Opportunities for COTS SiC JFETs in space power applications

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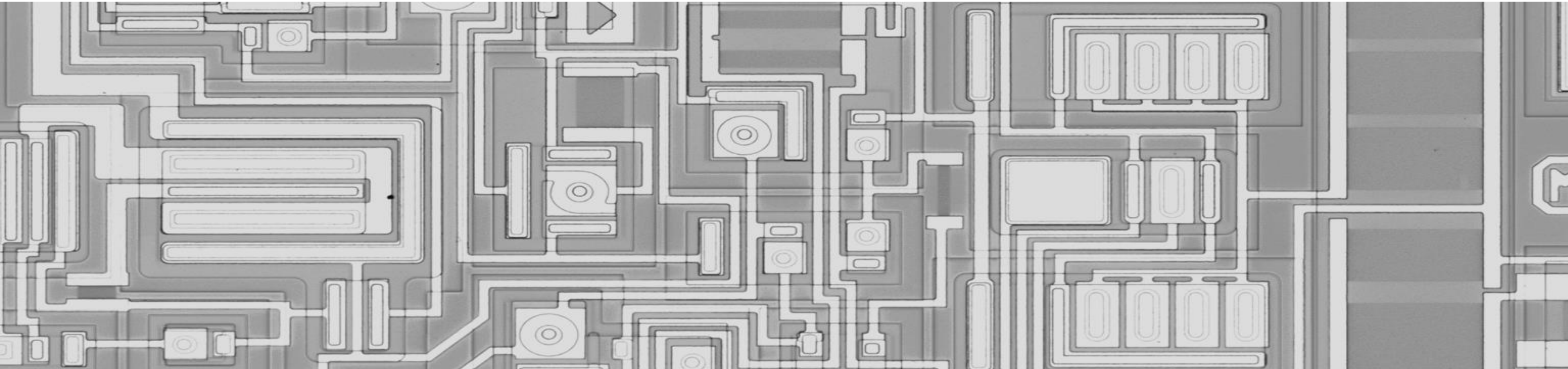
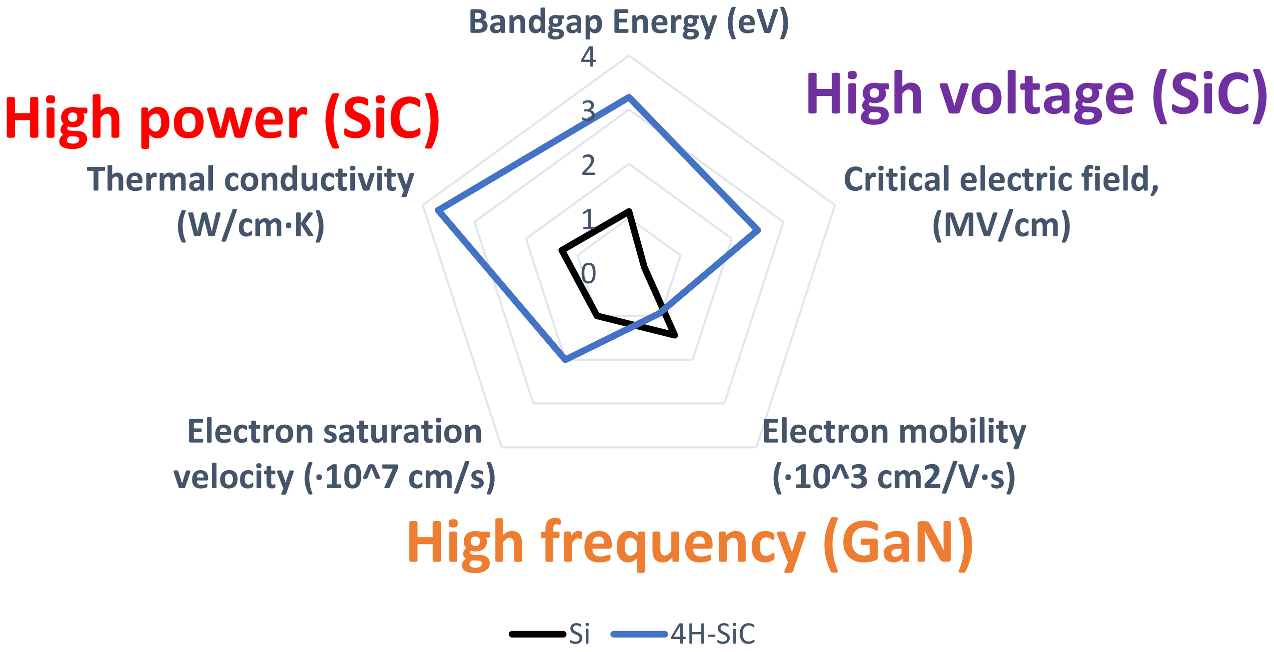
Space Power & Electronic Systems



Introduction

Silicon Carbide (SiC) offers much **better performance** than **Si** in power conversion: **Are there opportunities for SiC power devices in space applications?**



Power levels & applications & power semiconductor technology

Regulated bus	Unregulated bus		
Bus voltage	*Bus voltage*	*Power*	*Standard*
28V		< 1.5kW	ECSS-E-ST-20C AS5698 AIAA S-122
	22V – 38V 23V – 36V		ECSS-E-ST-20-20C AS5698
50V		< 5kW	ECSS-E-ST-20C AIAA S-122
	32V – 52V		ECSS-E-ST-20-20C
70V		< 10kW	AIAA S-122
100V		< 20 kW	ECSS-E-ST-20C AIAA S-122
120V		< 30 kW	ECSS-E-ST-20C AS5698
	98V – 136V		AS5698

Applications

LEO satellites, interplanetary probes…

Telecom GEO satellites…

Large satellites, Electric Propulsion, ISS…

HP electric prop., space stations…
Microgrids (Lunar, Mars…)

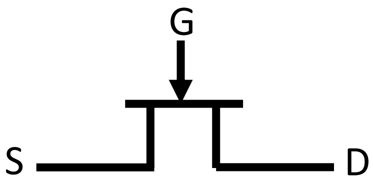
Si

GaN

SiC

Power semiconductor: basic requirements

SiC JFET



- Maximum voltage **PASS**
- Conduction and switching losses **PASS**
- Normally-off device (transistors) **FAIL**

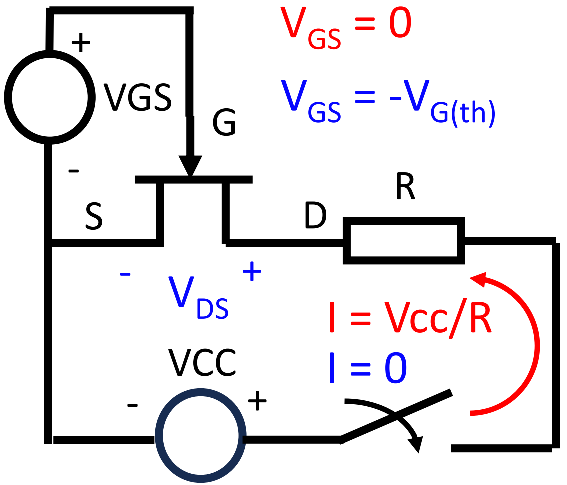
COTS for space applications: additional requirements

- Robustness and reliability
  - Temperature **TO STUDY**
  - Radiation (TID & SEE) **TO STUDY**
  - Electrical stress **TO STUDY**
- Availability & traceability **PARTLY**
- Versatility (technology building blocks) **TO STUDY**

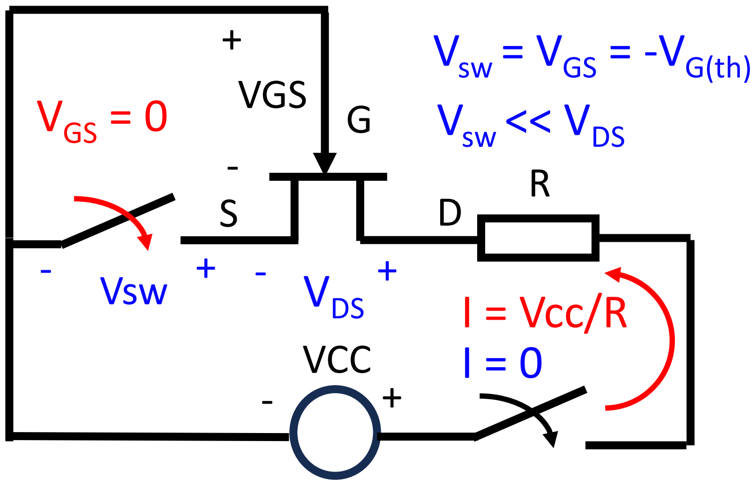
Normally-on to normally-off device: cascode configuration

- Serialization of a depletion mode normally-on device (i.e. $V_{GS} < 0V$ to turn-off) and a control device, transforming the arrangement into a normally-off device

SiC JFET: normally-on



SiC JFET cascode: normally-off



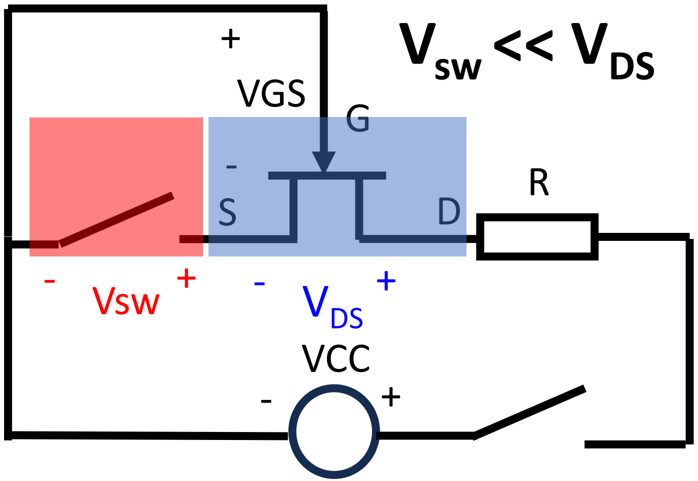
Cascode configuration: some interesting features (I)

1) SiC JFET highlights:

- High voltage device (650 V – 1200 V)
- No gate oxide
- Lowest R_{DSon} in the market
- Strong short-circuit withstand
- Fast switching
- High-temperature operation

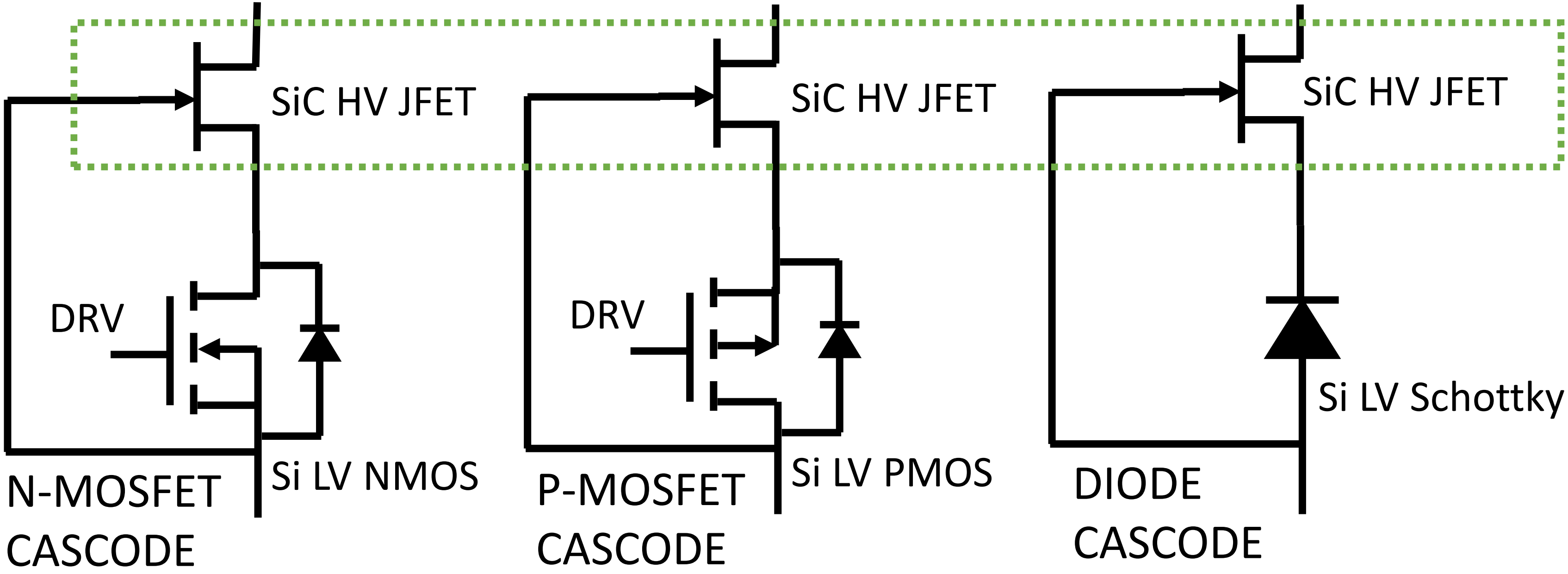
2) Control device highlights:

- Low voltage device
- Very low conduction losses
- Fast switching
- Easy to drive



Cascode configuration: some interesting features (II)

3) Basic power switches can be implemented using different control devices



ALL BASIC POWER PROCESSING FUNCTIONS COVERED WITH THE SAME HV DEVICE

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SiC JFET test campaign: Electrical stress

4 SiC JFET refs.
16 devices / ref

FT0 → **HTOL:** 1000h, 75%·Inom, 100-120ºC → FT1 → **Overload:** 1000 rep, 100V, 1A -> 20A, CL – 10A,15ms → FT2 → **Inrush curr.:** 1000 rep, 100V, CL – 10A, 15ms → FT3 → **Short circuit:** 1000 rep, 100V, CL – 10A, 15ms → FT4

FT4 → Overload: **300V**

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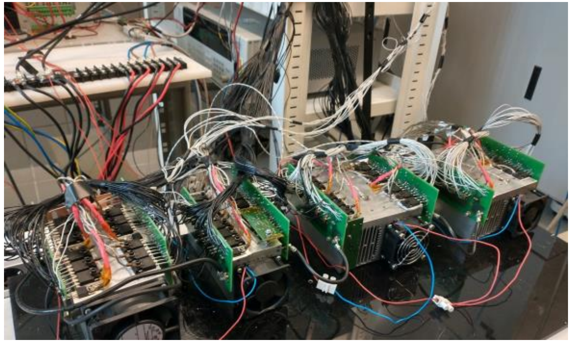
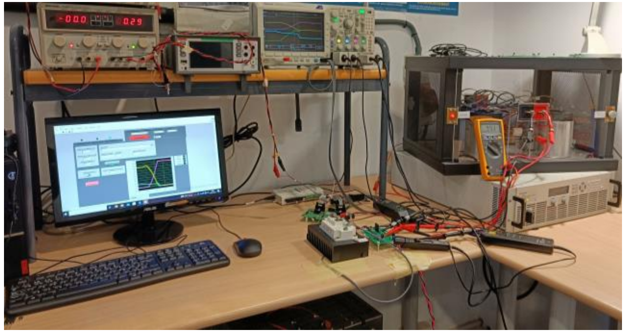




SiC JFET test campaign: TID & SEE

Centro Nacional de Aceleradores

Infraestructuras Científicas y Técnicas Singulares

4 SiC JFET refs.
12 devices / ref

FT0

TID:
Co-60, 1.25 MeV, 200krad (Si)
Conduction state
On-line monitoring: V & I

FT1

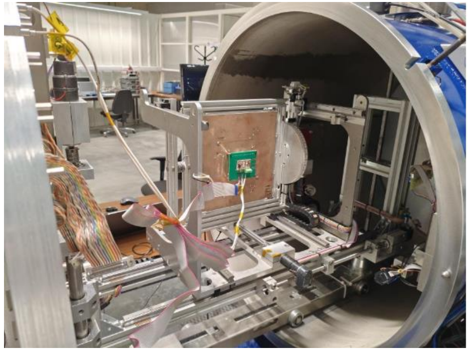
ALTER

1 SiC JFET refs.
6 devices

FT0

SEE:
UCL, Cyclone
Blocking state
I_{DS} monitoring, V_{DS} stepping
Ions (Ar, Ni, Kr, Xe)

FT1



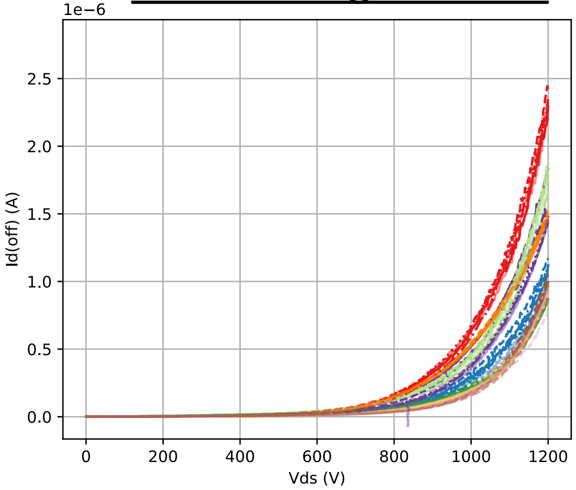
Electrical stress tests: results (I)

- Superimposed curves after each characterization of the devices (FT0 – FT5)

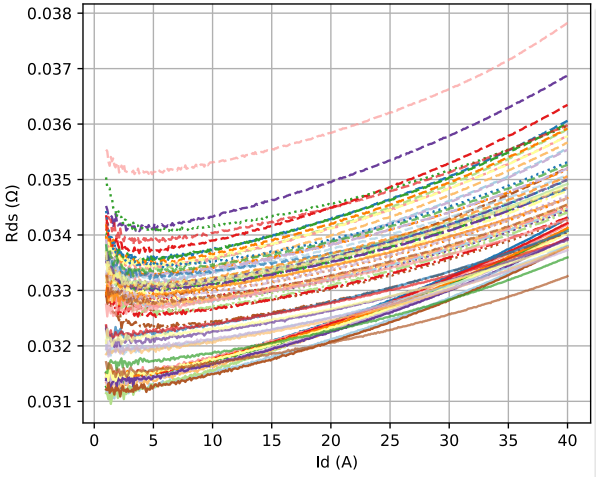
Output characteristics: $I_{d(off)}$ vs V_{DS}

Input characteristics: $I_{d(off)}$ vs V_{DS}

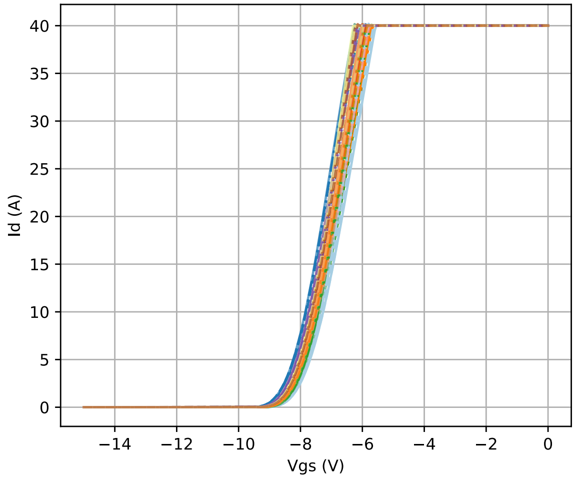
Drain leakage current



ON resistance



Transconductance and Vth



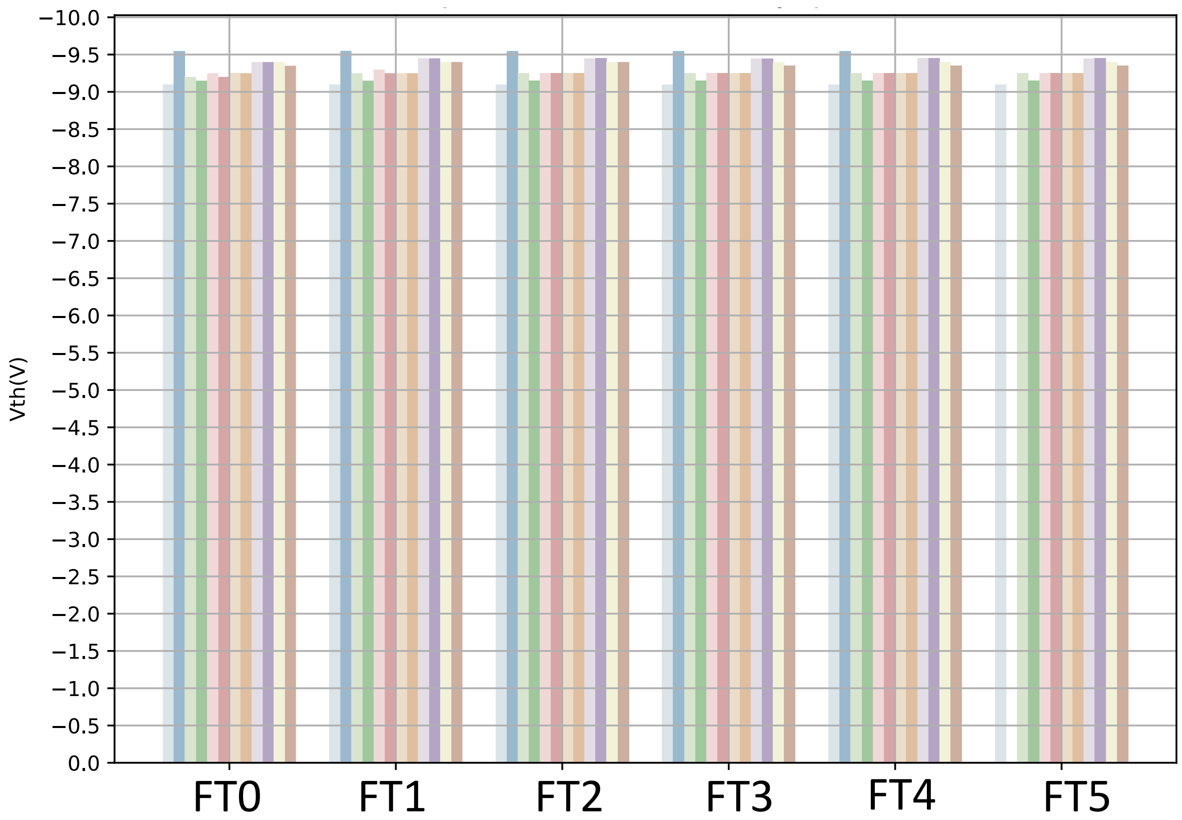
VGS= -20V, Tamb.
Datasheet NOM: Id(off) = 10 uA
Datasheet MAX: Id(off) = 60 uA

VGS= 0V, Id max =0 to 40A, Tamb.
Datasheet NOM: Rds(on)=35mΩ
Datasheet MAX: Rds(on)=45mΩ

VGS= -20V to 0V,
Id max =40A, Tamb.

Electrical stress tests: results (II)

- Threshold voltage V_{TH} after each test (FT0 – FT5)



Method Id(Vth) = 10mA

SPES

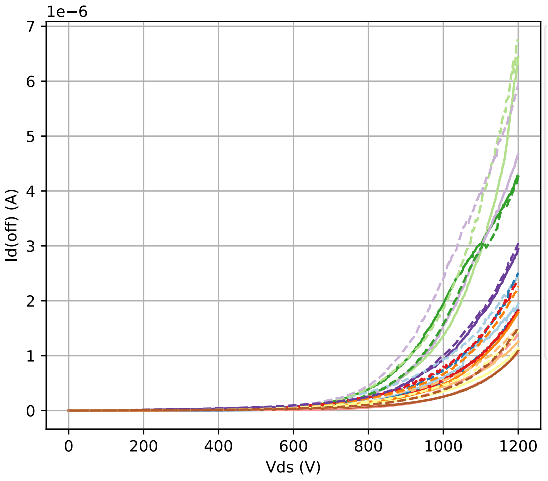
Total Ionizing Dose tests: results

- Superimposed curves pre and post irradiation (FT0 – FT1)

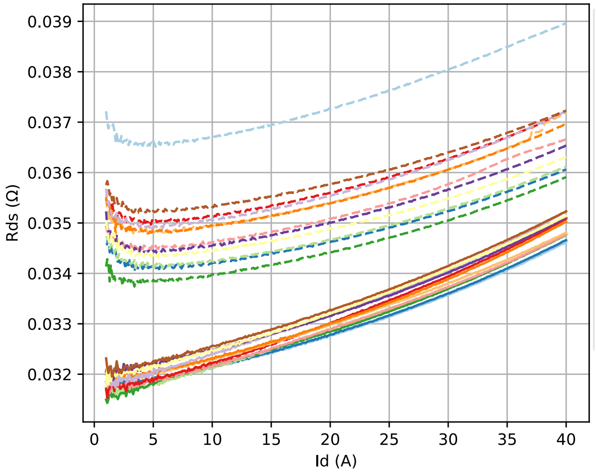
Output characteristics: $I_{d(off)}$ vs V_{DS}

Input characteristics: $I_{d(off)}$ vs V_{DS}

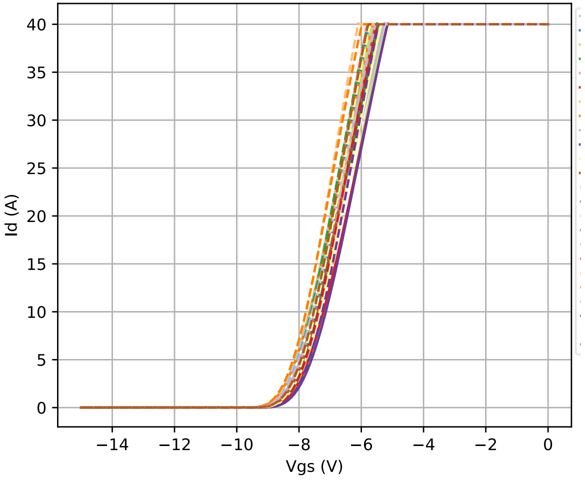
<u>Drain leakage current</u>



<u>ON resistance</u>



<u>Transconductance and Vth</u>



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VGS= 0V, Id max =0 to 40A, Tamb.
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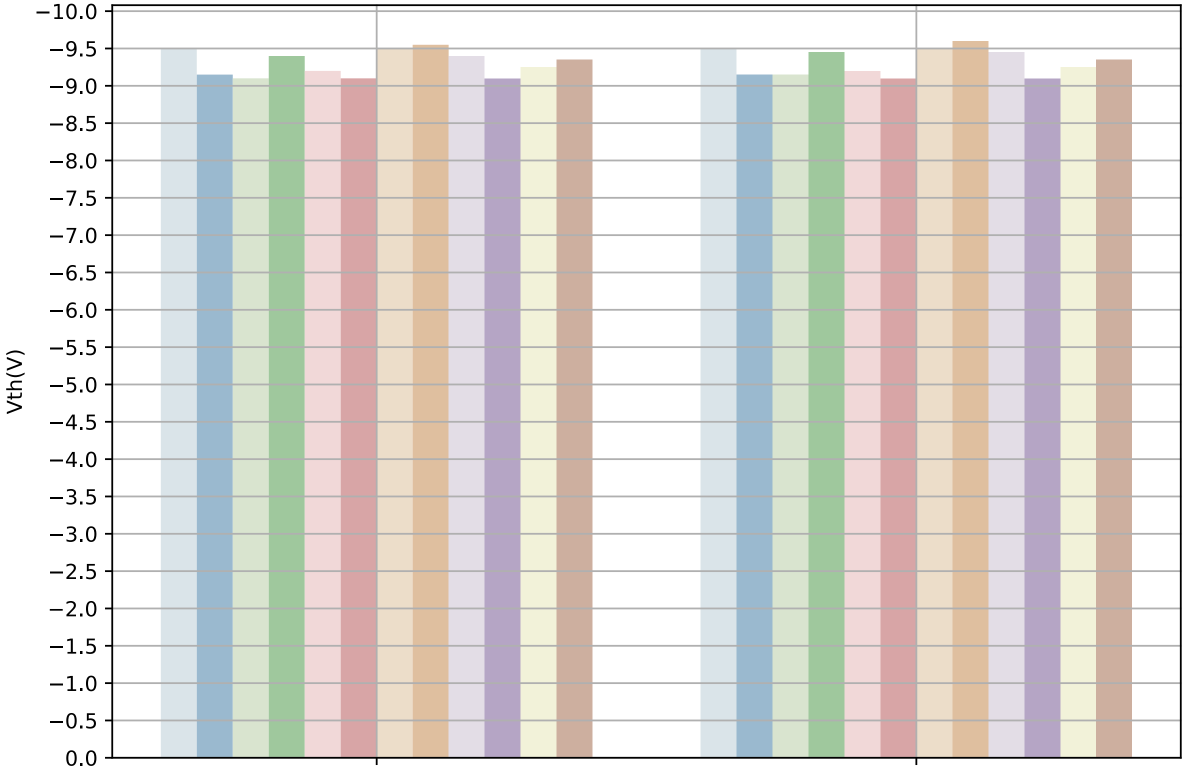
VGS= -20V to 0V,
Id max =40A, Tamb.

Total Ionizing Dose test: results (II)

- Threshold voltage V_{TH} after each test (FT0 – FT1)

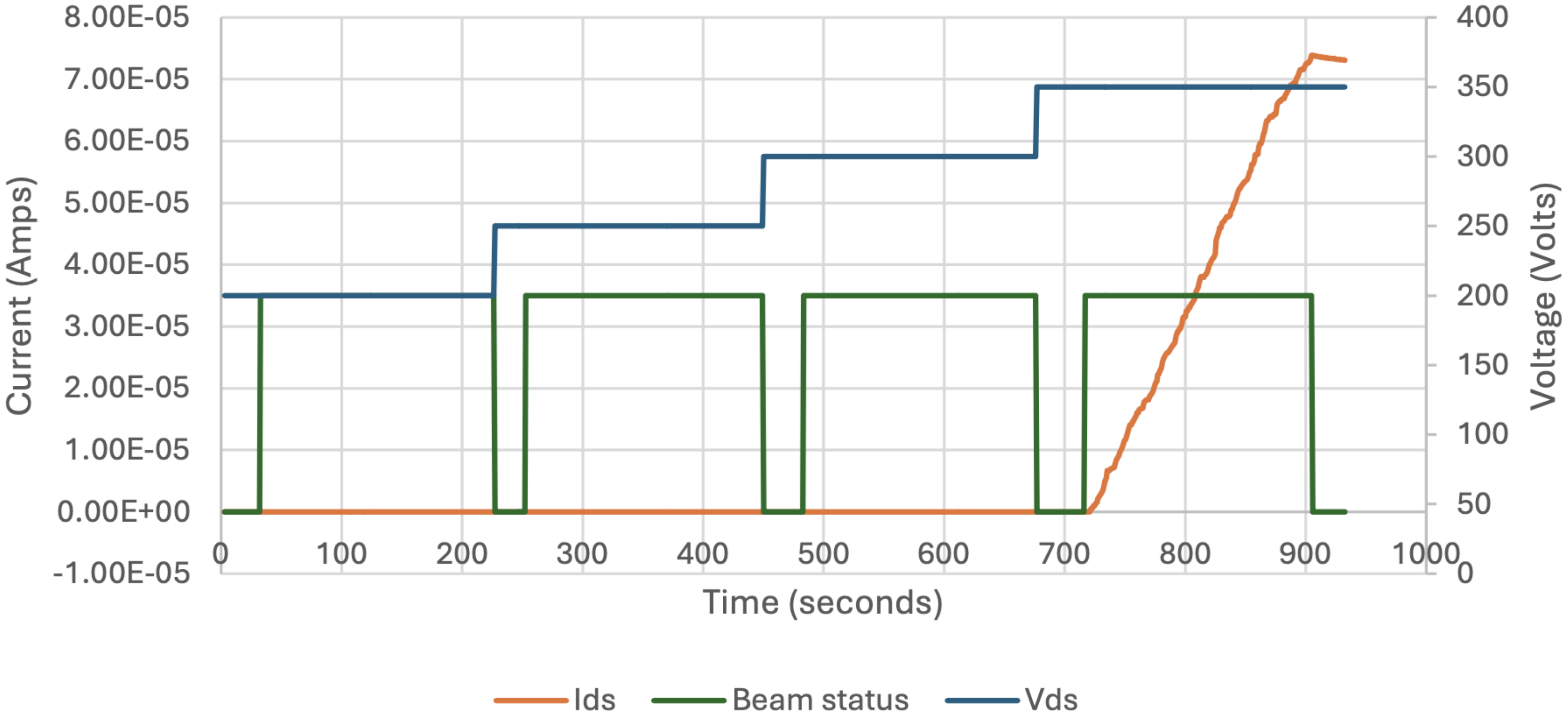


PRE-IRRADIATION POST-IRRADIATION

Method Id(Vth) = 10mA

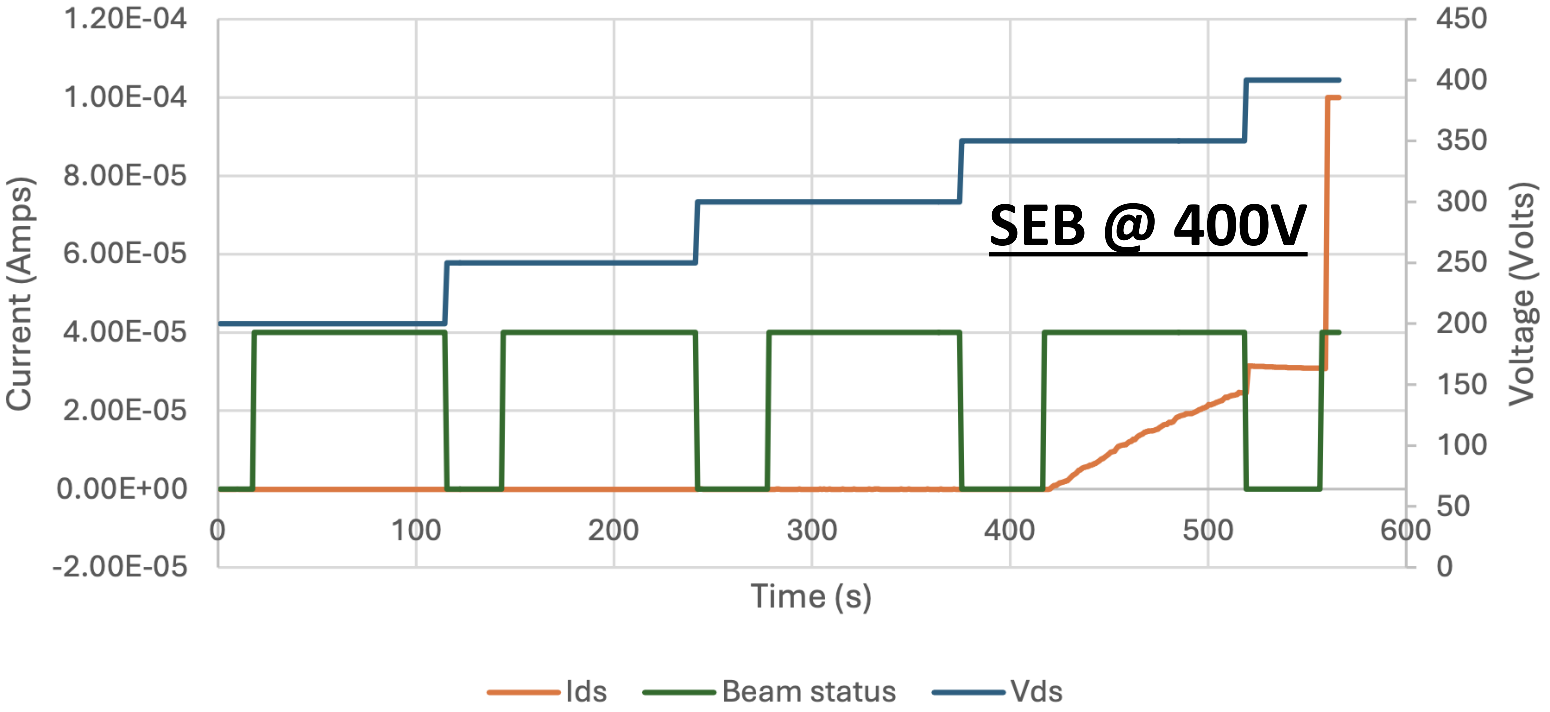
Single Event Effects test: results (I)

- Xe, 995 MeV, LET (Si) = 62.5 MeV cm^2/mg), 1000 ions/s/cm^2
- I_{DSS} stable up to 300V, 0.37uA/1000 ions @ 350 V, PIGS passed

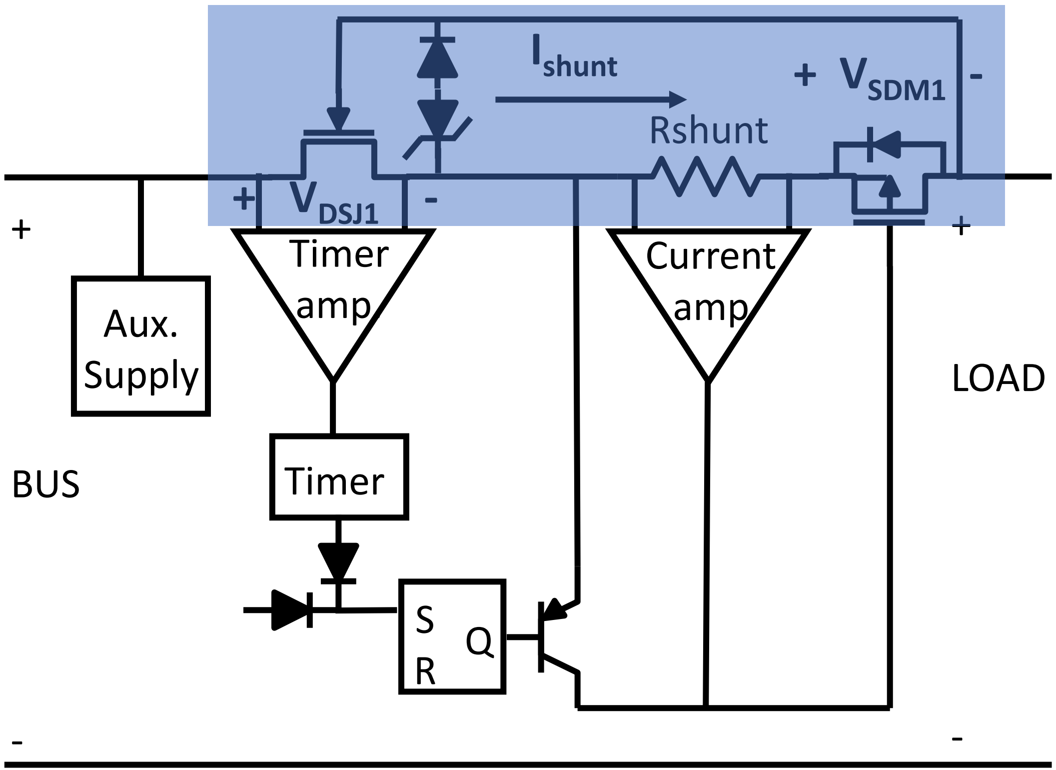


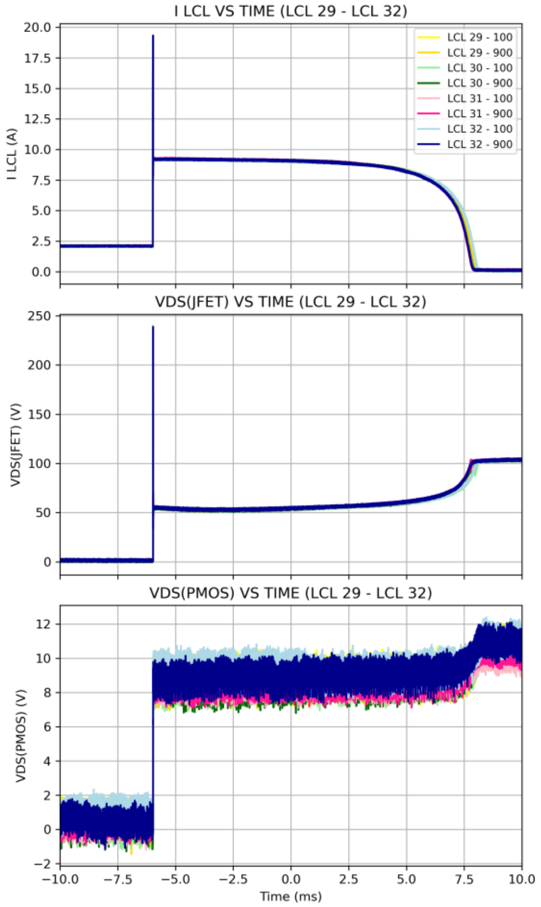
Single Event Effects test: results (II)

- Kr, 769 MeV, LET (Si) = 32.4 MeV cm^2/mg), 2000 ions/s/cm^2
- I_{DSS} stable up to 300V, 0.115uA/1000 ions @ 350 V, PIGS passed



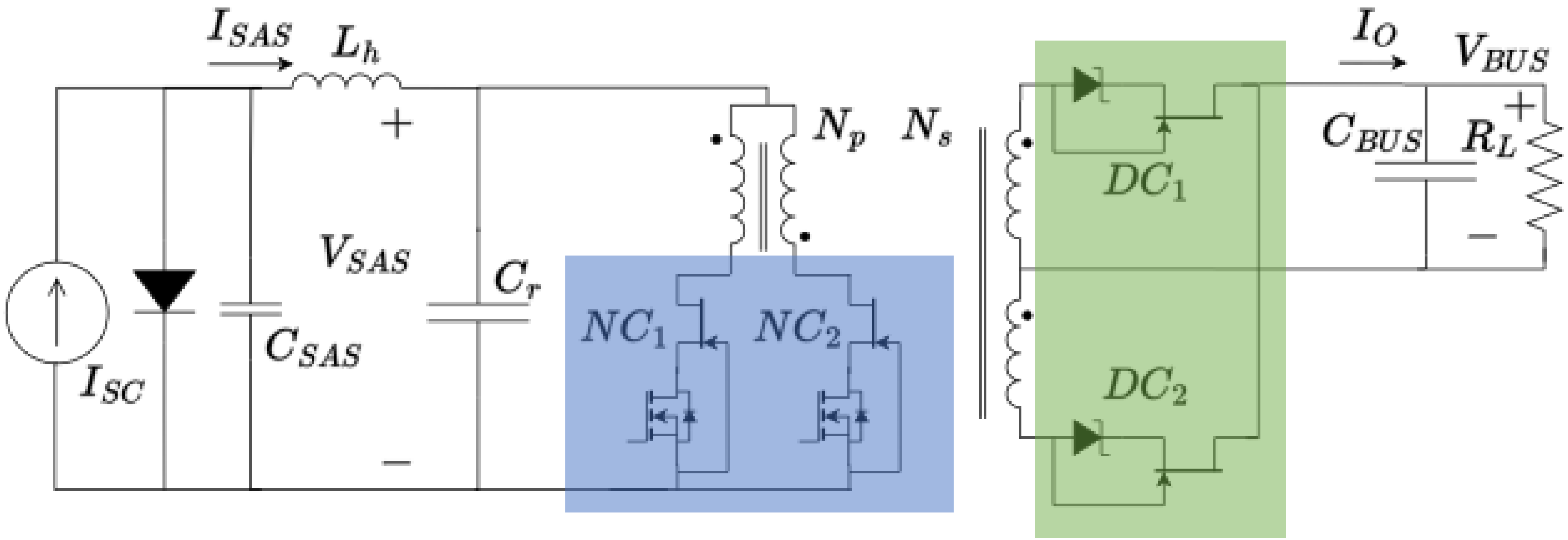
Application P-MOSFET cascode: Latching Current Limiter





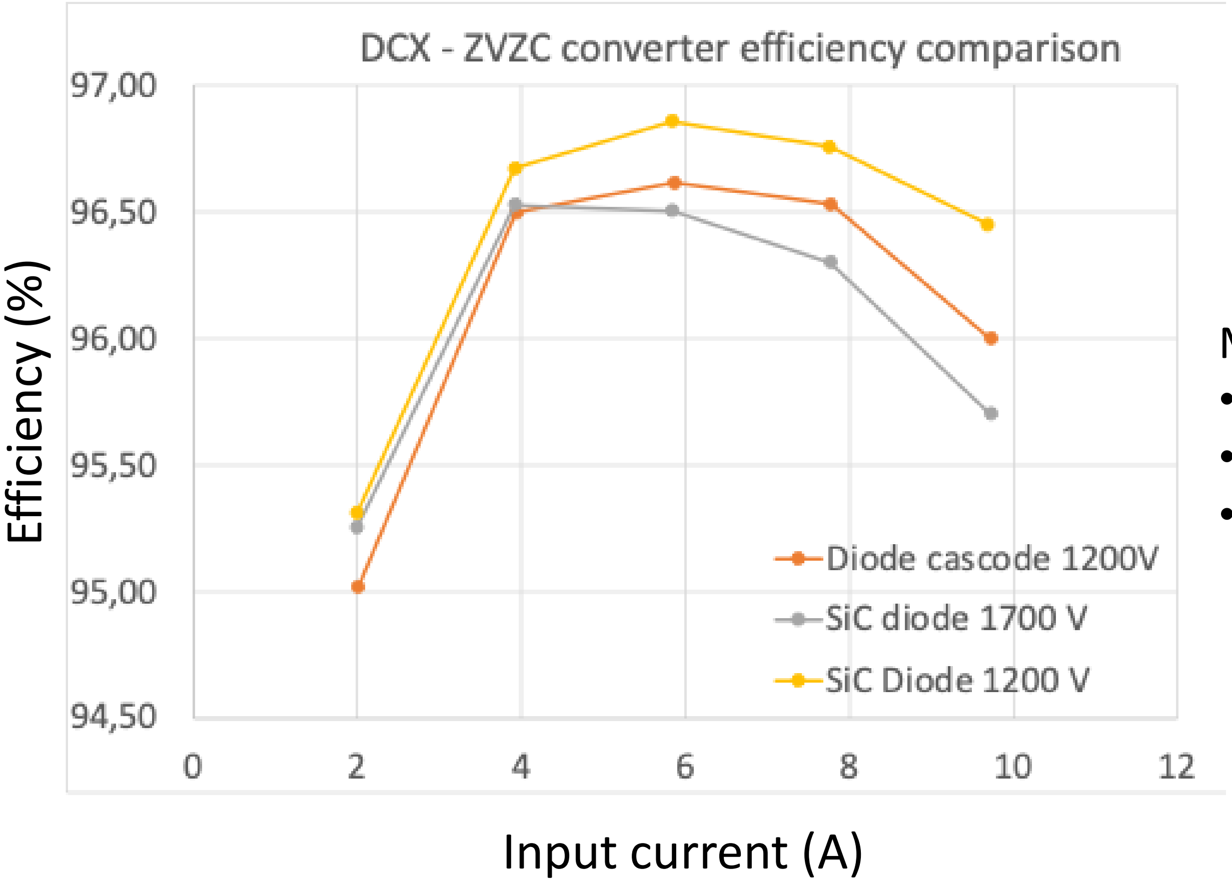
✓ The LCL has been stressed with **5.000 current limiting events** with no failure (at **100V** and **300V**)

Application N-MOSFET cascode and diode cascode: SAR-DCX



- ✓Push-pull structure: primary & secondary
- ✓100V to 300V (1:3 transformer)
- ✓ZVS and ZCS converter
- ✓All SiC JFET cascode

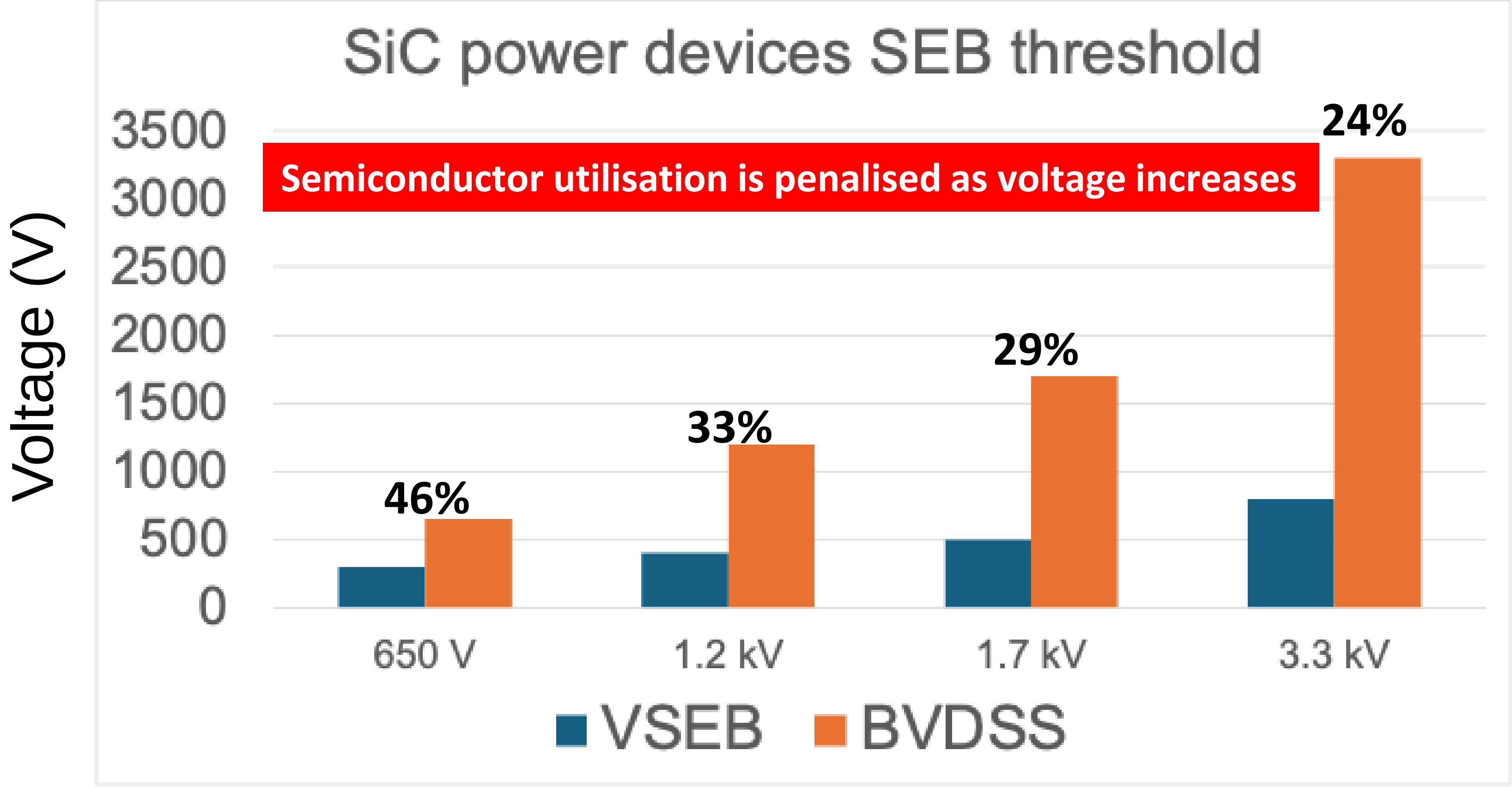
Application N-MOSFET cascode and diode cascode: SAR-DCX results



Measurement conditions:

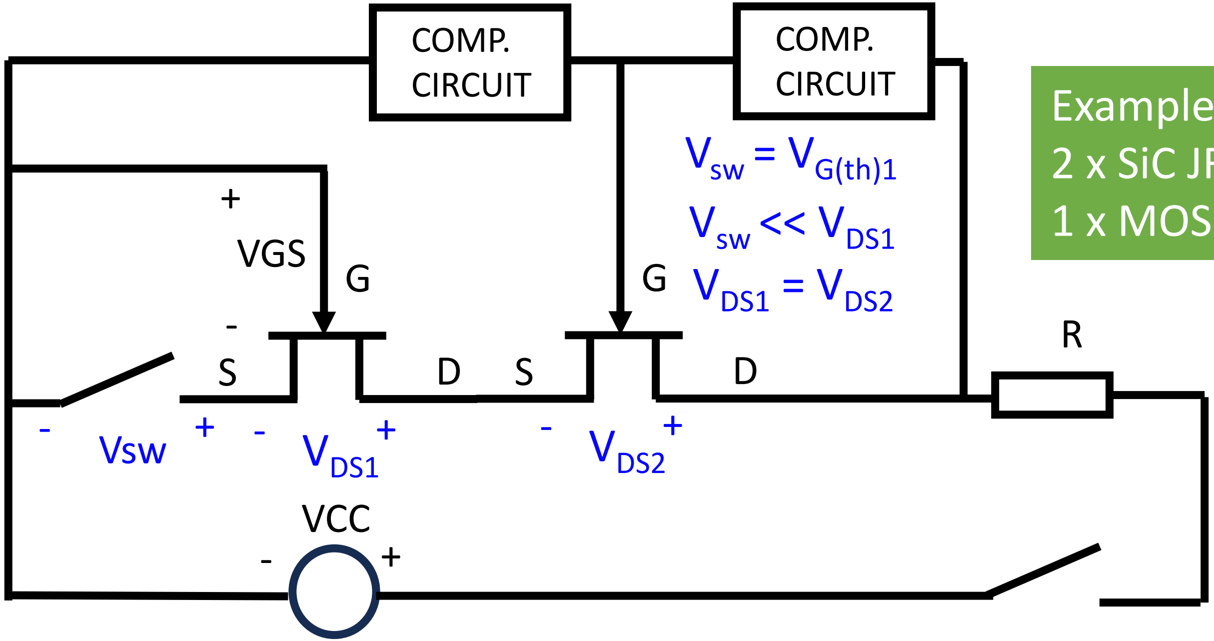
- Vin = 100 V; Vo = 300V
- Similar t_{on}
- Different switching frequency

Next steps: very high voltage applications



Next steps: very high voltage applications

- Supercascode: serialization of more than one depletion mode normally-on device (i.e. V_{GS} < 0V to turn-off) and a control device.



Example:
2 x SiC JFET 1.2 kV -> VSEB=800V
1 x MOSFET 3.3 kV -> VSEB=800V

Conclusions

- High voltage, high current power devices are demanded for future space applications: **WBG power devices.**
- SiC JFET is a competitive alternative: **robust and basic building block**.
- SiC JFET cascodes: **versatile**.
- SiC JFET supercascodes: **SEB**.

Thank you for your attention!!!

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