MERSEN SOLUTIONS FOR SIC ELECTRONICS IN EV / HEV APPLICATIONS

June 2021

☑ Public
☐ Internal
☐ Confidential

Mersen in brief
A France-headquartered traded company with global positions

Sales	Staff	Geographies
€850M	6,500	• 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**

** As of December 31, 2020*

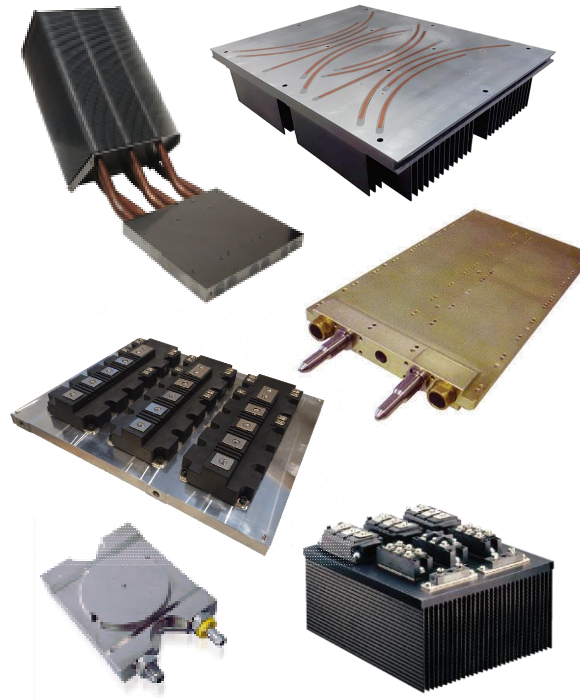
SPM Product Portfolio

High-speed Fuse and Hybrid Pyro-Fuse

- UL Round and Square Body
- British Standard AC Protection
- IEC Cylindrical and Square Body (French / DIN)
- AC Low and Medium Voltage
- DC Rated For Traction
- DC protection for EV and EES

Cooling Solutions

- Air and Liquid Cooled Heatsinks
- Embedded Heat-Pipe Heatsinks
- Heat-pipe Assemblies



Bus Bar

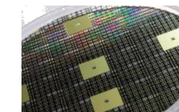
- Laminated / Multi-layer
- Flexible / High T° / Low L
- Battery cell connection
- Powder Coated

Capacitors

- Customized capacitors:
  - Film
  - Electrolytic
  - Sub-assembly

SiC Semiconductors

- Protection devices
- Custom designs



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MERSEN SOLUTIONS FOR EV/HEV

One of 16 Trophée Andros 2021, 100% electric race car, equipped with Mersen Busbar and Fuses

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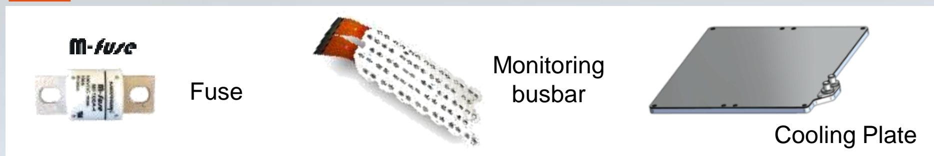
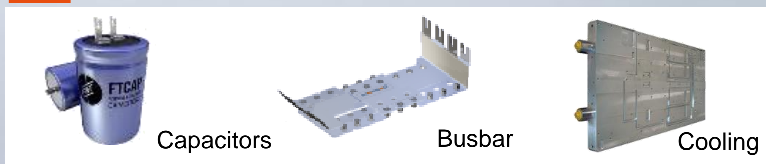
MERSEN SOLUTIONS IN EV/HEV APPLICATIONS

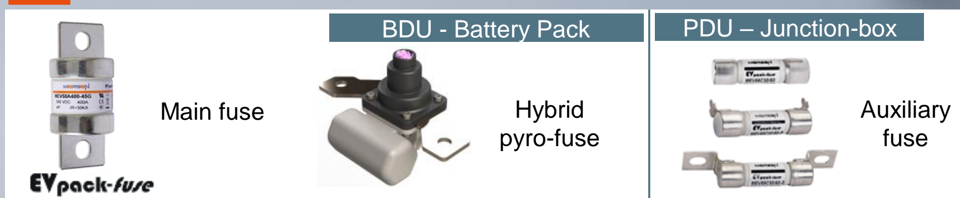
BATTERY MODULE

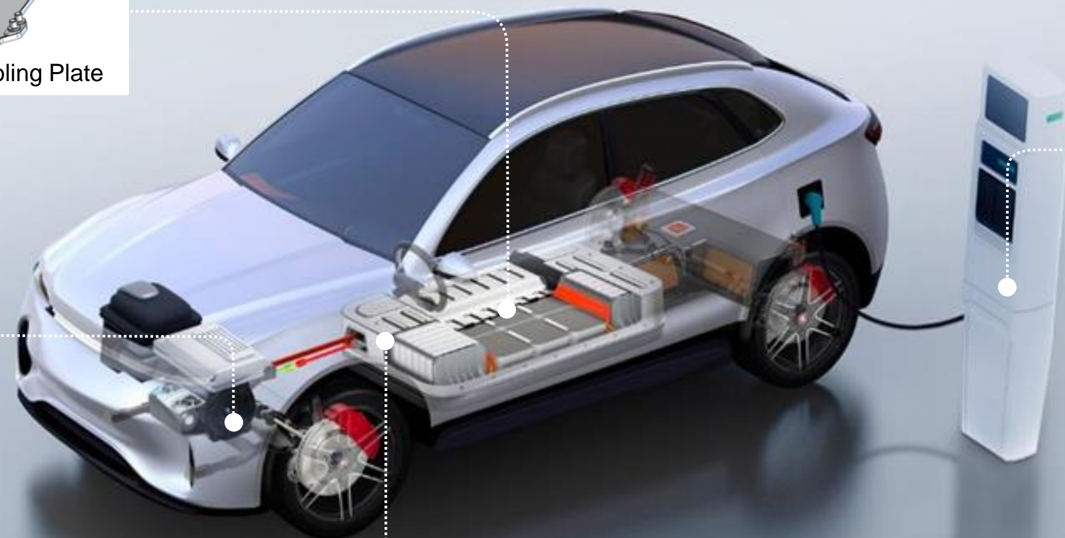


POWER INVERTER

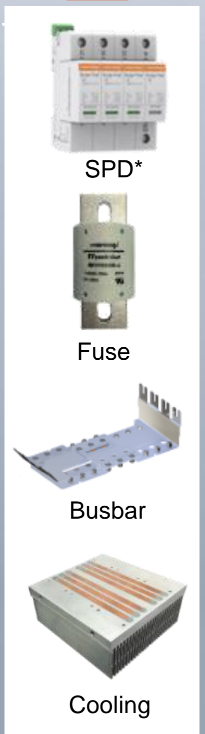


ELECTRICAL PROTECTION OF VEHICLES





DC FAST CHARGING STATION 50kW-350kW+



BDU: Battery Disconnect Unit
PDU: Power Distribution Unit

**: Surge Protection Device*

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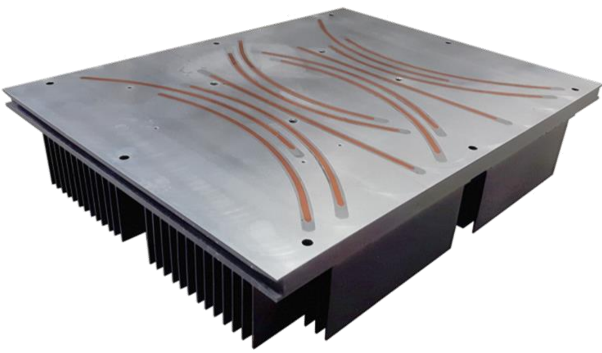
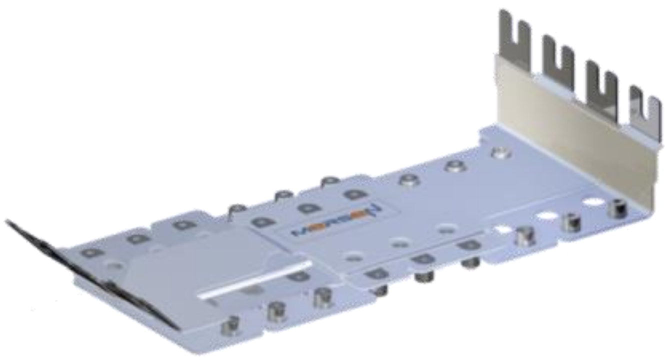
SPECIAL FOCUS ON SIC ELECTRONICS IN THE EV INDUSTRY





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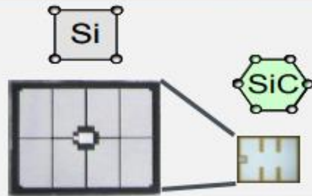
Impact of SiC for power inverter manufacturers

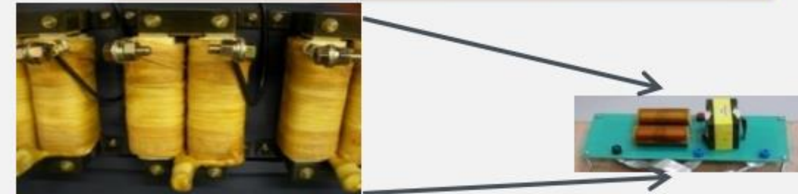
Lower Resistance



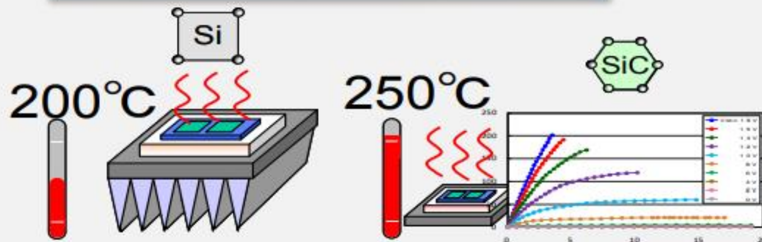
Smaller Size / Higher Efficiency

Higher Frequency Operation

Smaller Passive Components



Higher Temp Operation



Simpler Cooling System

SiC DRAMATICALLY IMPROVES CONVERSION EFFICIENCY…

…BY REDUCING CONDUCTION AND SWITCHING LOSSES. THE HIGHER THE FREQUENCY, THE BETTER

Power converter family:	Expected improvement (%) compared with Silicon	Efficiency value improvements
DC-DC (POL, boost…)	+3% points	90% → 93%(1)
AC-DC (PFC, UPS…)	+1.5% points (2)	88% → 90%
DC-AC (Motor, PV…)	+2 to +3% points	96% → 99%(3)

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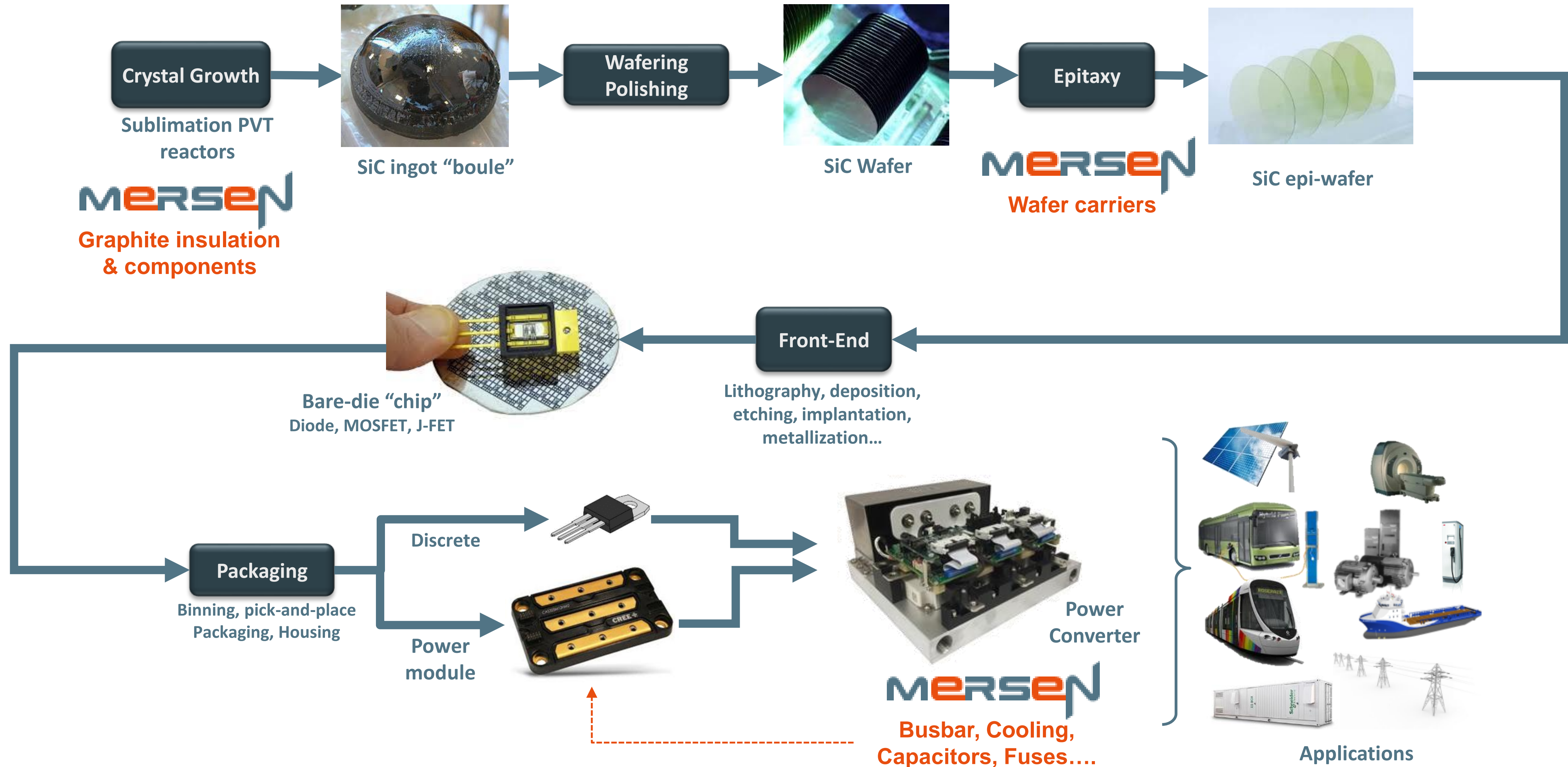
Introduction: Mersen is active all over the SiC value-chain

Crystal growth, epitaxy and power conversion



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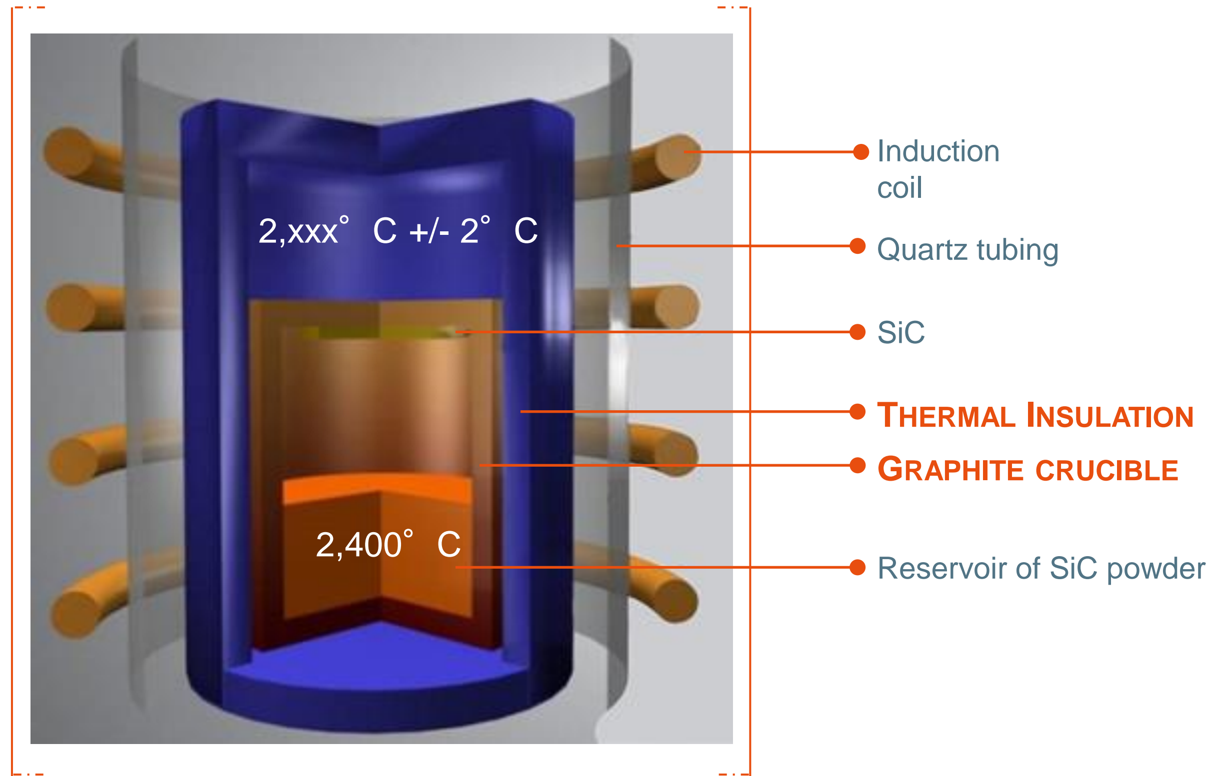
MERSEN HAS A COMPREHENSIVE RANGE OF GRAPHITE AND INSULATION SOLUTIONS FOR SiC PRODUCTION



Graphite crucible

- contributes to the chemical composition of the single crystal
- controlled CTE, controlled reactivity with the gases, controlled thermal conductivity
- extreme purity (7N) of the graphite

CALCARB® insulation

- spatial consistency,
- low thermal conductivity at 2,400 C
- ability to be precision machined
- high purity

Running temperature	Cycle duration	Ingot weight
2,400° C	3-5 days	5-10 kg

INFLUENCE OF SILICON CARBIDE ON SELECTED POWER COMPONENT SPECIFICATIONS

High power density specific cooling
Ultra-low induct. Busbar
Ultra-low induct. Fuses
High T° busbar & film caps

Standard cooling
Cables or busbars
Standard caps
Standard fuses

Reference: Full Silicon: Si IGBT + Si diode @ 16kHz

Start here

+ SiC diode

Hybrid Si IGBT + SiC diode @ 16kHz

+ SiC MOS

Full SiC @ 16kHz

Full SiC @ 24kHz

Full SiC @ 48kHz

Full SiC @ 100kHz

Advanced small dimension cooling
Low induct. Busbar
Low induct. Fuses
Film caps

Small dimension cooling
Laminated busbars
Advanced fuses
Advanced caps (film or elect.)

Normalized System Losses (← Better): 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0

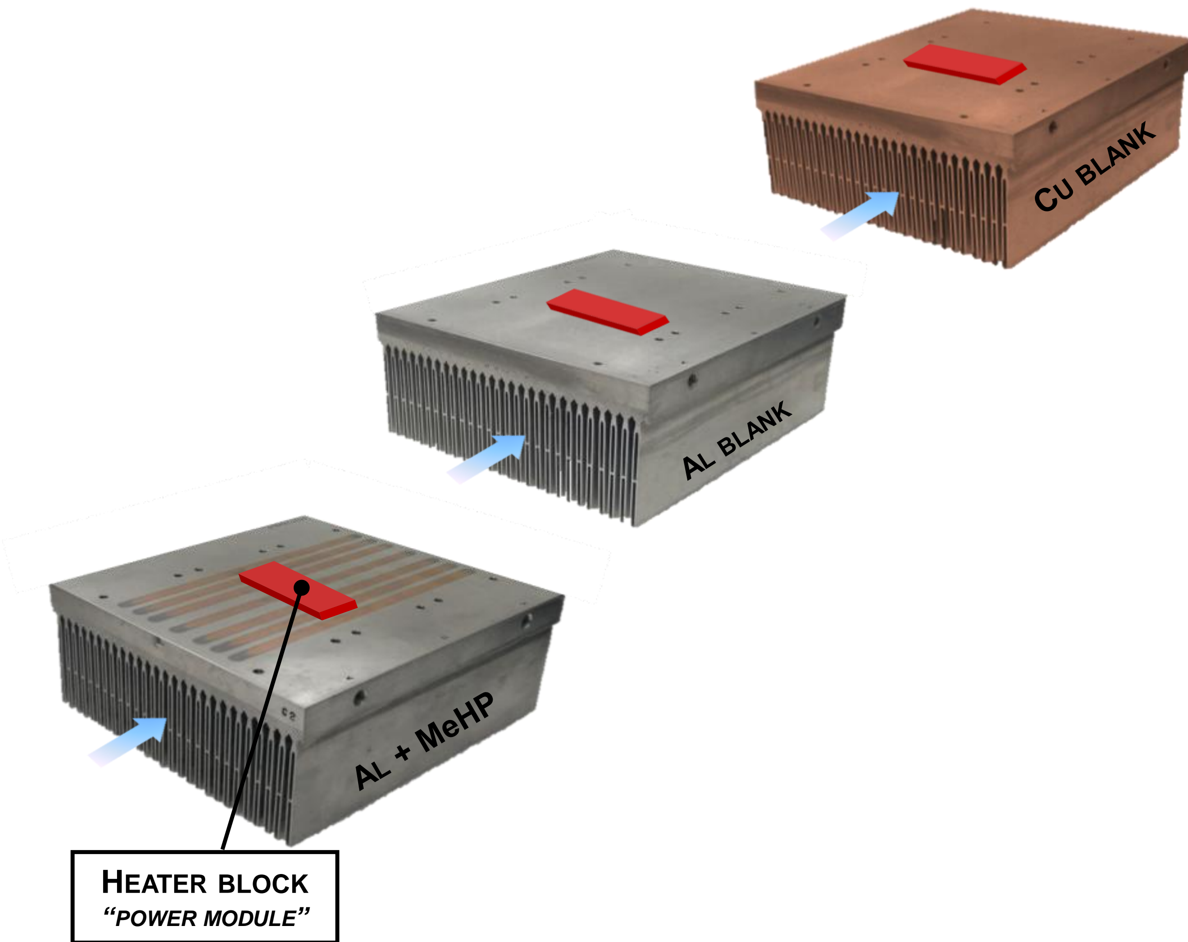
Normalized System Size (← Better): 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0

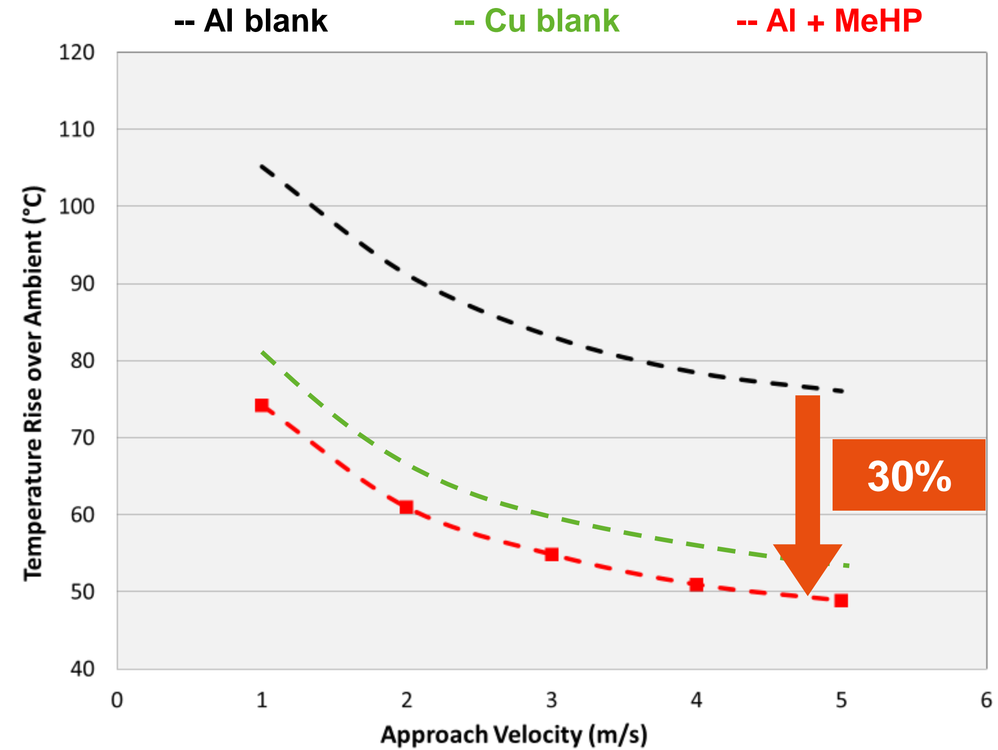
Credit: ABB

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

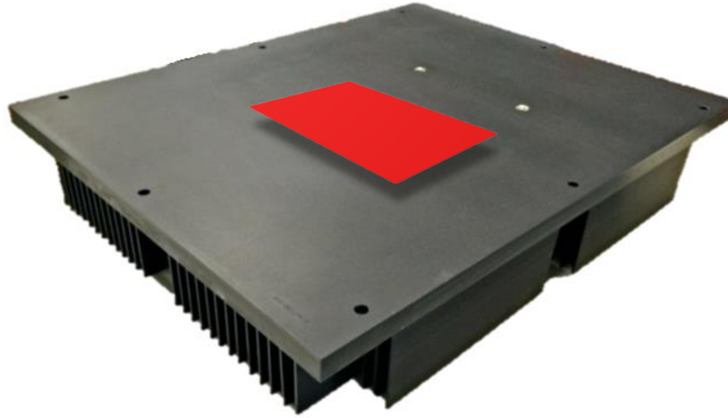




	Al blank	Cu blank	Al + MeHP
Average T° rise	Ref = 1	-23%	-30%
Cost comparison	Ref = 1	x 4	x 1.25
Weight	Ref = 1	x 3.5	1

IMPACT OF eHP ON SiC MODULE THERMAL SPREADING

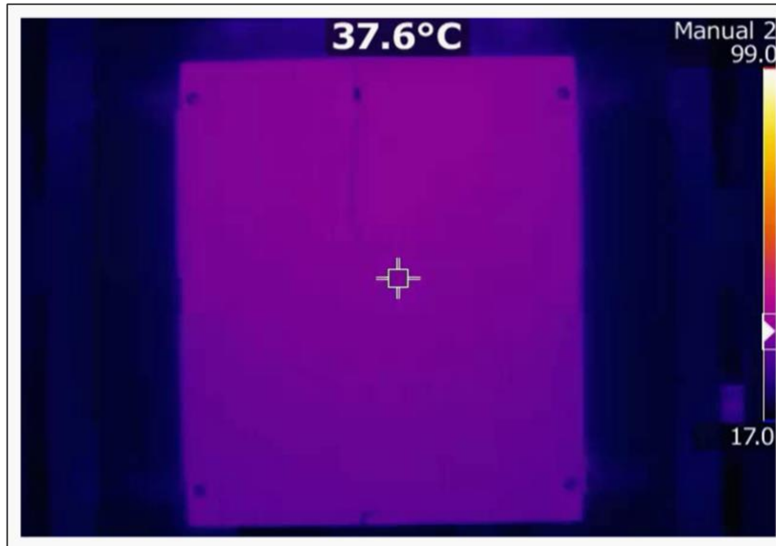
NO HOT-SPOT ANYMORE!

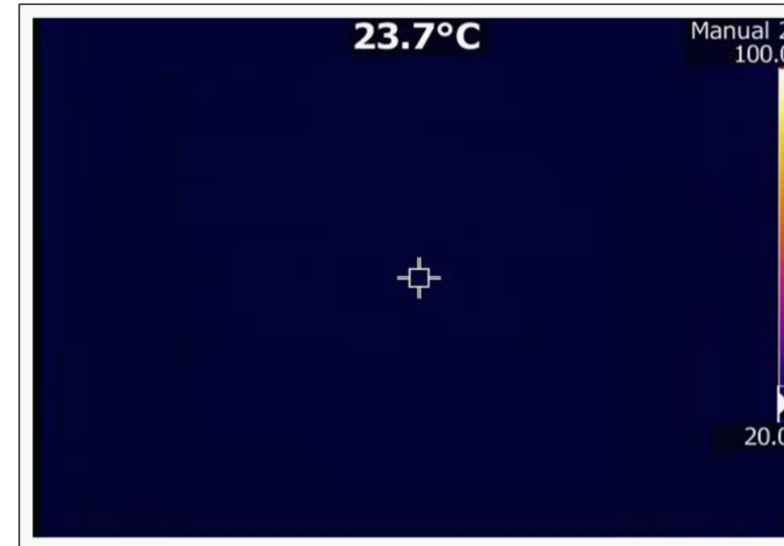


BLANK HEATSINK

EMBEDDED HEAT PIPE MeHP

(INSERTED INSIDE THE BASEPLATE)





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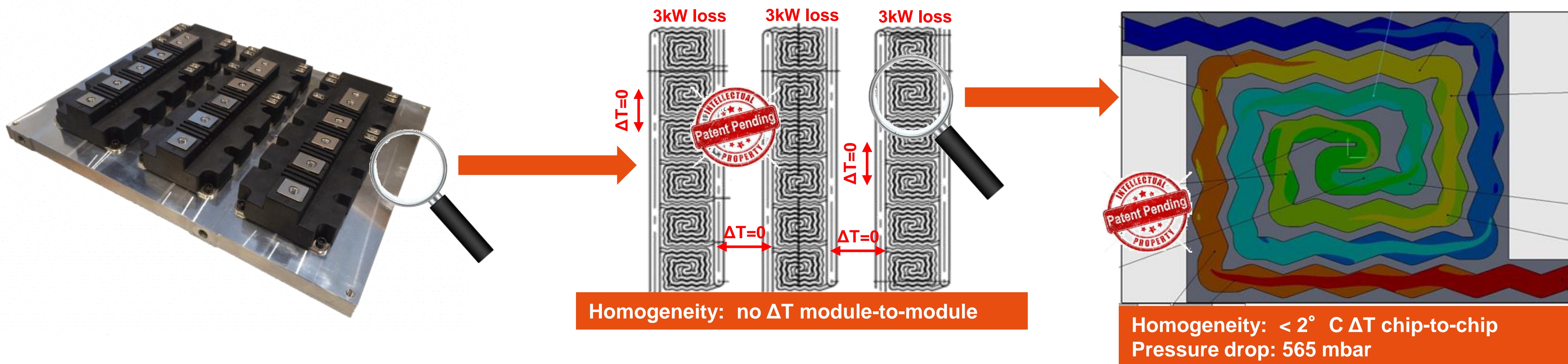
IsoMAXX™: The ultimate liquid cooling solution for modules

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

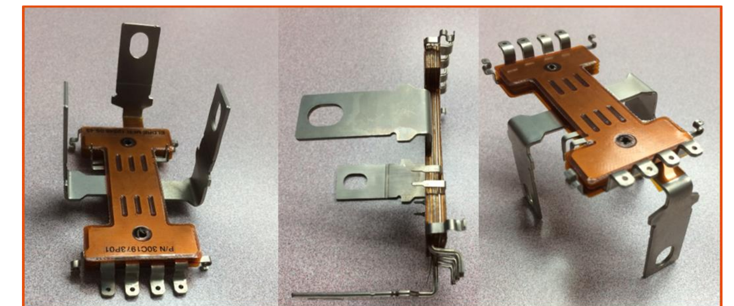
Credit: CREE

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



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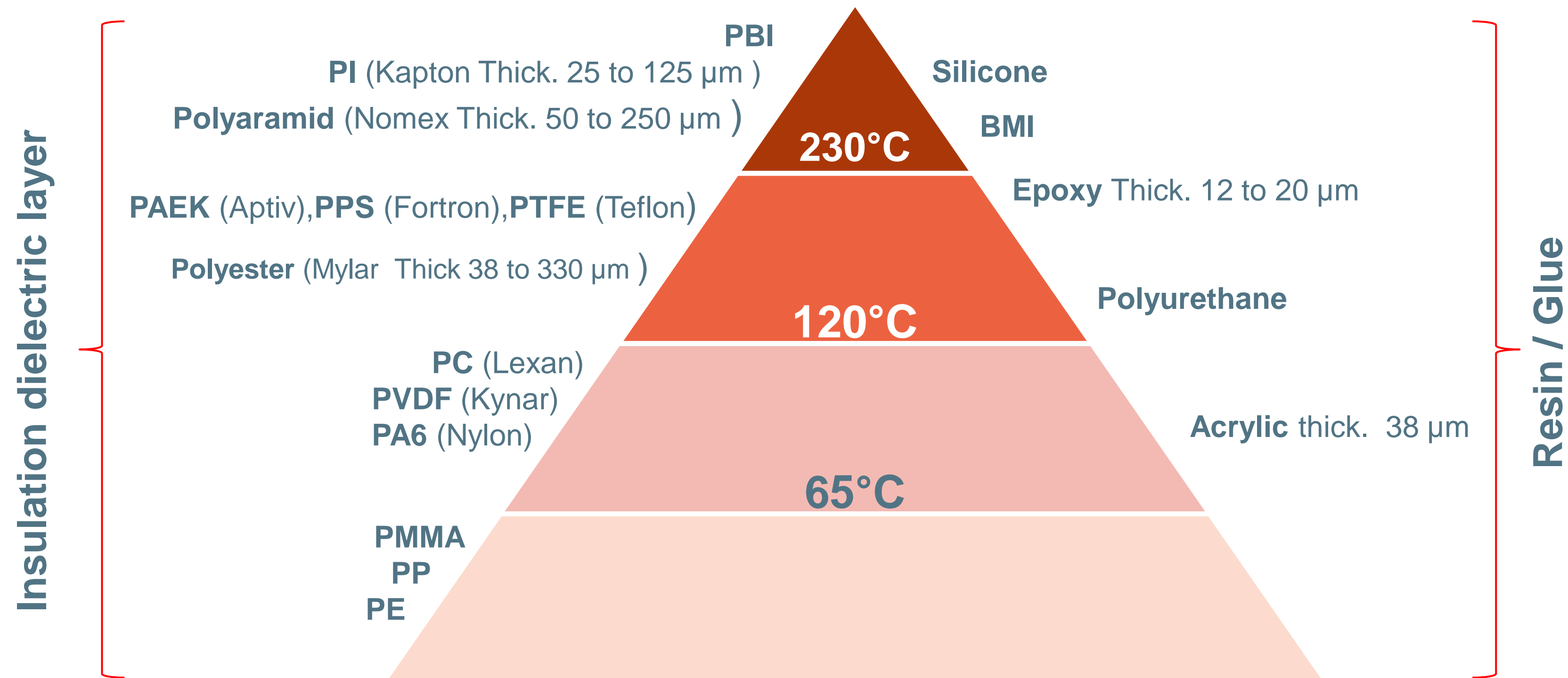
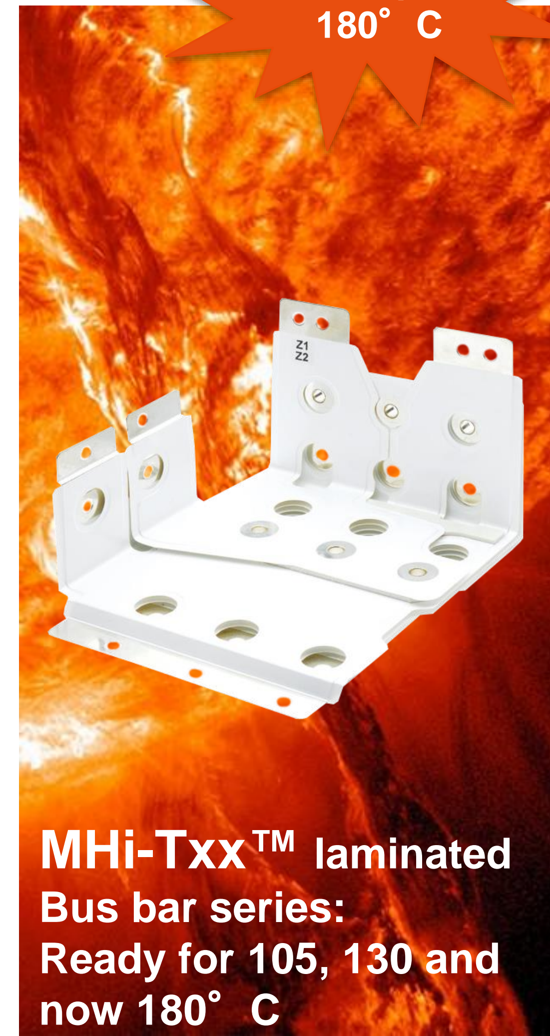
LAMINATED BUS BAR: HOW TO MATCH WBG MODULE HIGH T° REQUIREMENTS ?

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°:**





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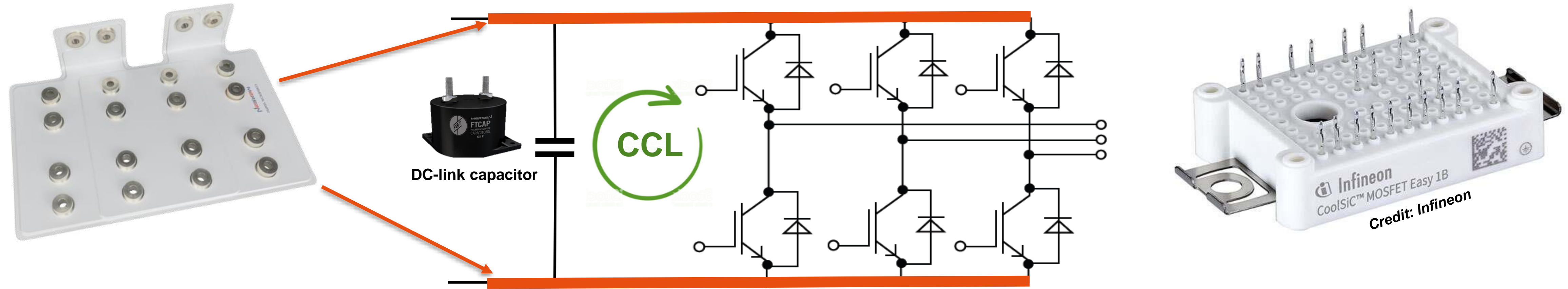
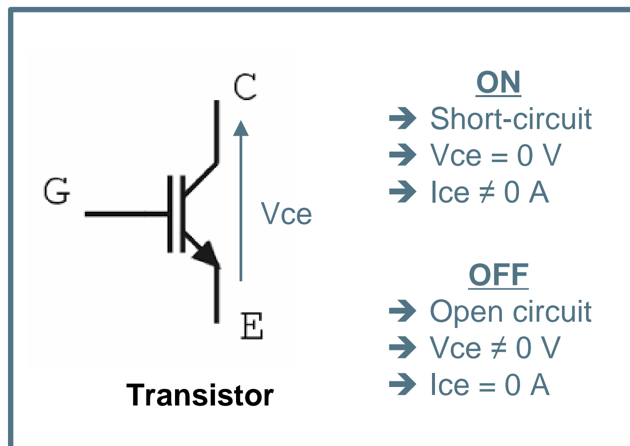
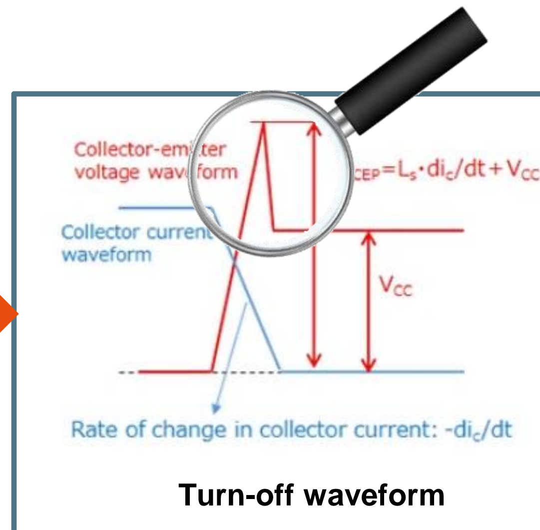
INDUCTANCE FUNDAMENTALS IN POWER CONVERTER DESIGN

HIGH INDUCTANCE CREATES VOLTAGE OVERSHOOT AND SURGE AT COMMUTATION



CCL: Commutation current loop





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

L_s = inductance of CCL*

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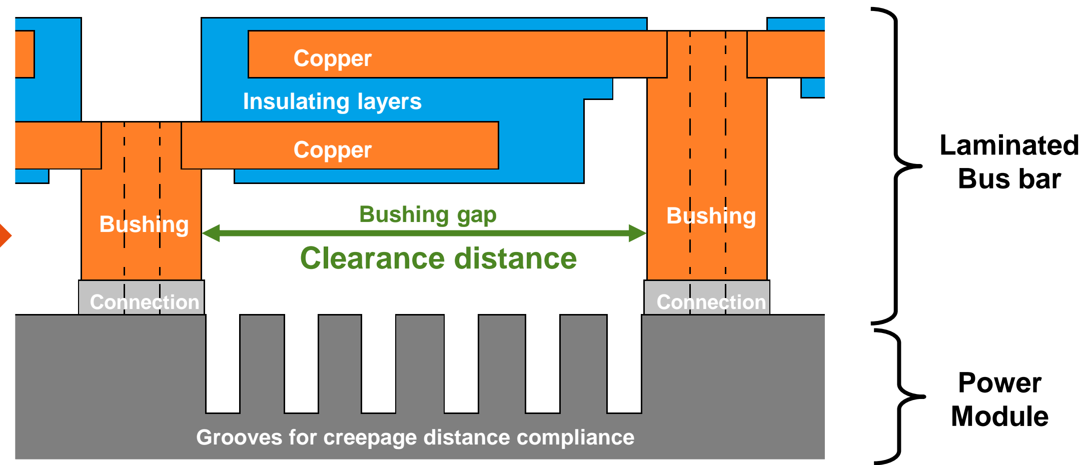
HOW TO DECREASE CLEARANCE DISTANCE IN POWER MODULE DESIGN ?

CONFORMAL BUS BAR IS AN ENABLER…

Today's industry standard



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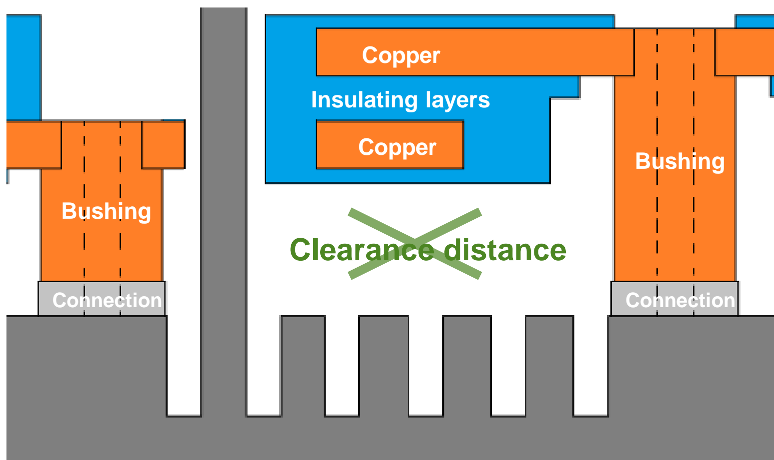
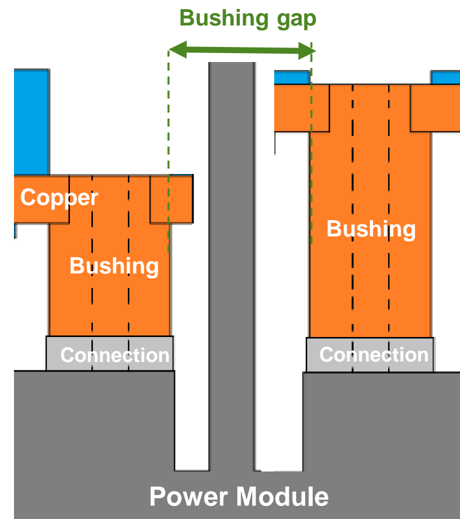
STEP 1

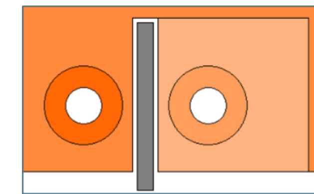


Additional tall insulating barrier on power module housing

STEP 2



Removal of intermediate grooves

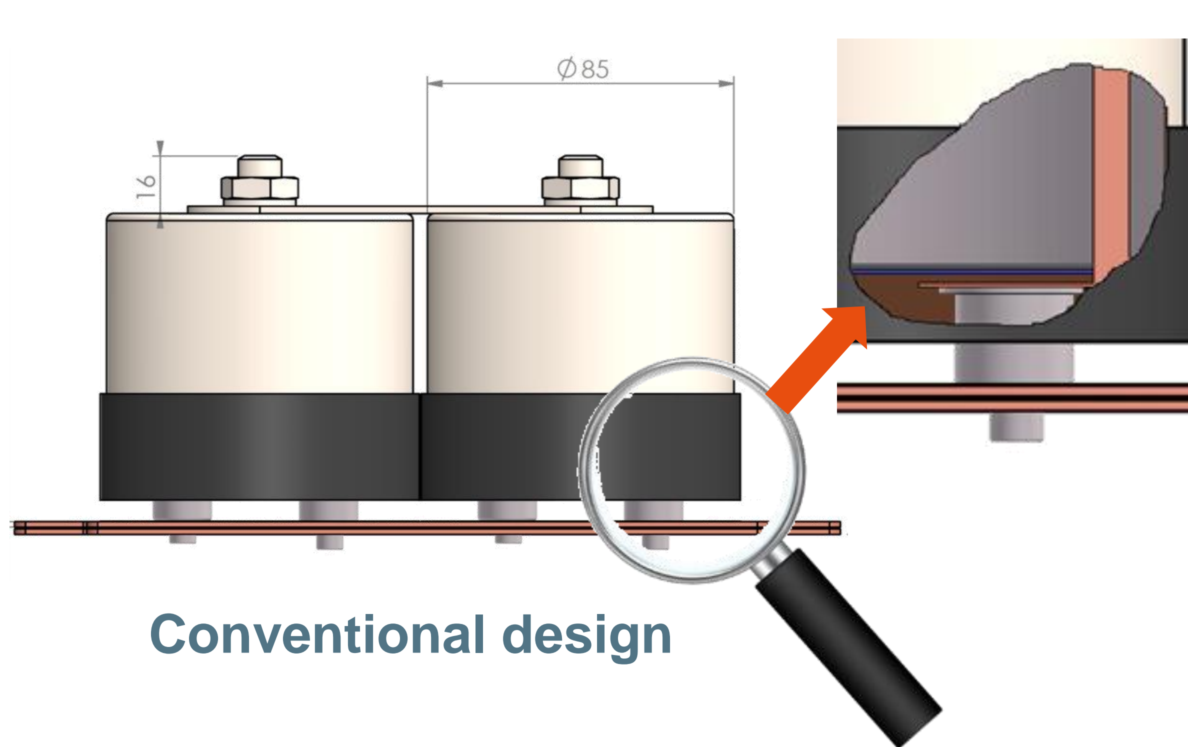


Top view of the bushings gap with tall insulating barrier and conformal bus bar design

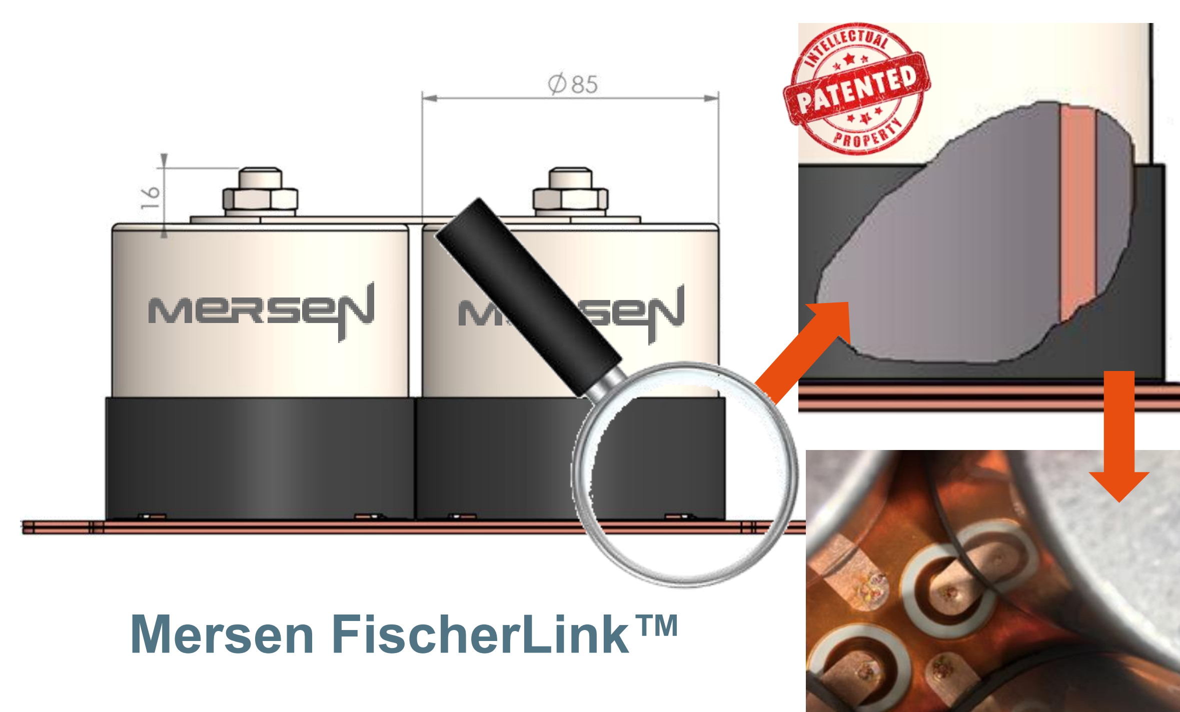
Gap between bushings can be significantly reduced → More compact module design

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

FISHERLINK™



Conventional design



Mersen FischerLink™

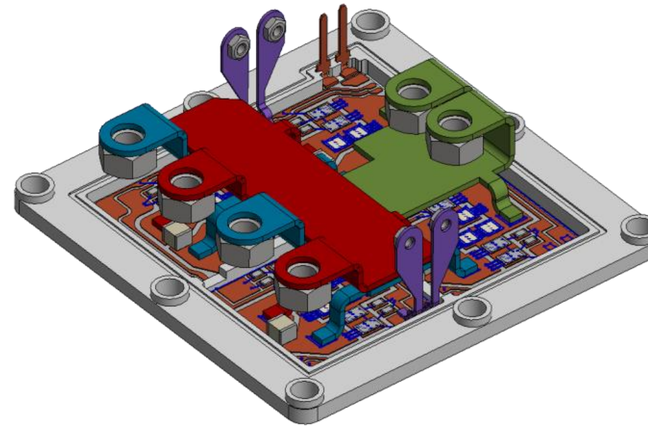
- SHORTER CONNECTION OF THE CAP WINDING TO THE BUSBAR BY **DIRECT CONNECTION OF THE WINDING TABS TO THE BUSBAR BY LASER WELDING**
- Up to **+20 % capacitance** in a given volume (e.g. from 400µF to 480µF @ 1100 Vdc | 4-cap assembly)
- Extremely low inductance **<9nH**
- Capacitors and busbars packaged 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 !

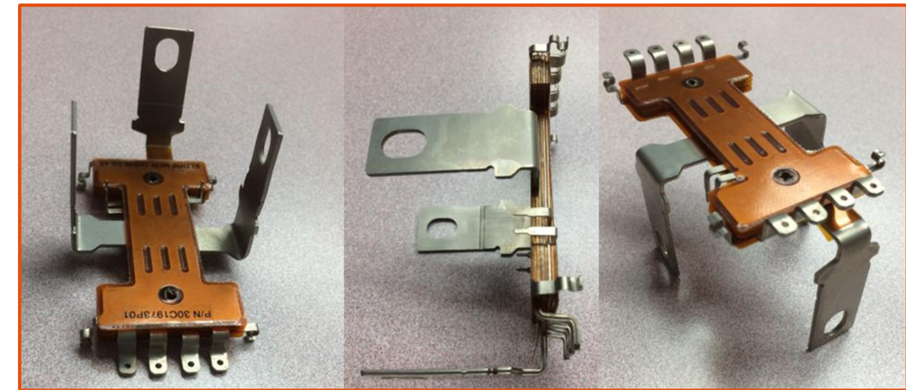
- **The aim:**
  - Get very low internal inductance by
    - laminated/symmetrical bus bar structure
    - Maximizing metallic conductor overlap
  - 50% reduction in switching loss for higher switching frequency (> 20KHz)
  - Safe turn-off possible at large current without snubber capacitor

- **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



Customer A
GaN module, 160° C Tj

Customer B
SiC 1,700 V module
150° C Tj



Customer C
SiC 1,200 V module
180° C Tj

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Synthesis and Conclusion

- Now that SiC has 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 component supplier but also as **solution provider** made of 2 or more components, **co-designed** and perfectly **optimized** together
- Let's discuss circuit topology along with physical, electrical, mechatronic, thermal, EMI constraints: **we can definitely ease customer journey in module and/or inverter design**

Co-design & optimization