Assessment of SOI Integrated Circuits at Extreme Temperatures

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ABSTRACT

Electronics designed for use in future NASA space exploration missions are expected to encounter extreme temperatures and wide thermal swings. Such missions include planetary surface exploration, bases, rovers, landers, orbiters, and satellites. Electronics designed for such applications must, therefore, be able to withstand exposure to extreme temperatures and to perform properly for the duration of mission. The Low Temperature Electronics Program at the NASA Glenn Research Center focuses on research and development of electrical devices, circuits, and systems suitable for applications in deep space exploration missions and aerospace environment.

Silicon-On-Insulator (SOI) technology has been under active consideration in the electronics industry for many years due to the advantages that it can provide in integrated circuit (IC) chips and computer processors. Faster switching, less power, radiation-tolerance, reduced leakage, and high temperature capability are some of the benefits that are offered by using SOI-based devices. A few SOI circuits are available commercially. However, there is a noticeable interest in SOI technology for different applications. Very little data, however, exist on the performance of such circuits under cryogenic temperatures.

In this work, the performance of SOI integrated circuits, evaluated under low temperature and thermal cycling, are reported. In particular, three examples of SOI circuits that have been tested for operation at low at temperatures are given. These circuits are SOI operational amplifiers, timers and power MOSFET drivers. The investigations were carried out to establish a baseline on the functionality and to determine suitability of these circuits for use in space exploration missions at cryogenic temperatures. The findings are useful to mission planners and circuit designers so that proper selection of electronic parts can be made, and risk assessment can be established for such circuits for use in space missions.

Assessment of SOI Devices and Circuits at Extreme Temperatures

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Reliability of Advanced Electronic Packages and Devices
in Extreme Cold Environment

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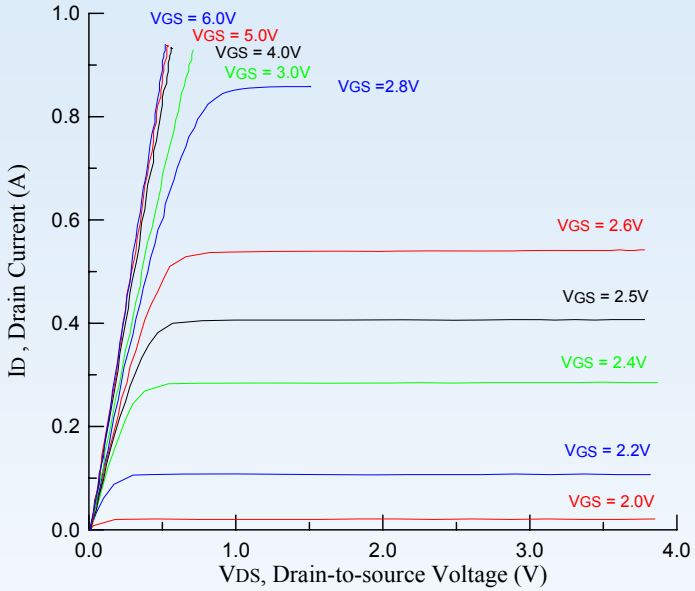
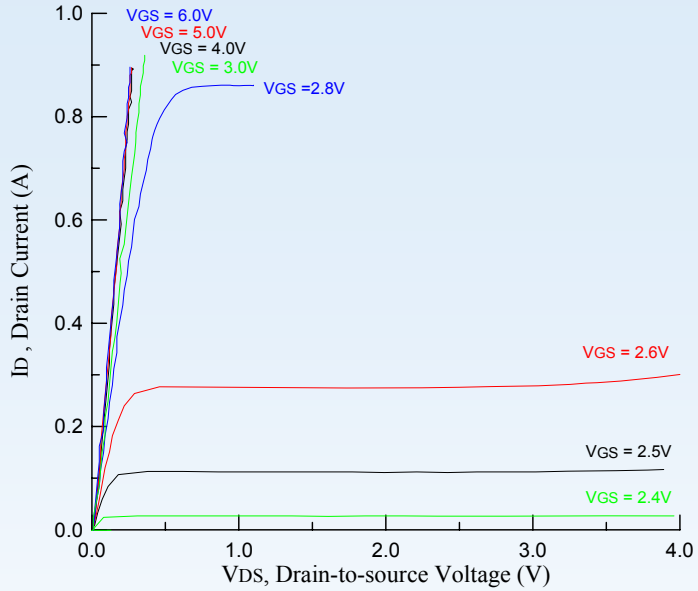
SOI-Based Devices

- Exhibit fast switching speeds
- Low power consumption
- Reduced leakage currents
- Good radiation tolerance
- Extreme temperature operability
- SOI CMOS offers a 20–35% performance gain over bulk CMOS.
- High-performance microprocessors using SOI CMOS are commercially available
- SOI application is spreading to lower-end microprocessors, SRAMs and ASIC.
- Higher Drive Currents
- S/D Capacitance Reduction
- Reduced Short channel effects
- Better Sub-Threshold slope
- No Latch-up
- Better SER at smaller dimensions

Output Characteristics of an SOI power FET Device



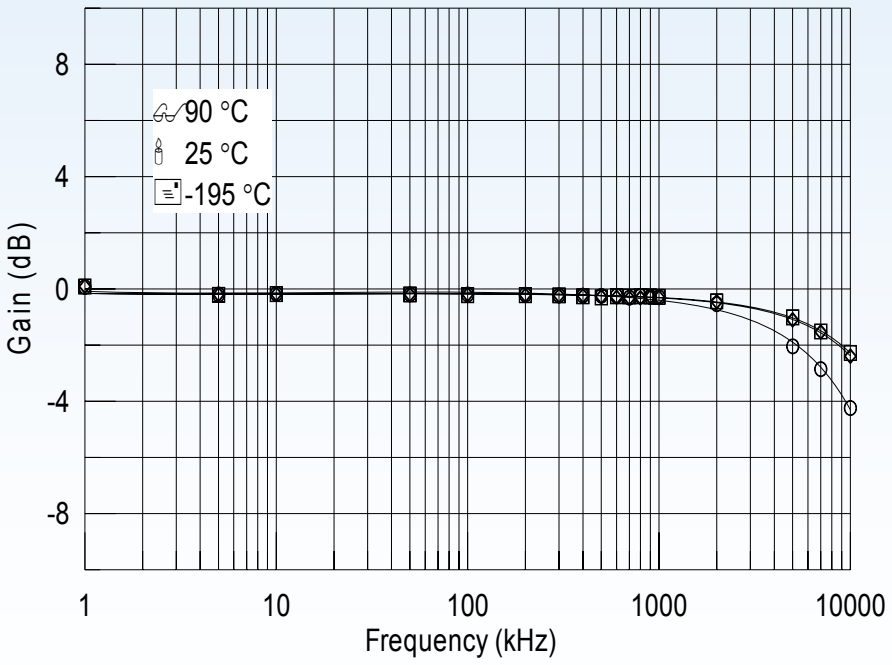
at 20 °C

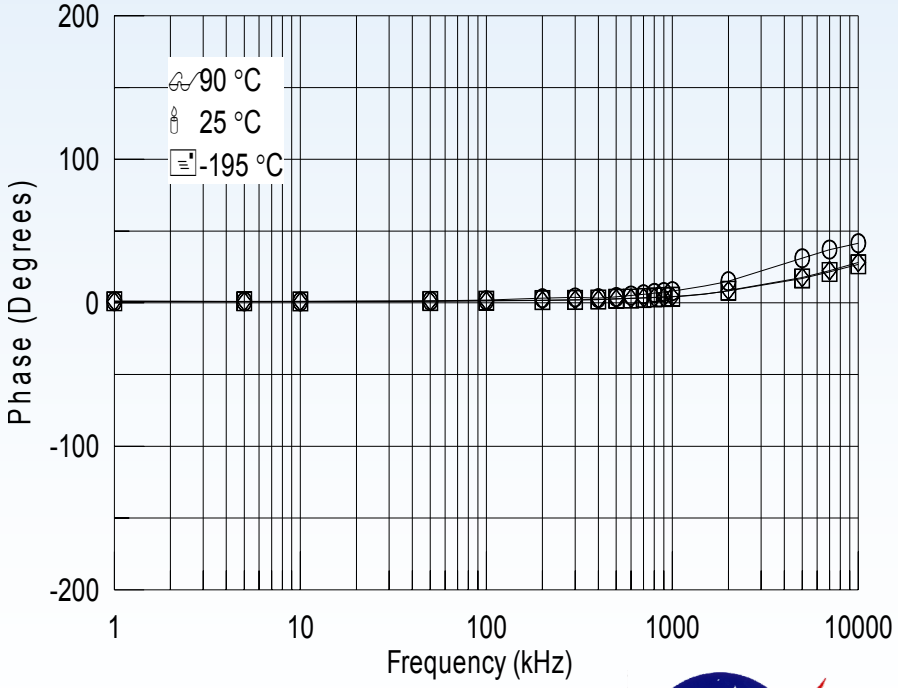


at -190 °C

- Device was evaluated in the temperature range of -190 °C to +20 °C
- The gate threshold voltage (VGS(th)), drain-to-source on-state resistance (RDS(on)), and drain current (ID) versus drain-to-source voltage (VDS) curves at various gate voltages (VGS).
- Cold re-start at -190°C

Gain & Phase of an SOI Operational Amplifier Analog Devices AD8065



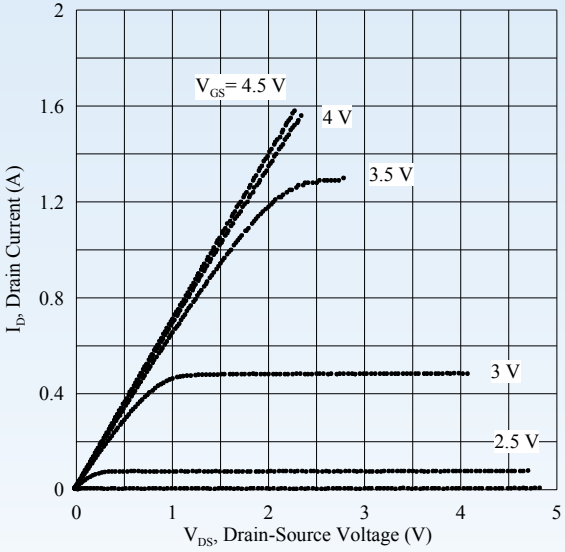


Performance of an SOI HTNFET device

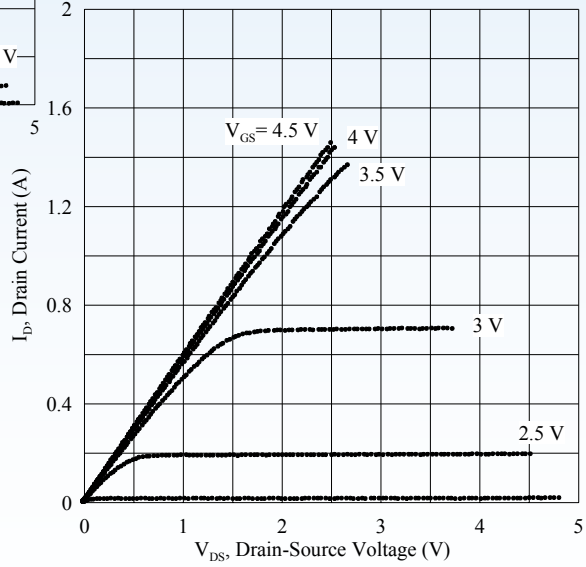
- The performance of an SOI HTNFET device was evaluated in the temperature range of -195 °C to +100 °C for potential use at extreme temperatures.
- The properties investigated included gate threshold voltage (VGS(th)), drain-to-source on-state resistance (RDS(on)), and drain current (ID) versus drain-to-source voltage (VDS) curves at various gate voltages (VGS).
- Cold re-start at -195 °C and thermal cycling between -195 °C and +70 °C were also performed on the transistor.

SOI N-Channel Power Field Effect Transistor

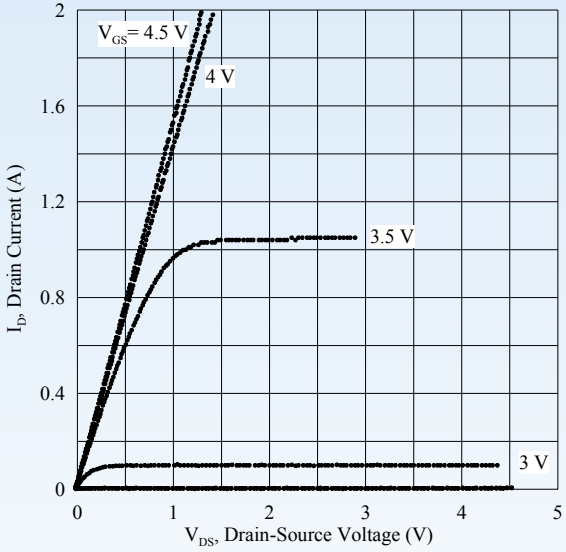
Characteristic curves of the SOI HTNFET test temperatures between -195 °C and +100 °C.



(25 °C)



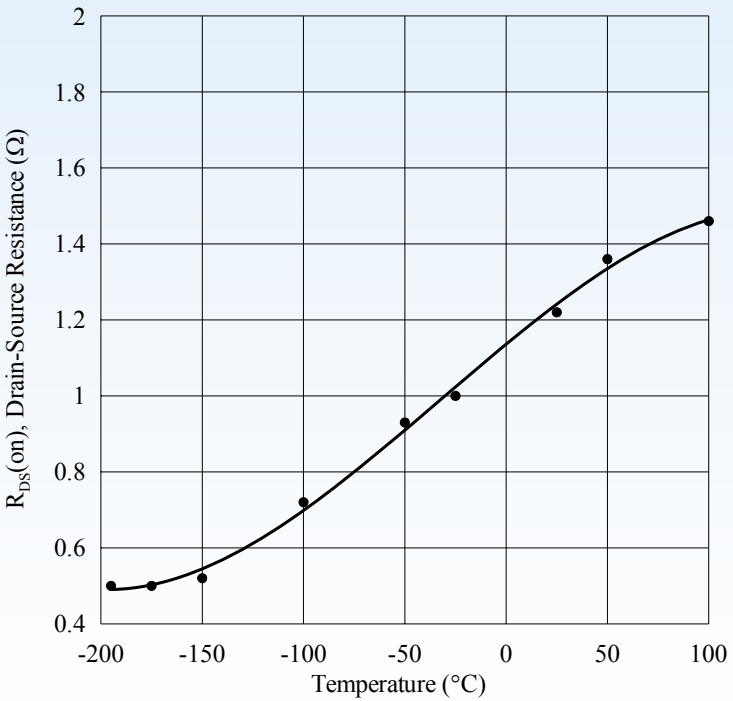
(100 °C)



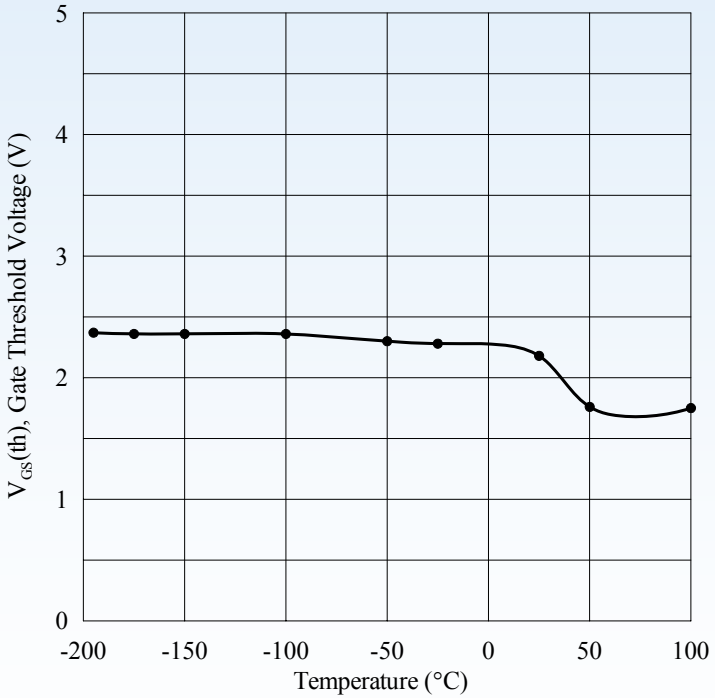
(-195 °C)

SOI N-Channel Power Field Effect Transistor

Drain-source resistance (@ ID=0.1A, VGS=4V) of SOI HTNFET versus temperature.



Gate threshold voltage of the SOI HTNFET as a function of temperature.

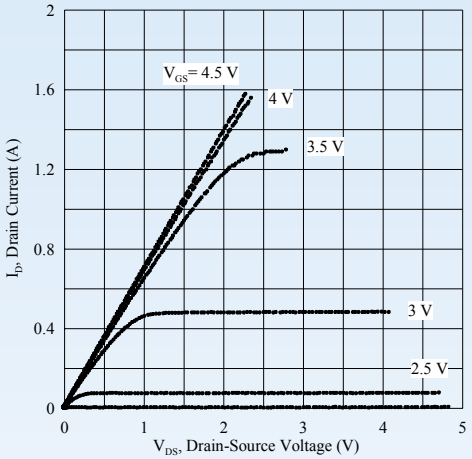


Discussions

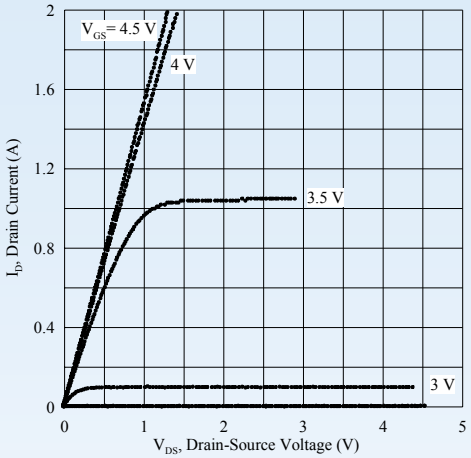
Two changes in its characteristics are observed with decreasing test temperature.

- The increase in the slope of its ID/VDS in the transistor's linear region as temperature is decreased is an indication of a decrease in the transistor drain-to-source on-state resistance RDS(on).
- The second change, that was exhibited by the HTNFET ID/VDS performance when test temperature was varied from ambient to -195 °C, was the downward shift in the characteristic curves in the saturation region. This behavior is indicative of an increase in the gate threshold voltage (VGS(th)) with lowering temperature as more gate-to-source voltage (VGS) is needed to maintain a constant drain current.

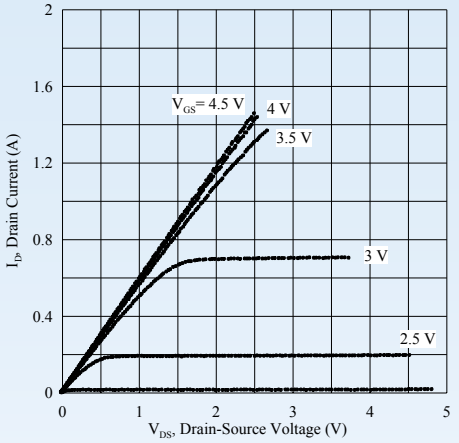
Effect of Thermal Cycling



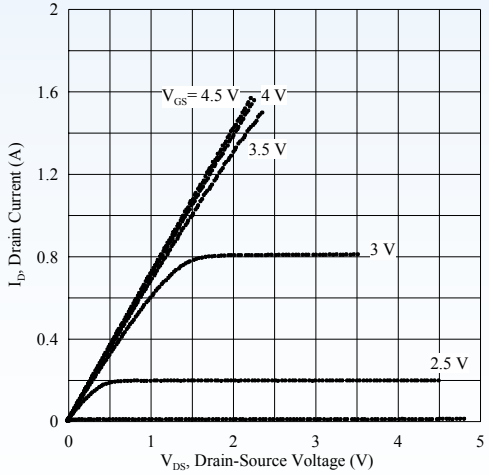
Pre-cycling at +25 °C



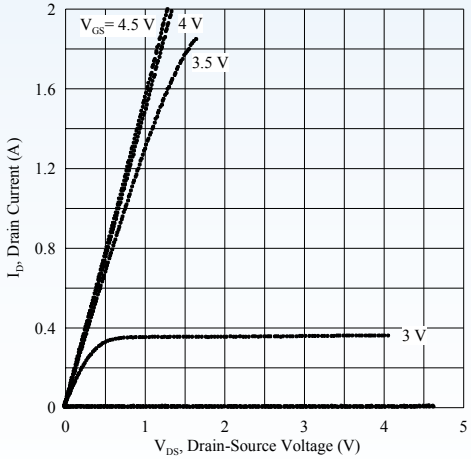
Pre-cycling at -195 °C



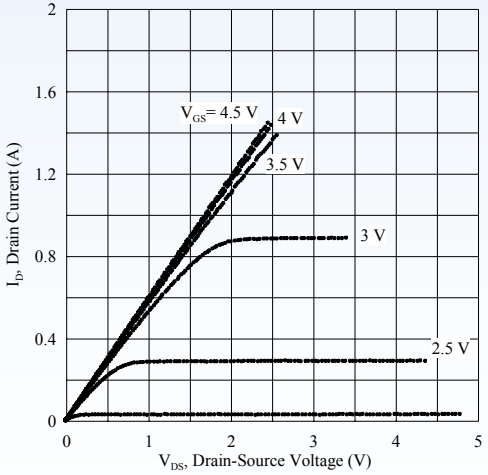
Pre-cycling at +100 °C



Post-cycling at +25 °C



Post-cycling at -195 °C



Post-cycling at +100 °C

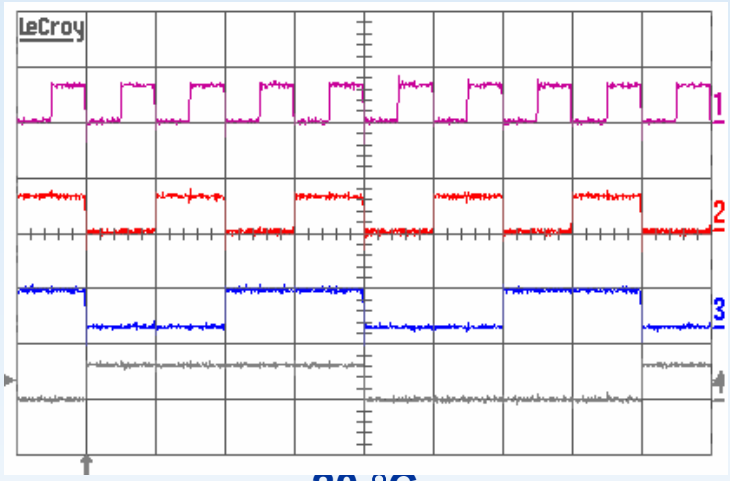
Results & Discussions

- The results indicate that the temperature-induced changes consisted of a slight increase in the gate threshold voltage and a slight decrease in the on-state resistance when test temperature was varied from ambient to -150 °C.
- These changes reversed trend when the transistor was subjected to high temperatures, i.e. +50 °C and +100 °C.
- Exposure of the transistor to cryogenic temperatures between -150 °C and -195 °C produced no further effect on its characteristics.
- It was also found that this SOI HTNFET was able to cold re-start at -195 °C, and the applied limited thermal cycling has yielded insignificant changes in its characteristics.
- Comprehensive testing is required to assess reliability and address suitability of such and other devices for long term use under extreme temperatures in space exploration missions.

SOI high temperature crystal clock generator

- The performance of an SOI high temperature crystal clock generator (HTCCG) was evaluated in the temperature range of -195 °C to +100 °C for potential use at cryogenic temperatures.
- The four frequency outputs of the clock generator (FOUT, FOUT/2, FOUT/4, and FOUT/8) were recorded at selected test temperatures using an external square wave clock signal with frequency of 500 kHz and 1 MHz.
- The chip output signal characteristics in terms of rise time, fall time, and duty cycle were also obtained as a function of temperature.
- Cold re-start capability of the device was investigated at -195 °C.

SOI high temperature crystal clock generator



F_{OUT}

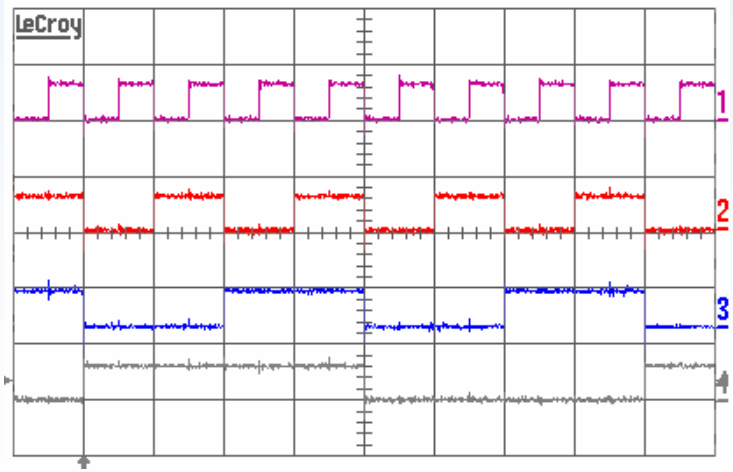
$F_{OUT/2}$

$F_{OUT/4}$

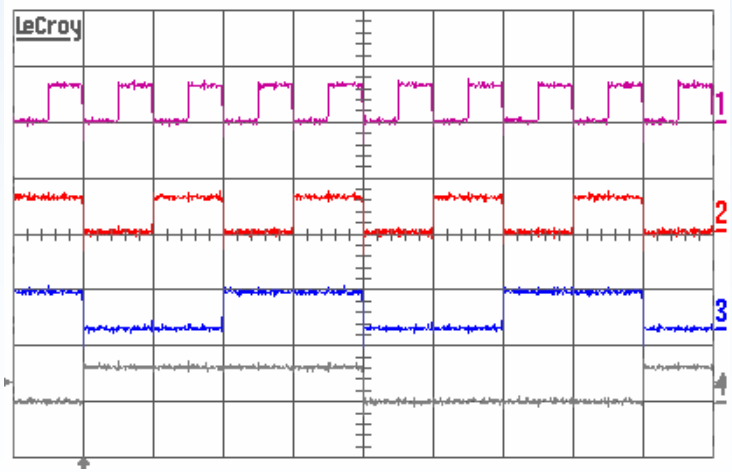
$F_{OUT/8}$

20 °C

Output Waveforms of an SOI Crystal Clock Generator At Various Temperatures @ 1 MHz (Honeywell HTCCG)



-195 °C



+100 °C

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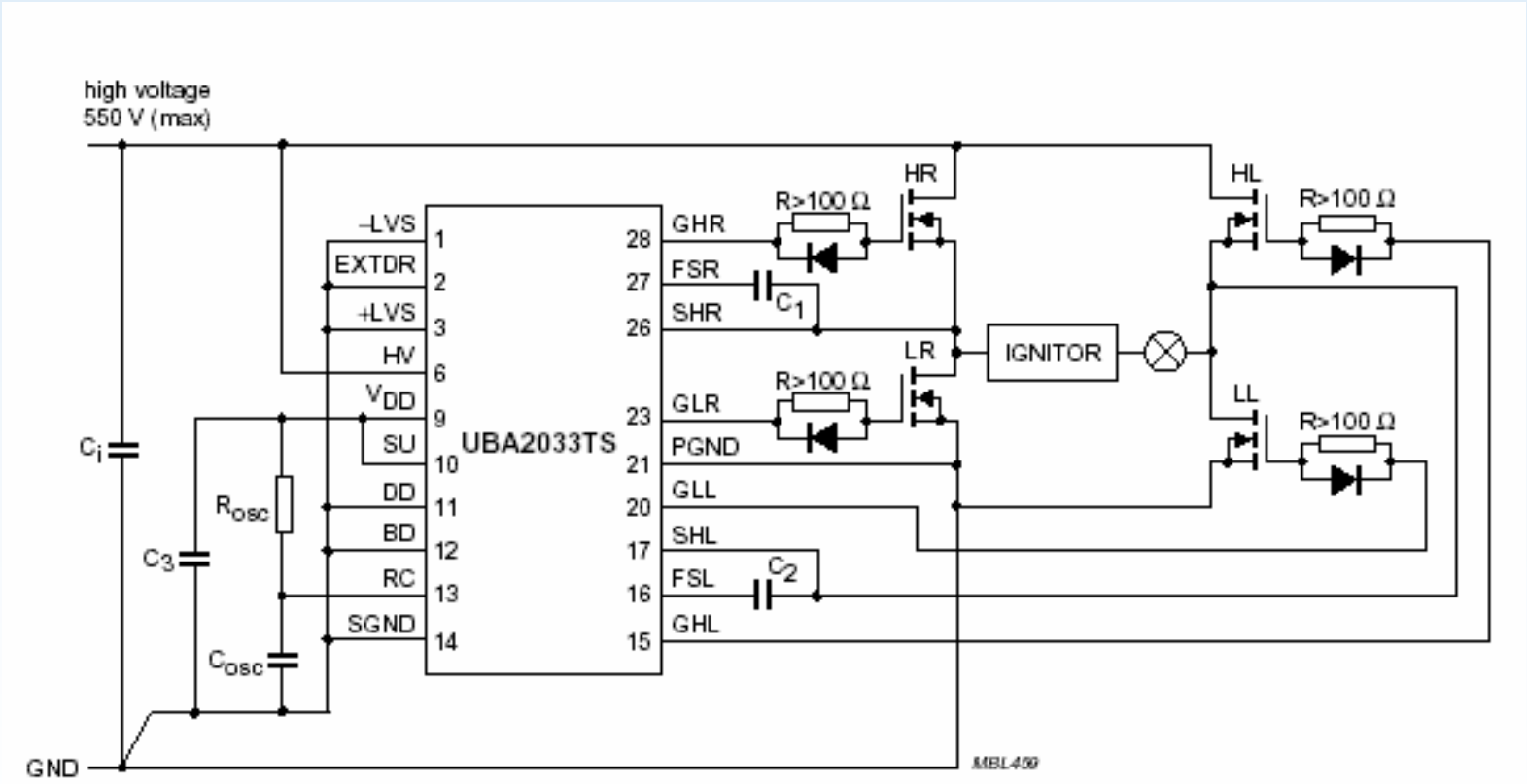
SOI high temperature crystal clock generator Results & Discussions

- SOI-based device, which is designed for high temperature applications, could potentially be used at cryogenic temperatures.
- No significant change in the performance of the device or major deviation in its output characteristics were observed upon exposure to extreme temperatures between -195 °C to +100 °C.
- It was also found that this SOI HTCCG was able to cold re-start at -195 °C.
- The ceramic-packaged device experienced no structural or physical damage due to the extreme temperature exposure.
- Comprehensive testing be carried out to assess the reliability of these devices for long term use under extreme temperatures in space exploration missions.

SOI MOSF Driver Integrated Circuit

Schematic of circuit used in the evaluation



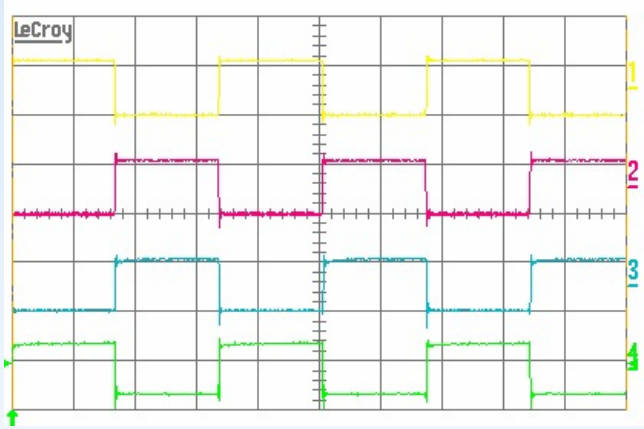
SOI MOSF Driver Integrated Circuit

Results & Discussions

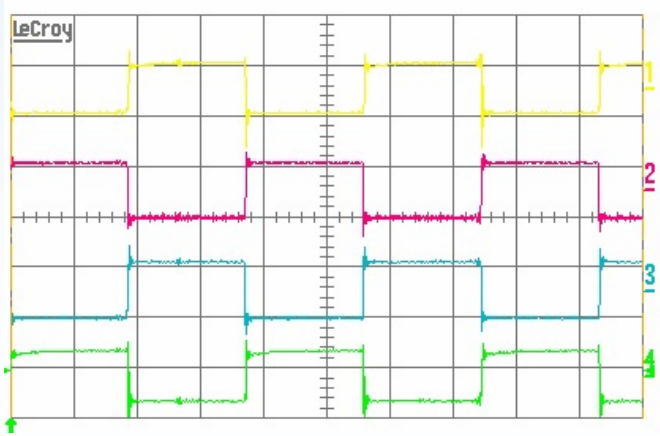
- The SOI full-bridge driver integrated circuit, Philips UBA2033, was evaluated for operation between -195 °C and +85 °C.
- The effects of thermal cycling under a wide temperature range on the operation of this chip
- Cold-restart capability were also investigated.
- The driver circuit was able to maintain good operation between -195 °C and +85 °C with minimal changes in its characteristics.
- The limited thermal cycling performed on the device had no effect on its performance, and the driver chip was able to cold start at -195 °C.
- The results indicate that this SOI-based full- bridge driver integrated circuit potentially could be used in space exploration missions under cryogenic environments.

SOI MOSF Driver Integrated Circuit

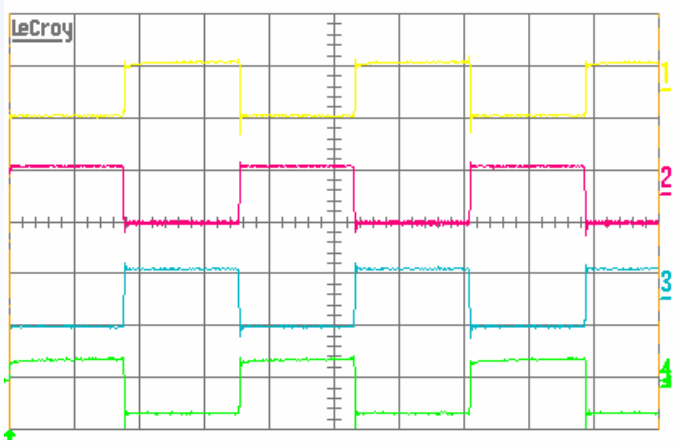
Waveforms of the driver output signals GHR, GLR, GHL, and GLL.



at +20°C



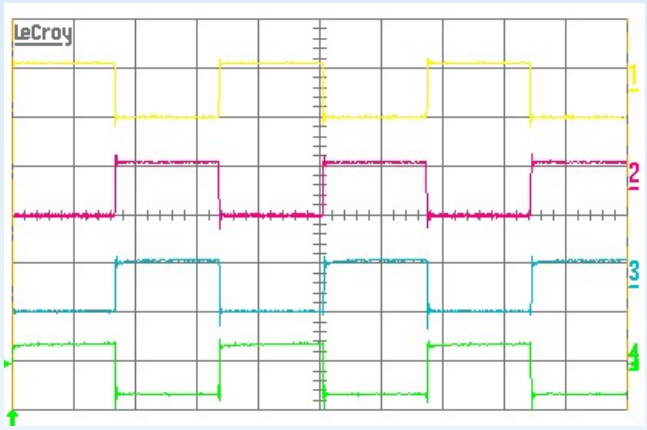
at -195°C



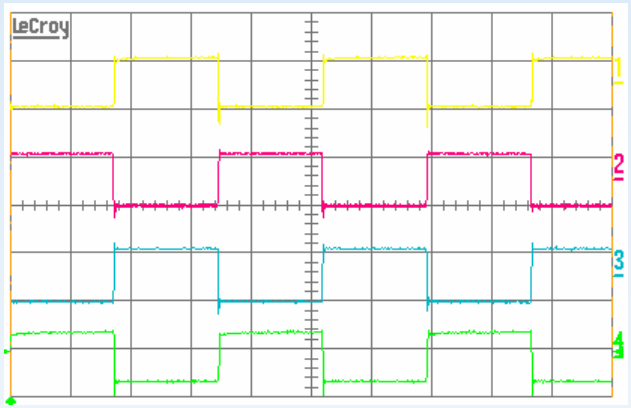
at +85°C

SOI MOSF Driver Integrated Circuit

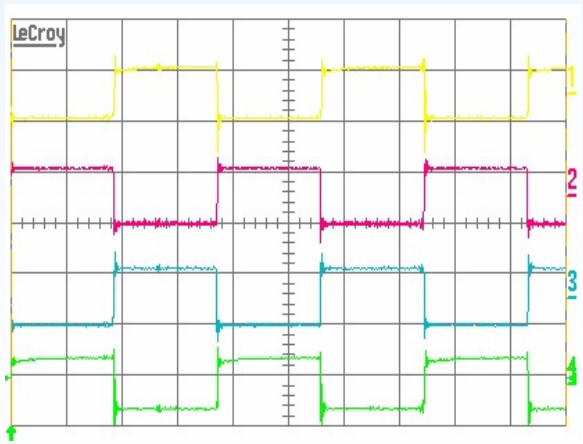
Waveforms of the driver output signals GHR, GLR, GHL, and GLL



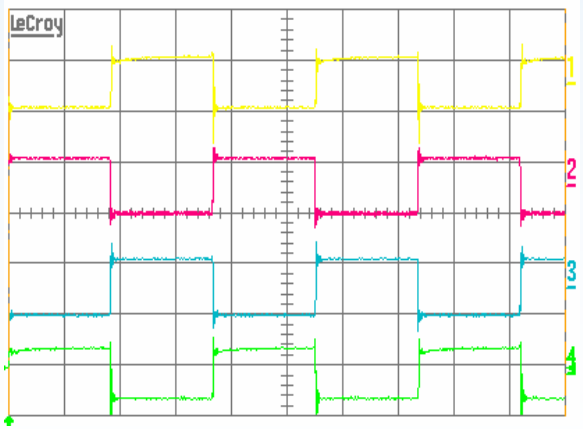
Pre-cycling at +20 °C.



Post-cycling at +20 °C.



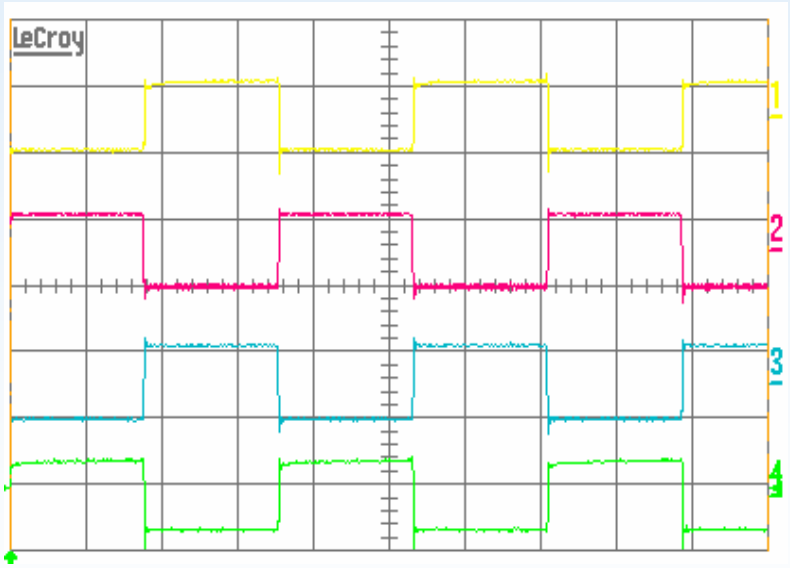
Pre-cycling at -195 °C



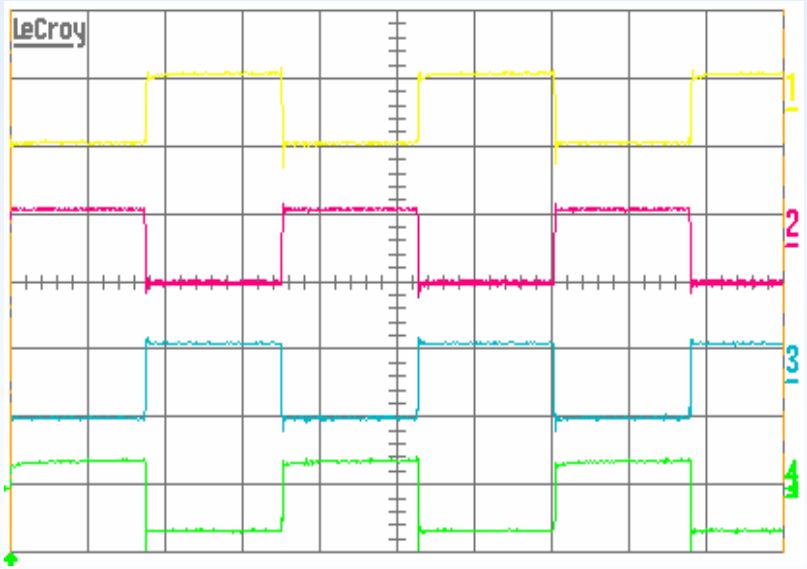
Post-cycling at -195 °C.

SOI MOSF Driver Integrated Circuit

Waveforms of the driver output signals GHR, GLR, GHL, and GLL.



Pre-cycling at +85 °C



Post-cycling at +85 °C.

Conclusions

- The Silicon-On-Insulator (SOI) Devices & integrated circuit, Philips UBA2033, were evaluated for operation between -195 °C and +85 °C.
- Effects of thermal cycling under a wide temperature range on the operation of this chip
- cold-restart capability were also investigated.
- The Devices & circuits were able to maintain good operation between -195 °C and +85 °C with minimal changes in its characteristics.
- The limited thermal cycling performed on the devices & circuits had no effect on its performance, and the driver chip was able to cold start at -195 °C.
- These preliminary results indicate that this SOI-based devices & integrated circuit potentially could be used in space exploration missions under cryogenic environments.
- Further testing under long-term cycling is, however, required to fully establish the reliability of such devices and to determine their suitability for extended use in extreme temperature environments