn-on and turn-off propagation delay times as a function of temperature.

The rise and fall time times of the output signal of the gate driver are shown in Figure 7 as a function of temperature. Effect of temperature was negligible on these parameters of the driver as their values exhibited little change throughout the test temperature range.

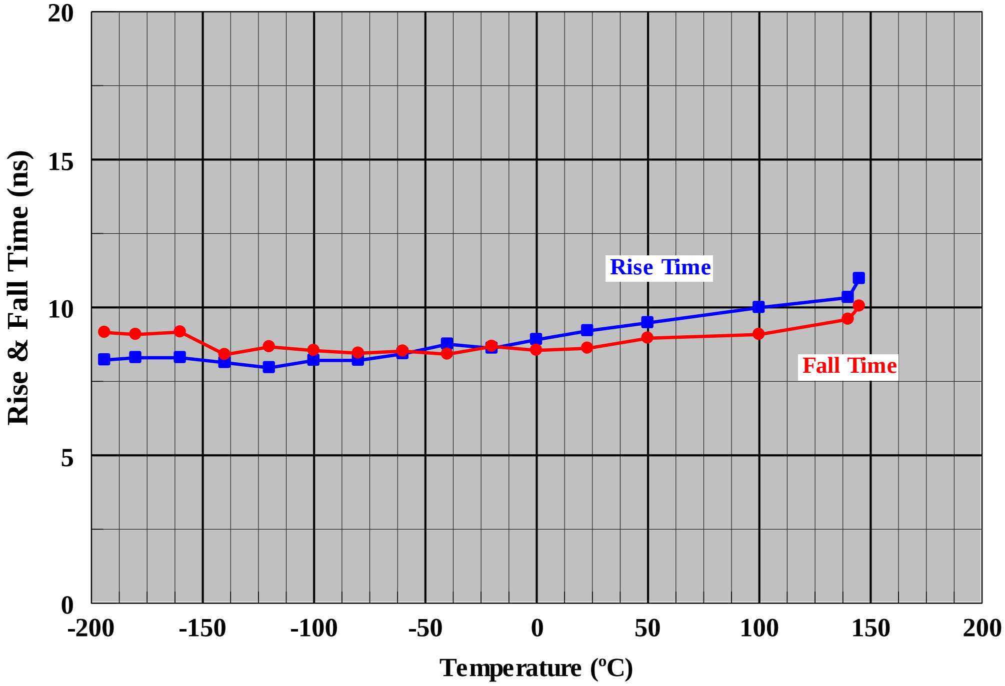


Figure 7. Rise and fall times of gate driver output signal versus temperature.

While the quiescent current remained unaffected with temperature change, the input current exhibited variation only in the cryogenic region, as shown in Figure 8. While the current held a steady value between +145 °C and -100 °C, it underwent a gradual increase as the test temperature was further decreased below -100 °C. This behavior was the same under no load or when the circuit had a capacitive load of 2.5 nF.

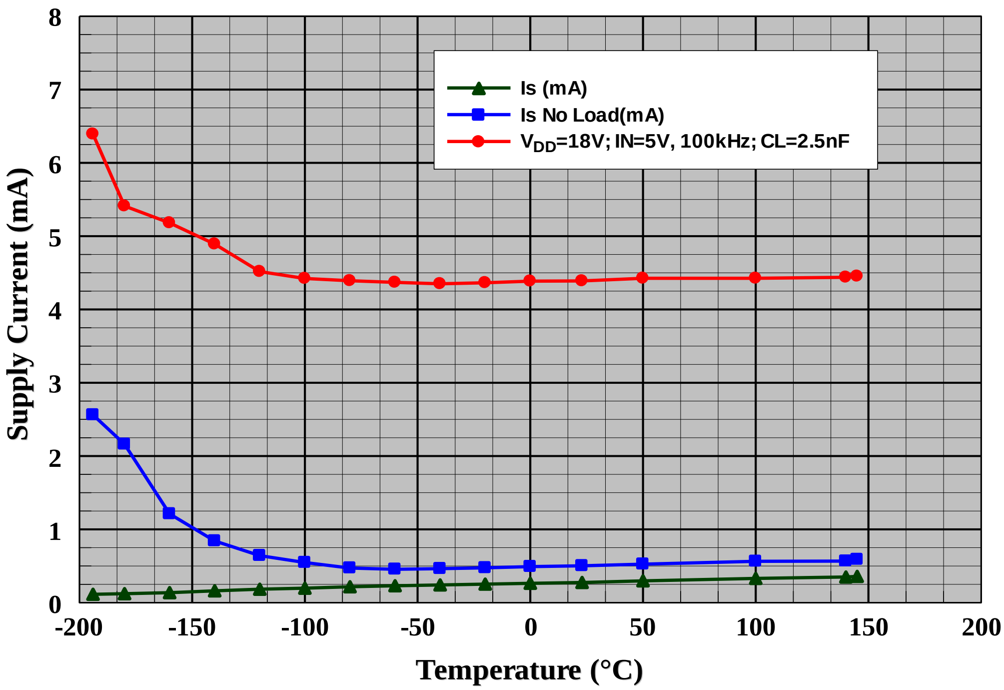


Figure 8. Supply current under different conditions versus test temperature.

Restart at Extreme Temperatures

Restart capability of the UCC27531 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 -194 °C and +145 °C without electrical bias. Power was then applied to the driver 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 Limited Thermal Cycling

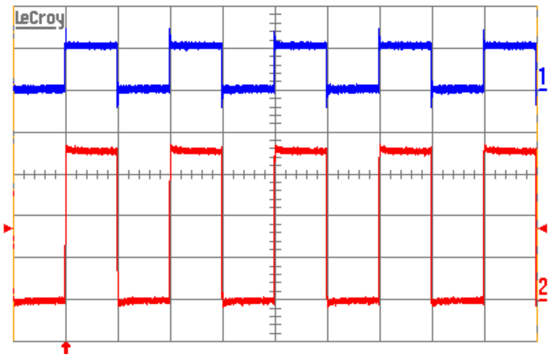
The effects of limited thermal cycling under a wide temperature range on the operation of the UCC27531 gate driver IC chip were investigated by subjecting it to a total of 12 cycles between -194 °C and +145 °C at a temperature rate of 10 °C/minute. A dwell time of 15 minutes was applied at the extreme temperatures. Following cycling, measurements of the investigated parameters were taken again as a function of temperature. A comparison of the driver's input and output signals at the selected test temperatures of +23, -194, and +145 °C for pre - and post-cycling conditions are shown in Figure 9. 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 current, as depicted in Table II at the selected three test temperatures. Based on this preliminary investigation, it can be concluded that the extreme temperature exposure and the limited thermal cycling did not induce much change in the behavior of this gate driver integrated circuit chip. This limited 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, & input current.

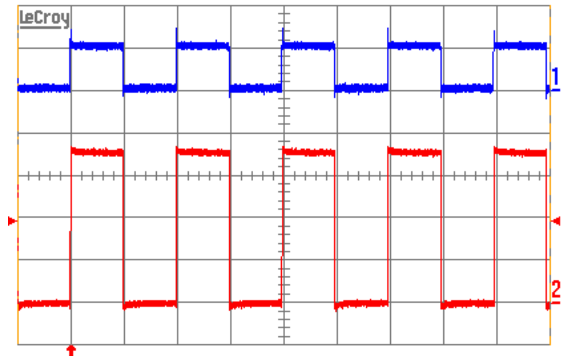
	Turn-on Propagation Delay, t_{D1} (ns)		**Turn-off Propagation Delay, t_{D2} (ns)**		**Rise Time, t_R (ns)**		**Fall Time t_R (ns)**		**Input Current (mA)**	
T (°C)	Prior	Post	Prior	Post	Prior	Post	Prior	Post	Prior	Post
+23	8.90	8.56	10.00	11.40	9.21	9.18	8.62	9.02	4.39	4.39
-194	3.84	4.99	4.37	5.88	8.22	8.18	9.15	8.69	6.39	6.41
+145	13.02	13.29	16.47	16.20	10.30	10.97	9.62	10.04	4.46	4.44

Long-Term Thermal Cycling

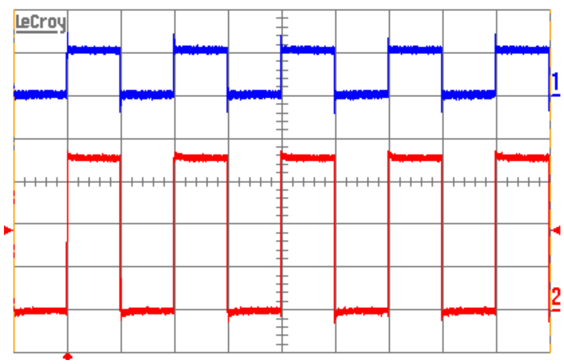
Although this work provided some insight on the capability of this driver chip to operate in temperature zones that extended beyond its specified low and high temperature limits without impact on its performance as well as surviving exposure to limited cycling under a very wide temperature range, these preliminary results are not sufficient to address its reliability for inclusion in systems designed for space use. Extensive long-term thermal cycling and other test criteria need to be carried out so that the reliability of such a device can be determined.



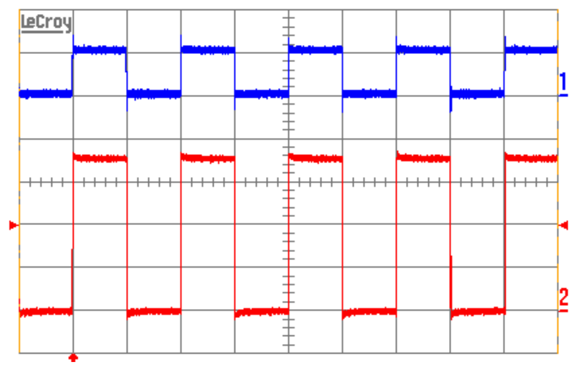
Pre-cycling @ 23 °C



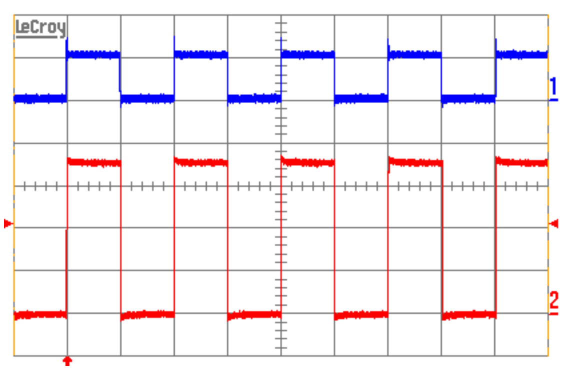
Post-cycling @ 23 °C



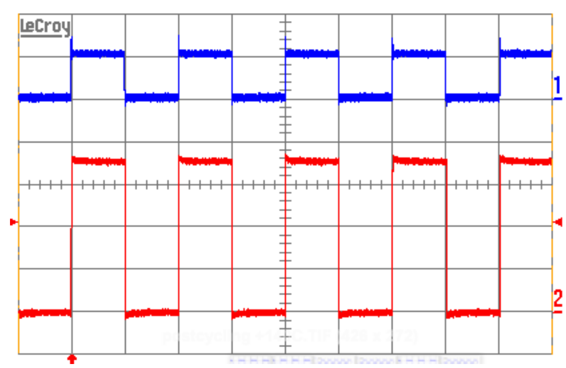
Pre-cycling @ -194 °C



Post-cycling -194 °C



Pre-cycling @ +145 °C



Post-cycling @ +145 °C

Figure 9. Pre- & post-cycling waveforms of Input (trace 1) and output (trace 2) signals of UCC27531 gate driver at selected temperatures.

Conclusions

Wide-band gap semiconductors, such as silicon carbide, have much higher operating temperature, higher breakdown voltage, and a capability of switching at much higher frequencies with negligible power loss when compared to their silicon counterparts. Switching at high speed results in more efficient and smaller power circuitry. An automotive-grade, commercial-off-the-shelf (COTS) gate driver UCC27531, recently developed by Texas Instruments to drive SiC power FETs, was evaluated for operation at temperatures beyond the recommended limits of -40 °C to +140 °C. The effects of limited thermal cycling under the extended test temperature, which ranged from -194 °C to +145 °C, on the operation of this chip as well as restart capability at the extreme cryogenic and hot temperatures were also investigated. The driver circuit was able to maintain good operation throughout the entire test regime between -194 °C and +145 °C without undergoing any major changes in its outputs signal and characteristics. The limited thermal cycling performed on the device also had no effect on its performance, and the driver chip was able to successfully restart at each of the extreme temperatures of -194 °C and +145 °C. The plastic packaging of this device was also not affected by either the short extreme temperature exposure or the limited thermal cycling.

These preliminary results indicate that this COTS SiC FET driver has the potential for use in space exploration missions under extreme temperature environments. Further testing and long-term cycling are, however, recommended to fully assess its reliability and to determine suitability for extended use in the harsh environments of space.

References

[1]. A. Elasser & T. Paul Chow, "Silicon Carbide Benefits and Advantages for Power Electronics Circuits and Systems," Proceedings of the IEEE, Vol. 90, No. 6, June 2002. http://www.researchgate.net/publication/2986009_Silicon_carbide_benefits_and_advantages_for_power_electronics_circuits_and_systems

[2]. N. Bowers, "AEC-Q100 gate drivers for automotive applications," Electronic Specifier/Automotive, May 2, 2014. http://automotive.electronicspecifier.com/automotive-components/aec-q100-gate-drivers-for-automotive-applications

[3]. Texas Instruments "UCC2753x 2.5A and 5-A, 35-VMAX VDD FET and IGBT Single-Gate Driver" Data Sheet, SLUSBA7E - December 2012 - Revised March 2015. http://www.ti.com/lit/ds/symlink/ucc27531.pdf

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