# Wide Bandgap Reliability and Application Guidelines

## NEPP-Supported GRC Activities

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# 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 |
| HEMT | High Electron Mobility Transistor |
| HTGB | High Temperature Gate Bias |
| HTRB | High Temperature Reverse Bias |
| JPL | Jet Propulsion Laboratory |
| JSC | Johnson Space Center |
| LaRC | Langley Research Center |

| Acronym | Definition |
|---|---|
| LBNL | Lawrence Berkeley National Laboratory |
| 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 |
| Si | Silicon |
| SiC | Silicon Carbide |
| TAMU | Texas A&M University |
| TID | Total Ionizing Dose |
| ULA | United Launch Alliance |
| WBG | Wide Bandgap |

# NEPP-Supported GRC Activities

- **NASA Wide Bandgap (WBG) Working Group**
  - **Publication of Body-of-knowledge (BOK) on WBG power devices**
    - ✓ **Completed BOK on SiC (in collaboration with GSFC)**
    - ✓ **Generating BOK on GaN (in collaboaration JPL)**
    - ✓ **NEPP-Website report publishing**
  - **Collaboration on pre- and post-irradiation of GaN & SiC devices**
- **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**

# 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**

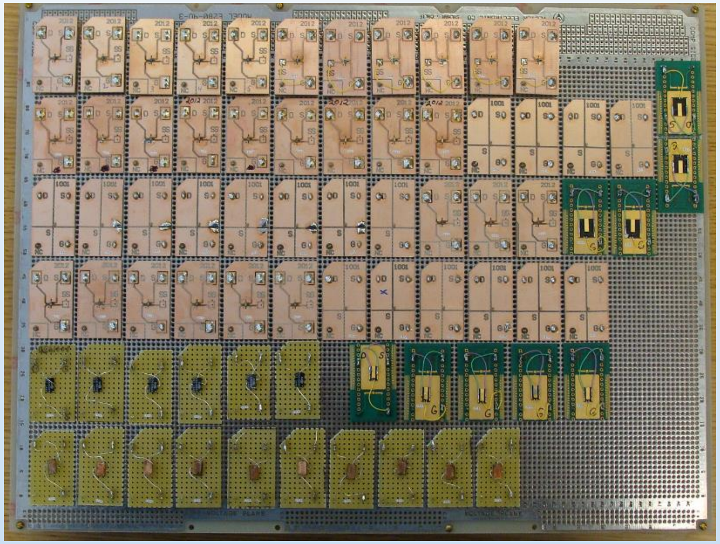
# Collaborative Performance Assessment of WBG Power Devices

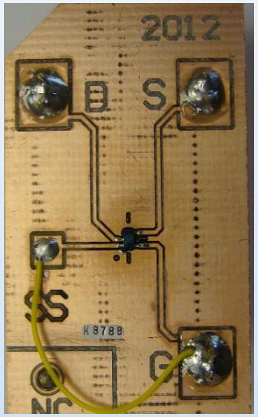
- Collaboration with GSFC and JPL
- Characterization of pre- & post-irradiated of power devices
- Extreme temperature exposure and wide-range thermal cycling
- High temperature reverse bias (HTRB) & high temperature gate bias (HTGB) tests of control & irradiated parts
- Determination of degradation &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

# GRC Extreme Temperature Electronics Lab

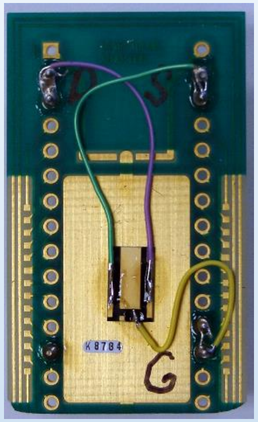
- Two environmental chambers (0.37 $ft^3$; 2.2 $ft^3$)
- Extreme temperature exposure, thermal cycling, and life-testing
- Programmable temperature rate, dwell time, and number of cycles
- Temperature range: -194 ºC to +315 ºC; rate: 0.1 ºC/min to 36 ºC/min
- Built-in feed-throughs for multi-stress (electrical/thermal)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

# Device-Mounted Boards

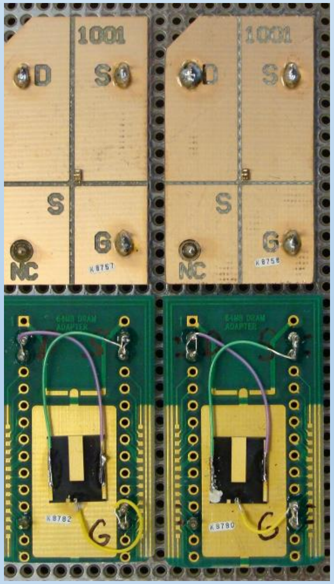


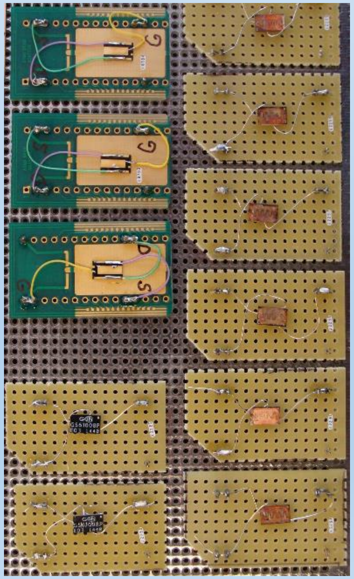


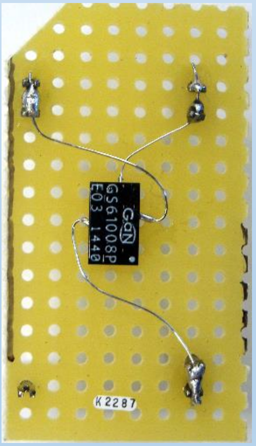
EPC 2012



GaN GS66508P








GaN GS61008P

GaN GS61008P
(Un-capped/irradiated)

# Radiation and Thermal Cycling on GaN Parts

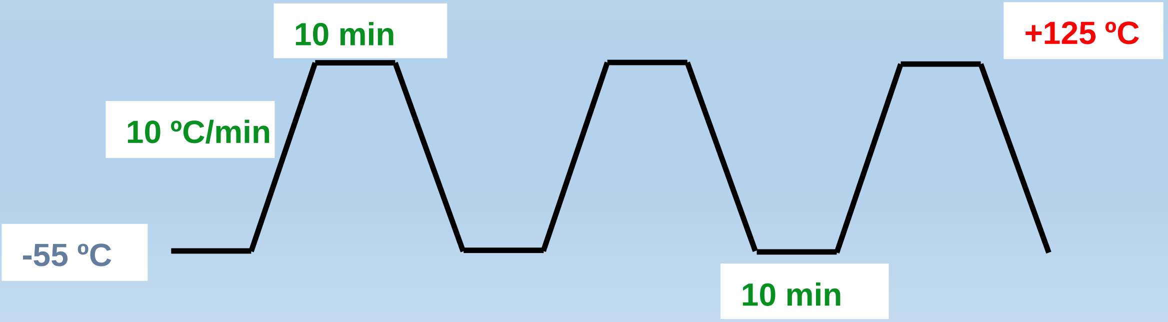
| Manufacturer | Part # | Parameters | # Samples (control/Irradiated) | Radiation | Cycling |
|---|---|---|---|---|---|
| EPC | 2012 | 200V, 3A, 100mΩ | 15/26 | ✓ | ✓ |
| GaN Systems | GS61008P | 100V, 90A, 7.4mΩ | 11/10 | ✓ | ✓ |
| | GS66508P | 650V, 30A, 52mΩ | 4/0 | Planned | ✓ |

| 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* |

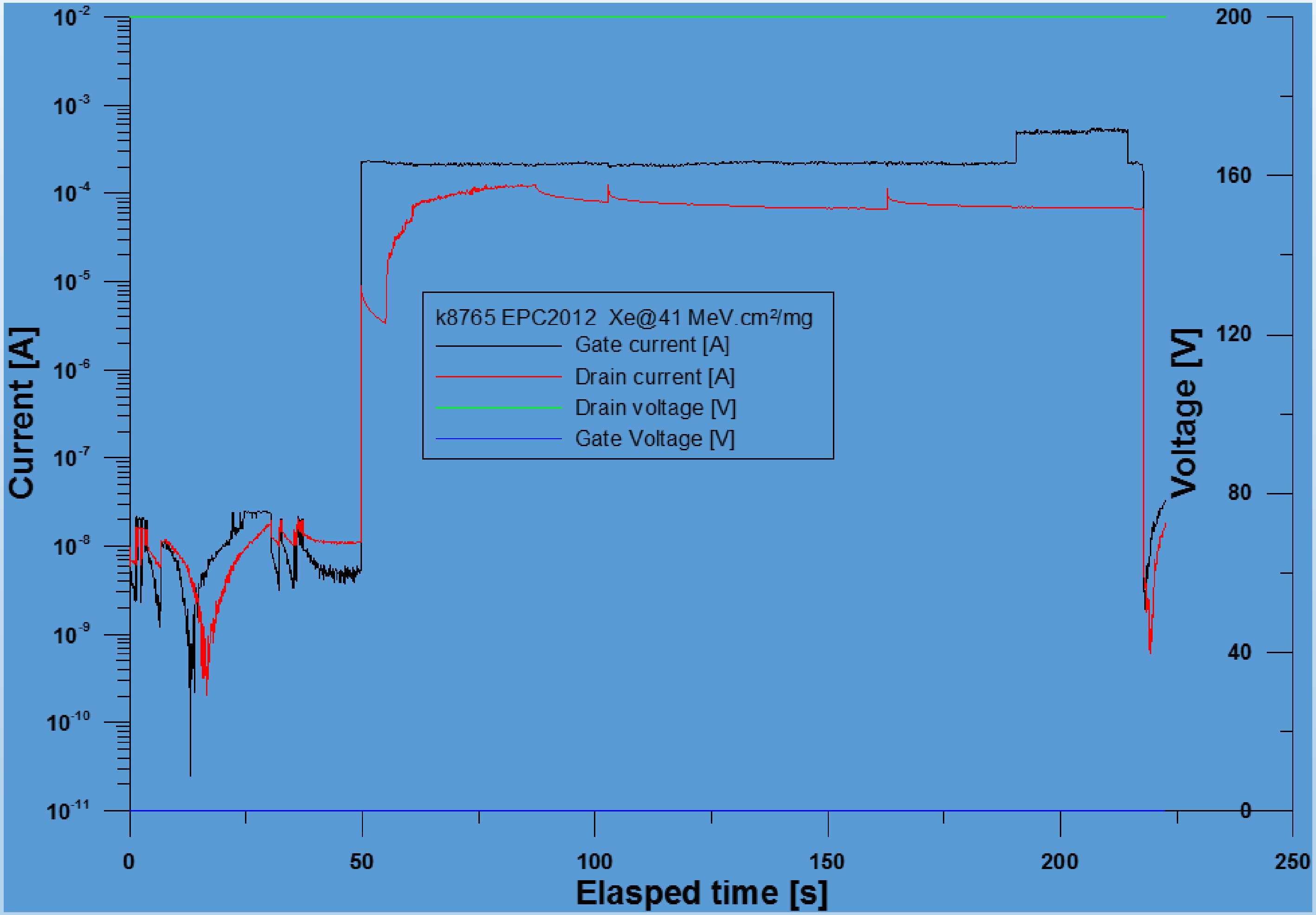
* TAMU: Texas A&M University;  LBNL: Lawrence Berkley National Lab

## Thermal Cycling:

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



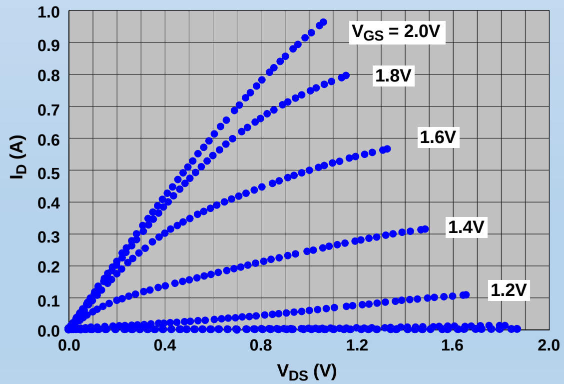
# EPC 2012 Enhancement Mode Power FET



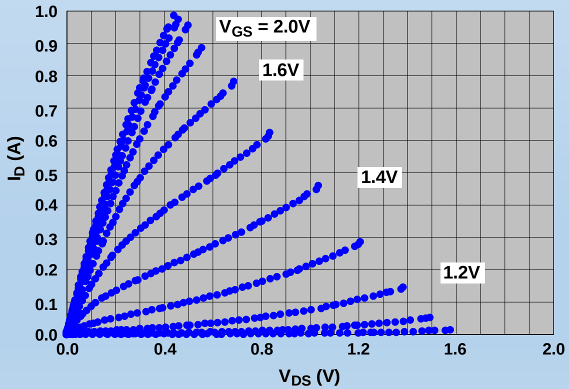

**Heavy ion response of EPC2012 device k8765 at normal incidence. (Leakage current recovers after irradiation)**

# EPC 2012 Enhancement Mode Power FET

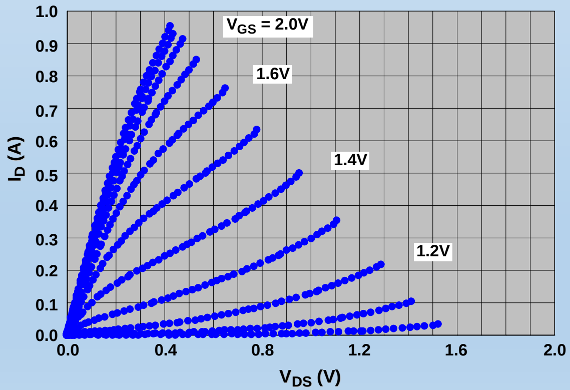
| EPC2012 | Pre cycling | | Post 500 cycles | | Post 750 cycles | | Post 1000 cycles | |
|---|---|---|---|---|---|---|---|---|
| | Cont | Irrad | Cont | Irrad | Cont | Irrad | Cont | Irrad |
| $V_{TH}$ (V) | 1.14 | 0.82 | 1.12 | 0.93 | 1.12 | 0.94 | 1.12 | 0.95 |
| $I_{GLF}$ (µA) | 1.19 | 1.48 | 1.08 | 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**

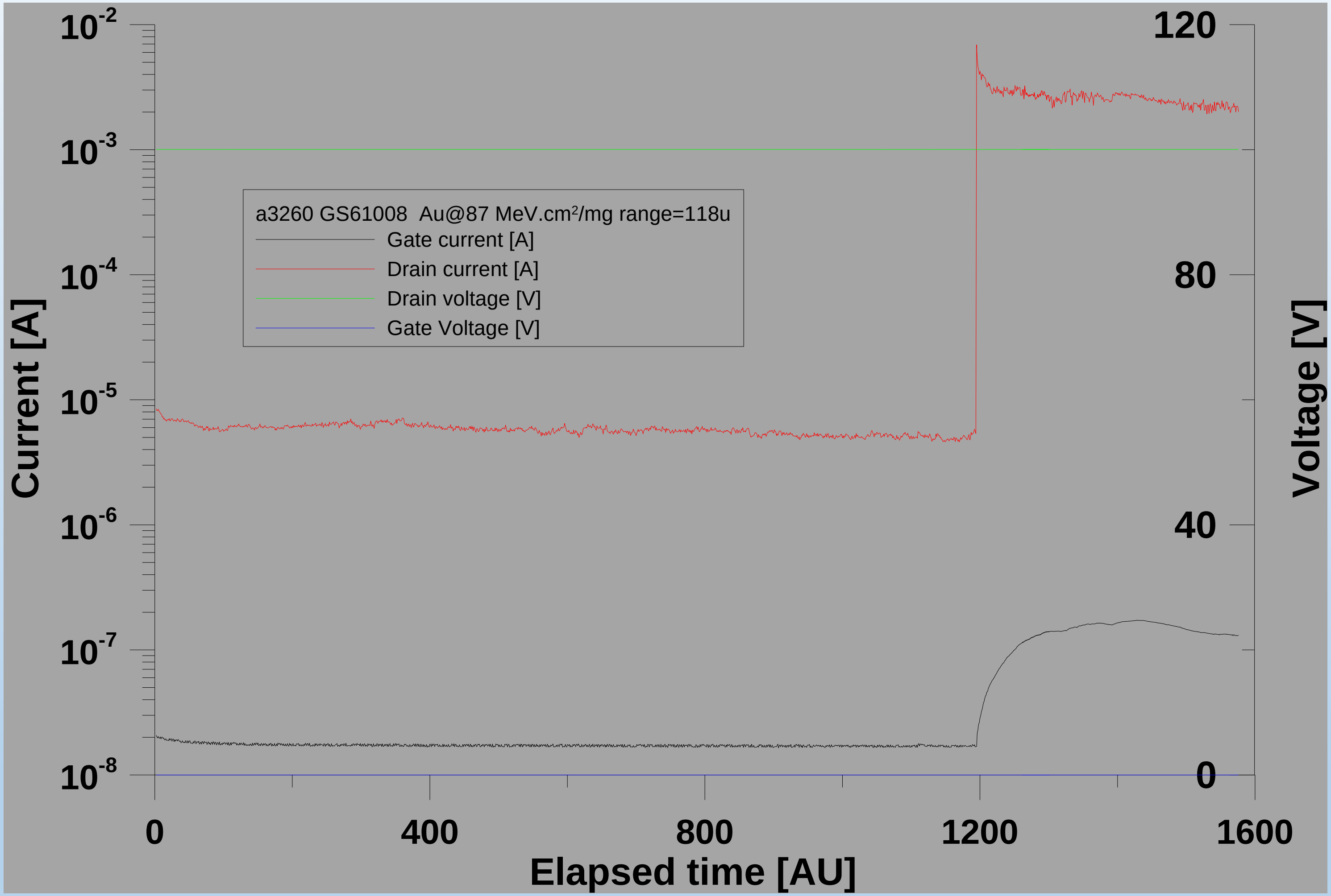



**Pre-cycling Irradiated part**




**Post-cycling Irradiated part**

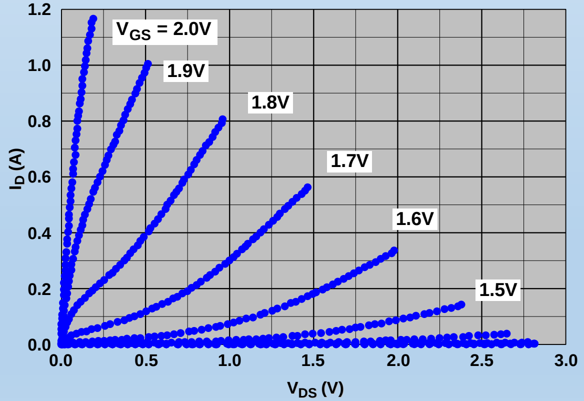
# GaN Systems GS61008P Power FET



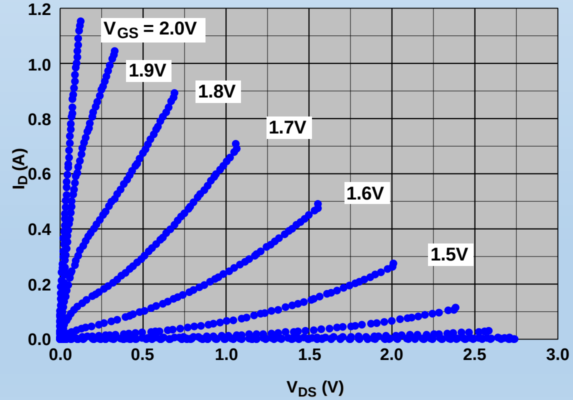

**Heavy ion response of GS61008 device a3260 at normal incidence. (Destructive SEE observed at $V_{DS}$ of 100 V)**

# GaN Systems GS61008P Power FET

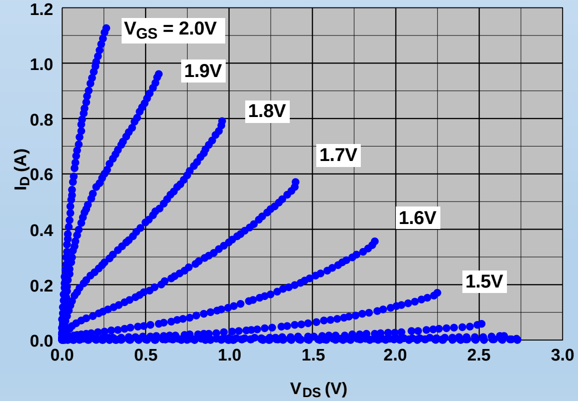
| GS61008P | Pre cycling | | Post 500 cycles | | Post 750 cycles | | Post 1000 cycles | |
|---|---|---|---|---|---|---|---|---|
| | Cont | Irrad | Cont | Irrad | Cont | Irrad | Cont | Irrad |
| $V_{TH}$ (V) | 0.90 | 0.98 | 0.87 | 0.98 | 0.90 | 0.99 | 0.90 | 0.99 |
| $I_{GLF}$ (µA) | 35.23 | 73.05 | 35.45 | 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**



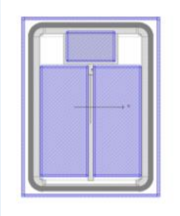

**Pre-cycling Irradiated part**




**Post-cycling Irradiated part**

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

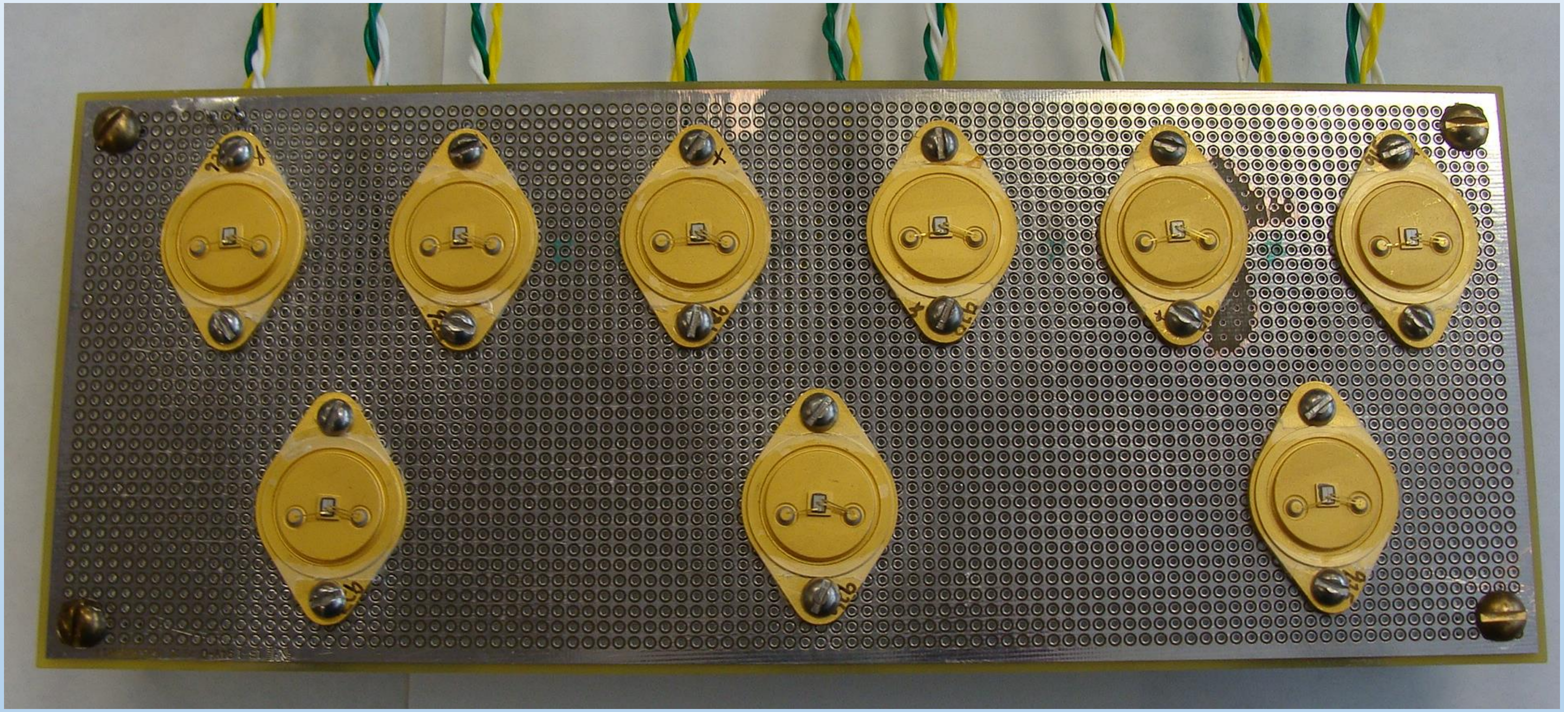
| Parameter | Value |
|---|---|
| Drain-Source Voltage, $V_{DS}$ (V) | 900 |
| Gate Threshold Voltage, $V_{TH}$ (V) | 2.1 @ $V_{DS}$ = 10V, $I_D$ = 5mA |
| Drain Current, $I_D$ (A) | 36 |
| Drain-Source On-Resistance, $R_{DS}$(ON) (mΩ) | 65 @ $V_{GS}$ = 15V, $I_D$ = 20A |
| Zero Gate Voltage Drain Current, $I_{DSS}$ (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 |



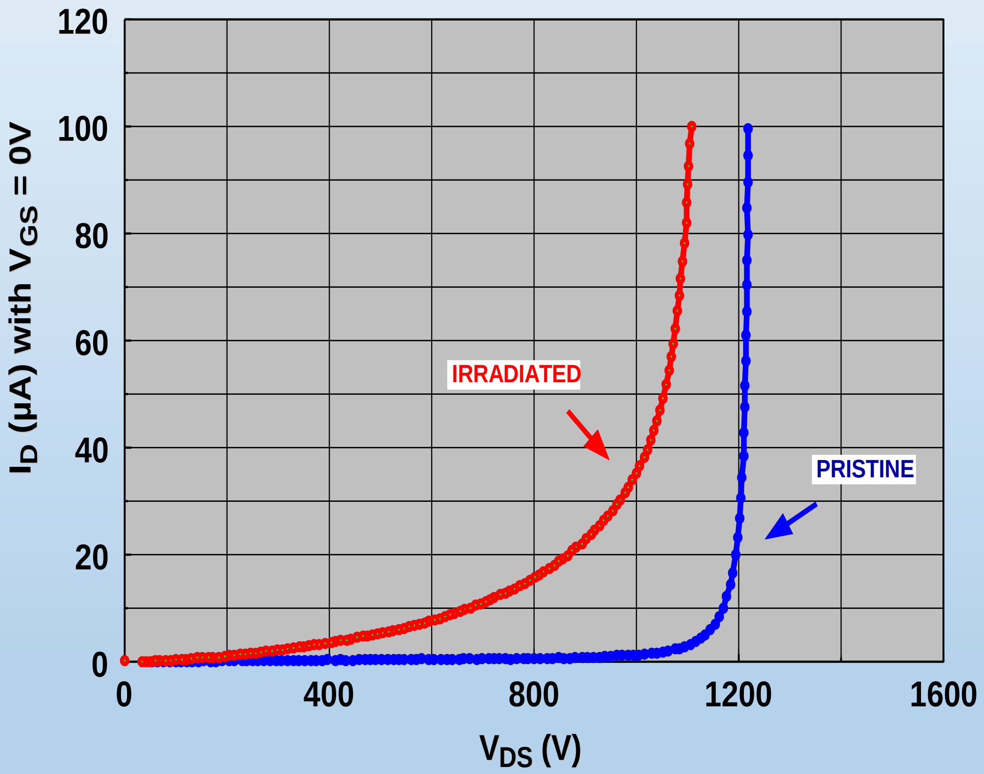
# HTRB Test

- 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)

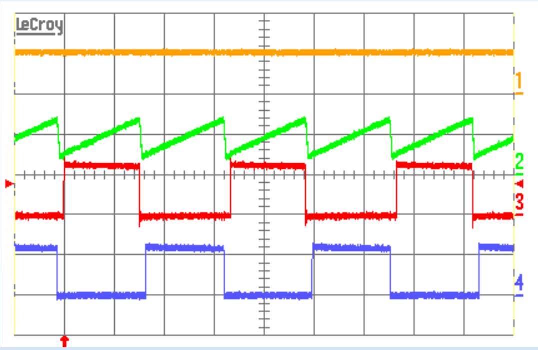


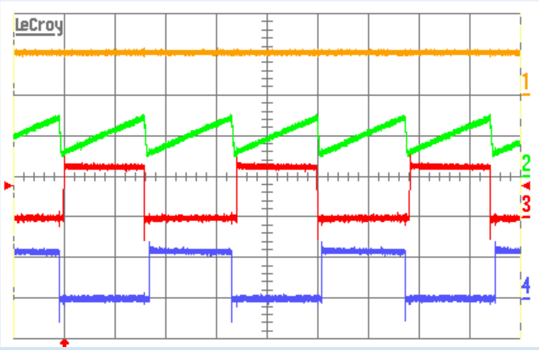
# Performance & Reliability Assessment of Supporting Electronics for WBG Power Devices

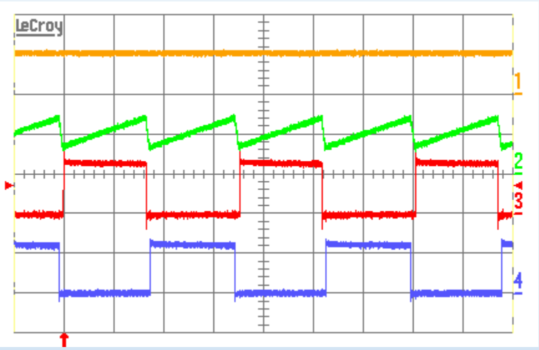
## Evaluation of TI 1846-sp rad-tolerant PWM controller

- QML-V part, TID 40krad (Si) tolerant, current-mode controller
- Temperature range -192 ºC to +140 ºC, cold-restart, thermal cycling

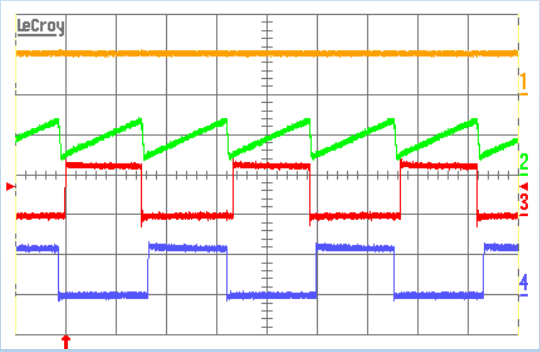
# Evaluation of TI 1846-sp Rad-Tolerant PWM Controller

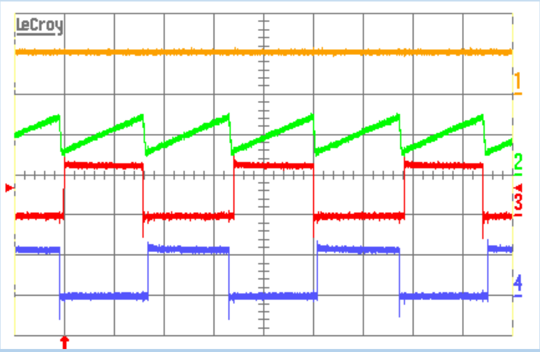


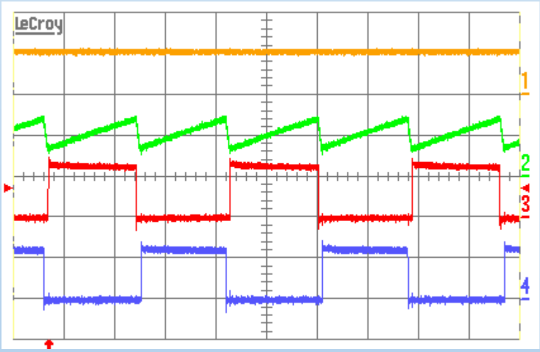




Pre-cycling waveforms of reference (yellow), oscillator (green), and output (red and blue) signals at +140 ºC, +23 ºC, & -120 ºC (L to R)



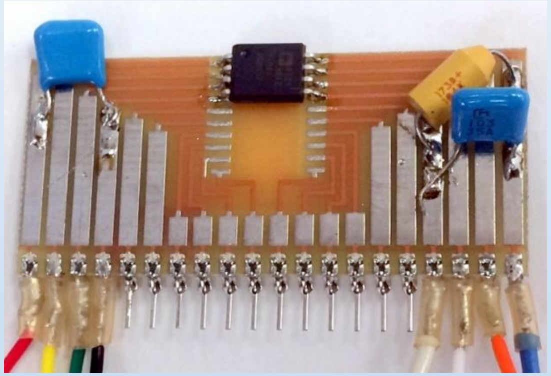




Post-cycling waveforms of reference (yellow), oscillator (green), and output (red and blue) signals at +140 ºC, +23 ºC, & -120 ºC (L to R)

# Performance & Reliability Assessment of Supporting Electronics for WBG Power Devices

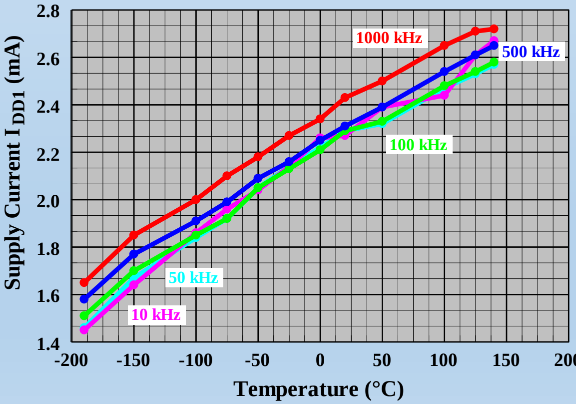
## Evaluation of Isolated Gate Driver, ADuM4121



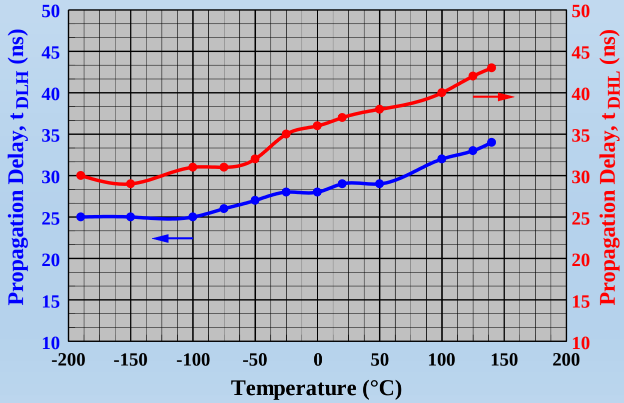
ADuM4121 driver chip mounted on test board

| | 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 |

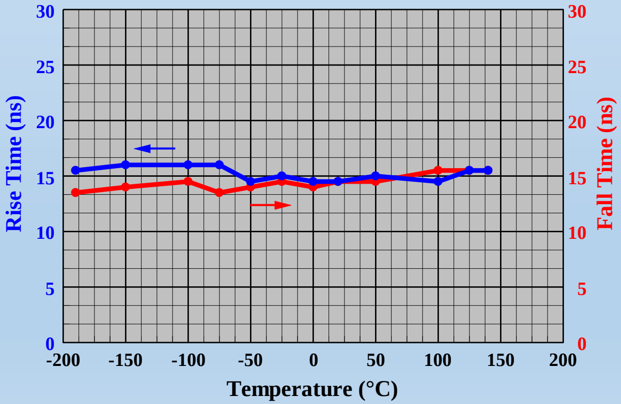
Pre- & post-cycling propagation delays, switching times, & supply current at 10 kHz frequency




Supply current versus temperature at various frequencies of ADuM4121 gate driver



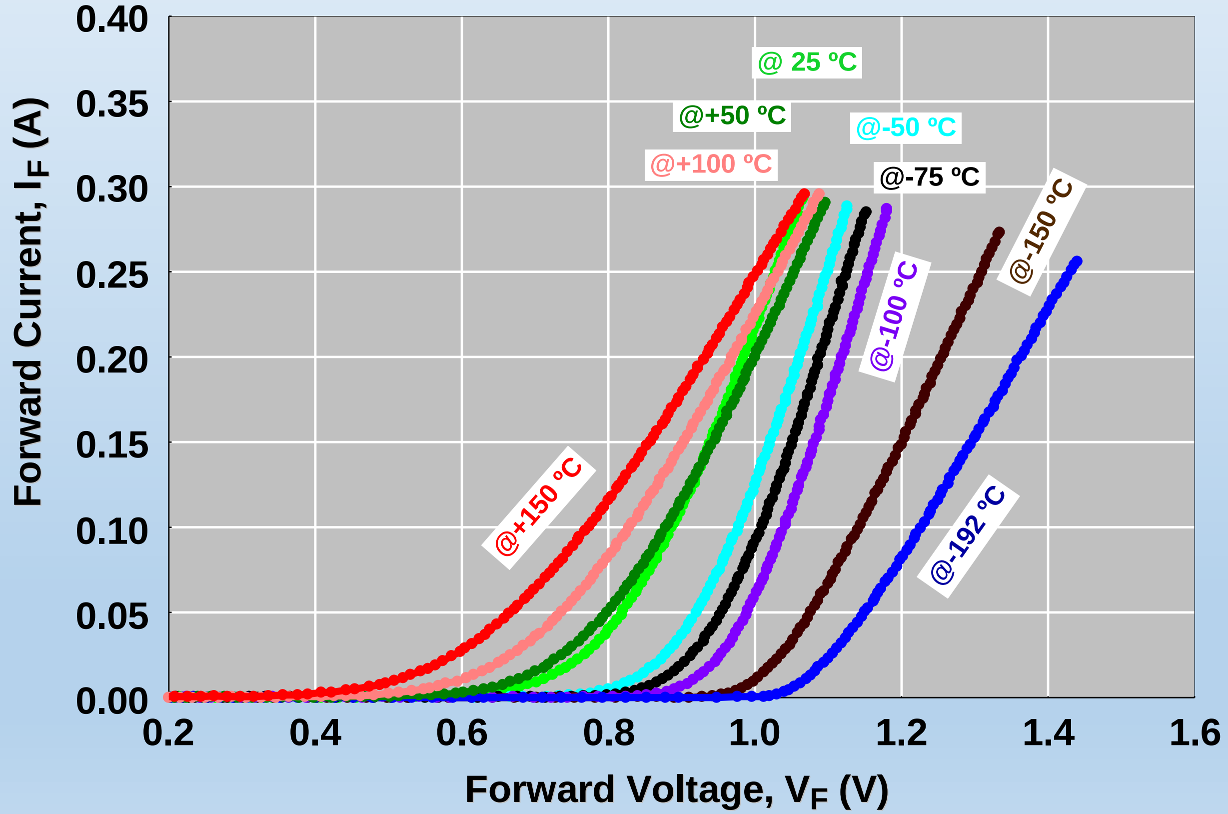

ADuM4121 turn-on & turn-off propagation delays versus temperature




Rise & fall times of ADuM4121 as a function of temperature

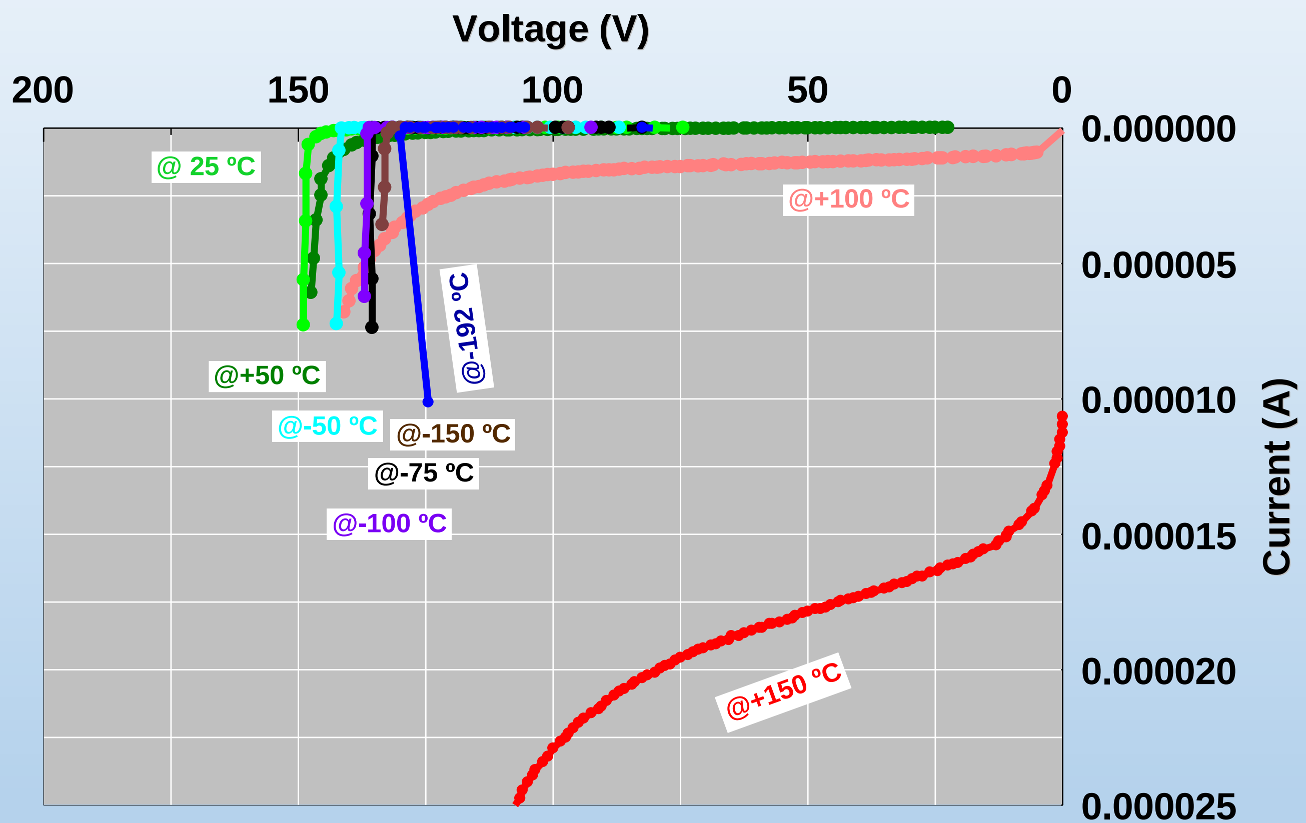
# Evaluation of COTS & Automotive-Grade EEE Parts Under Extreme Temperatures and Thermal Cycling

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



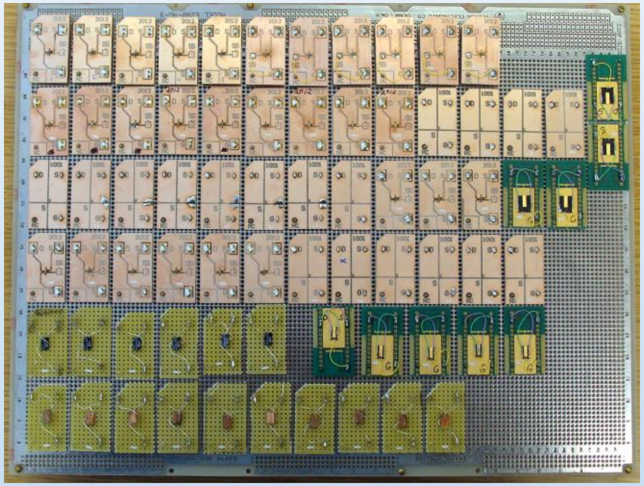

FORWARD CHARACTERISTICS

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

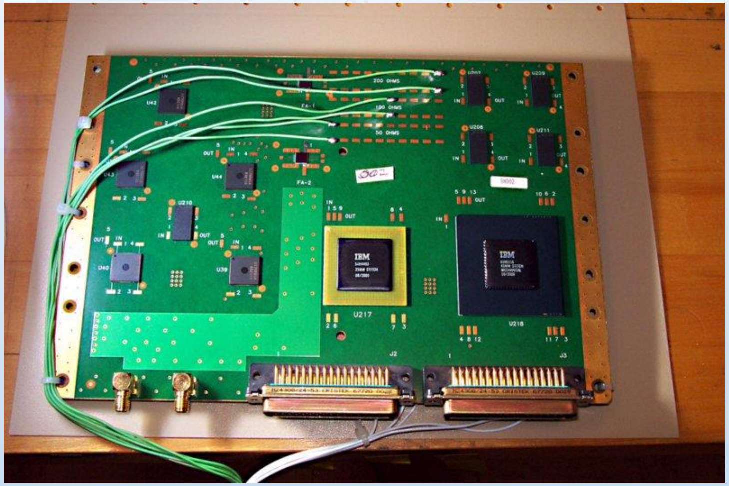



DIODE REVERSE CHARACTERISTICS

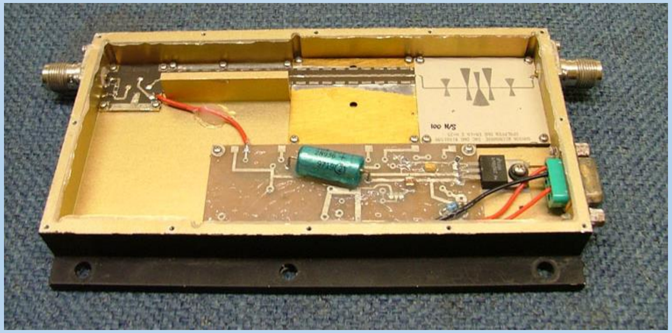
# GRC Extreme Temperature Electronics Lab Collaborations



GaN power transistors (GSFC/JPL)



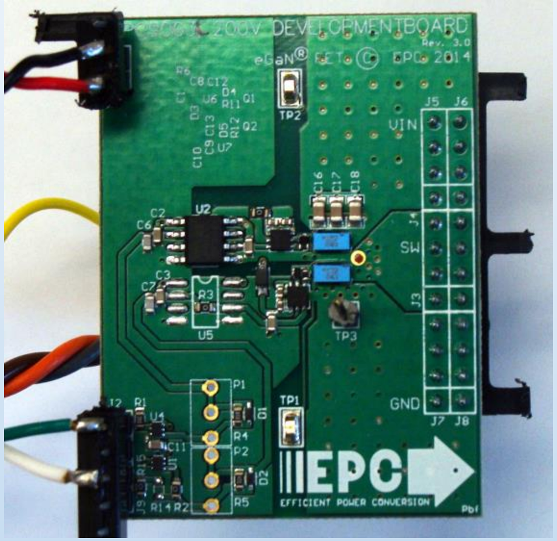
Flip-chip and ball-grid array (JPL)



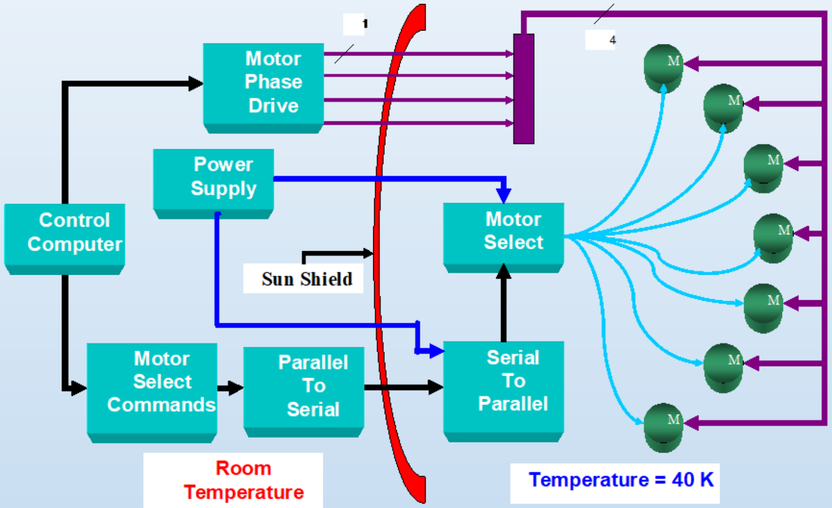
Shuttle GPS preamplifier (JSC/Boeing/ULA)

Automotive-grade diodes (MSFC/Navy)

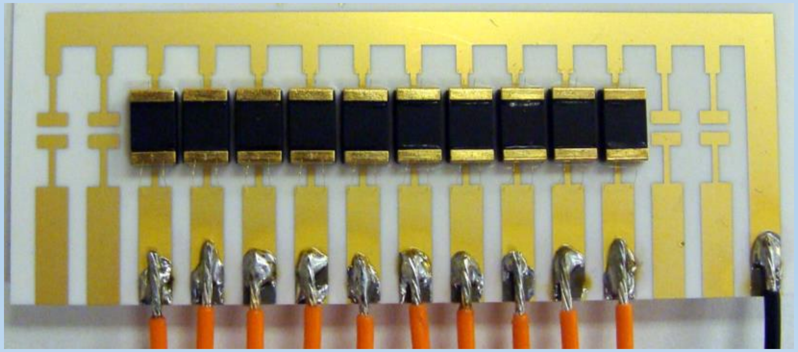
# GRC Extreme Temperature Electronics Lab Collaborations



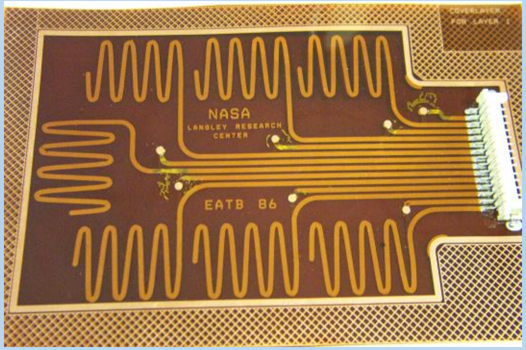
GaN-based motor controller (GRC)




JWST cryogenic stepper motor controller (GSFC)



Space-qualified capacitors (Aerospace Corporation)



Flexible printed circuit board (LaRC)

# ACKNOWLEDGMENT

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