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Performance Evaluation of High-Speed, Low-Side Gate Driver, FAN3122, Over Extended Temperature Range

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Scope

Emerging power metal-oxide semiconductor field-effect transistor (MOSFETs) based on silicon carbide and gallium nitride technology are finding widespread use in many electronic applications such as motor control and DC/DC converters due to their higher voltage, higher temperature tolerance, and higher frequency switching capabilities [1]. To utilize these power devices and to meet circuit/system compactness, modularity, and operational functionality, gate drivers that provide unique attributes, such as fast switching and high-current handling capability, are needed. In addition, power systems geared for use in space mission applications require on-board devices to withstand exposure to extreme temperatures and wide thermal swings. Very little data, however, exist on the performance of such devices and circuits under extreme temperatures. In this work, the performance of a high-speed gate driver with potential use in 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 a single-channel, high-speed gate driver capable of driving N-channel enhancement MOSFETs in low-side switching applications. The ON Semiconductor FAN3122 single gate driver, a device AEC-Q100 qualified for automotive applications, provides high peak current pulses, up to 7.1 A sourcing and 9.7 A sinking, and has a wide input voltage range from 4.5 V to 18 V [2]. The device features internal under-voltage lockout circuitry and provides low propagation delays with an operating temperature range of -40 °C to +125 °C. Table I shows some of the device manufacturer's specifications. The operation of the gate driver was investigated over a wide temperature range that extended beyond the component's 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. These parametric evaluations were performed at different frequency and supply voltage levels. Diagram of the timing characteristics is shown in Figure 1. The operational characteristics of the drive circuit were obtained, using a 6V, square-wave input at various frequencies (1 kHz, 10 kHz, 50 kHz, 100 kHz, 500 kHz, and 1 MHz) and a supply voltage of 8, 12, and 15 volts, over the test temperature range between -160 °C and +140 °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 +140 or -160 °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 -160 °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, -160, 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 FAN3122 gate driver [2].

Parameter	**Symbol**	
Supply Voltage (V)	V_{DD}	4.5 - 18
Input Voltage (V)	V_{IN}	0 - 18
Start-up Current (mA)	I_{DD}	0.58 - 0.65
Source/Sink Current (A)	I_O	7.1/9.7
Operating Temperature (°C)	T(oper)	-40 to +125
Turn-on Propagation Delay (ns)	t_{D1}	9 - 35
Turn-off Propagation Delay (ns)	t_{D2}	9 - 35
Output Rise Time (ns)	t_R	12 -31
Output Fall Time (ns)	t_F	12 - 27
Part #		FAN3122TMX
Package		SOIC-8
Lot Number		DZH160364B

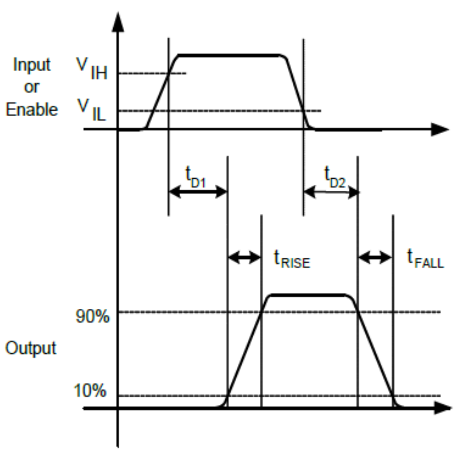


Figure 1. Timing diagram of input/output signals [2].

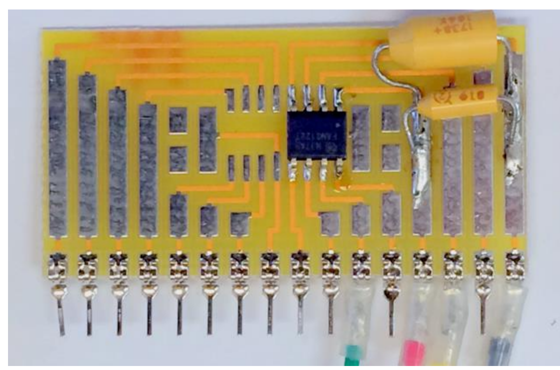


Figure 2. FAN3122 gate driver chip with capacitors mounted on test board.

Test Results

Two devices of this gate driver 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 FAN3122 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 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, and -160 °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 -160 °C to +140 °C. For illustrative purposes, only waveforms obtained at the extreme temperatures of -160 °C and +140 °C are reported, as shown in Figures 4 and 5, respectively. Upon further decrease in temperature to around -165 °C, however, the output of the gate driver became unstable and jittery but recovered when the test temperature was brought back to -160 °C.

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 -160 °C.

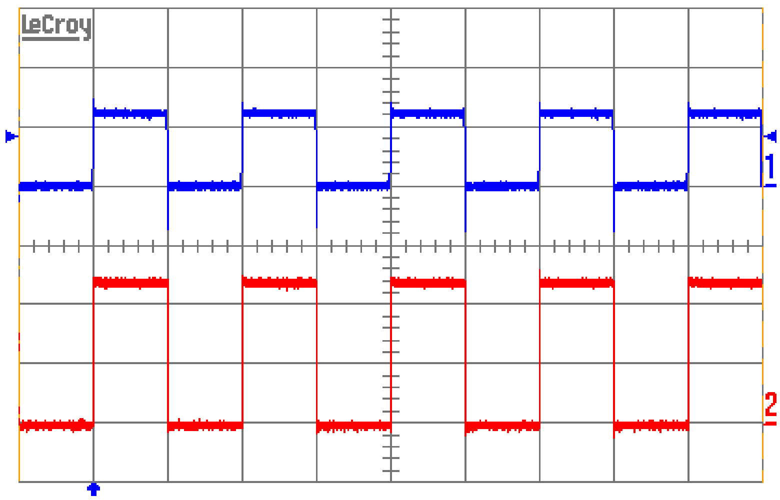


Figure 3. Input (trace 1) and output (trace 2) signals at +20°C.
(Scale: Vertical 5V/div; Horizontal 50µs/div)

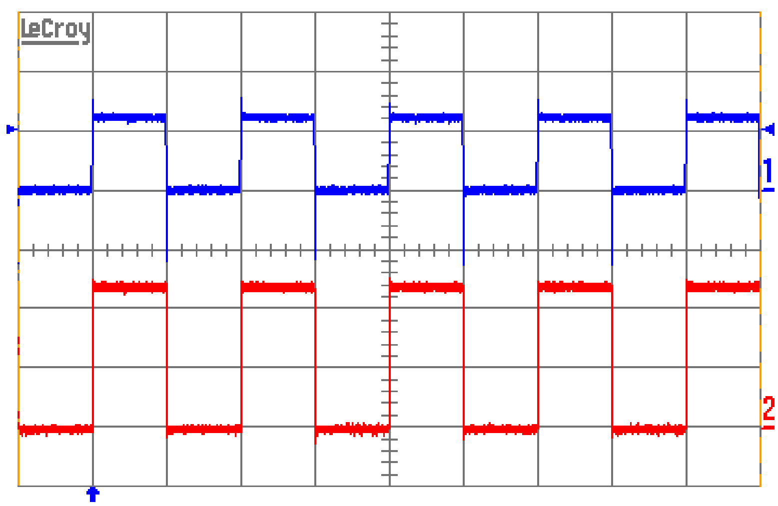


Figure 4. Input (trace 1) and output (trace 2) signals at -160°C.
(Scale: Vertical 5V/div; Horizontal 50µs/div)

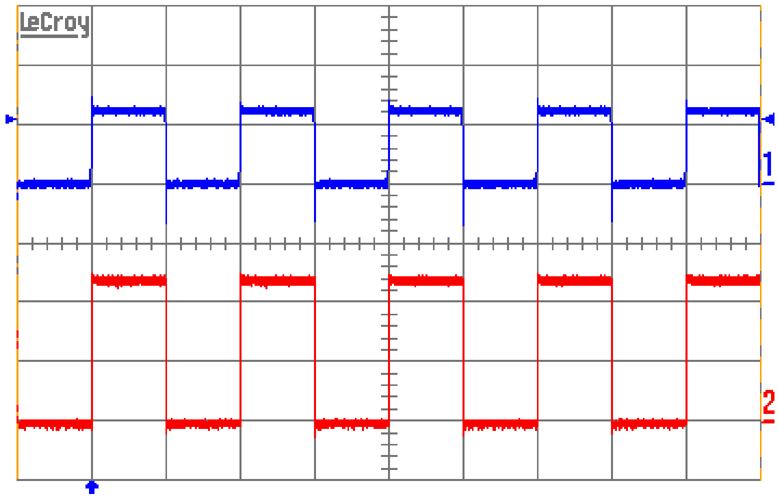


Figure 5. Input (trace 1) and output (trace 2) signals at +140°C.
(Scale: Vertical 5V/div; Horizontal 50µs/div)

The rise and fall times of the output signal of the gate driver are shown in Figure 7 as a function of temperature. Unlike the propagation delays, the rise and fall times of the gate driver behaved differently in response to change in test temperature. While the fall time exhibited a gradual increase as the temperature varied from cryogenic to high temperature, the rise time, on the other hand, displayed sharp decrease as temperature swept from -160 °C to about -50 °C with the trend being reversed, albeit to a lesser degree, when the test temperature increased from about +35 °C to +140 °C . In the mid temperature region of -50 °C to +35 °C, the rise time did not seem to undergo any significant variation with change in temperature.

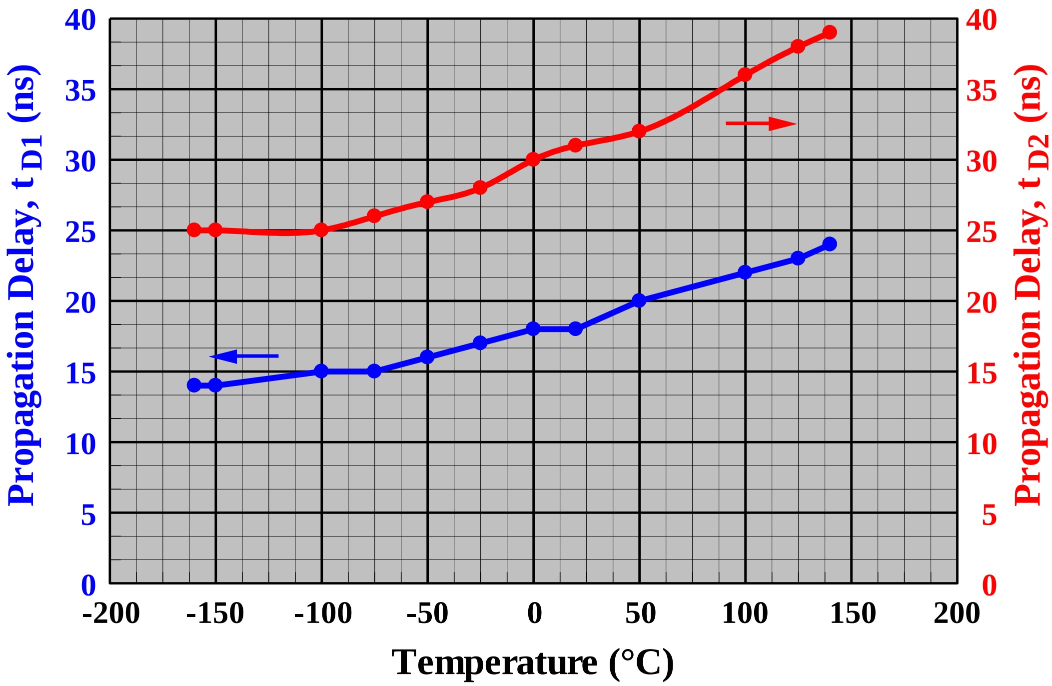


Figure 6. Turn-on and turn-off propagation delays as a function of temperature.

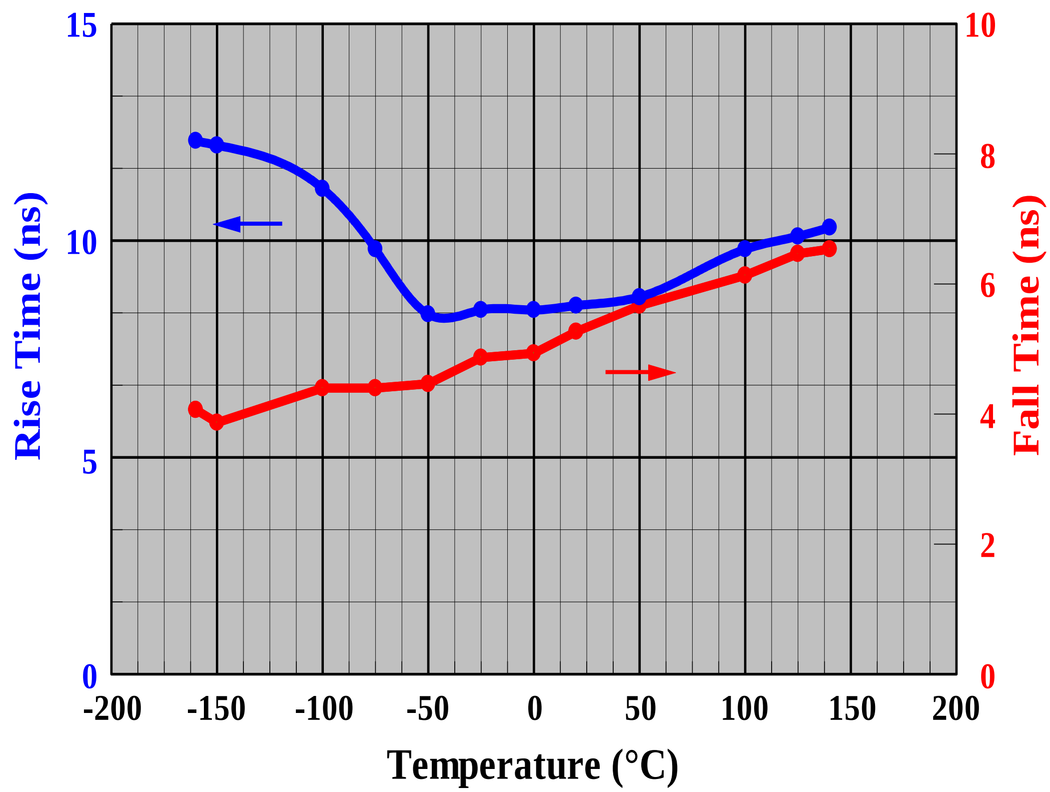


Figure 7. Rise and fall times of gate drive output signal versus temperature.

The supply current of the FAN3122 gate driver showed great dependency on supply voltage level, input frequency, and test temperature. For any given voltage, the supply current increased linearly with frequency irrespective of test temperature as shown on Figures 8-10. As expected, higher supply voltage leads to increase in current drawn by the drive circuit. To illustrate the effect of temperature, the current recorded using a 12 V supply voltage at various frequencies between 1 kHz and 1 MHz is shown in Figure 11. As stated earlier, the current seemed to increase almost linearly with increase in temperature, however, the increase in the current tends to be much more profound at frequencies above 100 kHz.

Restart at Extreme Temperatures

Restart capability of the FAN3122 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 -160 °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.

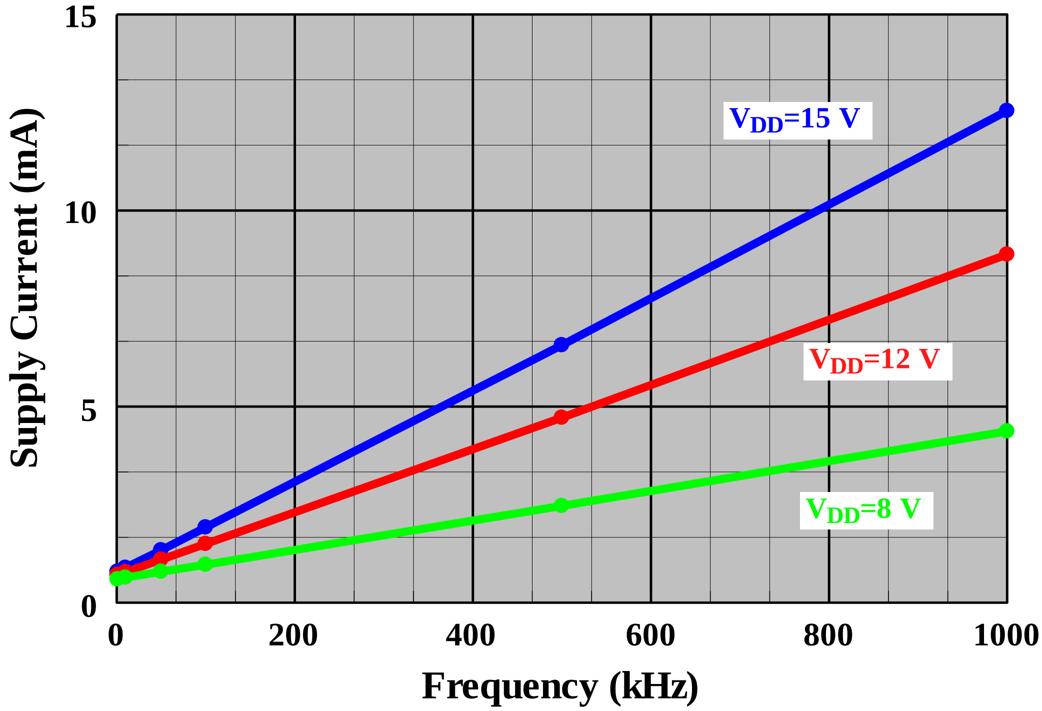


Figure 8. Supply current at different supply voltages versus frequency at 20 °C.

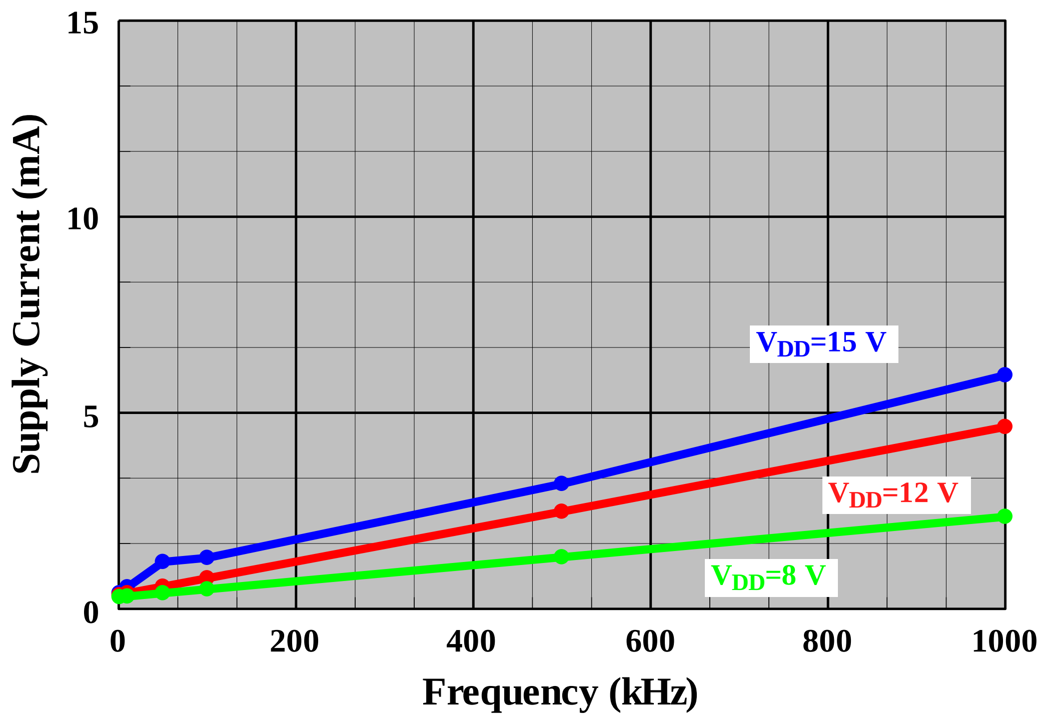


Figure 9. Supply current at different supply voltages versus frequency at -160 °C.

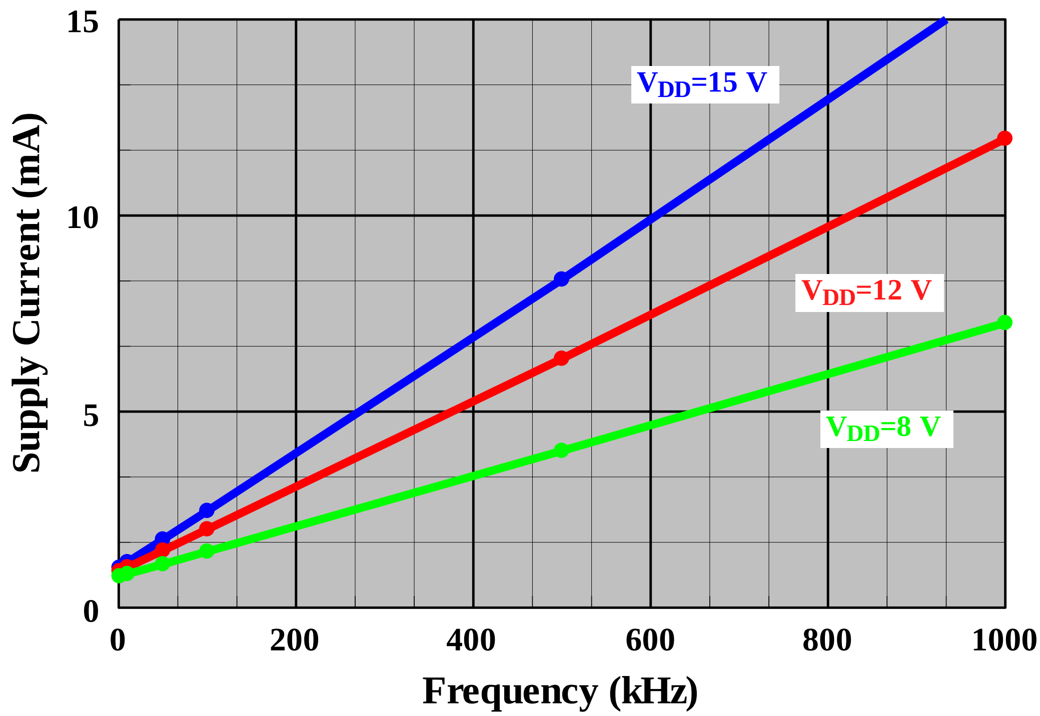


Figure 10. Supply current at different supply voltages versus frequency at +140 °C.

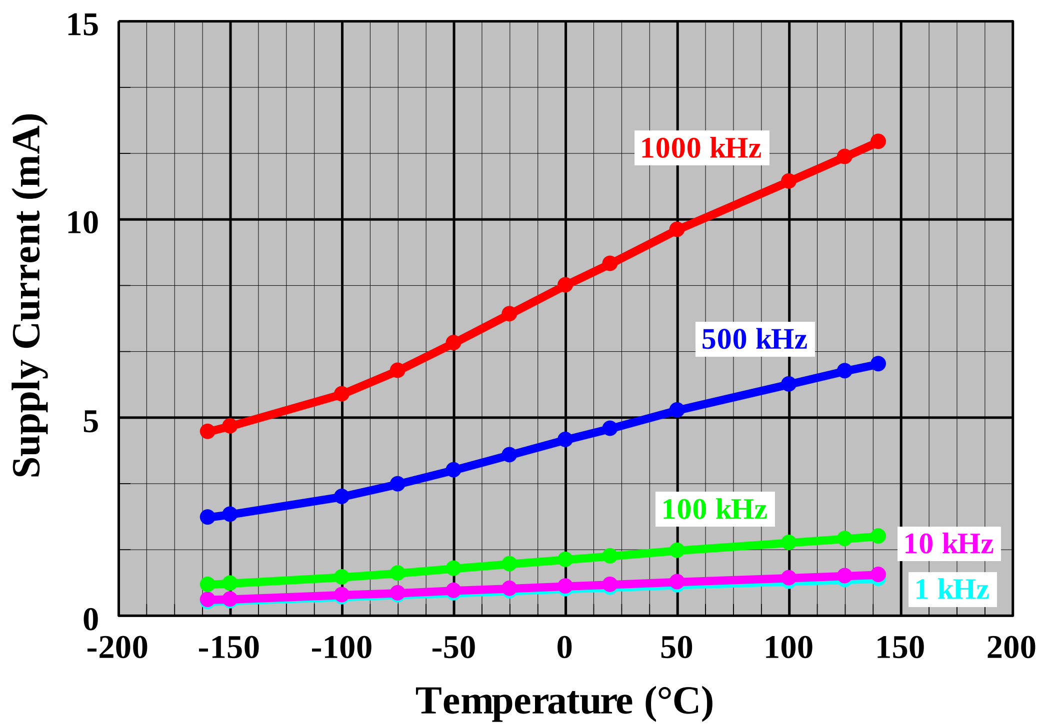


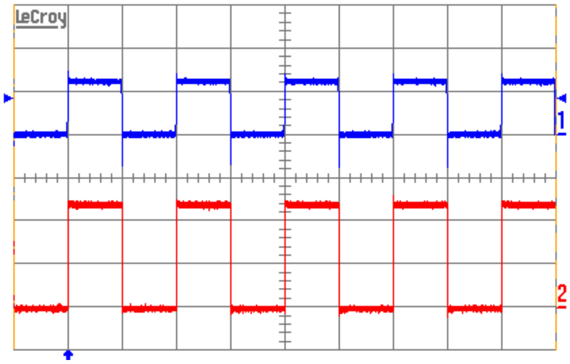
Figure 11. Supply current versus test temperature at various frequencies.

Effects of Thermal Cycling

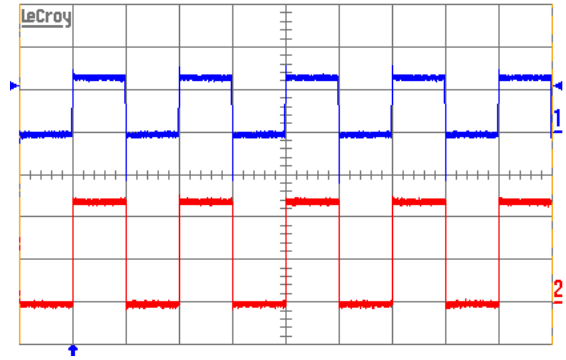
The effects of thermal cycling under a wide temperature range on the operation of the FAN3122 gate driver chip were investigated by subjecting it to a total of 100 cycles between -160 °C and +140 °C at a temperature rate of 20 °C/minute. A dwell time of 15 minutes was applied at the extreme temperatures. 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, -160 ºC, and +140 °C for pre- and post-cycling conditions are shown in Figure 12. 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.

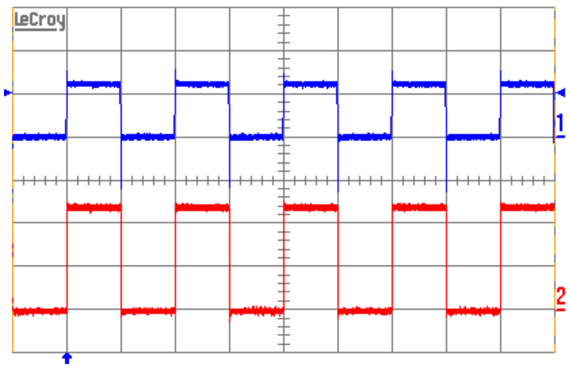
	Turn-on Propagation Delay, t_{D1} (ns)		**Turn-off Propagation Delay, t_{D2} (ns)**		**Rise Time, t_r (ns)**		**Fall Time t_f (ns)**		**Supply Current (mA)**	
T (°C)	Prior	Post	Prior	Post	Prior	Post	Prior	Post	Prior	Post
+20	18.00	19.00	31.00	30.00	8.50	8.20	7.90	7.80	1.50	1.50
-160	14.00	14.00	25.00	25.00	12.30	12.7	6.10	5.79	0.78	0.78
+140	24.00	24.00	39.00	39.00	10.30	10.10	9.80	9.60	2.00	2.01



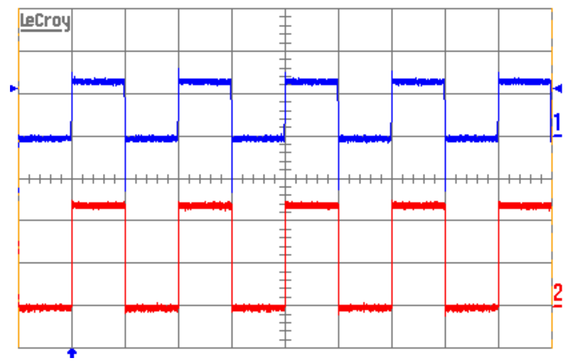
Pre-cycling @ 20 °C



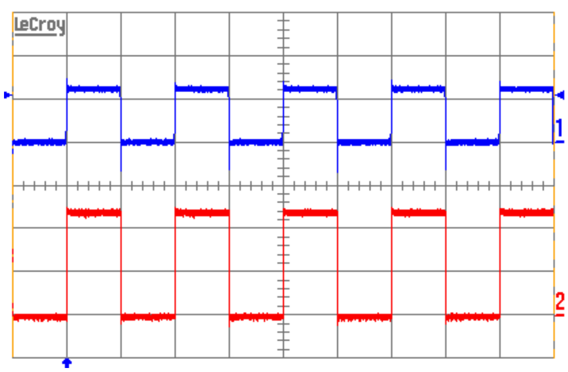
Post-cycling @ 20 °C



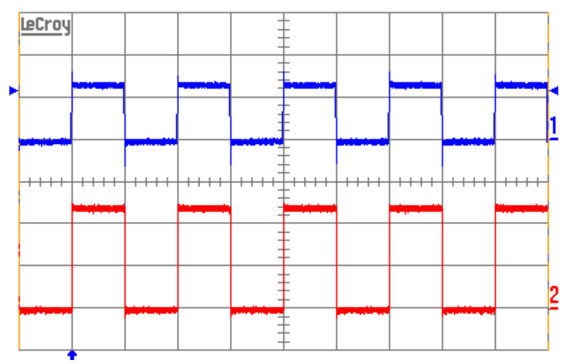
Pre-cycling @ -160 °C



Post-cycling -160 °C



Pre-cycling @ +140 °C



Post-cycling @ +140 °C

Figure 12. Pre- & post-cycling waveforms of input (trace 1) and output (trace 2) signals of FAN3122 gate driver at selected temperatures with 12 V supply and 10 kHz input. (Scale: Vertical 5V/div; Horizontal 50μs/div)

Conclusions

Wide bandgap semiconductor switching devices, such as those based on silicon carbide, can operate at higher operating temperatures, have higher breakdown voltages, and are capable of switching at very high frequencies as compared to their silicon counterparts. Switching at high speed results in more efficient and smaller power circuitry. A single-channel, high-speed gate driver capable of driving N-channel enhancement MOSFETs in low-side switching applications, ON Semiconductor FAN3122, 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 was also investigated. The gate drive was able to maintain good operation throughout the entire test regime between -160 °C and +140 °C, a broader temperature range than specified, without undergoing any major changes in its output signal and switching characteristics. Instability in the driver's output only started to appear when the test temperature was reduced further below the cryogenic value of about -165 °C. 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 -160 °C and +140 °C. The plastic packaging of such parts was also not affected by either the extreme temperature exposure or the thermal cycling. Although these preliminary results indicated the capability of this FAN3122 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]. K. Boomer et al., "Body of Knowledge for Silicon Carbide Power Electronics," NASA NEPP Report, May 2017. https://nepp.nasa.gov/files/27644/NEPP-BOK-2016-GRC-Boomer-SiC-TN35760.pdf

[2]. ON Semiconductor, "FAN3121/FAN3122 Single 9-A High-Speed, Low-Side Gate Driver," Publication FAN3122T-F085/D, Rev. 2, October 2017. https://www.onsemi.com/pub/Collateral/FAN3122T_F085-D.PDF

Acknowledgements

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