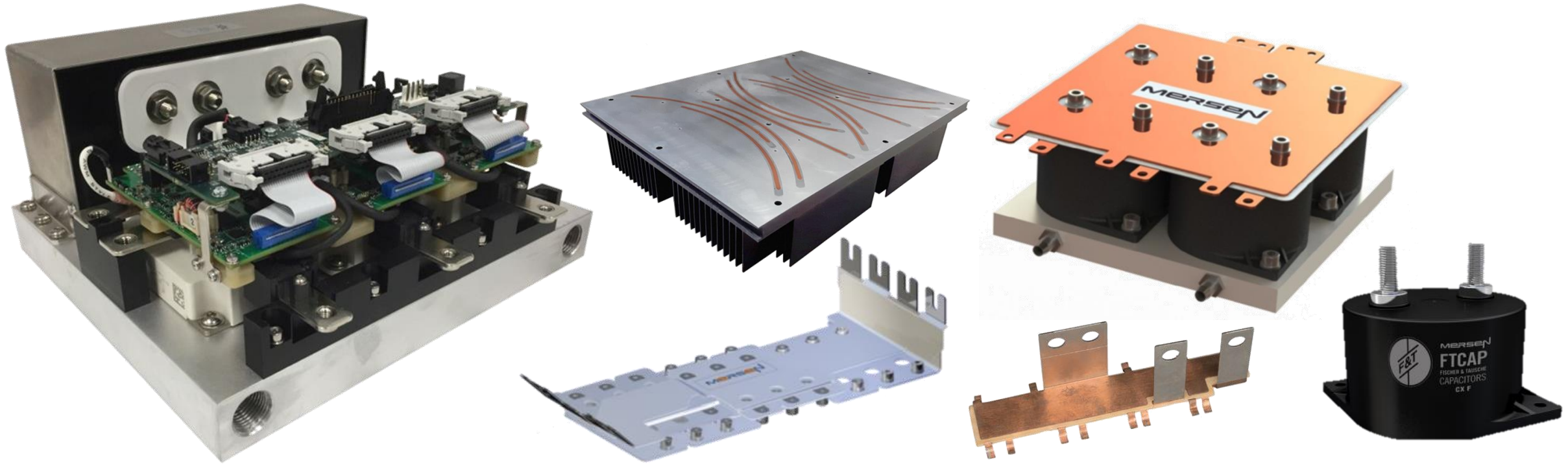
High performance cooling and low-inductance busbar-capacitor solutions for SiC modules & inverters

September 2020



MERSEN IN BRIEF

A FRANCE-HEADQUARTERED TRADED COMPANY. MERSEN USA CORP. IN ROCHESTER-NY

** As of December 31, 2019*

SALES

€950M

STAFF

7,000

GEOGRAPHIES

- 33 % NORTH AMERICA
- 34 % EUROPE
- 33 % ASIA AND ROTW

ADVANCED MATERIALS

ANTICORROSION EQUIPMENT

World's no. 1-2 in **graphite equipment**

GRAPHITE SPECIALTIES

World's no. 1-2 in **high-temperature applications**

POWER TRANSFER TECHNOLOGIES

World's no. 1-2 in **brushes for industrial motors**

ELECTRICAL POWER

ELECTRICAL PROTECTION & CONTROL

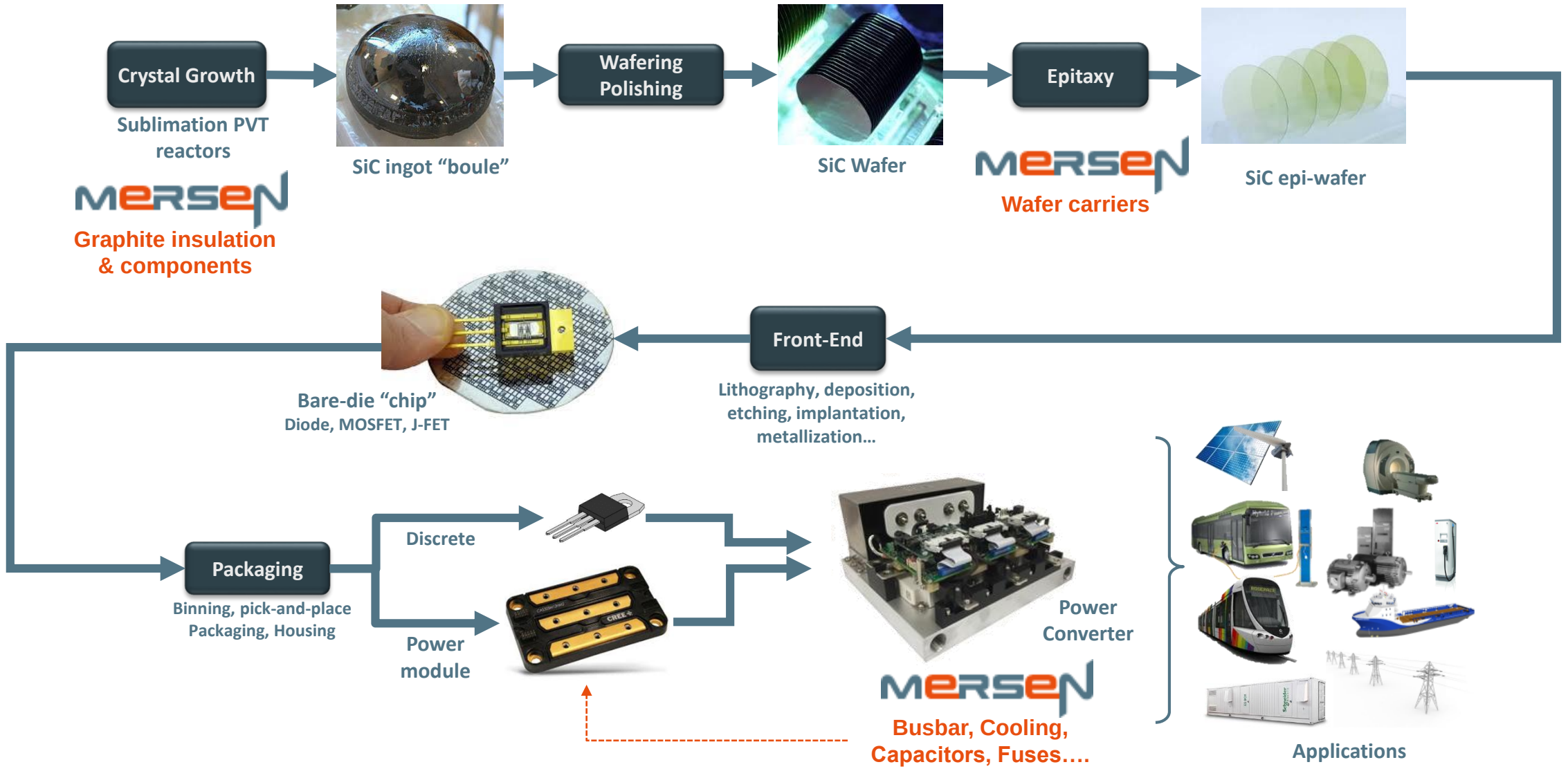
World's no. 2 in **industrial fuses**

SOLUTIONS FOR POWER MANAGEMENT

World's no. 2 in **passive components for power electronics**

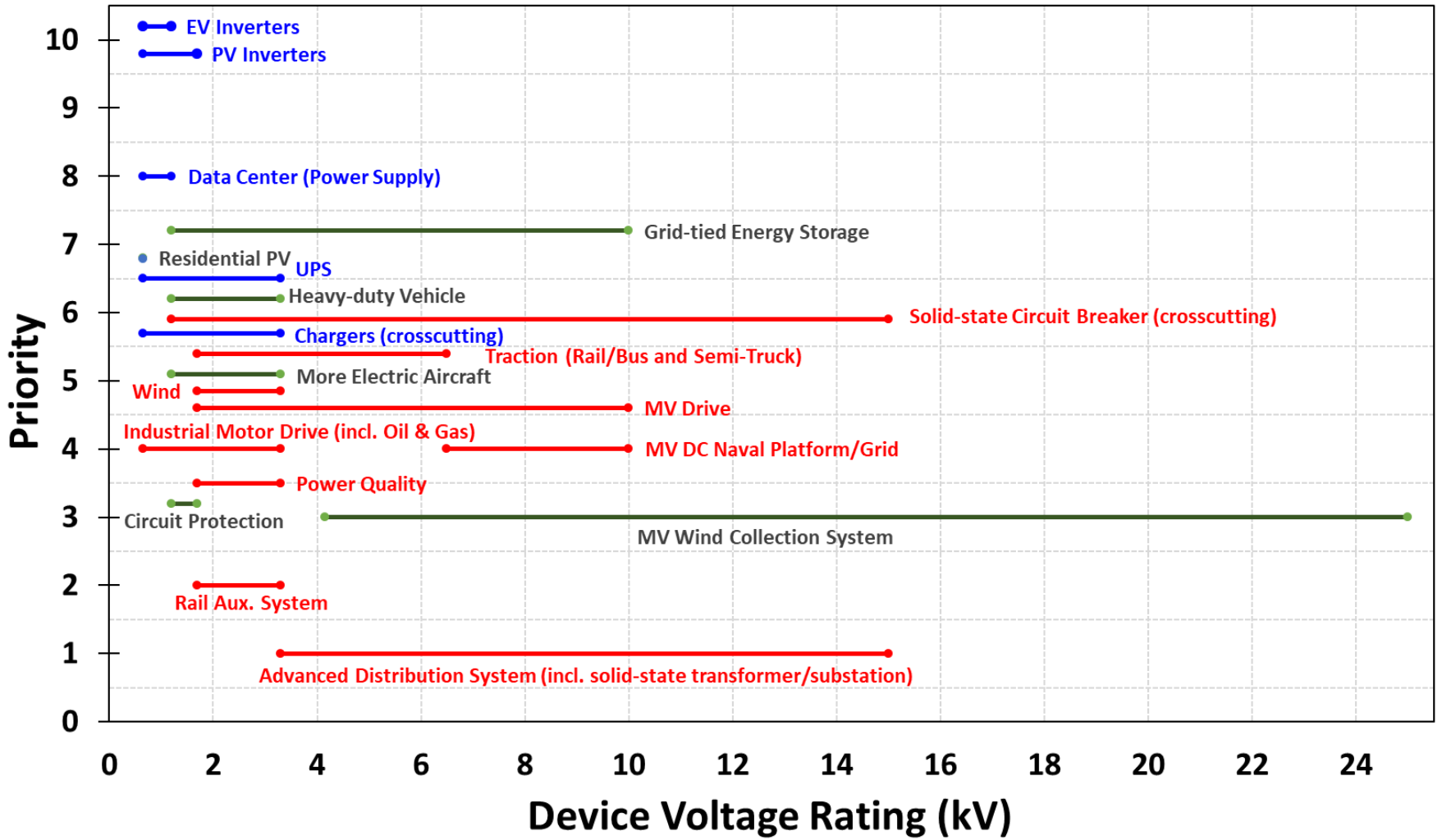
INTRODUCTION: MERSEN IS ACTIVE ALL OVER THE SiC VALUE-CHAIN

CRYSTAL GROWTH, EPITAXY AND POWER CONVERSION



THE FUTURE OF POWER ELECTRONICS

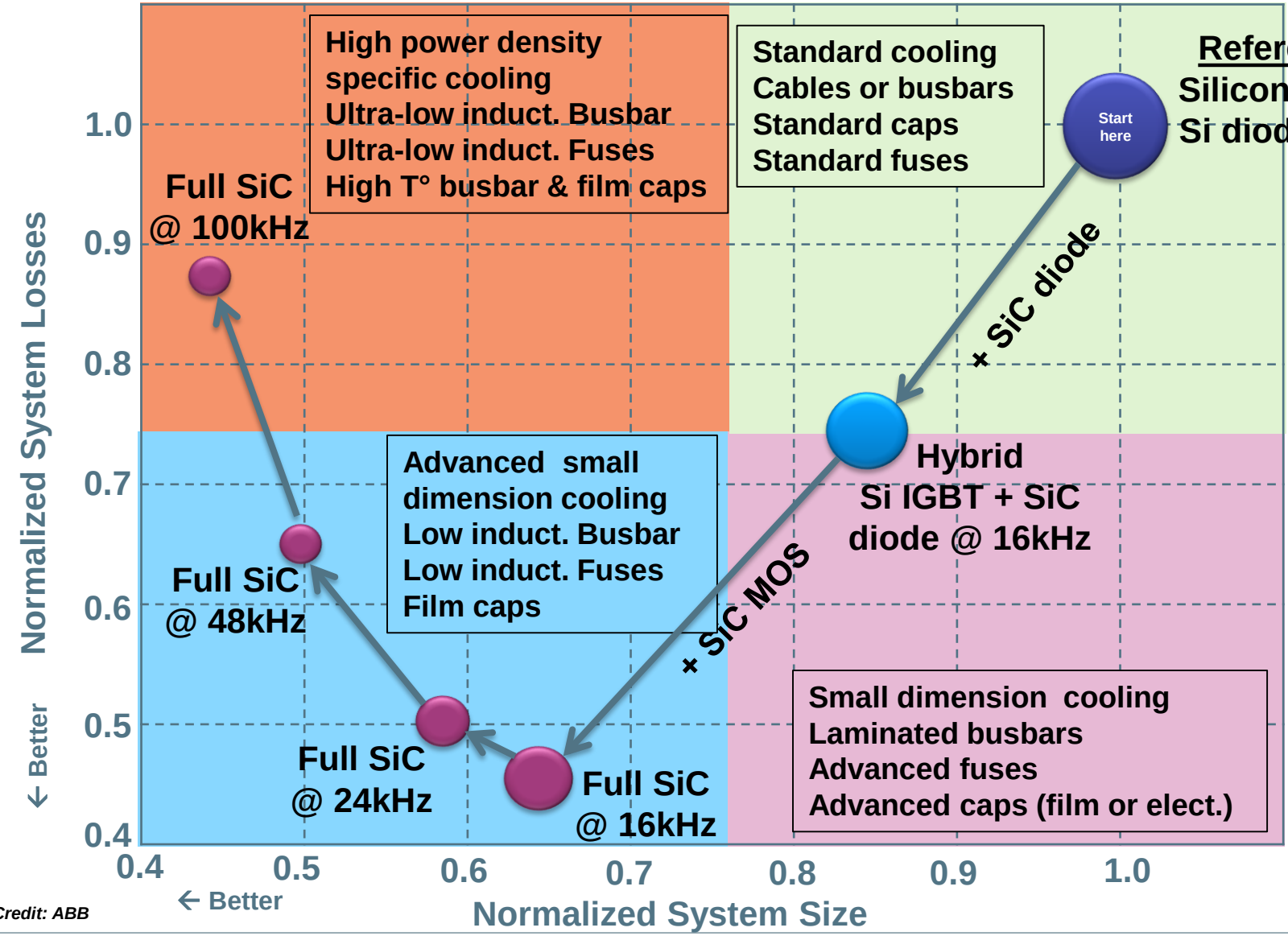
WHERE IS SiC EXPECTED TO PLAY A MAJOR ROLE…



Credit: PowerAmerica *roadmap 2020 edition*

- **A FEW KEY FINDINGS:**
  - EV, PV inverters and EES are among the top-3 applications
  - Solid-State breaker is set as high-priority with voltage requested up to 15kV
  - Overall we see the need to increase voltage beyond 10kV for many of these.

INFLUENCE OF SILICON CARBIDE ON SELECTED POWER COMPONENT SPECIFICATIONS



Credit: ABB

ADDRESSING SiC APPLICATIONS WITH MERSEN LINE OF PRODUCTS

Low inductance [cap-bus bar] connection: *Fischerlink*™

Cooling solutions for SiC applications

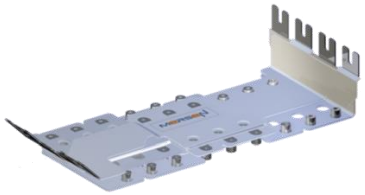
~ AC →

High temperature Capacitors

F_5

F_5

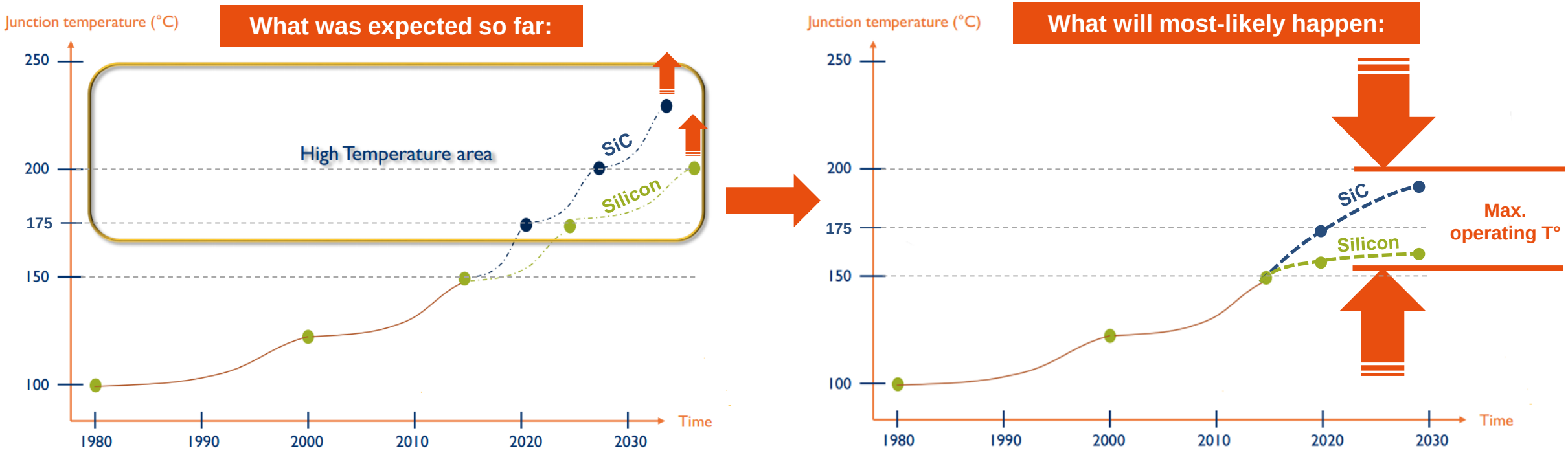
M



High temperature bus bar, 130°C and 180°C, Low Partial discharge, creepage and clearance up to 10kV. *Mhi-Txx™ series*

JUNCTION T° ROADMAP

A PARADIGM SHIFT…

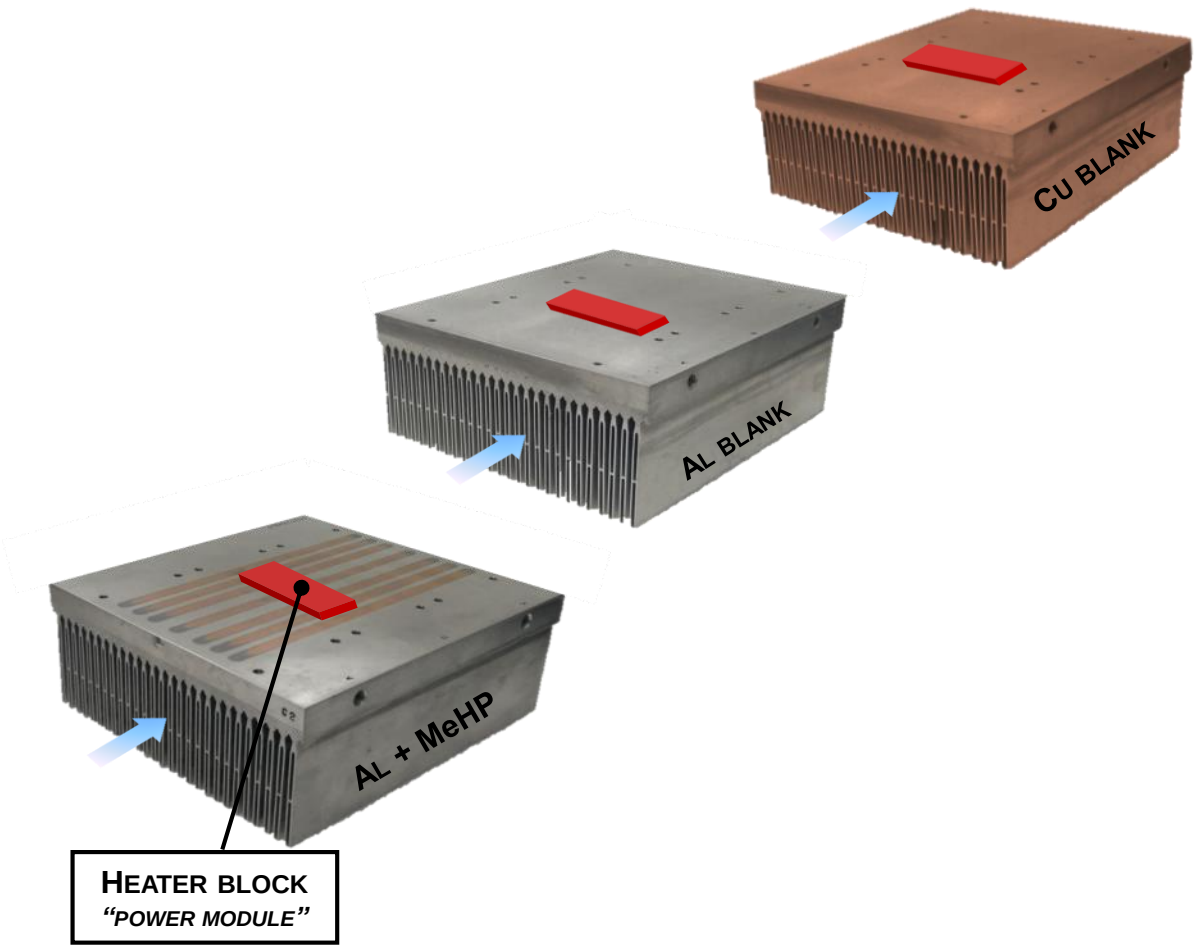


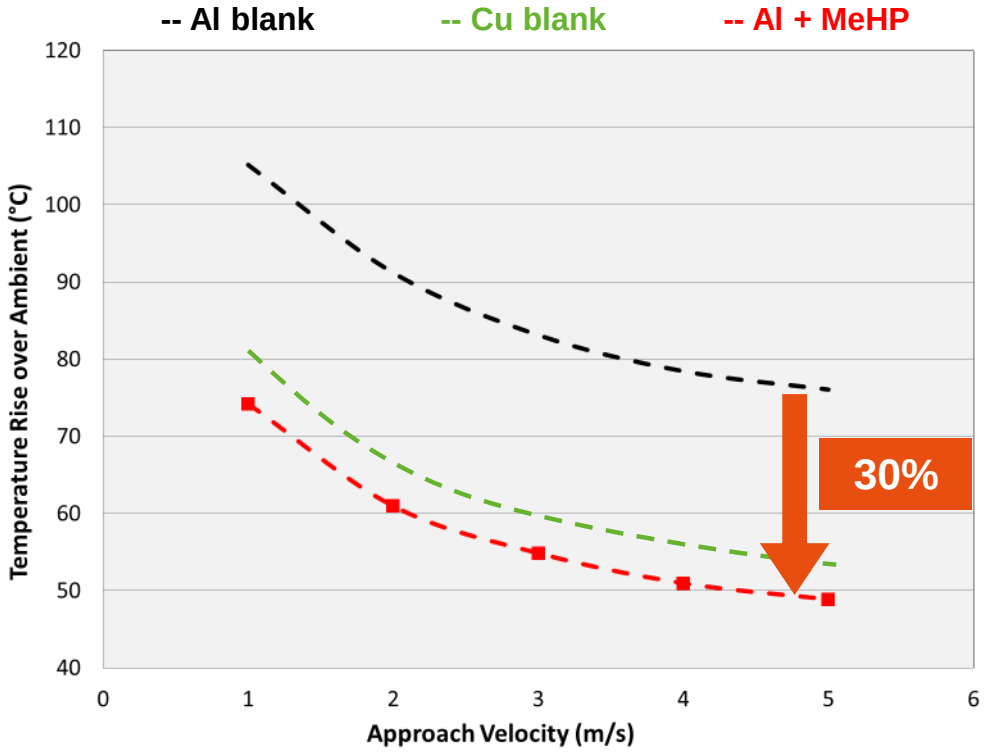
- **IT IS NOW CERTAIN THAT TJ MOST-LIKELY WON'T INCREASE AS INITIALLY FORECASTED, EXCEEDING 200°C FOR BOTH SILICON AND SIC OVER THE NEXT DECADE, FOR VARIOUS REASONS:**
  - Most of the power module packaging materials (Gel filling, housing polymer…) cannot handle such T° values
  - Gate oxide layer in SiC MOSFET rapidly degrades beyond 200°C
  - Chip-to-substrate soldering compounds are very unstable above 200°C
  - Overall conversion efficiency decreases as T° increases
  - We estimate Tj max will reach ~165°C for Silicon and < 200°C for SiC

EMBEDDED HEAT-PIPE: PUSHING THE LIMITS OF AIR COOLED HEAT-SINK

~30% REDUCTION IN T° RISE COMPARED TO STANDARD AL HEAT-SINK

- A HEATER BLOCK, SIMULATING A POWER MODULE, HAS BEEN PLACED AT THE SAME LOCATION ON 3 DIFFERENT HEAT SINKS (AL+MEHP, AL AND CU) WITH SAME GEOMETRY. T° RISE IS MEASURED AT THE HEATER LOCATION AS A FUNCTION OF AIR VELOCITY

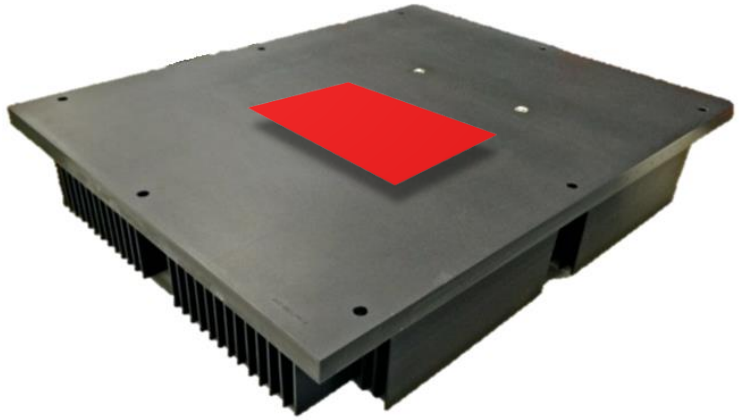




	Al blank	Cu blank	Al + MeHP
Average T° rise	Ref = 1	-23%	-30%
Cost comparison	Ref = 1	x 4	x 1.25
Weight	Ref = 1	x 3.5	1

IMPACT OF eHP ON SiC MODULE THERMAL SPREADING

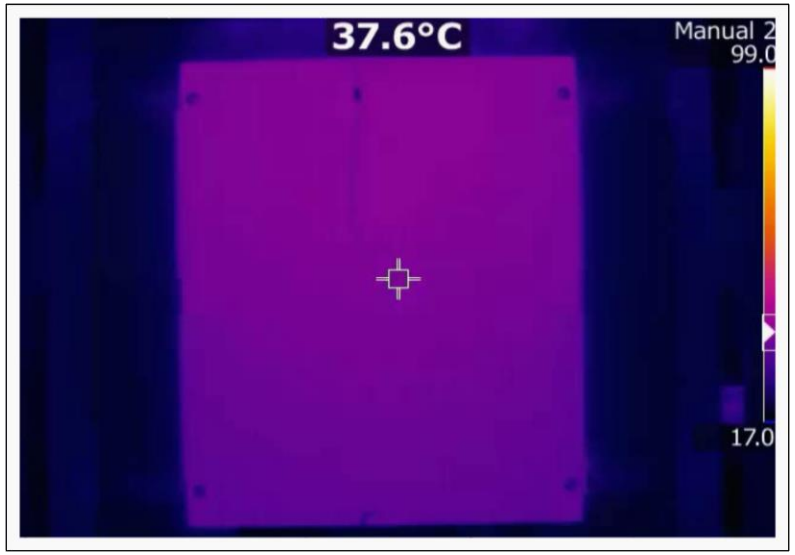
NO HOT-SPOT ANYMORE!

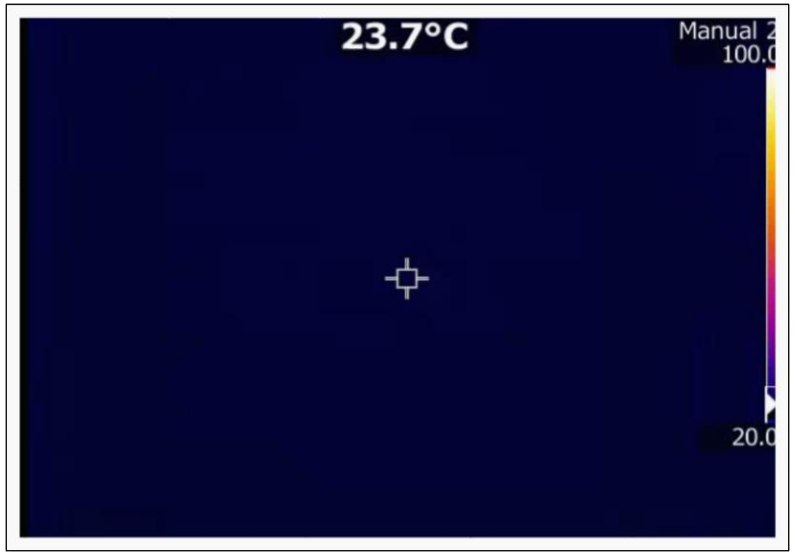


BLANK HEATSINK

EMBEDDED HEAT PIPE MeHP

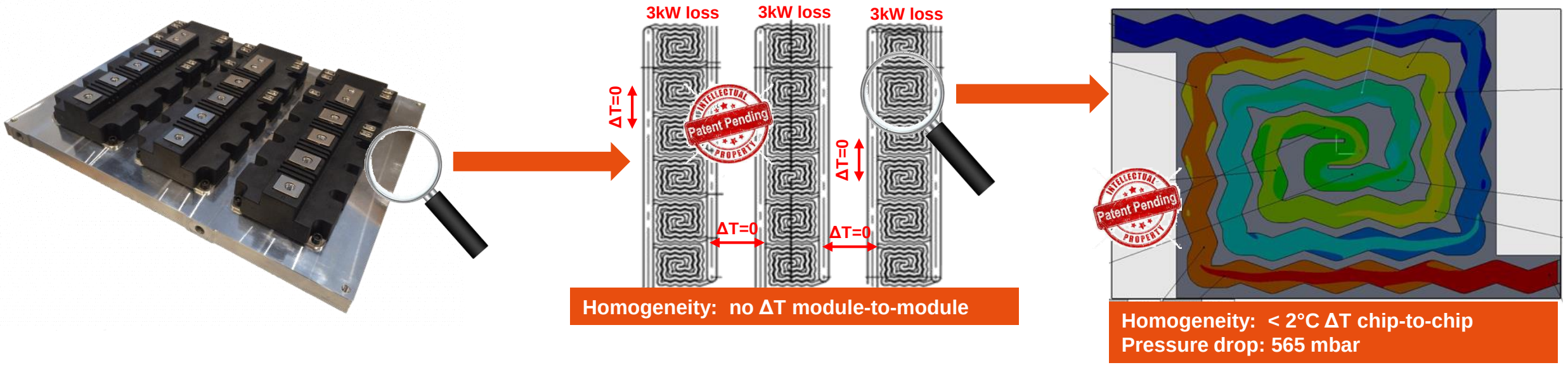
(INSERTED INSIDE THE BASEPLATE)





IsoMAXX™: The ultimate liquid cooling solution for modules

No ΔT module-to-module, no ΔT chip-to-chip



- **An innovating counter-flow "*wavy spiral*" design, has been developed for improving thermal management of latest generation of Si & SiC power modules. It offers:**
  - Better thermal performances: Rth ~ 6 °C/kW
    (EG 50%, 250 mm modules, 3kW power losses and 5 liter/min per component.)
  - Lower pressure drop than all existing designs (~600mbar)
  - Thermal homogeneity chip-to-chip (all chips at the same T°) and module-to-module on a multi-module cooling plate
  - Compact design: distance between modules can be optimized → Inverter size reduction
  - Modular solution : covers all PrimePACK™ types, whatever the number of modules on the plate
  - Cost competitive compared to others efficient designs

RECENT TRENDS IN WBG POWER CONVERSION

HOW TO REDUCE STRAY INDUCTANCE WHILE INCREASING OVERALL POWER DENSITY AND JUNCTION T°?

Reduce stray inductance together with higher Tj

New module design

Power module makers are working on new designs for their power modules in order to stay competitive against press-packs for high-voltage devices.
The most popular solution is reducing the distance between internal connections

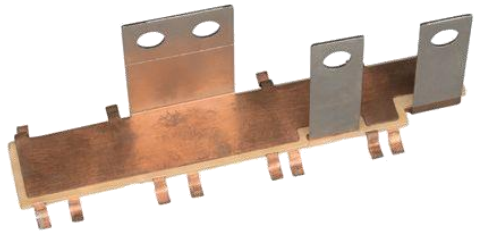
Credit: CREE

Use of external laminated busbar with low inductance connection

Outside the module, using laminated busbar offers strong reduction of parasitic inductance

Use of internal laminated busbar

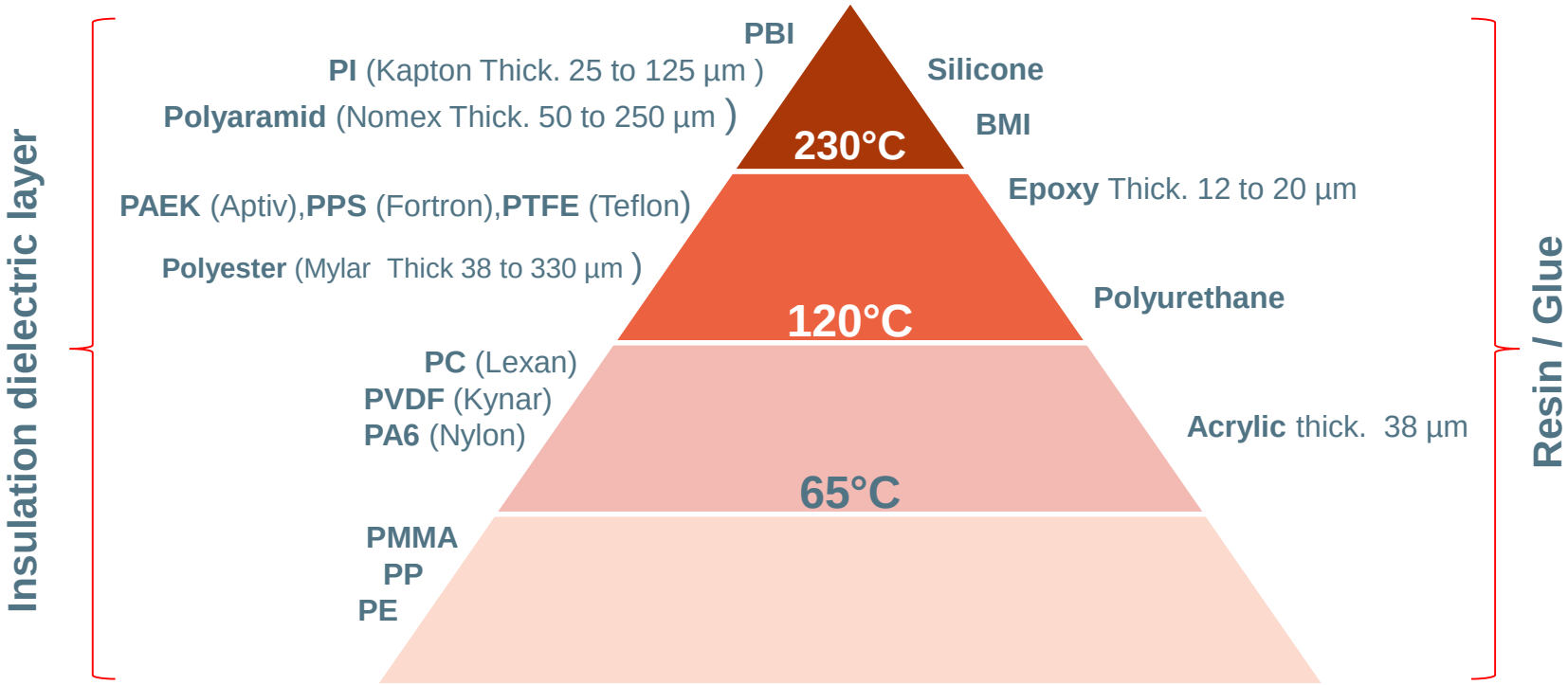
Along with the emergence of SiC, the switching frequency reaches several ten's of kHz. Internal laminated bus bar can offer a real added-value to decrease the inductance while connecting the chips together

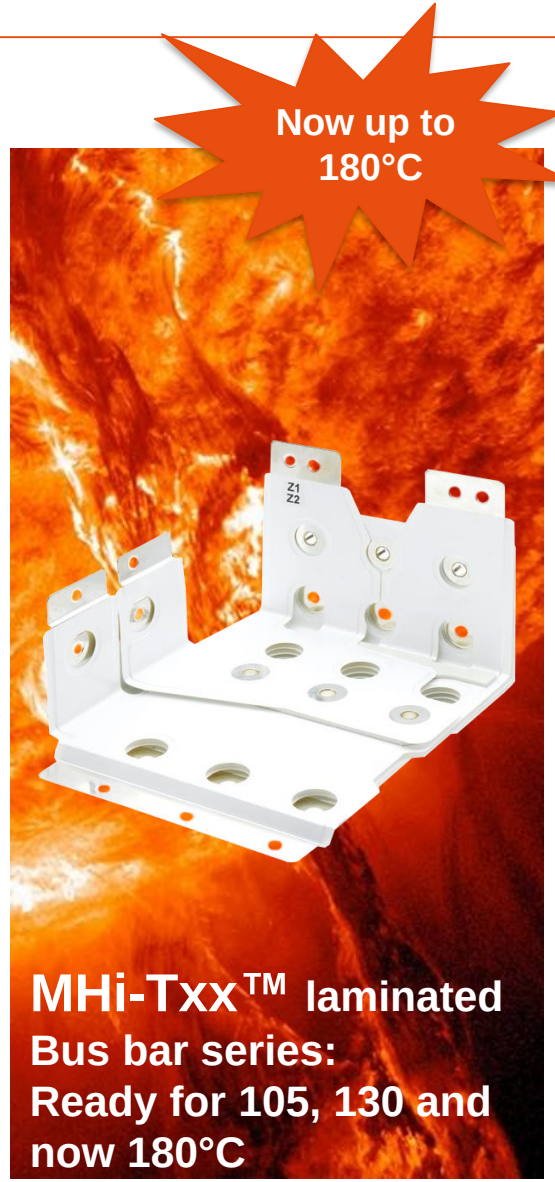


Laminated Bus bar: How to match WBG module high T° requirements ?

Selection of Insulation and Resin material as a function of operating T°

- **A perfect matching [Insulation – resin/glue]**
  - In order to perfectly match customer' specifications, Mersen aims at selecting the right material (Insulation and Resin / Glue) with the highest Temperature, Voltage and Mechanical resistance, keeping insulation as thin as possible (to meet low inductance value requirements)
- **Examples of material selection and related thickness range as a function of max. operating T°:**

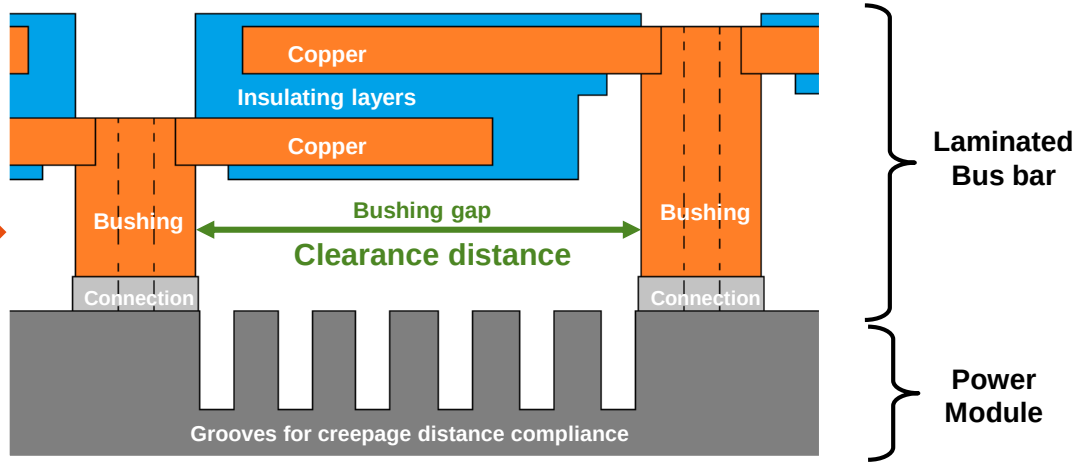




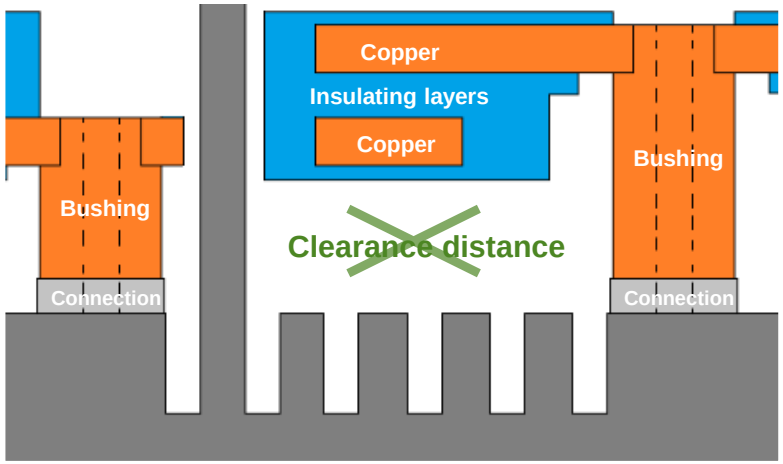
How to decrease clearance distance in power module design ?

Conformal bus bar is an enabler…

Today's industry standard

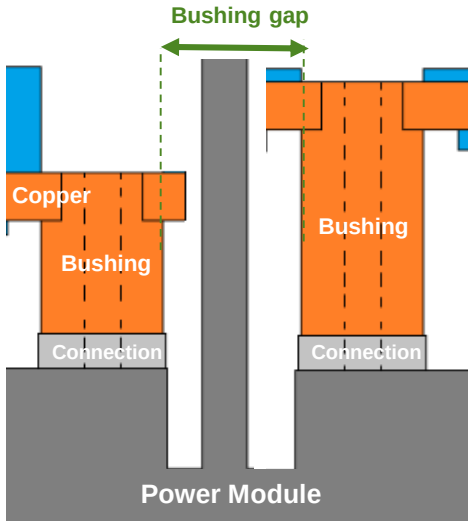


STEP 1

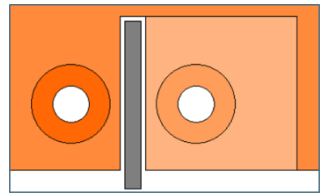


Additional tall insulating barrier on power module housing

STEP 2



Removal of intermediate grooves

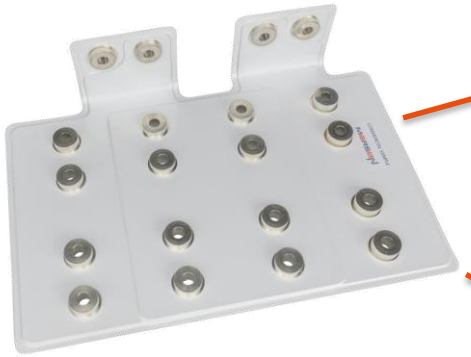


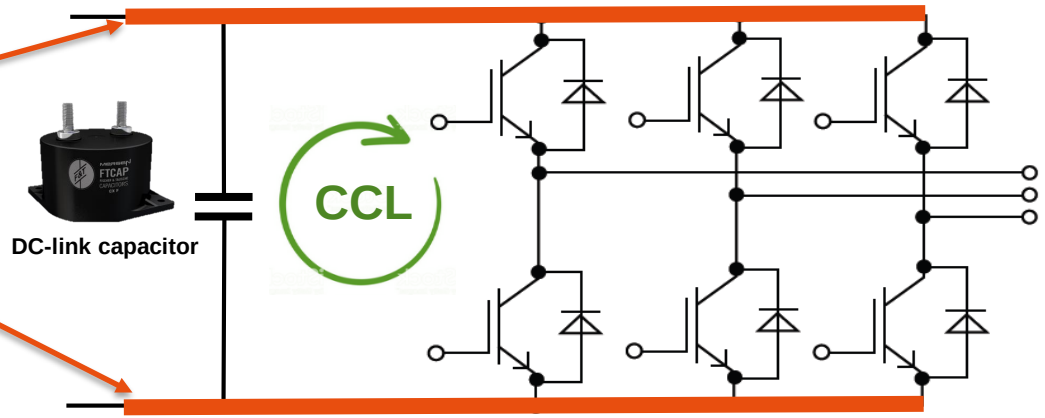
Top view of the bushings gap with tall insulating barrier and conformal bus bar design

Gap between bushings can be significantly reduced → More compact module design

INDUCTANCE FUNDAMENTALS IN POWER CONVERTER DESIGN

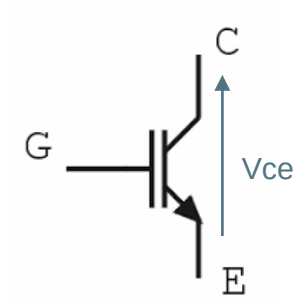
HIGH INDUCTANCE CREATES VOLTAGE OVERSHOOT AND SURGE AT COMMUTATION





Credit: Infineon

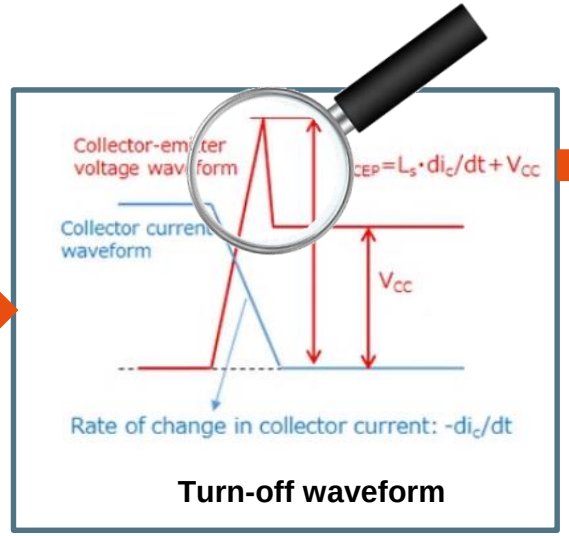
CCL: Commutation current loop



Transistor

ON
- ➔ Short-circuit
- ➔ Vce = 0 V
- ➔ Ice ≠ 0 A

OFF
- ➔ Open circuit
- ➔ Vce ≠ 0 V
- ➔ Ice = 0 A



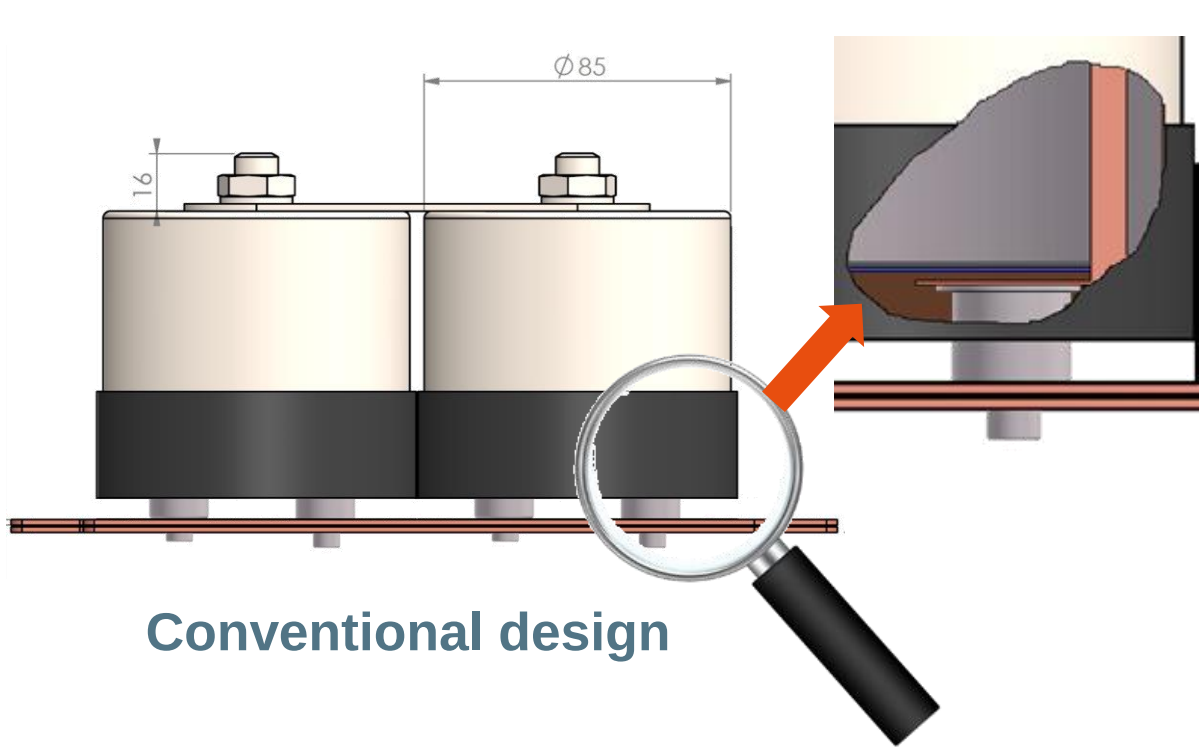
Turn-off waveform

$$Surge\ voltage = L_s * \frac{di}{dt}$$

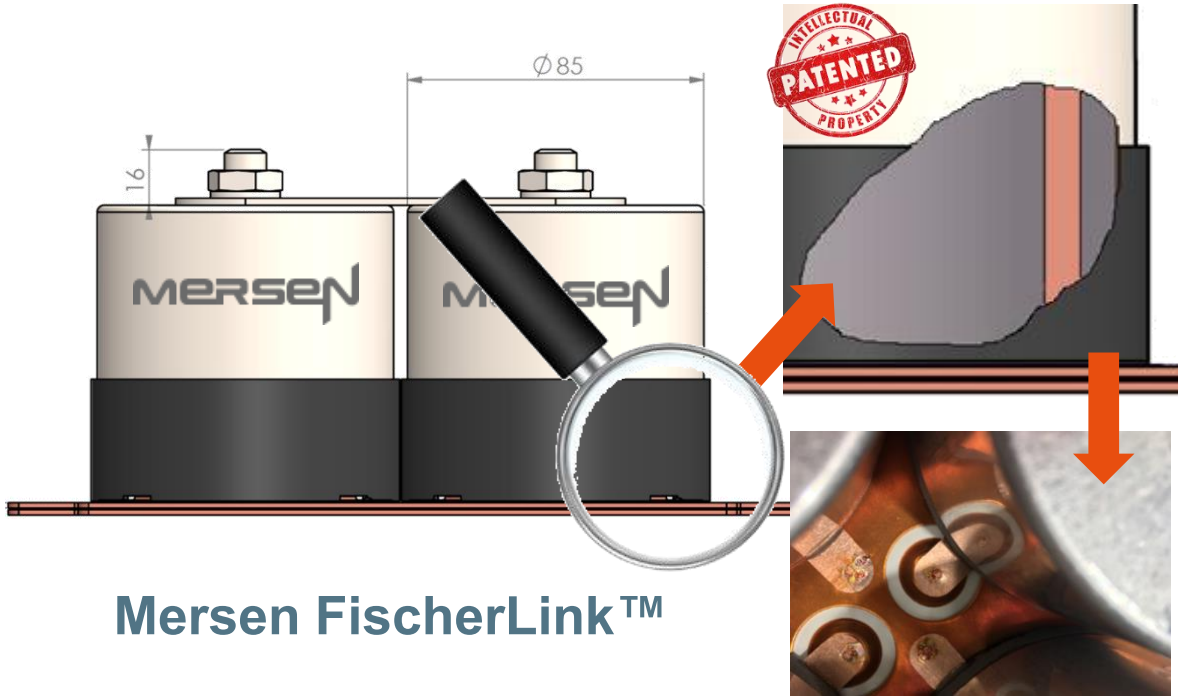
L_s = inductance of CCL*

LOW-INDUCTANCE [BUS BAR-CAP] CONNECTION FOR SiC DC-LINK

FISHERLINK™



Conventional design



Mersen FischerLink™

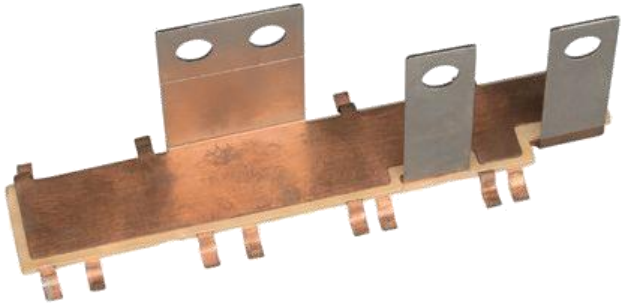
- SHORTER CONNECTION OF THE CAP WINDING TO THE BUSBAR BY DIRECT CONNECTION OF THE WINDING TABS TO THE BUSBAR BY LASER WELDING
- Up to +20 % capacitance in a given volume (e.g. from 400µF to 480µF @ 1100 Vdc | 4-cap assembly)
- Extremely low inductance <9nH
- Capacitors and busbars packaged together as sub-assembly and single part #
- Pre-assembled and 100% tested before delivery → ready for final assembly

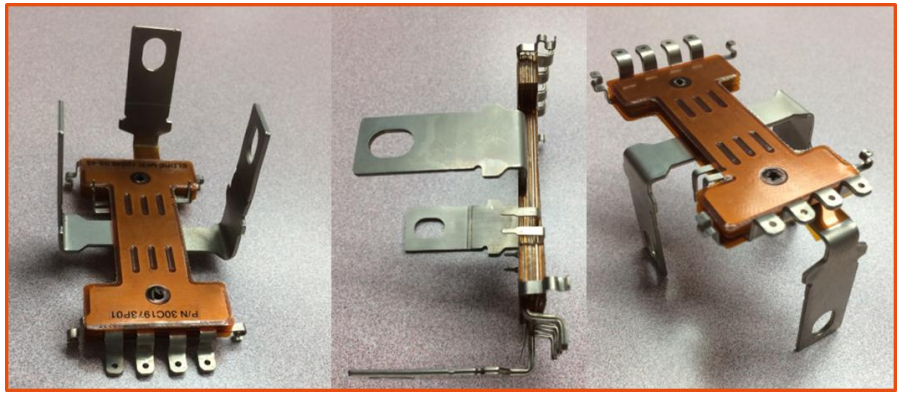
INTERNAL LAMINATED BUSBAR FOR WBG POWER MODULES

SOLUTIONS TO HANDLE 180° TJ @ 100 KHZ FSW… AND BEYOND !

- **THE AIM:**
  - Get very low internal inductance by
    - laminated/symmetrical bus bar structure
    - Maximizing metallic conductor overlap
  - 50% reduction in switching loss for higher switching frequency (> 20KHz)
  - Safe turn-off possible at large current without snubber capacitor

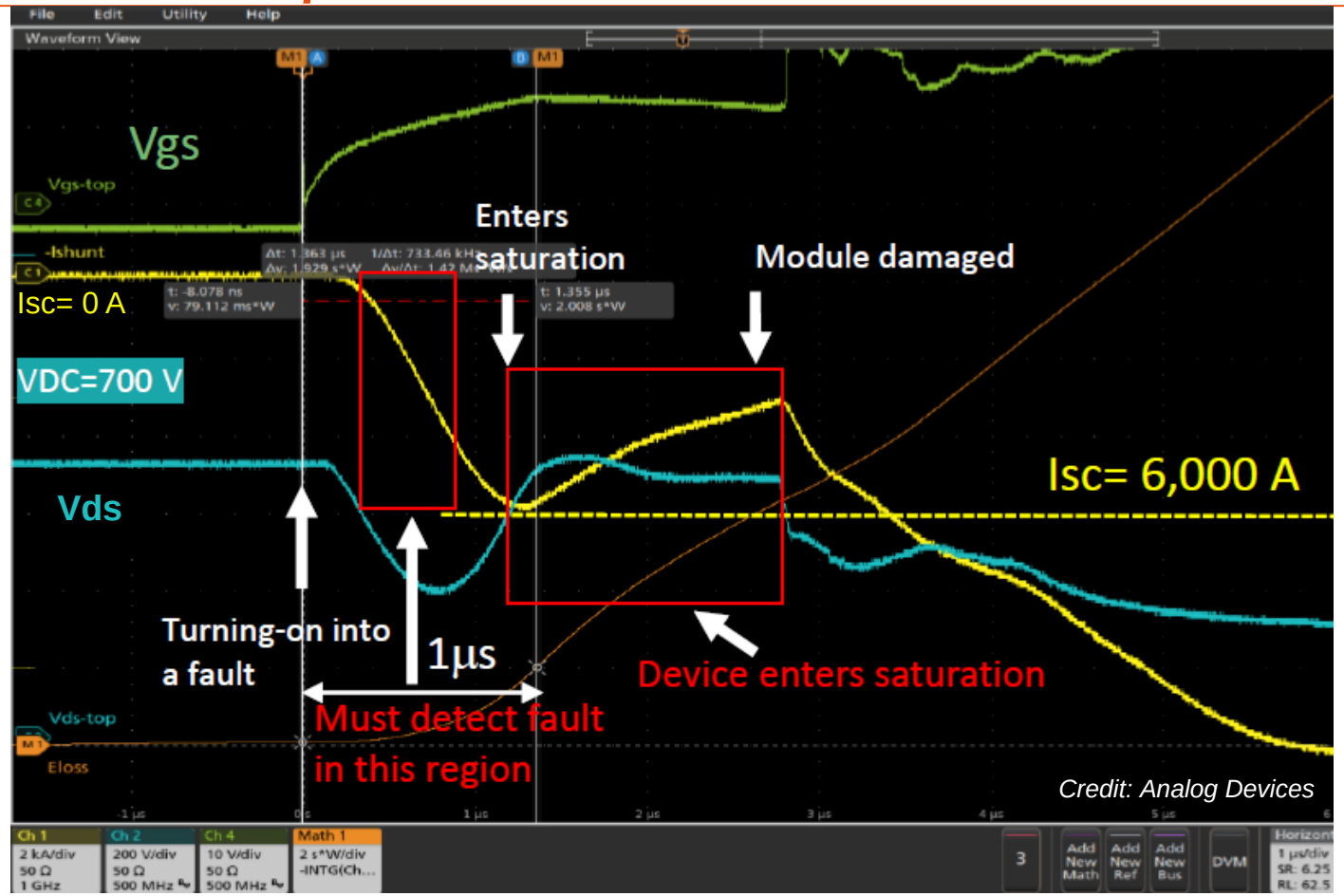
- **THE ACHIEVEMENT**
  - Our bus bars can now handle up to 200°C Tj with inductance as low as 35nH and a lifetime operation of 25 years

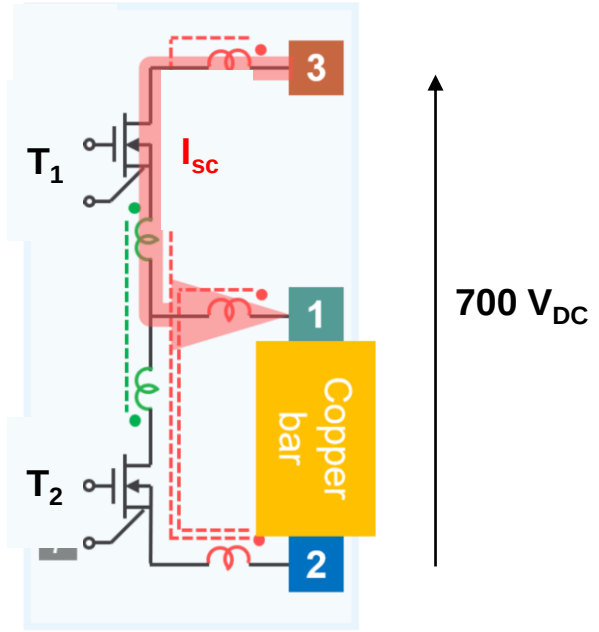




PROTECTION OF SiC POWER MODULES

LESS THAN 1 µS TO REACT !



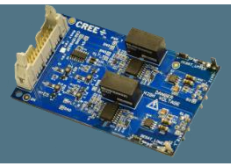


In this example the load between outputs [1] and [2] is artificially short-circuited by a copper bar. While T1 re-opens (Driven by Vgs), it generates a short-circuit Isc running through it.

- FAULT ON A SiC DEVICE MAY HAVE TO BE DETECTED BEFORE THE SHORT CIRCUIT CURRENT (ISC) REACHES A PEAK (HERE 6KA) AND SATURATES.
- IN MOST OF THE CASES, PROTECTION HAS TO OCCUR IN LESS THAN 1MS TO AVOID MODULE BEING DAMAGED

INVERTER PROTECTION USING FUSE OR GATE DRIVER (FUSE-LESS)

CAN'T WE GET THE BEST OF THE TWO WORLDS ?

	Gate Driver *(fuse-less)* 	Thermal Fuse 
Opening time	In the 1µs range or less…	A few µs to a few ms
Depends on external power supply	Yes	No (self-triggered)
Protect the semiconductor junction	Yes primarily	Possibly, but not primarily
Will save the power module from explosion	Yes	Yes
Protect the entire system whatever the fault conditions	No	Yes
Fault detection and analysis	Yes	No
Can protect in case of module end-of-life (Junction is so short-circuited)	No	Yes
Possible failure modes	Numerous	No

- **Gate driver / fuse-less protection is an elegant solution in the < 50kW range of applications, but we claim that, beyond 50kW, fuse remains the ultimate viable and reliable protective solutions**
- **Taking advantage of both Gate Driver and Fuse is probably a cleaver solution to efficiently protect power inverters**

Synthesis and Conclusion

- Now that WBG have reached the expected maturity, at semiconductor level, it is commonly admitted that remaining issues relate to passive surrounding components (Caps, magnetics, connections, thermal management, fuse…)
- Mersen positions himself not only as a stand-alone components supplier but also as solution provider made of 2 or more components, co-designed and perfectly optimized together
- Let us know your circuit topology along with your physical, electrical, mechatronic, thermal, EMI constraints: we can definitely ease your journey in module and/or inverter design

Co-design & optimization