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Operation of a New Half-Bridge Gate Driver for Enhancement-Mode GaN FETs, Type LM5113, Over a Wide Temperature Range

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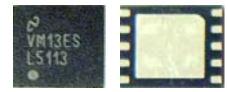
Scope

Semiconductor devices based on wide-bandgap materials, such as gallium nitride (GaN), are becoming more readily available as this enabling technology begins to mature, largely due to advancement in the manufacturing process by maximizing yield and reducing defects at the wafer level, ability to grow GaN structures on silicon substrates, and reduced production cost. The low on-resistance of wide-bandgap materials allows the development of a new generation of transistor devices that switch faster and with much reduced losses [1]. The combined higher switching speed and efficiency of GaN transistors, for example, allows the operation of DC/DC converters at very high frequencies, thereby reducing weight, saving board space, and conserving power. Because of the high switching frequencies, circuits populated with GaN switches, particularly the enhancement-mode field-effect transistor (eGaN FET), are sensitive to layout [1]. In addition, the gate construction of the normally-off eGaN device limits the range of the gate voltage that can be applied without damaging the device. While a typical gate voltage for eGaN FET is around 4.5 to 5.5 V, it is not recommended to exceed a 6-V level [2].

A new commercial-off-the-shelf (COTS) gate driver designed to drive both the high-side and the low-side enhancement-mode GaN FETs in a synchronous buck or a half bridge configuration was released by National Semiconductor Corporation. This 5A, 100V, LM5113 device can operate up to several MHz with low power consumption [3]. The high-side bias voltage is generated using a bootstrap technique and is internally clamped at 5V, which prevents the gate voltage from exceeding the maximum gate-source voltage rating of eGaN FETs [3]. The device is offered in a standard LLP-10 pin package, which contains an exposed pad to aid power dissipation, and is rated for -40 °C to +125 °C junction temperature range. Table I shows some of the device manufacturer's specifications [3].

The operation of the half-bridge LM5113 driver was investigated over a wide temperature regime that extended beyond its specified range. The driver was evaluated using the circuit configuration shown in Figure 1 with some modifications. These included the omission of the pull-up and pull-down resistors, which are optional for elimination of undesired spikes and reducing ringing and over-shoot, no load was applied, and V_{HS} was tied to V_{SS} at 0V. These were similar to the test conditions reported in the datasheet of the device. A switching frequency of 200 kHz was used.

Table I. Specifications of LM5113 half-bridge driver chip [1].

Parameter	**Symbol**	
Digital Supply Voltage (V)	V_{DD}	+4.5 to +5.5
Operating Current (mA)	I_{DDO}	1
High Side Floating Voltage (V)	V_{HS}	0 to 100
Source/Sink Current (A)	I_O	1 to 3
Operating Temperature (°C)	T(oper)	-40 to +125
Low Side Turn-On Propagation Delay (ns)	t_{LPLH}	30
High Side Turn-On Propagation Delay (ns)	t_{HPLH}	30
Output Rise Time (ns)	t_r	4
Output Fall Time (ns)	t_f	4
Part #		LM5113SDE
Package		LLP-10 (4mmx4mm)
Lot Number		M1118

The driver chip was characterized in terms of its high-side gate drive output (HO), low-side gate drive output (LO), outputs rise time, fall time, and turn-on delay time at specific test temperatures. The propagation delay times included t_{LPLH} (LI Rising to LO Rising) and t_{HPLH} (HI Rising to HO Rising). The rise and fall times of the driver output signals as well as the supply current were also recorded. The operational characteristics of the drive circuit were obtained over the test temperature range between -194 °C and +150 °C using a liquid nitrogen-cooled environmental chamber. Re-restart capability of the circuit at extreme temperatures, i.e. power switched on while the driver chip was soaking at extreme (hot or cold) temperature, 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 +150 °C at a temperature rate of 10 °C/minute. Following the thermal cycling, circuit measurements were then performed at the test temperatures of +23, -194, and +150°C using a soak time of at least 30 minutes at these test temperatures. Figure 2 shows the half-bridge driver chip mounted on a circuit board along with the ceramic bootstrap and decoupling capacitors.

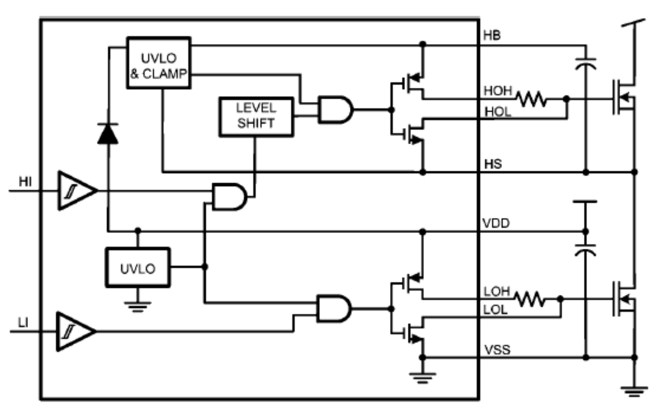


Figure 1. Schematic of test circuit of the LM5113 half-bridge driver [3].

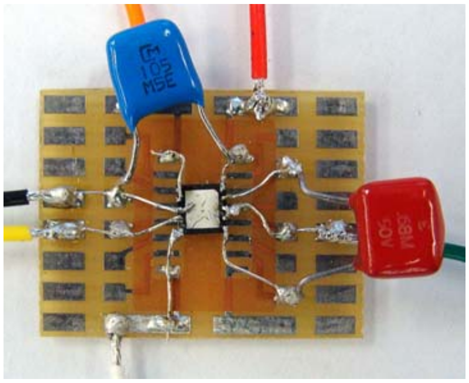


Figure 2. LM5113 half-bridge driver and ceramic capacitors mounted on test board.

Test Results

Temperature Effects

Waveforms of the LM5113 low-side driver (LO) and the high-side driver (HO) output signals along with the input signals for the low-side (LI) and high-side (HI) drives 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 +50, +75, +100, +125, +130, +140, +145, +150, 0, -25, -50, -75, -100, -125, -150, -175, -190, and -194 °C. The circuit maintained proper operation and no major change was observed in the shape or magnitude of these waveforms as test temperature was changed throughout the range of -194 °C to +150 °C. For illustrative purposes, therefore, only waveforms obtained at the extreme temperatures of -194 °C and +150 °C are also presented here as shown in Figures 4 and 5, respectively.

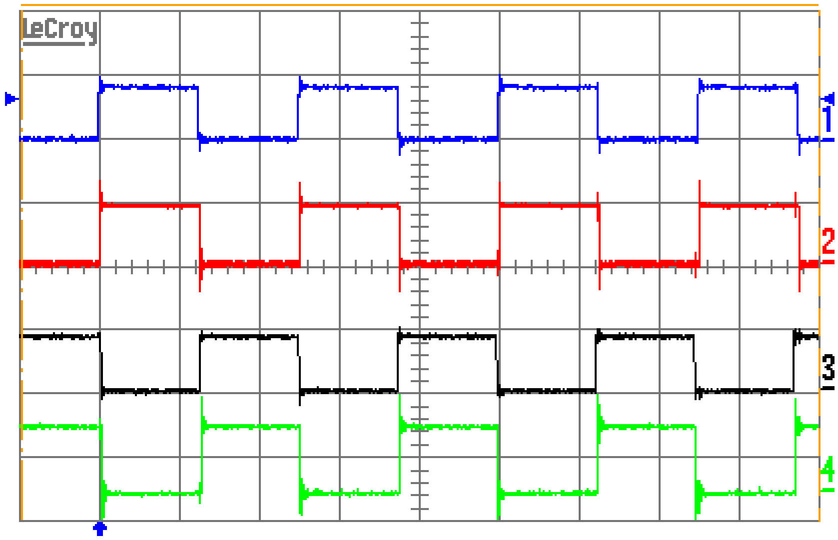


Figure 3. HI (trace 1), HO (trace 2), LI (trace 3), and LO (trace 4) signals at +23°C.
(Scale: Vertical 5V/div; Horizontal 2μs/div, for all signals)

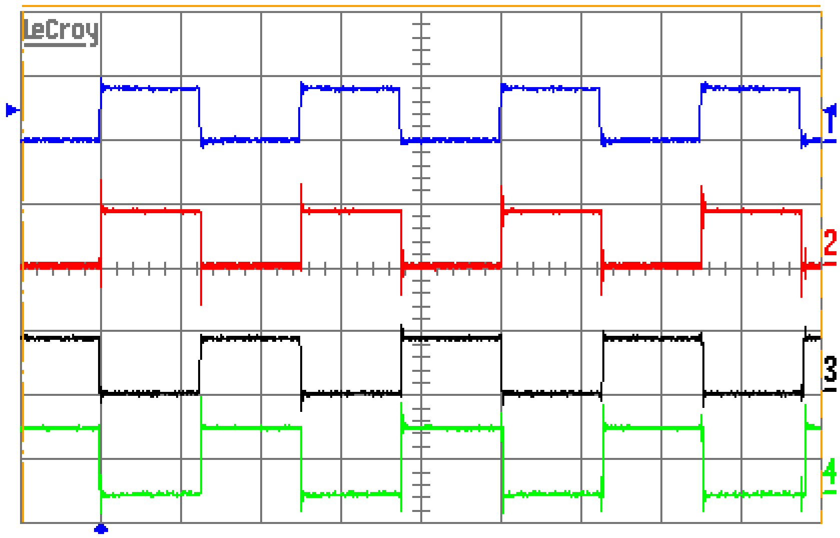


Figure 4. HI (trace 1), HO (trace 2), LI (trace 3), and LO (trace 4) signals at -194°C. (Scale: Vertical 5V/div; Horizontal 2μs/div, for all signals)

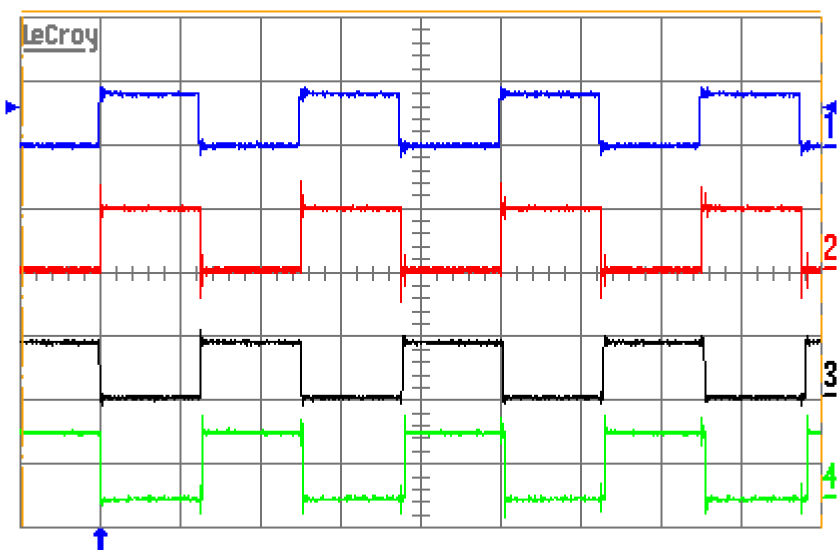


Figure 5. HI (trace 1), HO (trace 2), LI (trace 3), and LO (trace 4) signals at +150°C. (Scale: Vertical 5V/div; Horizontal 2μs/div, for all signals)

Figure 6 shows the turn-on propagation delay time t_{LPLH} for the low-side drive (LI rising to LO rising) and the turn-on propagation delay time t_{HPLH} for the high-side drive (HI rising to HO rising) of the half-bridge driver as a function of temperature. It can be seen that both drives, at any given test temperature, displayed comparable values in their turn-on propagation delay time. Similar trend was also observed in the these attributes with change in temperature as the propagation delay time, for either drive, exhibited gradual but slight increase as the test conditions varied from cryogenic to high temperature, as depicted in Figure 6. This increase amounted to little over doubling-up in the turn-on propagation delay time values as temperature was raised from -194 °C to + 150 °C.

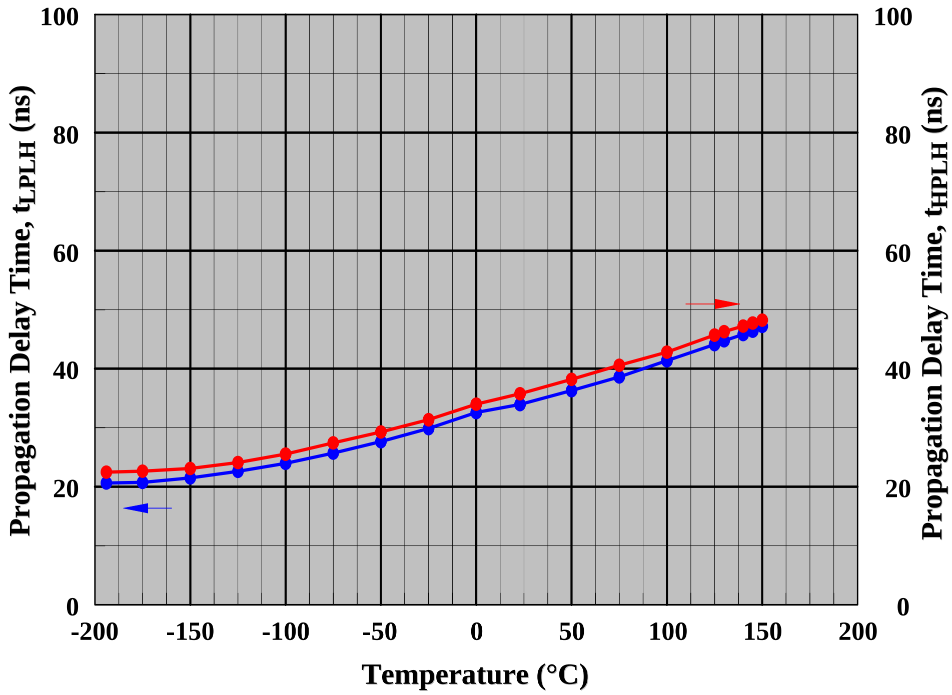


Figure 6. Turn-on propagation delay times, t_{LPLH} and t_{HPLH}, as a function of temperature.

The rise and fall time times of the output signal of the low-side driver are shown in Figure 7 as a function of temperature. Little effect of temperature was found on these characteristics of the driver as their values held almost a steady value throughout the test temperature range. Similar behavior was observed for these properties of the other drive, i.e. high-side, as shown in Figure 8.

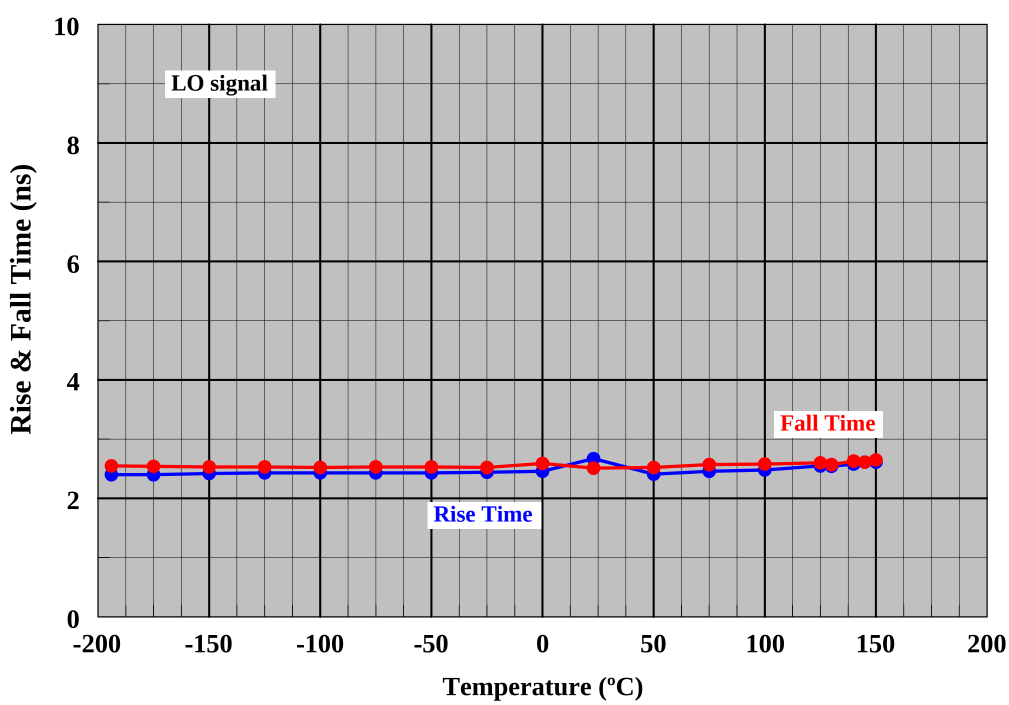


Figure 7. Rise and fall times of low-side driver output signal (LO) versus temperature.

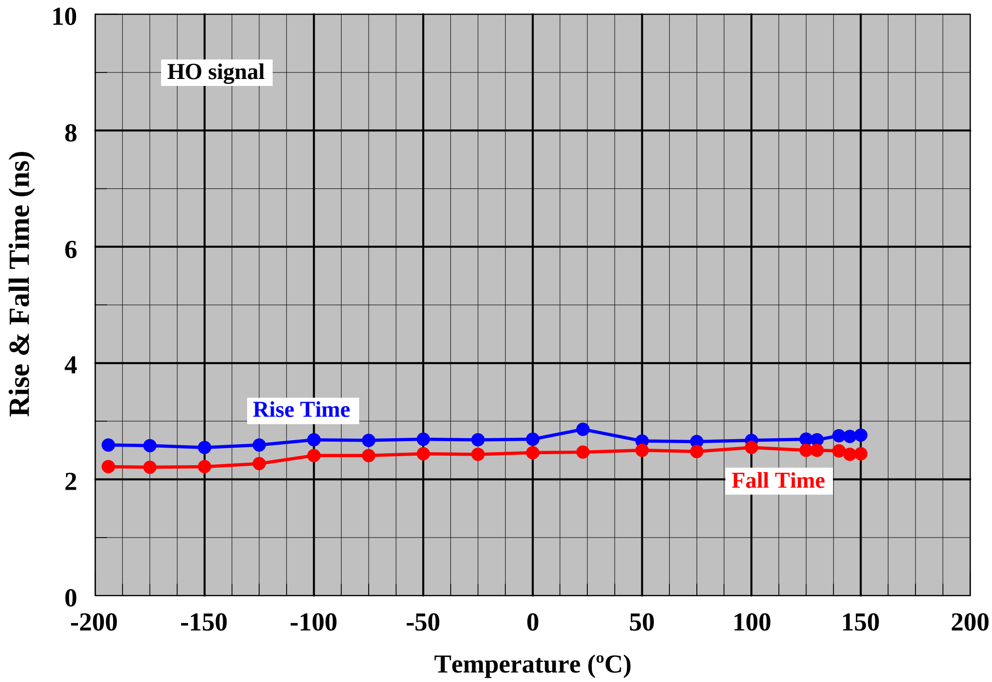


Figure 8. Rise and fall times of high-side driver output signal (HO) versus temperature.

The input current of the driver chip showed some modest dependency on temperature mostly in the cryogenic region, as shown in Figure 9. While the current did not undergo any significant change when test temperature increased from room to +150 °C, it exhibited gradual decrease as temperature was decreased below 23 °C. As illustrated in Figure 9, the current dropped from 0.72 mA at 23 °C to 0.5 mA at -194 °C.

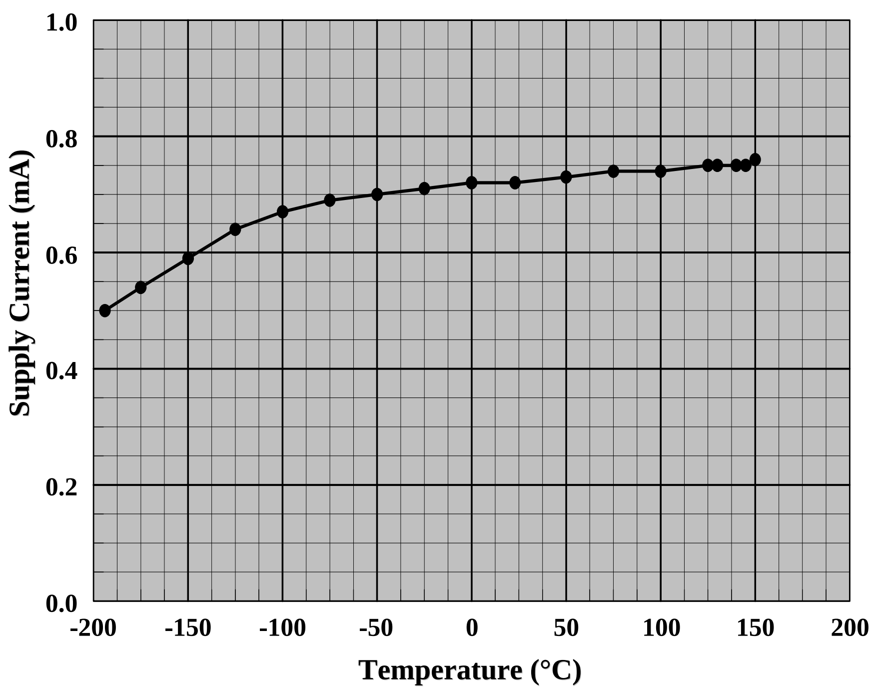


Figure 9. Supply current of the LM5113 driver as a function of temperature.

Restart at Extreme Temperatures

Restart capability of the LM5113 half-bridge 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 +150 °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

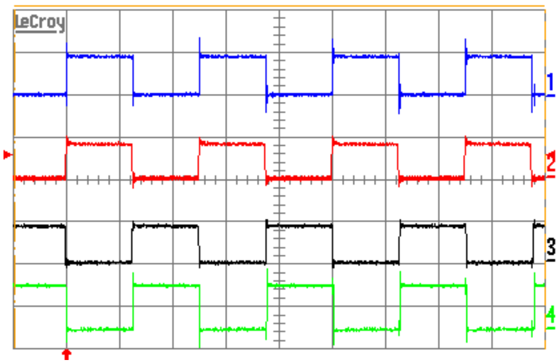
The effects of limited thermal cycling under a wide temperature range on the operation of the LM5113 eGaN FET half-bridge driver IC chip were investigated by subjecting it to a total of 12 cycles between -194 °C and +150 °C at a temperature rate of 10 °C/minute. A dwell time of 15 minutes was applied at the extreme temperatures. Following cycling, measurements of the investigated parameters were taken again as a function of temperature. A comparison of the input and output signals of both the low-side and high-side drivers at the selected test temperatures of +23, -194, and +150 °C for pre - and post-cycling conditions are shown in Figure 10. 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, switching characteristics, and the current, as depicted in Table II at the selected three test temperatures. Based on this preliminary investigation it, therefore, can be concluded that the extreme temperature exposure and the limited thermal cycling did not induce much change in the behavior of this half-bridge 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.

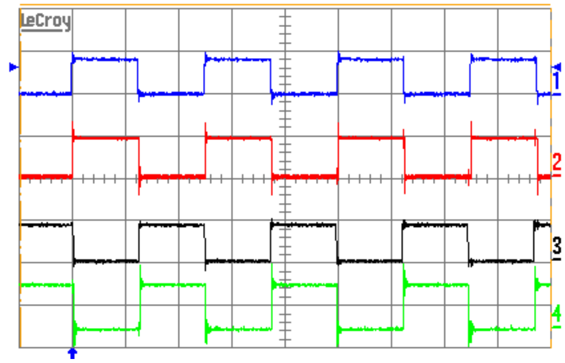
	Delay Time t_{LPLH} (ns)		**Delay Time t_{HPLH} (ns)**		**LO Signal t_r (ns)**	**LO Signal t_f (ns)**	**HO Signal t_r (ns)**	**HO Signal t_f (ns)**	**Input Current (mA)**	
Temp (°C)	Prior	Post	Prior	Post	Prior	Post	Prior	Post	Prior	Post
+23	33	34	35	36	2.67	2.89	2.86	2.81	0.72	0.73
-194	21	20	22	22	2.40	2.83	2.59	2.63	0.50	0.50
+150	47	47	48	48	2.61	3.08	2.76	2.72	0.76	0.76

Long-Term Thermal Cycling

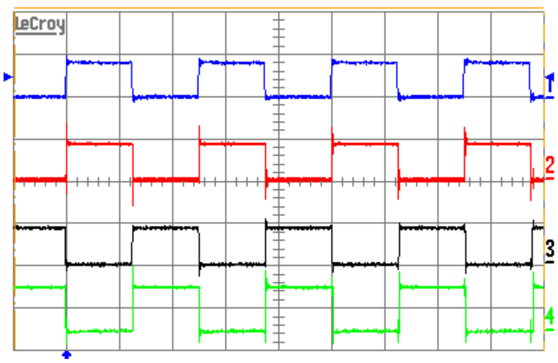
Although this work provided some insight on the capability of this driver chip to operate in temperature zones that extended beyond its specified low and high temperature limits without impact on its performance as well as surviving exposure to limited cycling under a very wide temperature range, these 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. A test plan is currently underway to perform long-term thermal cycling that adheres to NASA and/or military standards.



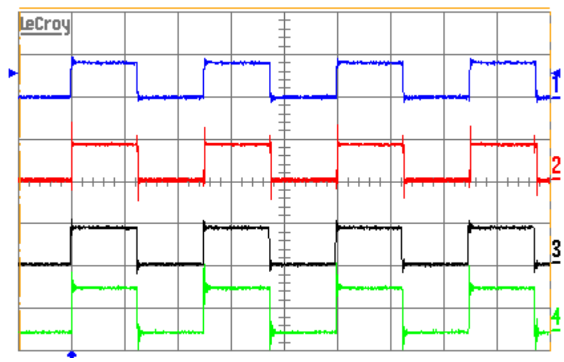
Pre-cycling @ 23 °C



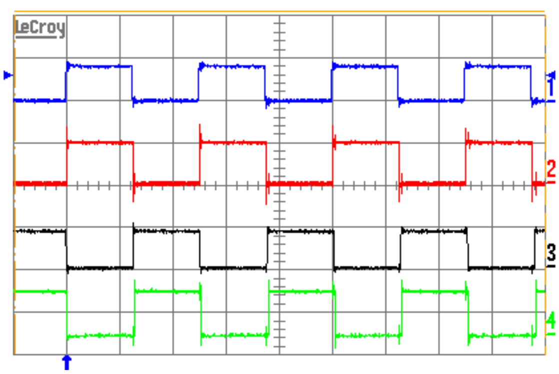
Post-cycling @ 23 °C



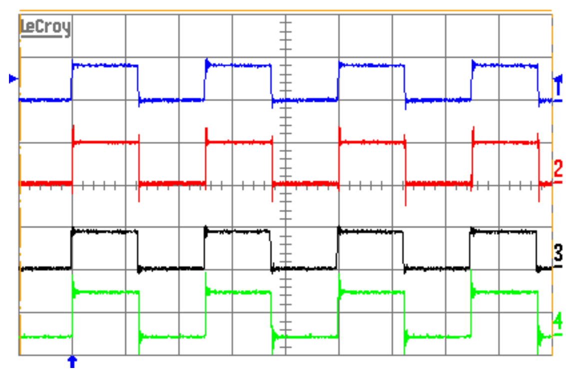
Pre-cycling @ -194 °C



Post-cycling -194 °C



Pre-cycling @ +150 °C



Post-cycling @ +150 °C

Figure 10. Pre- & post-cycling waveforms of HI (trace 1), HO (trace 2), LI (trace 3), and LO (trace 4) signals of LM5113 half-bridge driver at selected temperatures.

Conclusions

A new commercial-off-the-shelf (COTS) gate driver designed to drive both the high-side and the low-side enhancement-mode GaN FETs, National Semiconductor's type LM5113, was evaluated for operation at temperatures beyond its recommended specified limits of -40 °C to +125 °C. The effects of limited thermal cycling under the extended test temperature, which ranged from -194 °C to +150 °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 +150 °C without undergoing any major changes in its outputs signals 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 +150 °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 new commercial-off-the-shelf (COTS) half-bridge eGaN FET driver integrated circuit has the potential for use in space exploration missions under extreme temperature environments. Further testing is planned under long-term cycling to assess the reliability of these parts and to determine their suitability for extended use in the harsh environments of space.

References

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[2]. Margery Conner, "GaN and SiC: On Track for Speed and Efficiency," EDN Magazine, pp 33-39, August 25, 2011. http://www.edn.com

[3]. National Semiconductor "LM5113 5A, 100V Half-Bridge Gate Driver for Enhancement Mode GaN FETs" Data Sheet, Preliminary 301629, June 29, 2011. http://www.national.com

Acknowledgements

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