Wide Bandgap Reliability and Application Guidelines

NEPP-Supported GRC Activities

Kristen Boomer, NASA GRC

Ahmad Hammoud, HX5/NASA GRC

NASA NEPP Electronic Technology Workshop, Greenbelt, MD

June 15-18, 2020

Acronyms

Acronym	Definition
AEC	Automotive Electronics Council
BOK	Body of Knowledge
COTS	Commercial Off the Shelf
EEE	Electrical, Electronic, and Electromechanical
ETW	Electronics Technology Workshop
FET	Field Effect Transistor
GaN	Gallium Nitride
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HTGB	High Temperature Gate Bias
HTRB	High Temperature Reverse Bias
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LaRC	Langley Research Center
LBNL	Lawrence Berkeley National Laboratory

Acronym	Definition
MOSFET	Metal-Oxide-Semiconductor Field Effect Transistor
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
NEPP	NASA Electronic Parts and Packaging
PWM	Pulse Width Modulation
QML	Qualified Manufacturer List
SEE	Single Event Effect
SEP	Solar Electric Propulsion
Si	Silicon
SiC	Silicon Carbide
TAMU	Texas A&M University
TID	Total Ionizing Dose
ULA	United Launch Alliance
WBG	Wide Bandgap

Why Perform Reliability Tests?

- Power switching devices are a key component in power electronics and are subjected to many stresses in their normal operation within systems
- Examples of reliability tests
  - High Temperature Reverse Bias (HTRB)
  - High Temperature Gate Bias (HTGB)
  - Thermal cycling
  - Extreme temperature
  - Radiation

WBG Applicability in NASA Missions

- SiC and GaN are the Wide Bandgap (WBG) power devices of most interest to NASA
- Benefits include:
  - Higher breakdown voltage
  - Higher operating temperature
  - Higher frequency operation
  - Increased efficiency
  - Better size, weight, and power numbers
- NASA applications/missions include Solar Electric Propulsion (SEP), hybrid/electric aircraft propulsion, communications
- There are still challenges to be overcome before WBG power devices are widely adopted

NEPP-Supported GRC Activities

- **NASA Wide Bandgap (WBG) Working Group**
  - **Collaboration on pre- and post-irradiation of GaN & SiC devices**
  - **Publication of Body-of-knowledge (BOK) on WBG power devices**
    - ✓ **Completed BOK on SiC (in collaboration with GSFC)**
    - ✓ **Generating BOK on GaN (in collaboration with JPL)**
- **Performance and reliability assessment of supporting electronics for WBG power devices**
- **Evaluation of COTS and automotive-grade EEE Parts under extreme temperatures and thermal cycling**
- **NEPP website report publishing**

BOK on GaN Power Devices

- **Provide a brief guidance to GaN technology and create a "snapshot" of the current status**
  - **Technology overview**
  - **NASA applications**
  - **Ongoing work (government, industry, academia)**
  - **Challenges and limitations**
  - **Reliability**
  - **Future direction**

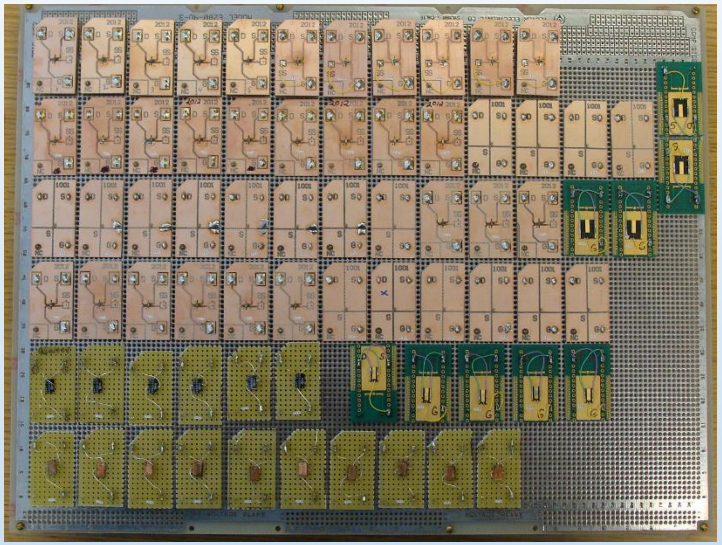
Collaborative Performance Assessment of WBG Power Devices

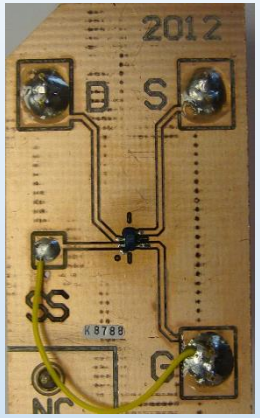
- **Collaboration with GSFC and JPL**
- **Characterization of pre- & post-irradiated power devices**
- **Extreme temperature exposure and wide-range thermal cycling**
- **High temperature reverse bias (HTRB) & high temperature gate bias (HTGB) tests of control & irradiated parts**
- **Determination of degradation & annealing**

GRC Extreme Temperature Electronics Lab

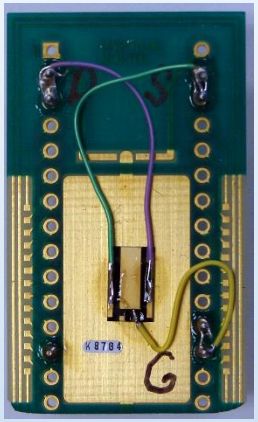
- **Two environmental chambers (0.37 ft^3; 2.2 ft^3)**
- **Extreme temperature exposure, thermal cycling, and life-testing**
- **Programmable temperature rate, dwell time, and number of cycles**
- **Temperature range: -194 ºC to +315 ºC; rate: 0.1 ºC/min to 36 ºC/min**
- **Built-in feed-throughs for multi-stress (electrical/thermal) testing**
- **Material, device, and circuit characterization**

Device-Mounted Boards

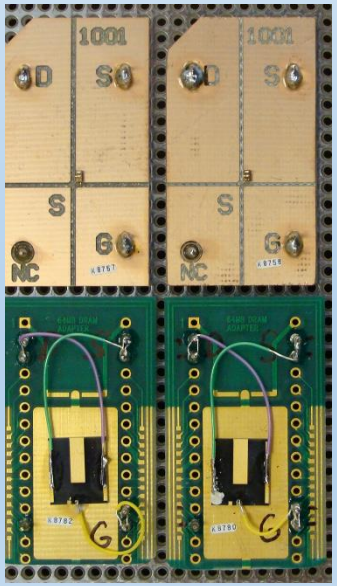


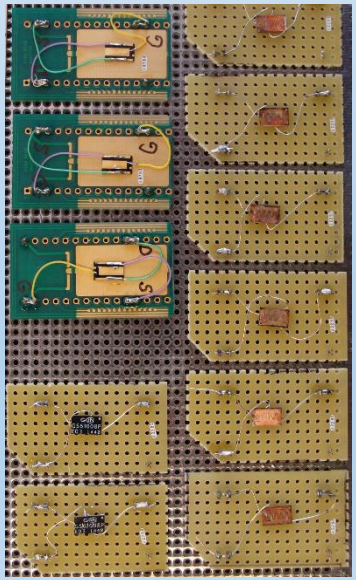


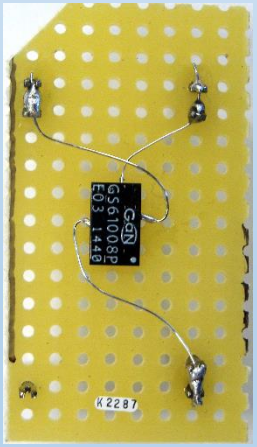
EPC 2012



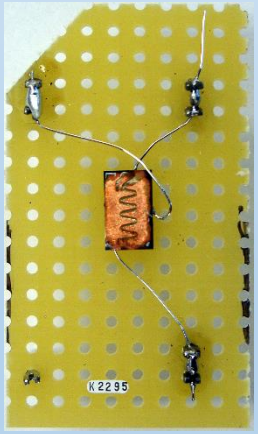
GaN GS66508P







GaN GS61008P



GaN GS61008P
(Un-capped/irradiated)

Radiation and Thermal Cycling on GaN Parts

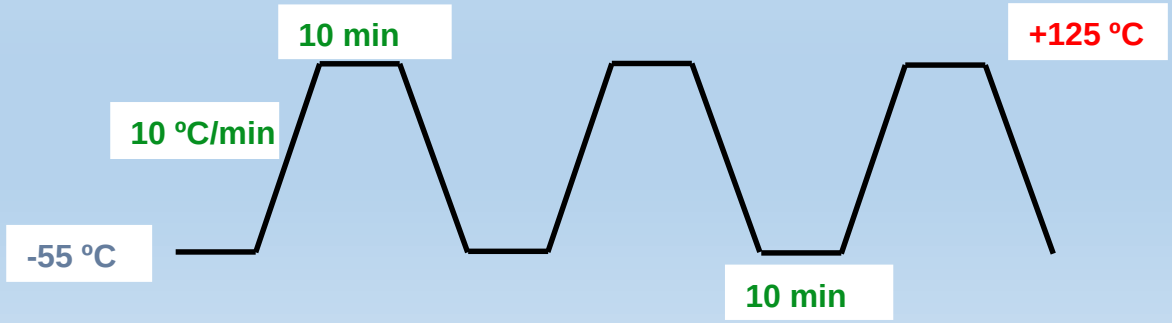
Manufacturer	Part #	Parameters	# Samples (control/Irradiated)	Radiation	Cycling
EPC	2012	200V, 3A, 100mΩ	15/26	✓	✓
GaN Systems	GS61008P	100V, 90A, 7.4mΩ	11/10	✓	✓
	GS66508P	650V, 30A, 52mΩ	4/0	Planned	✓

Radiation Exposure						
Device	Ion	Energy (MeV)	LET (MeV.cm^2/mg)	Range (μm)	Incidence Angle	Facility
EPC	Xe	3197	41	286	Normal	TAMU*
GaN Systems	Ag	2651	42 - 48	90	Normal	TAMU*/LBNL*
	Au	2594	87	118	Normal	TAMU*/LBNL*

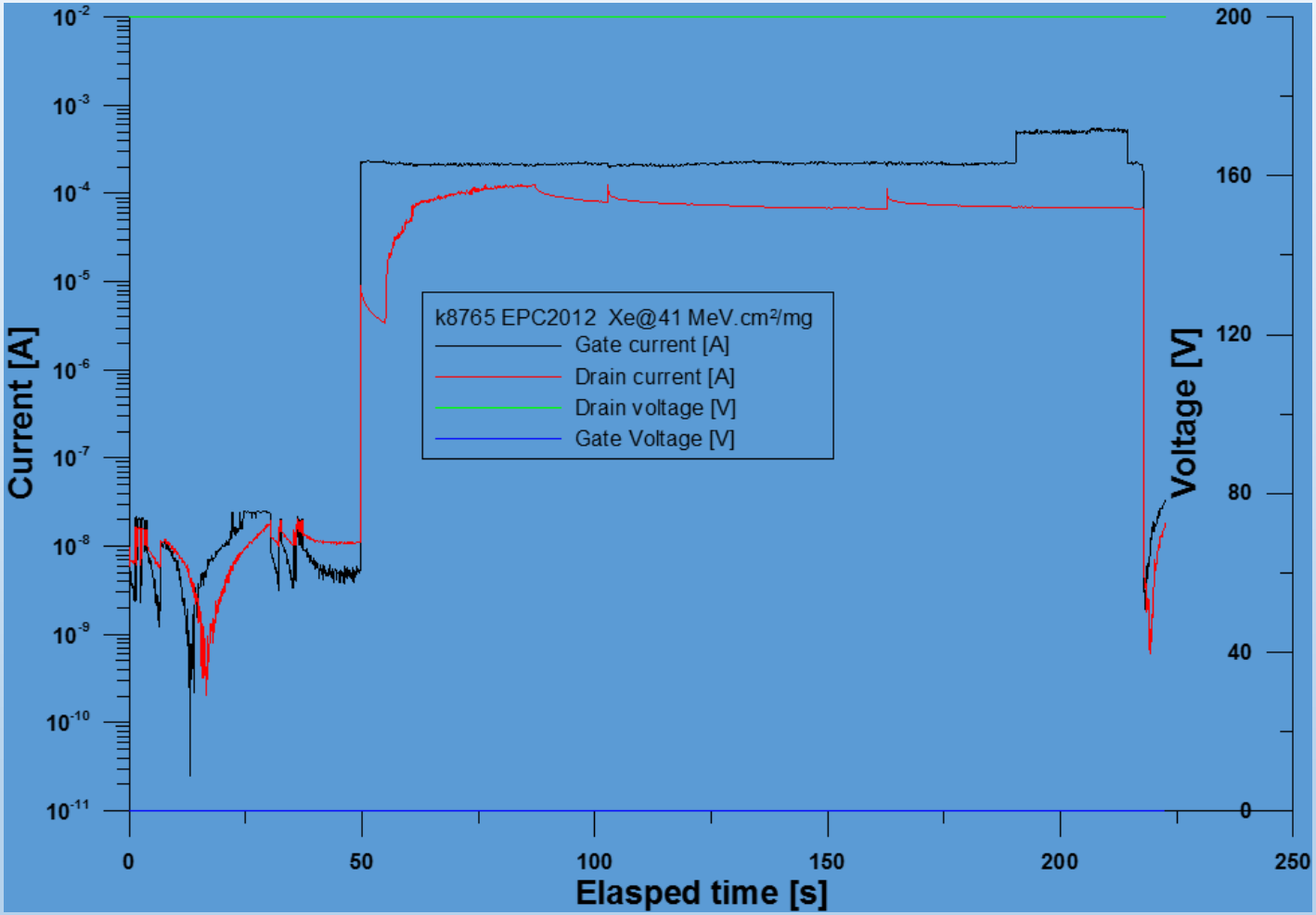
* TAMU: Texas A&M University; LBNL: Lawrence Berkley National Lab

Thermal Cycling:

- 1000 cycles
- Rate: 10 ºC/min
- Range: -55 ºC to +125 ºC
- Soak time: 10 min



EPC 2012 Enhancement Mode Power FET

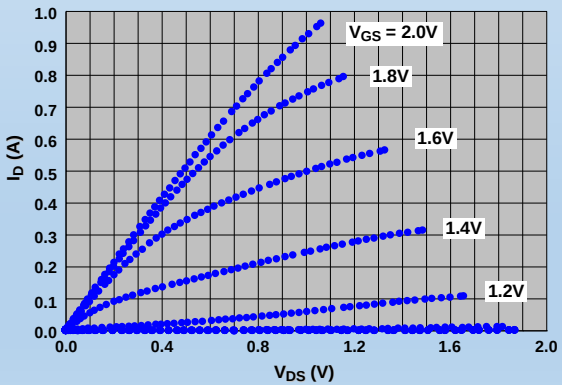


Courtesy: NASA JPL, L. Scheick

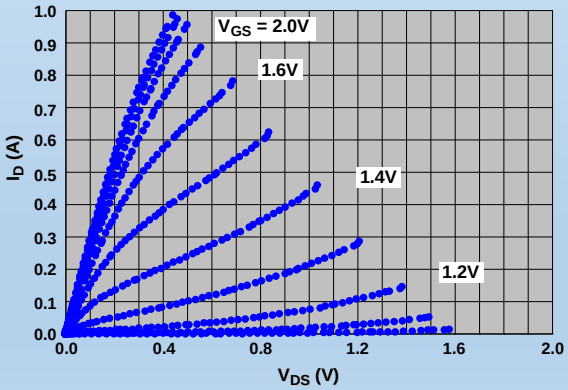
Heavy ion response of EPC2012 device k8765 at normal incidence. (Leakage current recovers after irradiation)

EPC 2012 Enhancement Mode Power FET

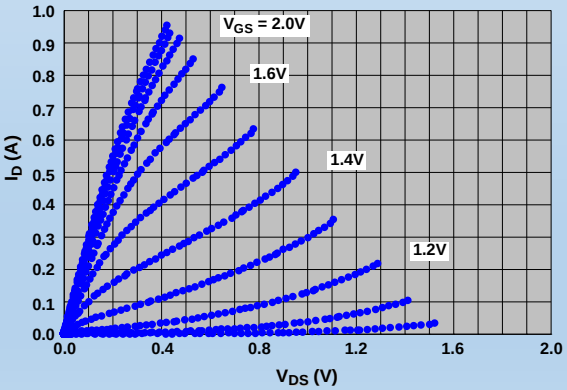
EPC2012	Pre cycling		Post 500 cycles		Post 750 cycles		Post 1000 cycles	
	Cont	Irrad	Cont	Irrad	Cont	Irrad	Cont	Irrad
V_{TH} (V)	1.14	0.82	1.12	0.93	1.12	0.94	1.12	0.95
I_{GLF} (µA)	1.19	1.48	1.08	1.54	1.05	1.44	1.03	1.40
I_{GLR} (nA)	109.25	153.58	100.05	134.56	97.66	139.13	95.22	128.61
I_{DL} (µA)	0.32	147.35	0.33	142.73	0.32	151.60	0.30	147.64



Pre-cycling Control part

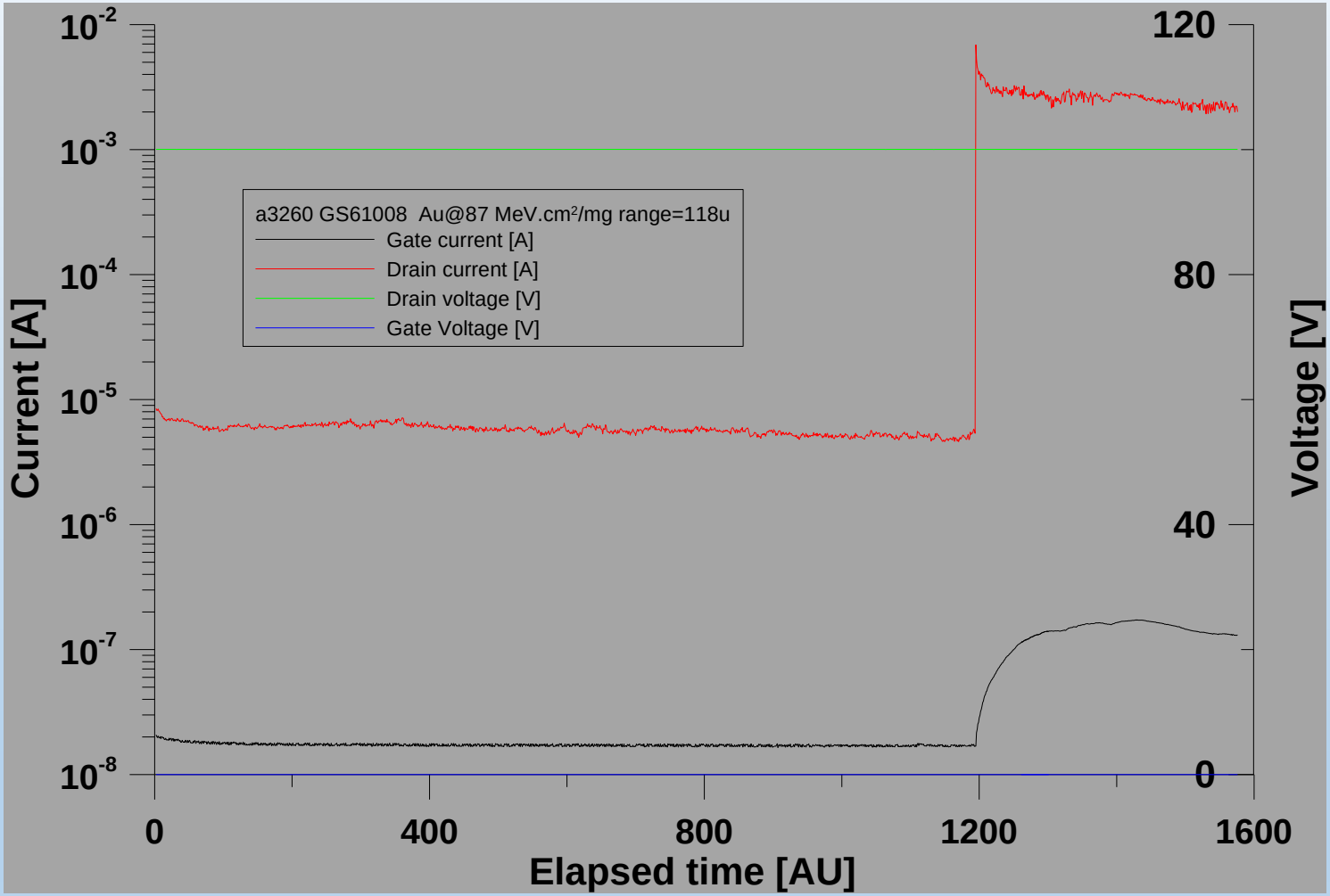


Pre-cycling Irradiated part



Post-cycling Irradiated part

GaN Systems GS61008P Power FET

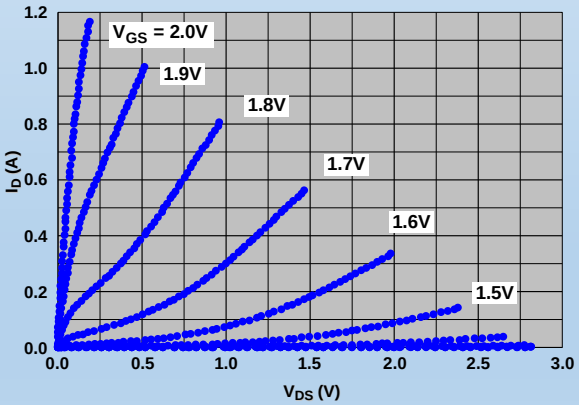


Courtesy: NASA JPL, L. Scheick

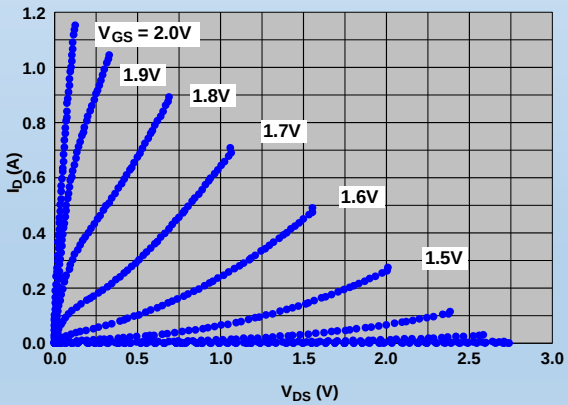
Heavy ion response of GS61008 device a3260 at normal incidence. (Destructive SEE observed at V_{DS} of 100 V)

GaN Systems GS61008P Power FET

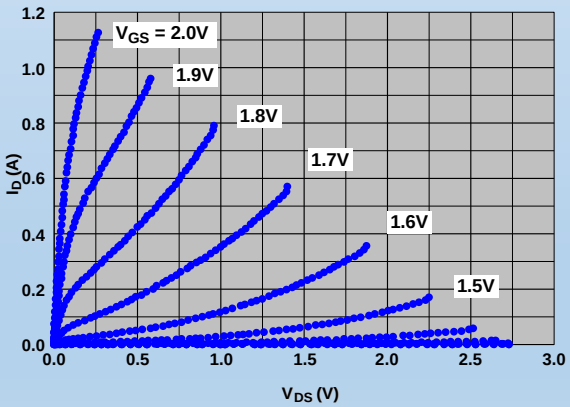
GS61008P	Pre cycling		Post 500 cycles		Post 750 cycles		Post 1000 cycles	
	Cont	Irrad	Cont	Irrad	Cont	Irrad	Cont	Irrad
V_{TH} (V)	0.90	0.98	0.87	0.98	0.90	0.99	0.90	0.99
I_{GLF} (µA)	35.23	73.05	35.45	82.27	35.15	81.09	35.20	80.53
I_{GLR} (nA)	1.21	1.26	1.11	1.25	1.07	1.24	1.06	1.22
I_{DL} (µA)	4.94	131.50	3.94	129.58	3.99	125.58	3.97	122.80



Pre-cycling Control part



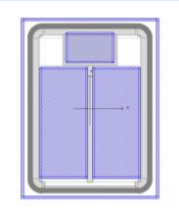
Pre-cycling Irradiated part



Post-cycling Irradiated part

HTRB Test of Cree 900V SiC N-Channel Power MOSFETs

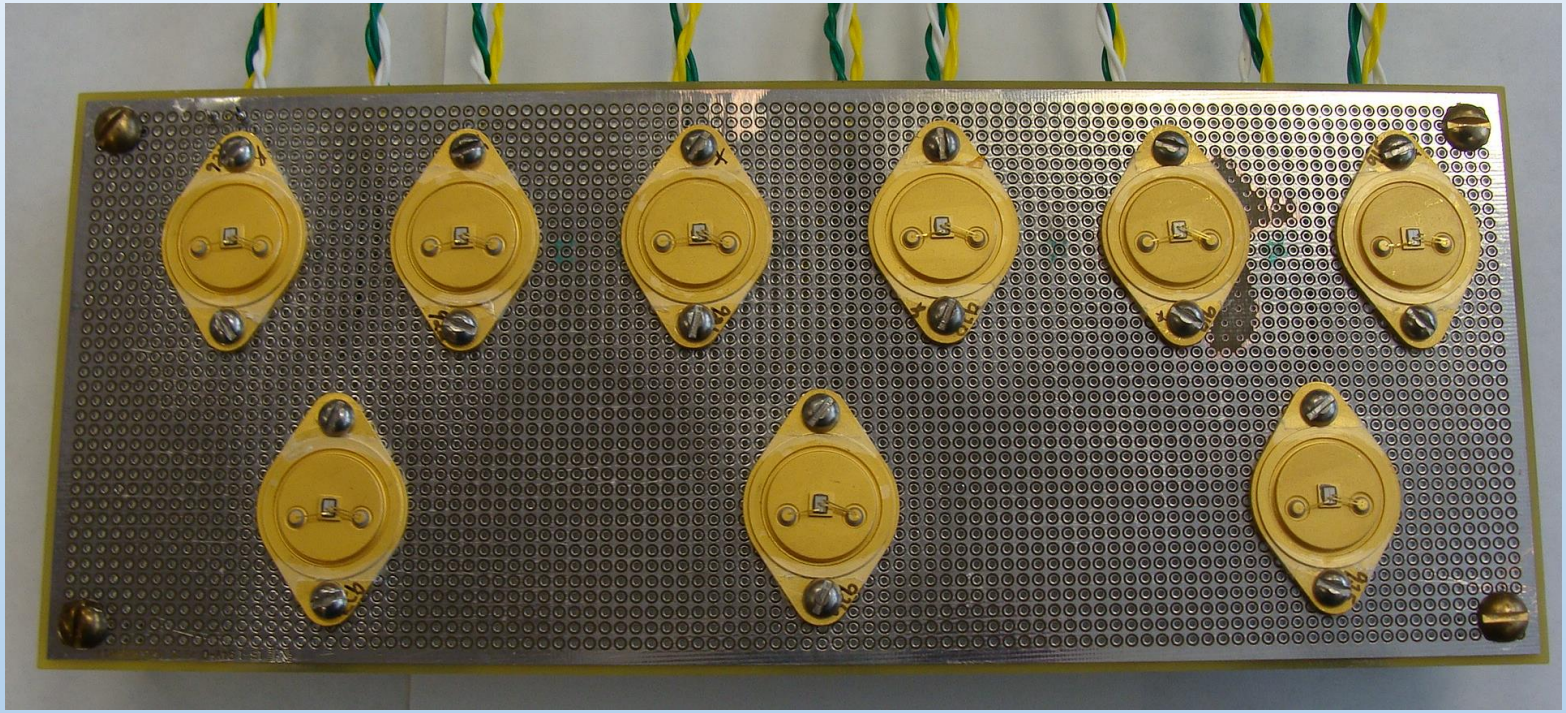
Parameter	Value
Drain-Source Voltage, V_{DS} (V)	900
Gate Threshold Voltage, V_{TH} (V)	2.1 @ V_{DS} = 10V, I_D = 5mA
Drain Current, I_D (A)	36
Drain-Source On-Resistance, R_{DS}(ON) (mΩ)	65 @ V_{GS} = 15V, I_D = 20A
Zero Gate Voltage Drain Current, I_{DSS} (µA)	1 @ V_{DS} = 900V, V_{GS} = 0V
Gate-Source Leakage Current, I_{GSS} (nA)	10 @ V_{GS} = 15V, V_{DS} = 0V
Operating Temperature, T (°C)	-55 to +150



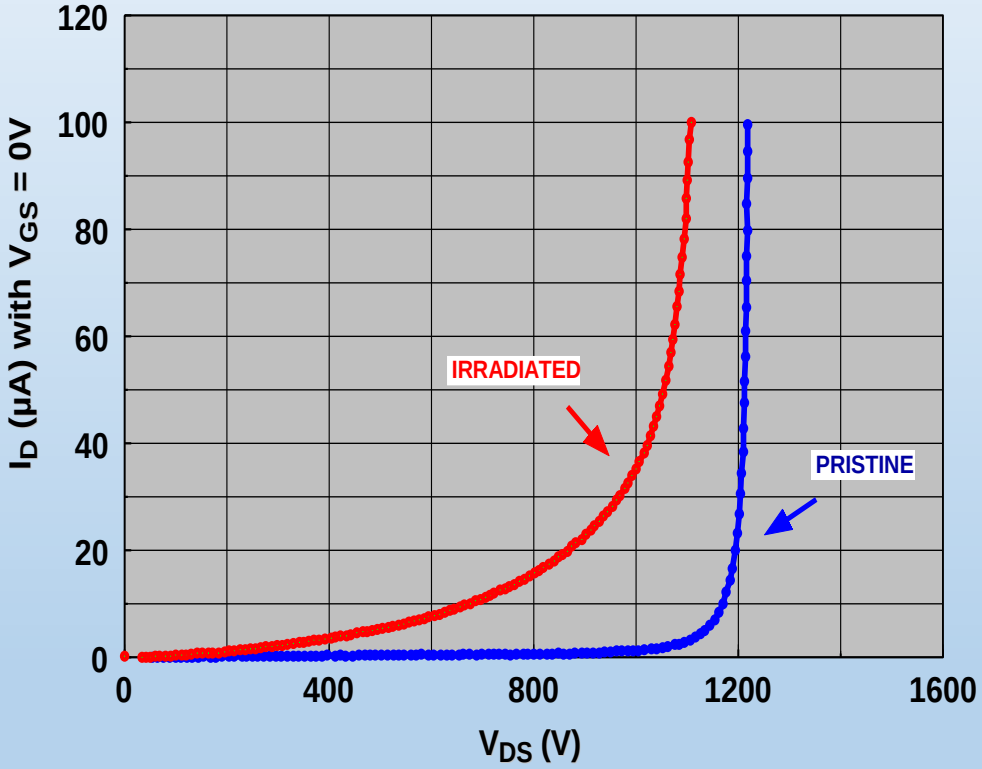
HTRB Test

- Samples: 3 pristine, 6 irradiated
- Duration: 1000 hours
- Temperature: 150 °C
- Bias: 80 % rated BV_{DSS}, V_{GS} = 0 V
- Procedure per MIL-STD-750 Method 1042.3 & NASA Guideline EEE-INST-002
- Parameters:
  - Gate threshold voltage
  - Drain leakage current
  - Gate leakage current
  - Drain-source breakdown voltage
- Measurements at 23 °C & at +150 °C at intervals

Test Board



Breakdown of Pristine & Irradiated SiC Devices (Pre-HTRB)



WBG Supporting Electronics Considerations

- In addition to WBG devices themselves, supporting electronics need to be identified/developed for use in designs
- Considerations for supporting electronics in WBG designs:
  - Responsive to faster switching speeds
  - Extended operating temperature range
  - Layout to minimize parasitics
- GRC has selected various supporting electronics such as gate drivers and pulse width modulation (PWM) controllers to test operation over extended temperature range

Test Conditions

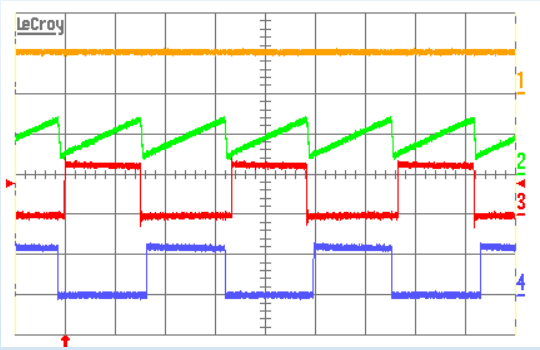
- Perform tests varying the following conditions:
  - Supply voltage
  - Switching frequency
  - Temperature
- Examples of parameters measured:
  - Rise and fall times
  - Turn-on and turn-off propagation delays
  - Current

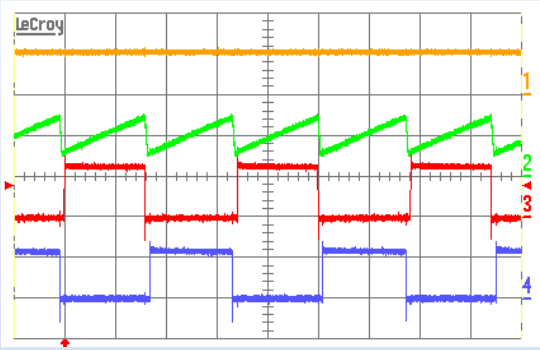
Performance & Reliability Assessment of Supporting Electronics for WBG Power Devices

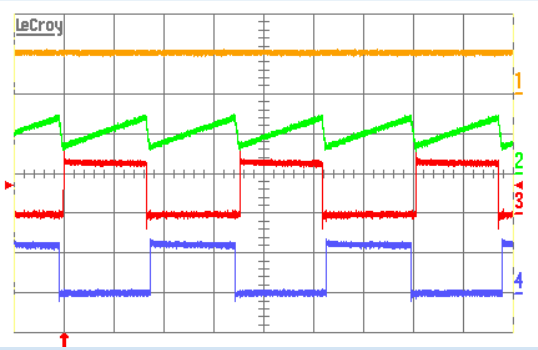
Evaluation of TI UC1846-SP rad-tolerant PWM controller

- QML-V part, TID 40krad (Si) tolerant, current-mode controller
- Rated for -55 ºC to +125 ºC
- Test temperature range -192 ºC to +140 ºC, cold-restart, thermal cycling

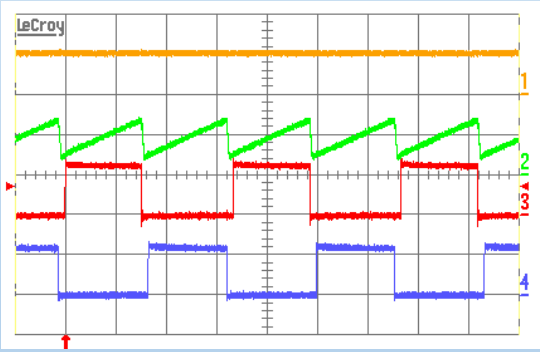
Evaluation of TI 1846-sp Rad-Tolerant PWM Controller

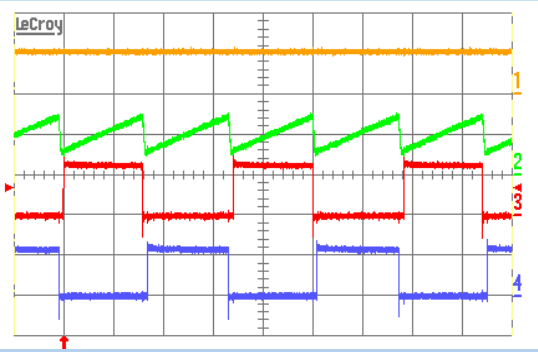


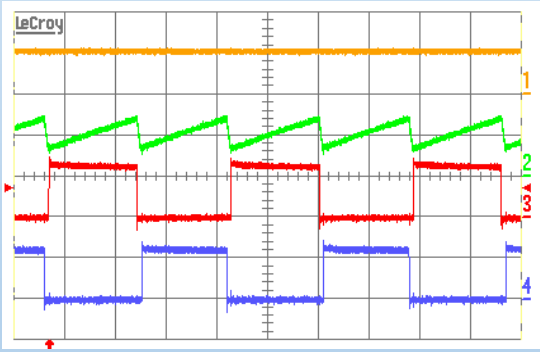




Pre-cycling waveforms of reference (yellow), oscillator (green), and output (red and blue) signals at +140 ºC, +23 ºC, & -120 ºC (L to R)



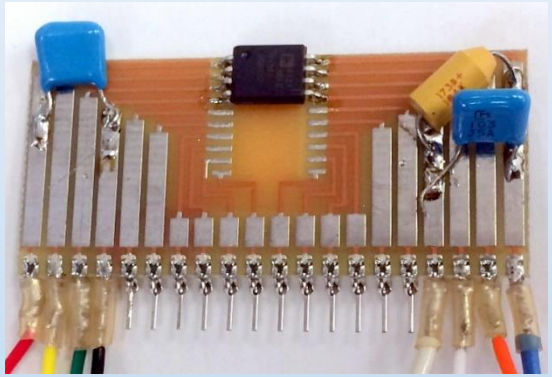




Post-cycling waveforms of reference (yellow), oscillator (green), and output (red and blue) signals at +140 ºC, +23 ºC, & -120 ºC (L to R)

Performance & Reliability Assessment of Supporting Electronics for WBG Power Devices

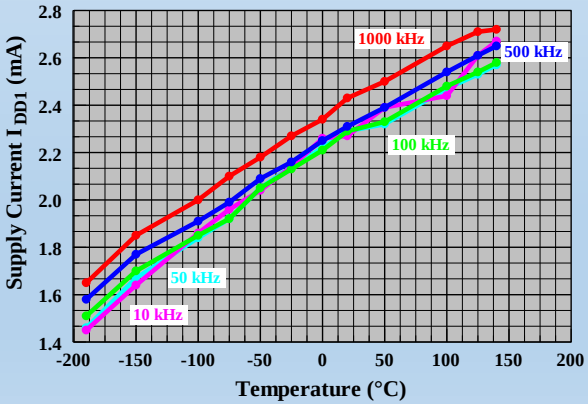
Evaluation of Isolated Gate Driver, ADuM4121



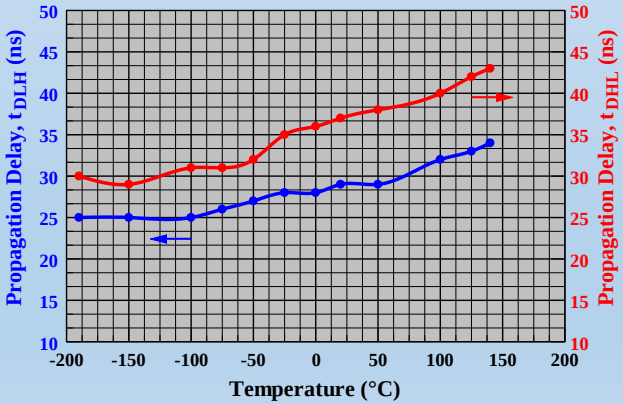
ADuM4121 driver chip mounted on test board

	Turn-on Propagation Delay, t_{DLH} (ns)		Turn-off Propagation Delay, t_{DHL} (ns)		Rise Time, t_r (ns)		Fall Time t_f (ns)		Supply Current (mA)	
T (°C)	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
+20	29.00	28.00	37.00	36.00	14.00	14.50	14.50	14.00	2.27	2.30
-190	25.00	25.00	30.00	30.00	15.50	17.50	13.50	15.50	1.45	1.50
+140	34.00	33.00	43.00	43.00	15.50	15.50	15.50	16.00	2.67	2.66

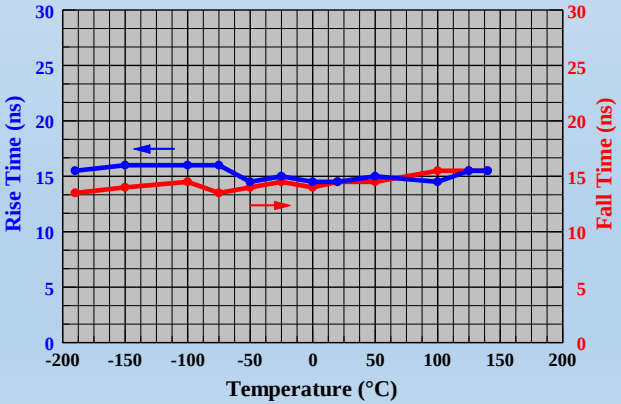
Pre- & post-cycling propagation delays, switching times, & supply current at 10 kHz frequency



Supply current versus temperature at various frequencies of ADuM4121 gate driver



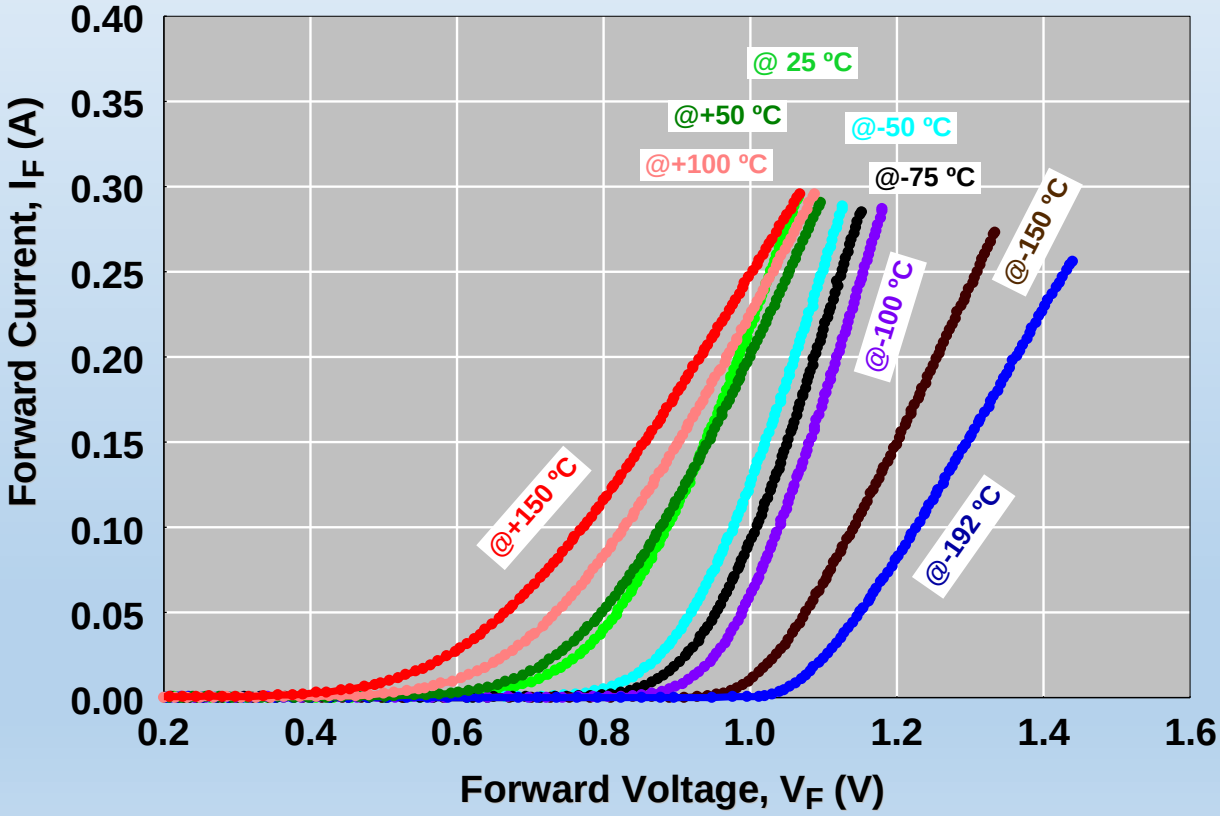
ADuM4121 turn-on (blue) & turn-off (red) propagation delays versus temperature



Rise (blue) & fall (red) times of ADuM4121 as a function of temperature

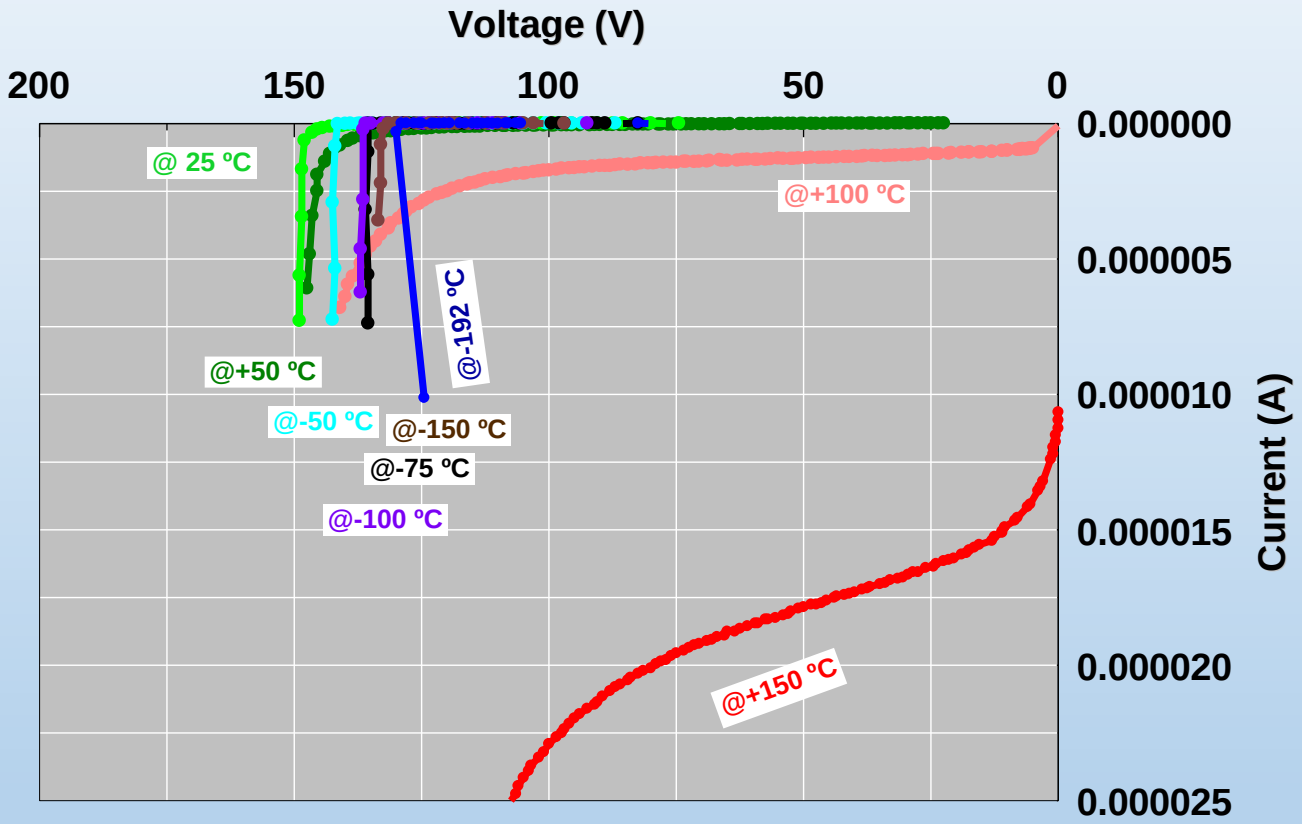
Evaluation of COTS & Automotive-Grade EEE Parts Under Extreme Temperatures and Thermal Cycling

- AEC-Q101 Qualified, 1N4448 WSF Diodes, Inc. 0.5A diode
- Rated temperature -65 ºC to +150 ºC
- Test temperature range -192 ºC to +150 ºC, thermal cycling
- Six pristine & six life-tested (at Navy Crane) samples



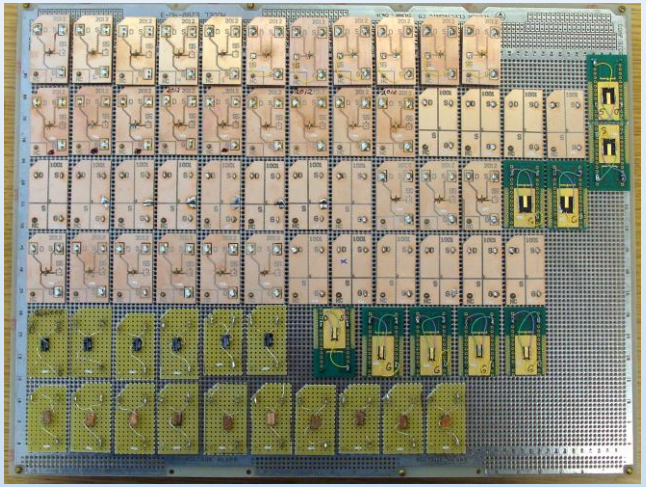
FORWARD CHARACTERISTICS

Evaluation of COTS & Automotive-Grade EEE Parts Under Extreme Temperatures and Thermal Cycling

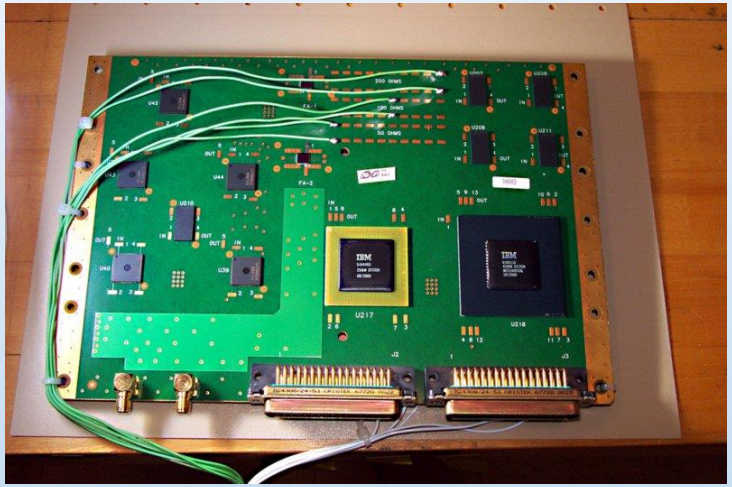


DIODE REVERSE CHARACTERISTICS

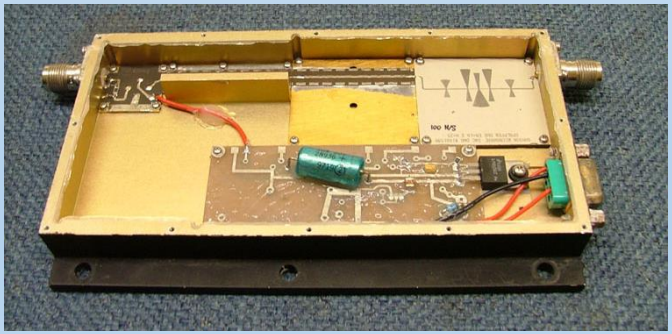
GRC Extreme Temperature Electronics Lab Collaborations



GaN power transistors (GSFC/JPL)



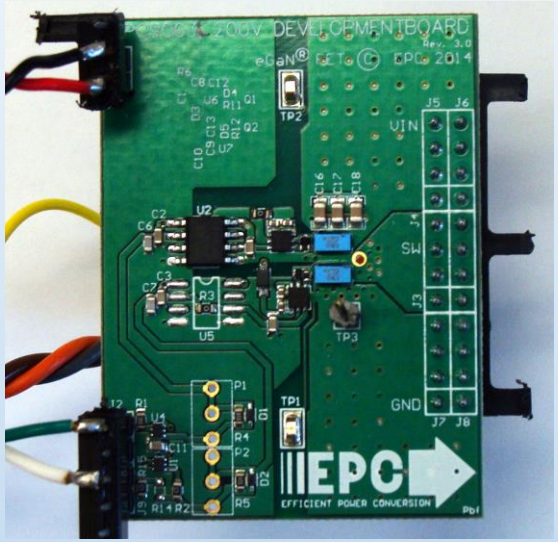
Flip-chip and ball-grid array (JPL)



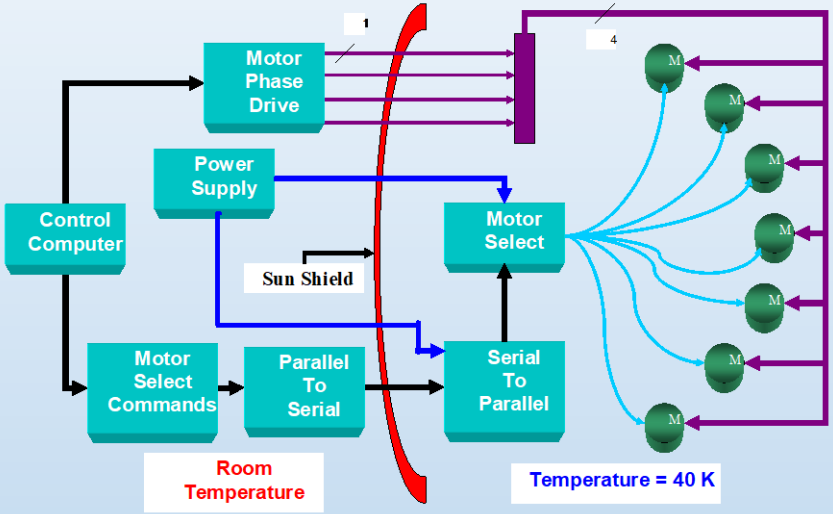
Shuttle GPS preamplifier (JSC/Boeing/ULA)

Automotive-grade diodes (MSFC/Navy)

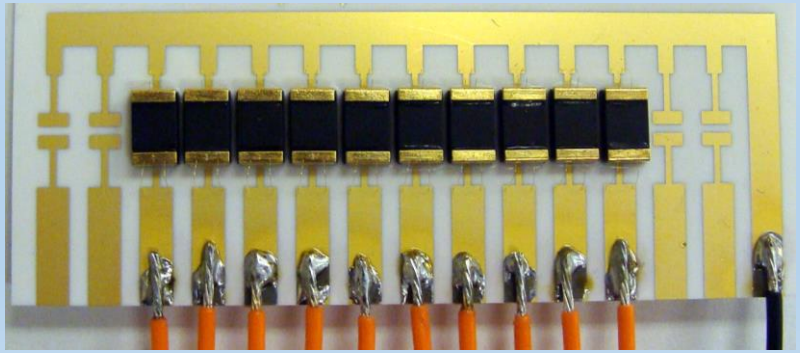
GRC Extreme Temperature Electronics Lab Collaborations



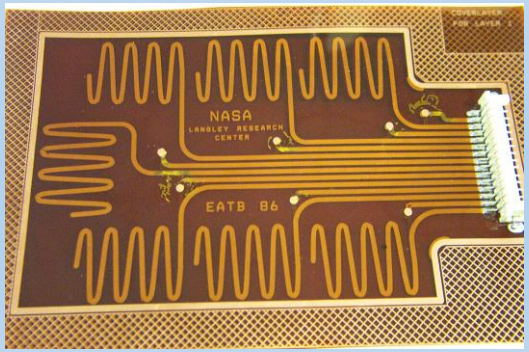
GaN-based motor controller (GRC)



JWST cryogenic stepper motor controller (GSFC)



Space-qualified capacitors (External customer)



Flexible printed circuit board (LaRC)

ACKNOWLEDGMENT

This collaborative work was performed in support of the NASA Electronic Parts and Packaging (NEPP) Program. Part of this work was done at the NASA Glenn Research Center under GEARS Contract # 80GRC020D003.