2nd Generation 1200 V SiC MOSFET: Robust against Radiation and Better in $R_{DS,ON}$

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Bodo's Wide Bandgap Event 2024

Making WBG Designs Happen

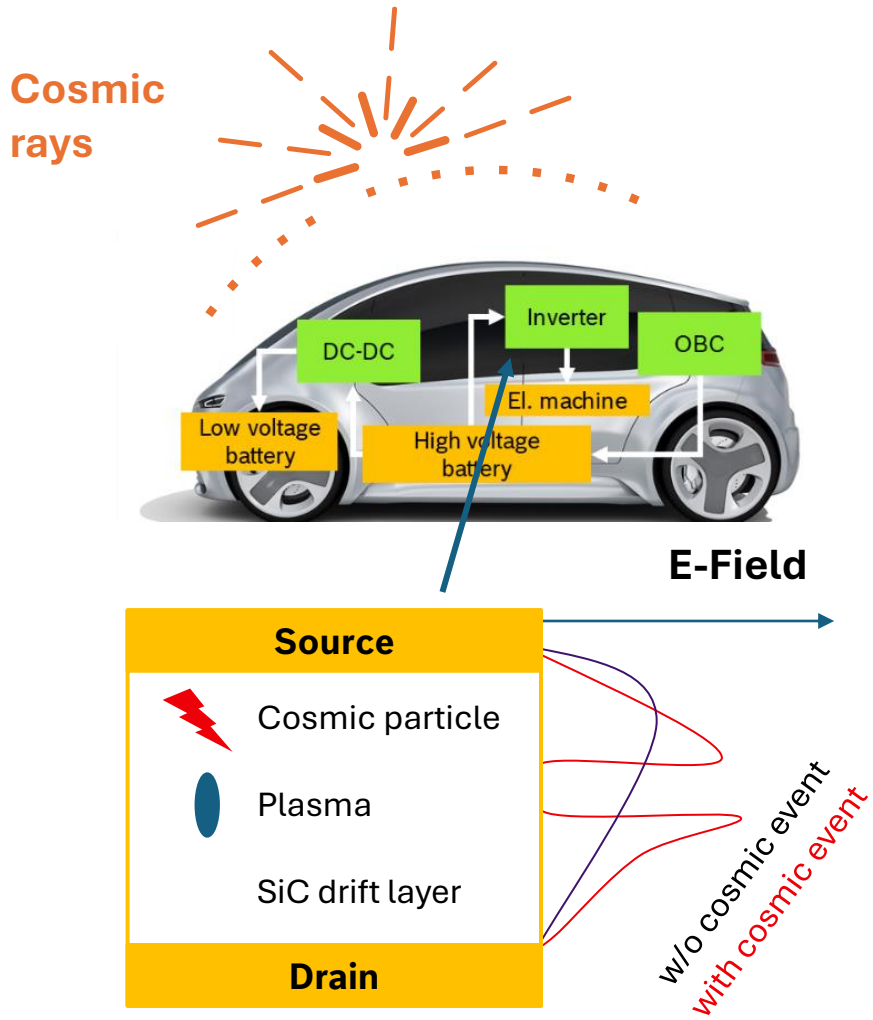
SiC

Introduction

Cosmic-Ray induced failure in the electric vehicles

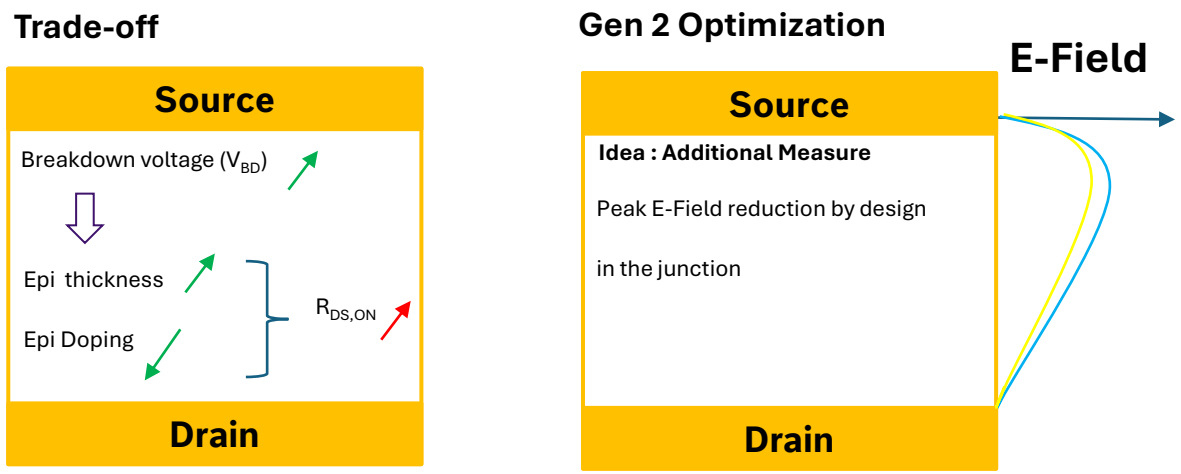
- High voltage power devices in electric vehicles are continuously influenced by cosmic particles
- These can potentially cause catastrophic failures
- Silicon carbide based wide band gap devices with their very high electric fields are prone to this failure
- The best remedy against a cosmic ray induced failure is an optimized and rugged semiconductor device!

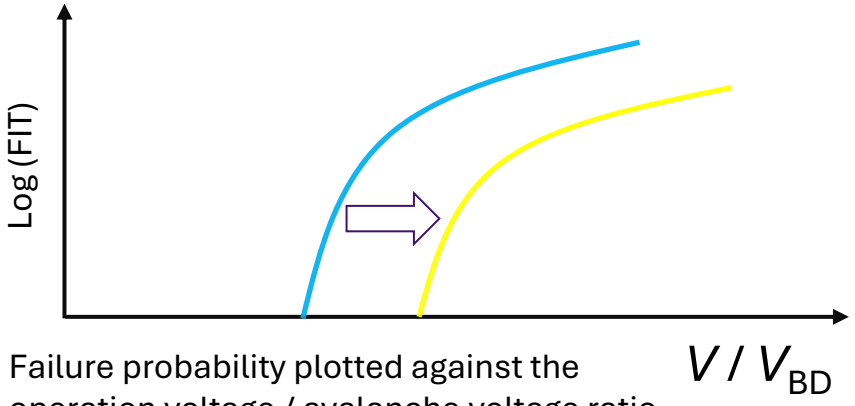
High voltage power devices can be destroyed during operation by cosmic particles



Trade-off and optimization in Gen. 2

Gen 2 optimization idea



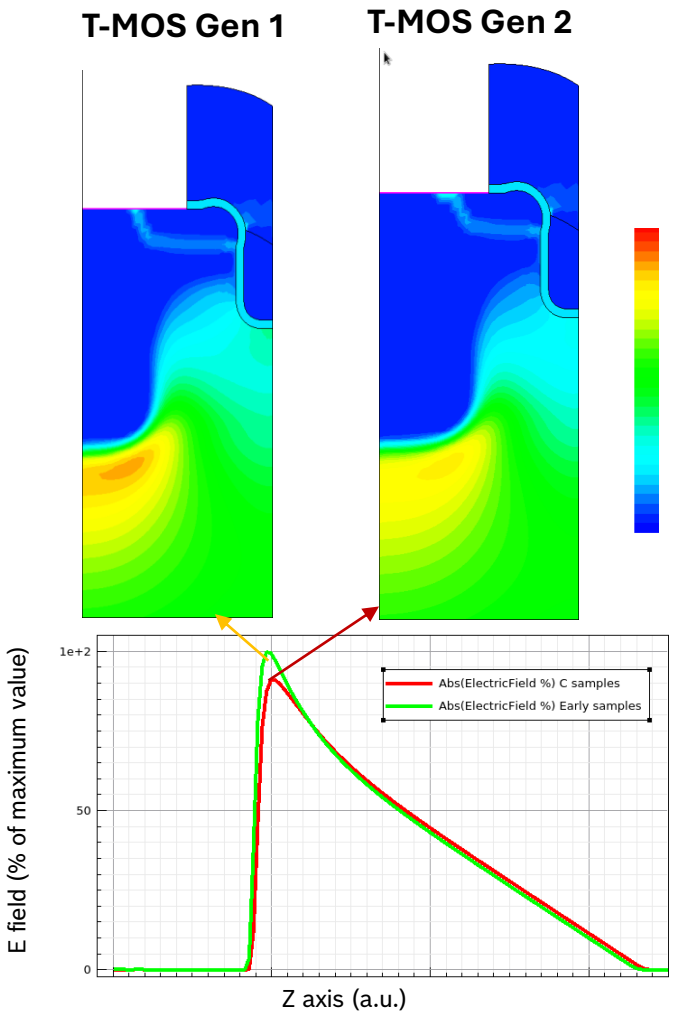


Failure probability plotted against the operation voltage / avalanche voltage ratio

- Higher radiation ruggedness is achieved either by thicker Epi/ drift layer or lower epi doping
- Gen 2 MOSFET additionally reduces the peak E-Field in the junction during the blocking state
- E-Field shaping results better $R_{DS,ON}$ improving radiation ruggedness significantly

Peak E-Field shaping enables radiation rugged device with better $R_{DS,ON}$

Device Optimization
Dynamic TCAD simulation



$$P_{\mathrm{lf}}(E(x)) = v_0 \exp\left(-\frac{E_{\mathrm{b}}}{E(x)}\right)$$

$$P_{\mathrm{f}} = \int_{\Omega} P_{\mathrm{lf}}(E)\mathrm{d}\Omega$$

v_0 and E_{b} are fitting parameters

- Since local failure rate (P_{lf}) depends exponentially on the local field *E(x)* (Akturk 2019) and is integrated over the entire device volume Ω, to get the total failure probability P_f, the improvement is significant
- T-MOS Gen 2 design reduces the electric field in the junction during the blocking state
- The reduction of the in the junction is achieved by wider P+ region and the larger radius (Syed 2024) in the junction

Reduction of the E-Field in the junction is achieved by suitable P+ region design

A. AKTURK et al, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 66, NO. 7, JULY 2019
B. Syed et al, PCIM Europe 2024; International Exhibition and Conference for Power Electronics, Intelligent Motion, renewable Energy and Energy Management, Nürnberg, Germany, 2024

Experiment

Neutron radiation accelerated test

- 250 devices irradiated vertically under the neutron Beam
- Radiation Flux increased for accelerated test
- Radiation spectrum is similar to terrestrial radiation

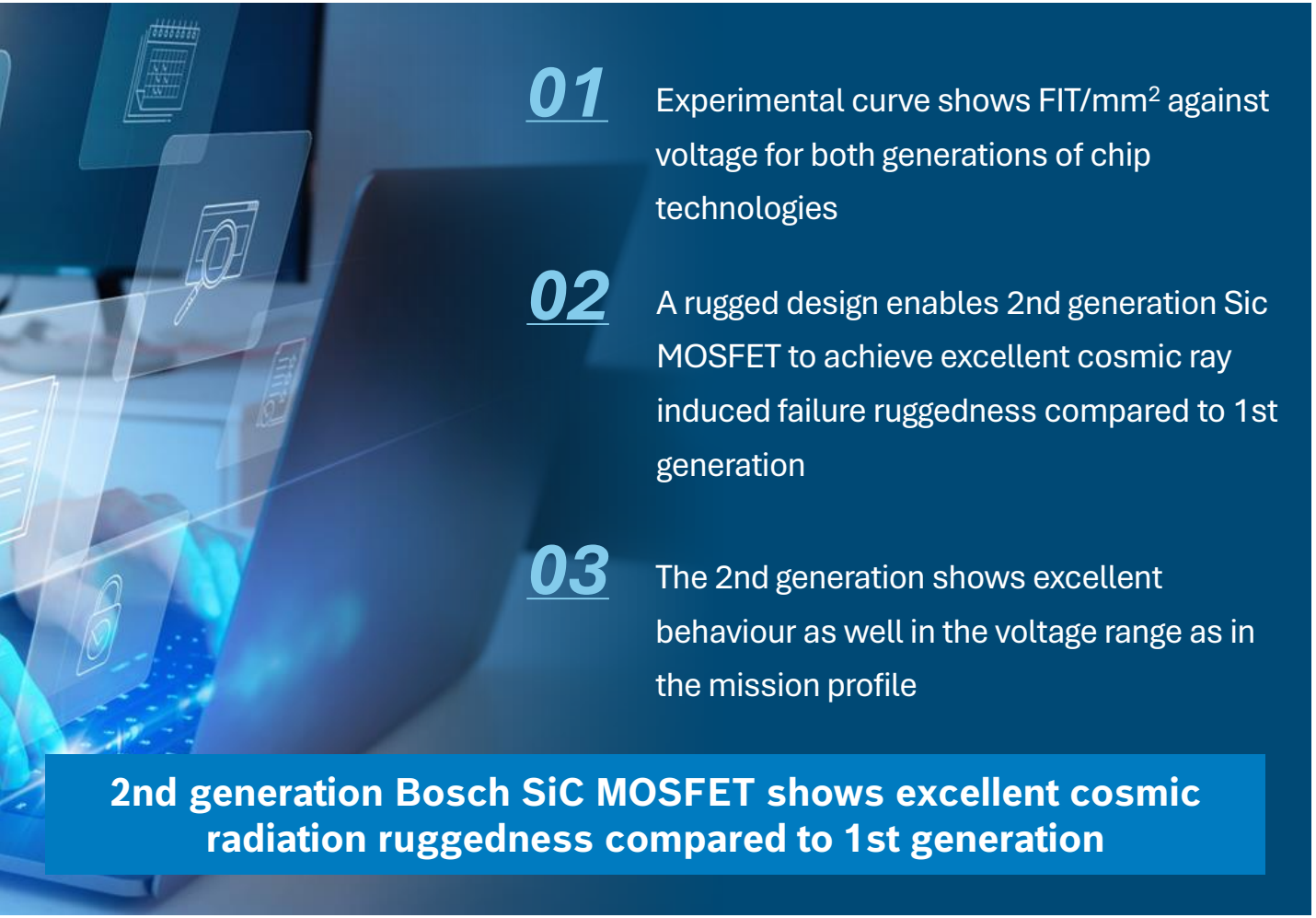
Neutron's flux ($cm^{-2}s^{-1}$)

- Radiation flux 6 to 8 orders of magnitude greater than the terrestrial radiation is produced by the neutron beam @ ChipIr facility in the UK
- The test set-up enables 250 devices to be irradiated simultaneously
- For each selected voltage point FIT rate is measured based on the experiment
- The tests conform JEDEC standard JEP 151 A

High energy accelerated neutron beam is used for fast derivation of FIT rates as a function of voltage

Experimental Result

FIT rate for Bosch 1st and 2nd generation SiC trench MOSFET

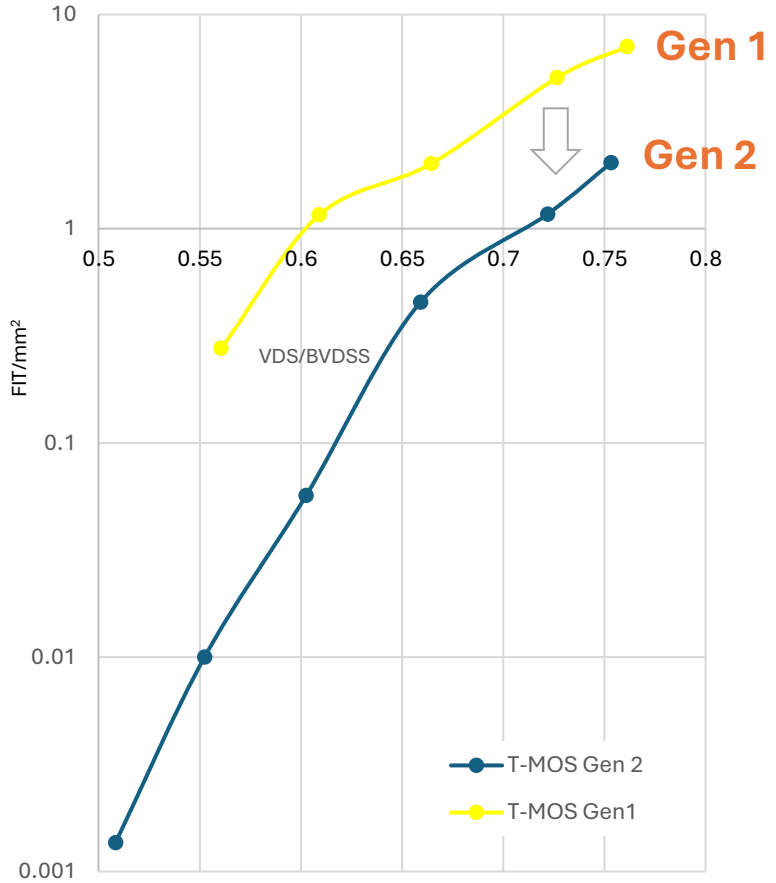


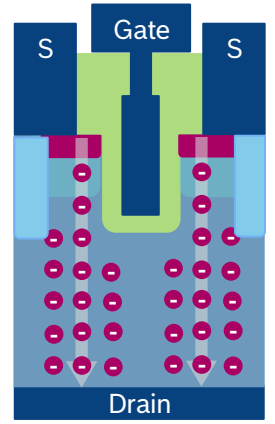
01 Experimental curve shows FIT/mm² against voltage for both generations of chip technologies

02 A rugged design enables 2nd generation Sic MOSFET to achieve excellent cosmic ray induced failure ruggedness compared to 1st generation

03 The 2nd generation shows excellent behaviour as well in the voltage range as in the mission profile

2nd generation Bosch SiC MOSFET shows excellent cosmic radiation ruggedness compared to 1st generation





Mission Profile

Driving / Charging / Altitude profile of an electric vehicle

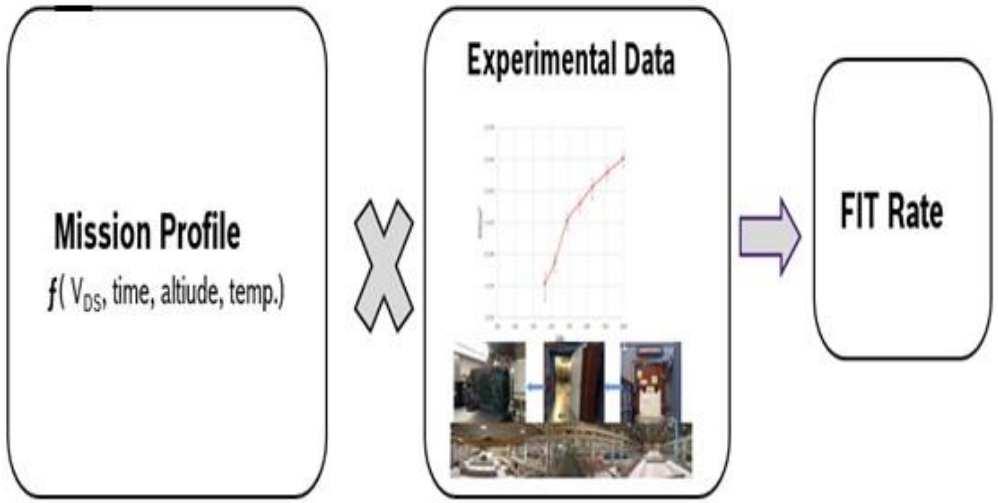
Driving		Charging		Altitude Profile	
VDS [V]	Time [h]	VDS [V]	Time [h]	Height [m]	Time [%]
600	0	240	0	250	70%
624	0	264	0	1000	20%
648	0	288	0	2000	8%
672	100	312	150	3000	2%
696	400	336	2250	4000	0
720	1200	360	5800	5000	0
744	3100	384	6100		
768	2600	408	6200		
792	500	432	6000		
816	100	456	3500		
840	0	432	6000		
		456	3500		
		480	0		

- Cosmic ray related failure is directly dependent on the specific ‘mission profile’ of the vehicle
- The mission profile defines which different voltage / current / temperature stress the power device experiences . It is influenced by different driving and charging scenarios & terrains.
- It is necessary to consider a real-life mission profile to calculate cosmic ray induced failure for a power device

A real- life EV mission profile is generated from various driving & charging conditions

Calculation

FIT Rate: mission profile and experimental data

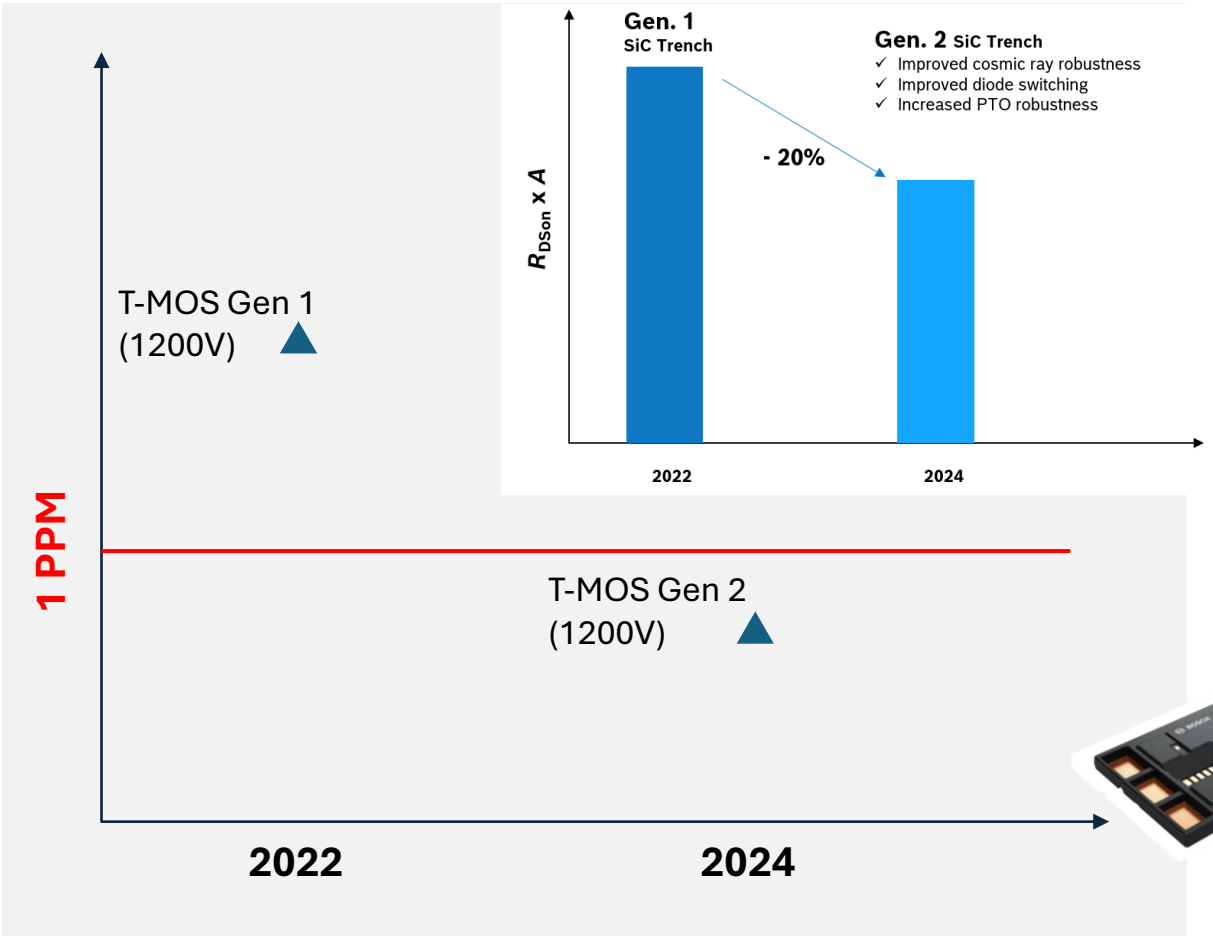


- Cosmic ray induced failures are calculated in FIT rate (failure in time) which can be converted to ppm (parts per million)
- The calculation is done by convoluting the mission profile with experimental data
- Experimental data is generated under an accelerated radiation test procedure according to the JEDEC standard JEP 151

Real life EV mission profile and accelerated test with neutron beams predict device failure rate

Comparison: T-MOS Gen 1 Vs T-MOS Gen 2

PPM rate and $R_{DS,ON} \times A$ comparison



PPM rate calculation for an eight-chip module shows that a 2nd generation Bosch SiC MOSFET achieves less than 1 PPM failure rate related to cosmic radiation with 20% better $R_{DS,ON} \times A$

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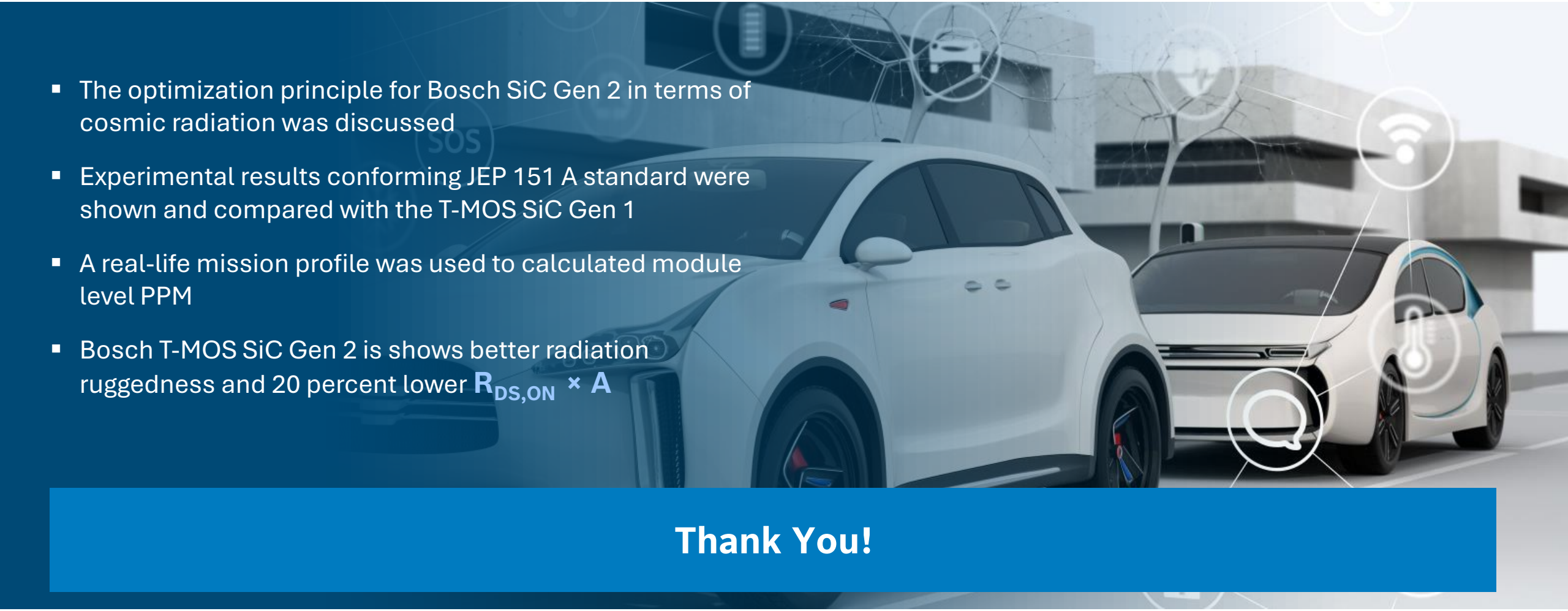
Conclusion



- The optimization principle for Bosch SiC Gen 2 in terms of cosmic radiation was discussed
- Experimental results conforming JEP 151 A standard were shown and compared with the T-MOS SiC Gen 1
- A real-life mission profile was used to calculated module level PPM
- Bosch T-MOS SiC Gen 2 is shows better radiation ruggedness and 20 percent lower $R_{DS,ON} \times A$

Thank You!