Wide bandgap DC-DC converter

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Context

Wide bandgap (WBG) power devices are of interest in electric vehicle, aeronautics, space and particle accelerator applications

These devices are in the core of switching power converter systems and failure of such device leads to failure or degradation of the power system

SiC power MOSFETs and diodes are known to be sensitive to destructive single event effects (SEB, SEGR) under neutron and heavy ion irradiation

To avoid these failures when operating in radiation environments, devices are derated -> long-term reliability?

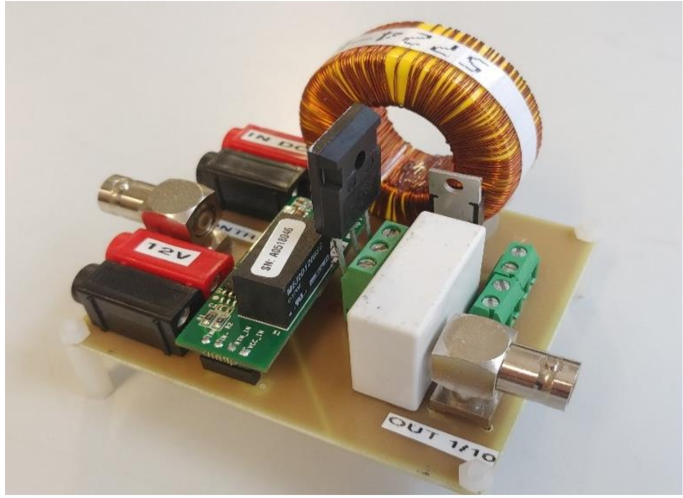
Test standards and guidelines

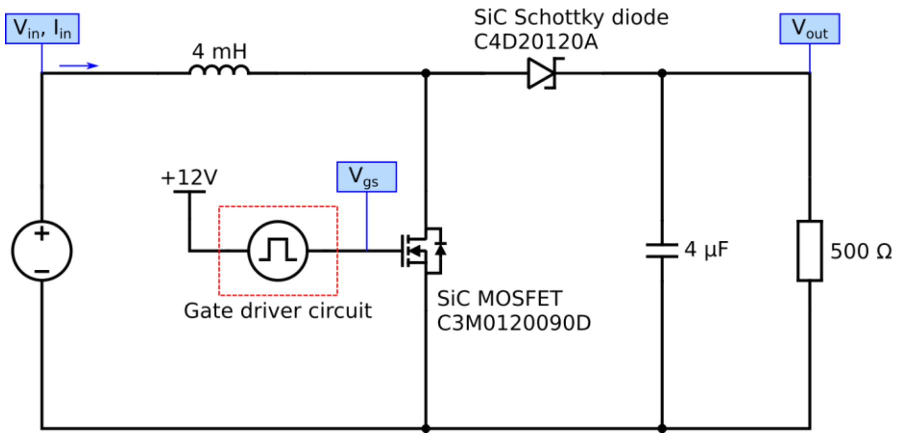
Component test standards and methods

- MIL-STD-750E METHOD 1080
  - Destructive SEE on power MOSFETs
- Single Event Effects Test Method and Guidelines, ESCC Basic Specification 25100
- Testing Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs, JPL Publication 08-10 2/08
- MIL-STD-750-1A METHOD 1017.1
  - Neutron testing
- MIL-STD-883K METHOD 1019.9
  - TID testing
- Total Dose Steady-State Irradiation Test Method, ESCC Basic Specification No. 22900
- IEC 62396-4:2013
  - Design of high voltage aircraft electronics managing potential SEEs
- Guidelines for Space Qualification of GaN HEMT Technology

No system level test standards for switching power converters

Description of the studied system





DC-DC converter

- Boost topology, ratio 1.25 (V_{in}/V_{out})
- Designed for SiC power MOSFET
- 500 W output (500 V, 1 A)

Custom design for research purpose

- Effect of failed or degraded device on the system response
- Irradiation of the system

All parts are COTS

Component vs. system level testing

Component level

Testing in off-mode [1][2]

- Worst case in terms of SEB

Statistical failure rate analysis

- Failure rate extraction based on large number of device failures [3][4]

Electrical parameter degradation analysis

- TID, DD

System level

Operation in switching mode

- Different stress modes compared to component level testing -> role of coupled effects?

Observability

- No possibility to distinguish between SEB and SEGR
- Possibility to observe, which component has failed

Complementary information to component level testing

- Possibility of different failure modes and/or different radiation sensitivity at system level

[1] MIL-STD-750E METHOD 1080
[2] SINGLE EVENT EFFECTS TEST METHOD AND GUIDELINES ESCC Basic Specification 25100
[3] RADECS2017 SC4
[4] Ferlet-Cavrois et al. TNS Vol. 59, 2012

Component vs. system level testing

Operation in switching mode

- Example: SiC power diode failure observed during the DC/DC-converter heavy ion testing [1]
- Example: different TID response of the device when irradiating in operation mode compared to zero-bias or positive bias irradiation [2]

Constraints with system level testing

- Not necessarily lower cost method
- High power supply needed -> more cabling considerations
- High dissipative load needed -> heat

Shortcomings of standards and guidelines

- Imprecise definition of irradiation conditions and test setup [3]
- Effect of aging on radiation sensitivity

[1] NSREC2017 Short Course
[2] Adell *et al.* 2002
[3] MIL-STD-750E METHOD 1080

State of the art: DC-DC converter test methodology

Analysis
- Converter design
- Identification of the most sensitive component

Characterization
- Radiation response of the critical component

Correlation
- Operational conditions of the converter
- Voltage bias conditions of the critical component

[1]

Analysis

- Circuit level modelling of the system (e.g. SPICE)

Characterization

- Statistical analysis in the component level
  - Failure rate based on large number of failures [2]
  - Operational mode-like test conditions at component level and evaluation of long-term reliability[3]

Correlation

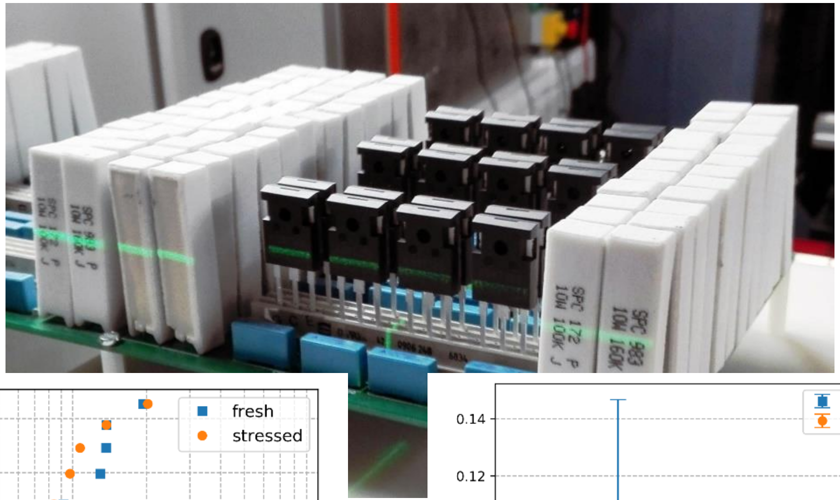
- Relationship between the operational conditions of the converter and the component
  - e.g. SEB vs. SEGR [3]

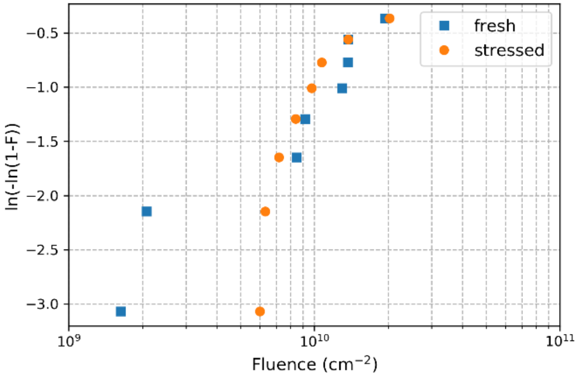
[1] C. Rivetta *et al*. RADECS2001
[2] Ferlet-Cavrois *et al.* 2012
[3] Ikpe *et al.* 2016

Methodology

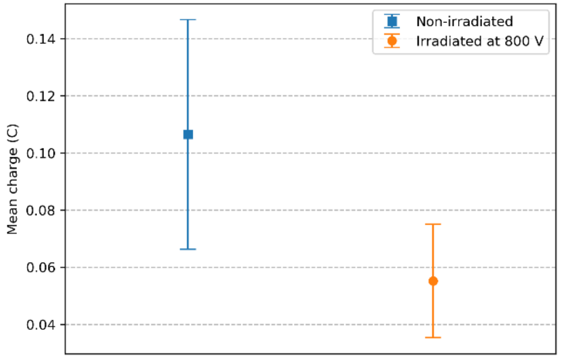
Component level:

- Effect of aging on radiation sensitivity
  - Accelerated aging of the components
  - Comparison of radiation sensitivity between pristine and aged devices
  - Statistical destructive failure rate analysis
  - Electrical parameter degradation analysis
- Long term reliability evaluation of irradiated devices
  - Post-irradiation stress tests





Fluence to failure under neutron radiation for fresh and electrically stressed devices

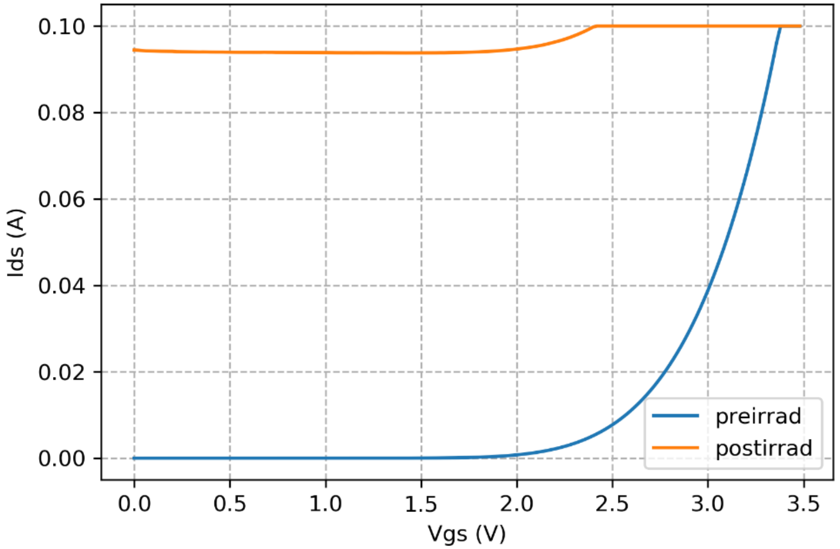


Mean charge to breakdown of gate oxide for non-irradiated and neutron irradiated devices

Device characteristics

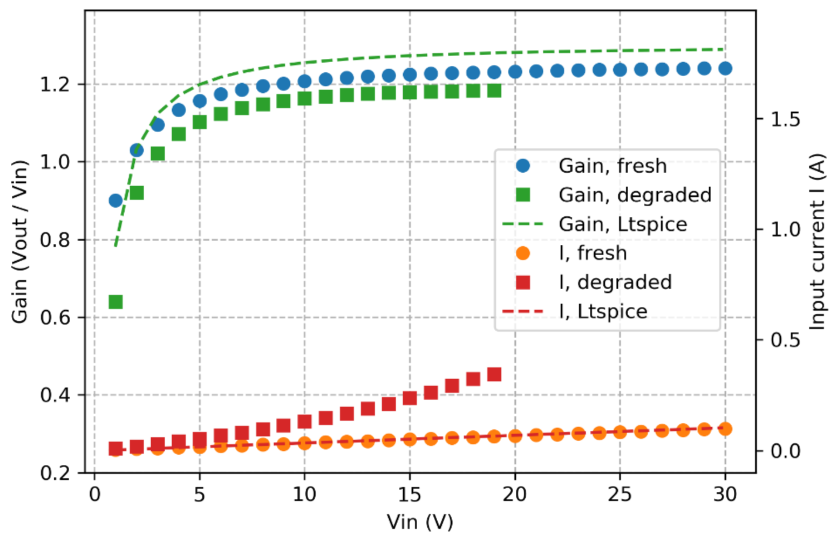
Strong neutron induced degradation in characteristics in device level

- Device considered as failed during the test
- Some of the voltage blocking capacity left

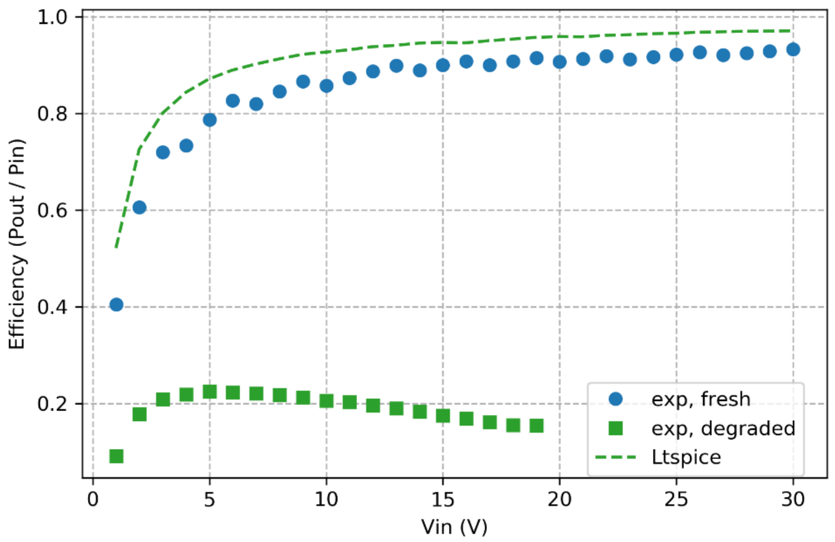


Implementation of device into the system

Converter characteristics



Voltage gain and input current



Efficiency

Converter characteristics with irradiated and degraded component

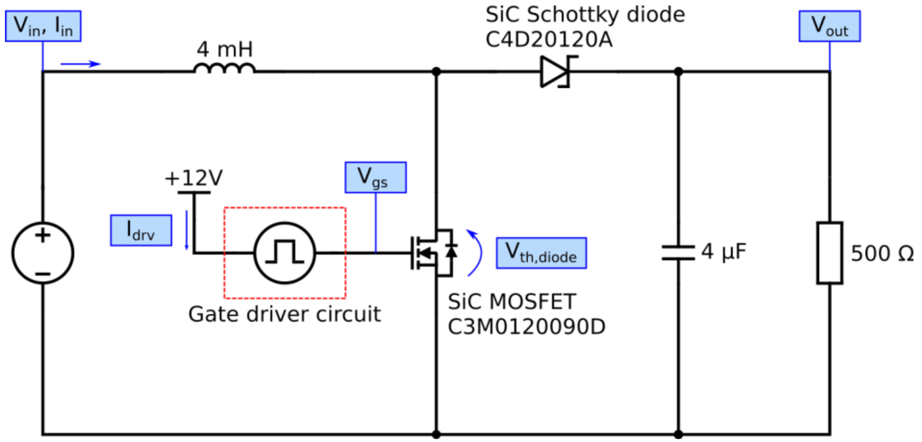
- Output voltage slightly degraded
- Efficiency strongly reduced due to high leakage of the MOSFET

Future work

System level testing:

- Implementation of degraded device model in the simulation
- Testing of the system with components of different degradation modes
- Irradiation test of the system

-> How degradation on the component level affects the reliability of the system?



Schematics and test points of the DC/DC converter