CISSOID
POWER SEMICONDUCTORS

A Modular SiC Inverter Reference Design for e-mobility applications

Pierre Delatte, CTO, CISSOID
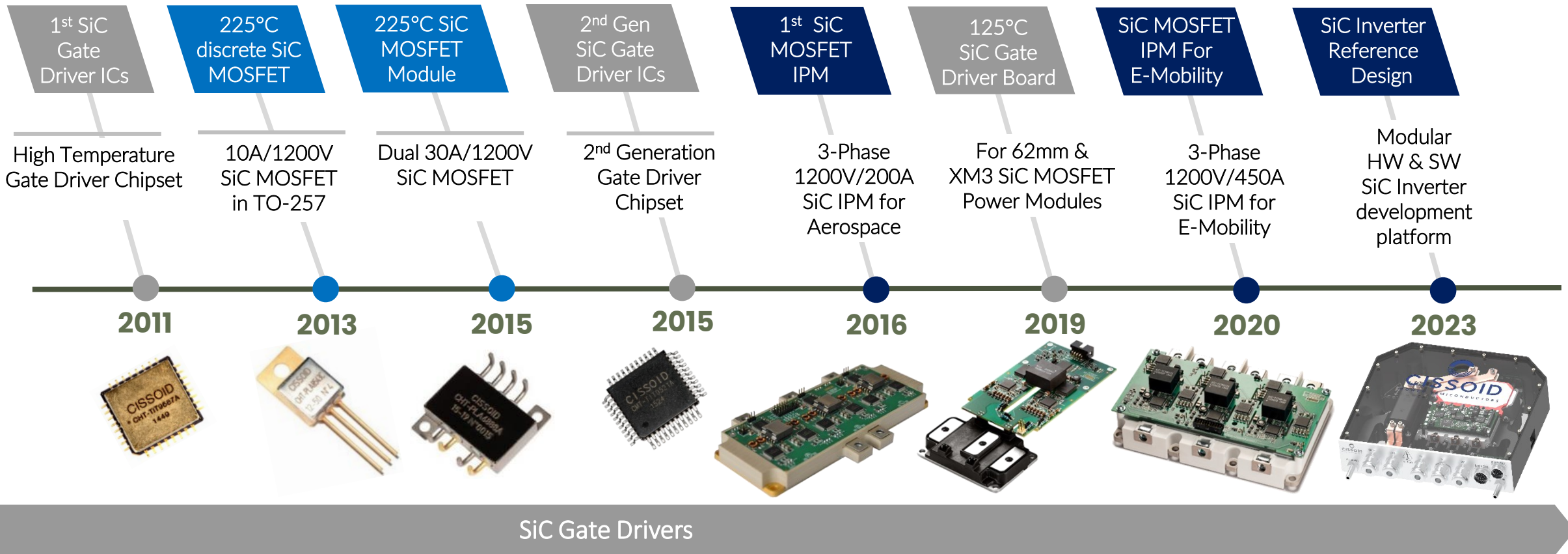Exhibitor stage, PCIM 2023, 11 May 2023

ISO 9001
BUREAU VERITAS
Certification

CISSOID

- Leader in High Temperature Semiconductors for Demanding Markets
- Solutions for efficient power conversion and compact motor drives

Belgium: HQ

Tarbes, France: Module Design

Shenzhen China: Sales & Technical Support

12 YEARS OF INNOVATION IN SiC GATE DRIVERS & POWER MODULES

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1st SiC Gate Driver ICs	225°C discrete SiC MOSFET	225°C SiC MOSFET Module	2nd Gen SiC Gate Driver ICs	1st SiC MOSFET IPM	125°C SiC Gate Driver Board	SiC MOSFET IPM For E-Mobility	SiC Inverter Reference Design
High Temperature Gate Driver Chipset	10A/1200V SiC MOSFET in TO-257	Dual 30A/1200V SiC MOSFET	2nd Generation Gate Driver Chipset	3-Phase 1200V/200A SiC IPM for Aerospace	For 62mm & XM3 SiC MOSFET Power Modules	3-Phase 1200V/450A SiC IPM for E-Mobility	Modular HW & SW SiC Inverter development platform
2011	**2013**	**2015**	**2015**	**2016**	**2019**	**2020**	**2023**

SiC Gate Drivers

Reliable SiC Power Packaging

SiC Intelligent Power Modules (IPM)

Global electrification is creating multiple opportunities for SiC besides mainstream EVs
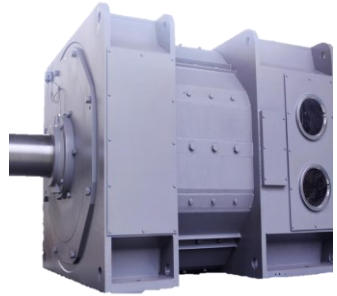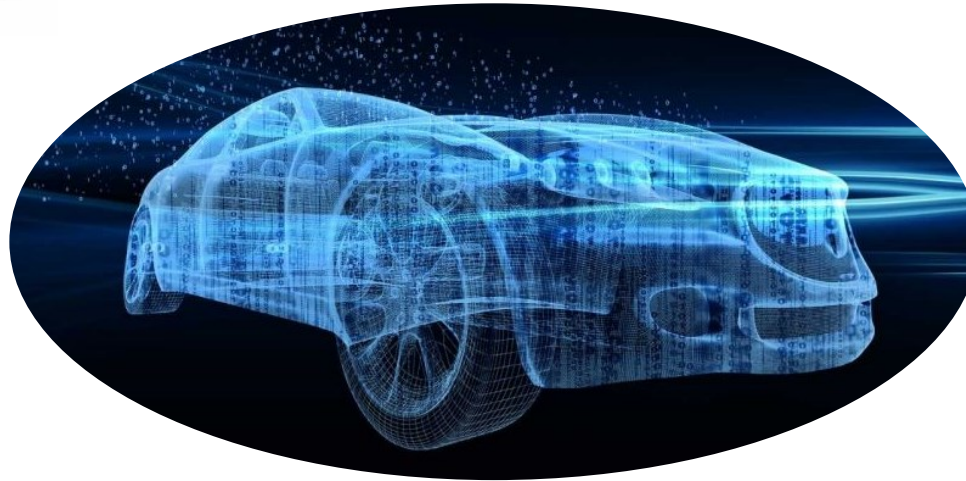

Heavy machines

E-Boats

E-Aviation

Industrial motor control

E-Busses

Autonomous vehicles

EV Supercars

E-Trucks

ELECTRIFICATION CHALLENGES WITH SiC FOR INDUSTRIES NOT PART OF MAINSTREAM EVs

- **Low volumes**
  - 100 ... 10Kpieces / year
- **Modularity**
  - Power, voltage, switching frequency
- **Specific requirements**
  - Housing, e-motor control, EMC, safety
- **Extreme environments**
  - Temperature, vibrations, chemical
- **Short Time-to-market**
  - With mechanical background & scarce electronic engineering resources
- **Supply chain for electronic components**
  - Long lead times, especially for SiC power modules

MODULAR HARDWARE AND SOFTWARE FOR THE DESIGN OF SiC INVERTERS

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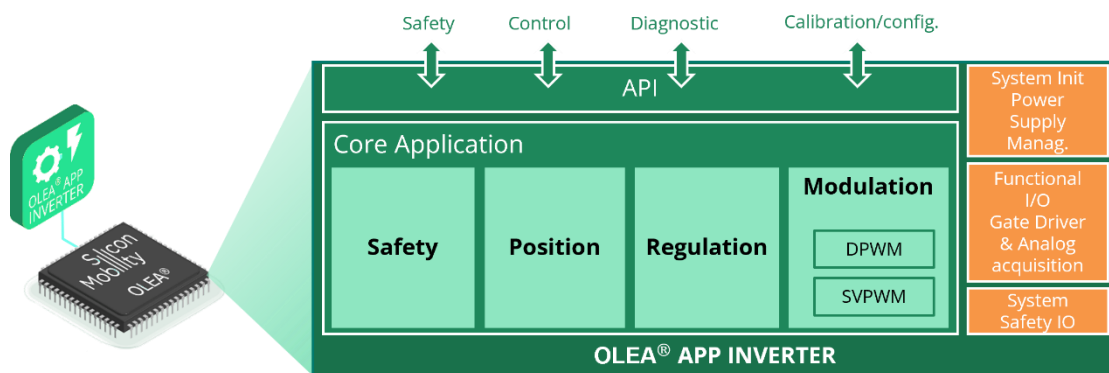POWER SEMICONDUCTORS

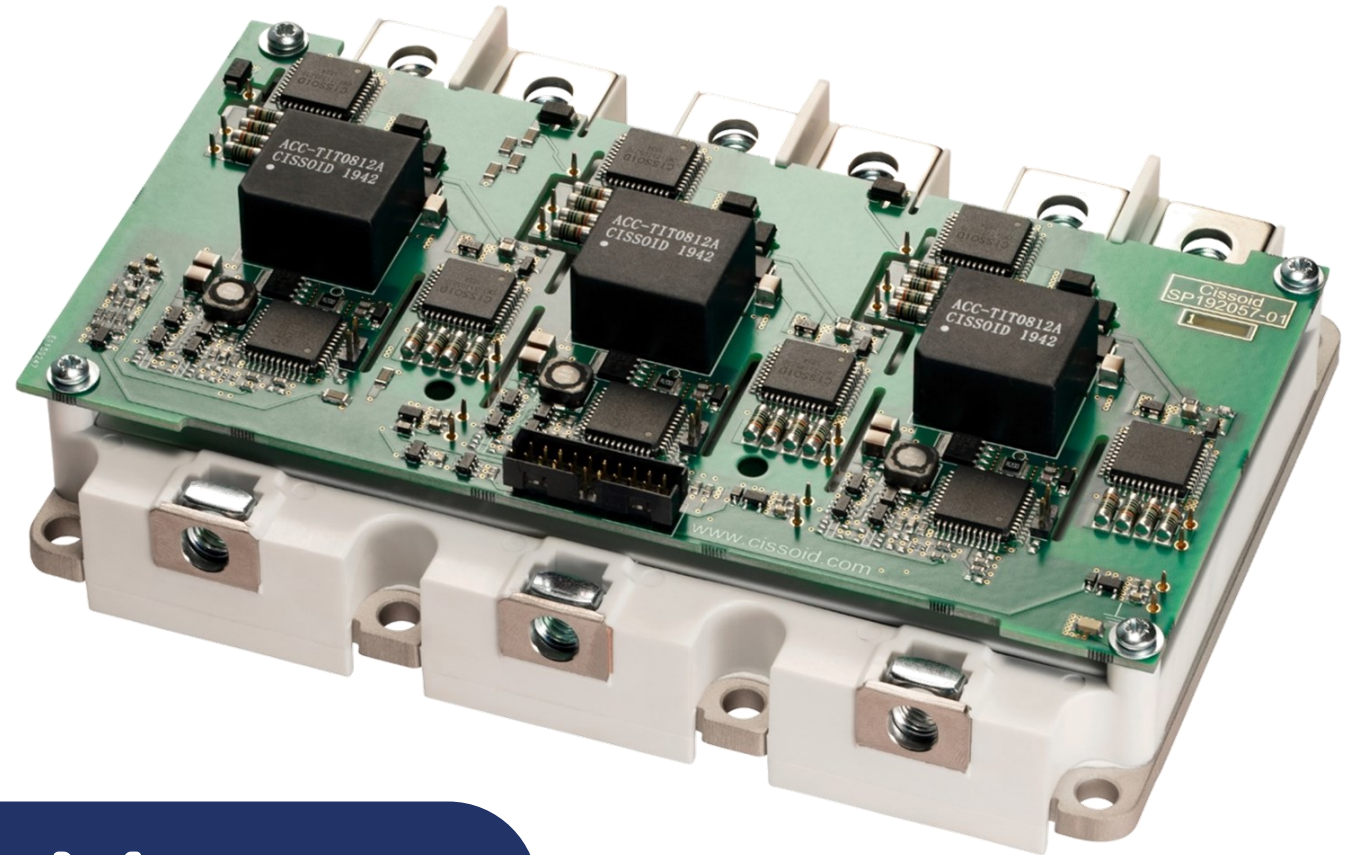**Modular 3-Phase SiC Intelligent Power Module & E-Motor Control Board**
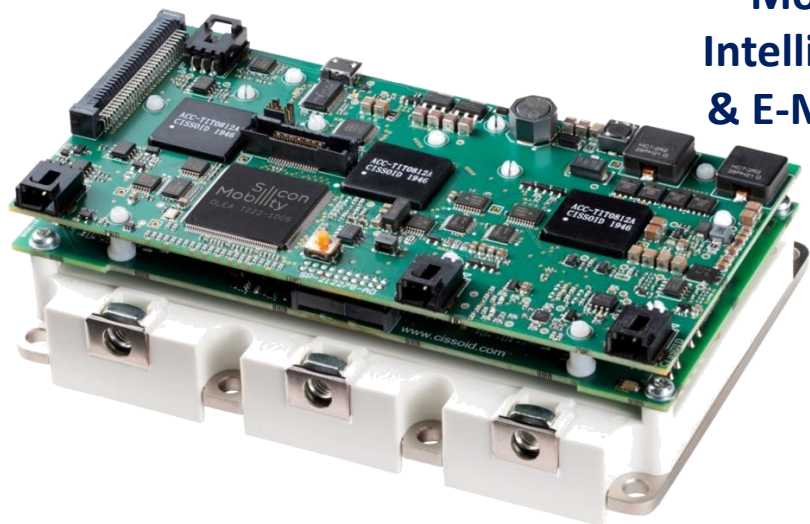
SiC Inverter Reference Design

**Configurable OLEA APP® INVERTER E-Motor Control Software**

SiC Intelligent Power Module

# MODULAR 3-PHASE 1200V SiC MOSFET INTELLIGENT POWER MODULE PLATFORM

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- Highly Integrated & **Modular** SiC Power Module **platform** with SiC-Optimized Gate Driver

- Drastically shortening the design cycle of SiC-based inverters or power converters

- Drain-Source breakdown voltage: 1200V

- Low On-Resistance: 2.53mΩ to 4.2mΩ

- Max Continuous Current: 340A to 550A

- Low Switching Energies

- Extended Operating Temperature

- Cooling thanks to Lightweight AlSiC Pin Fin (liquid cooling) or flat baseplates
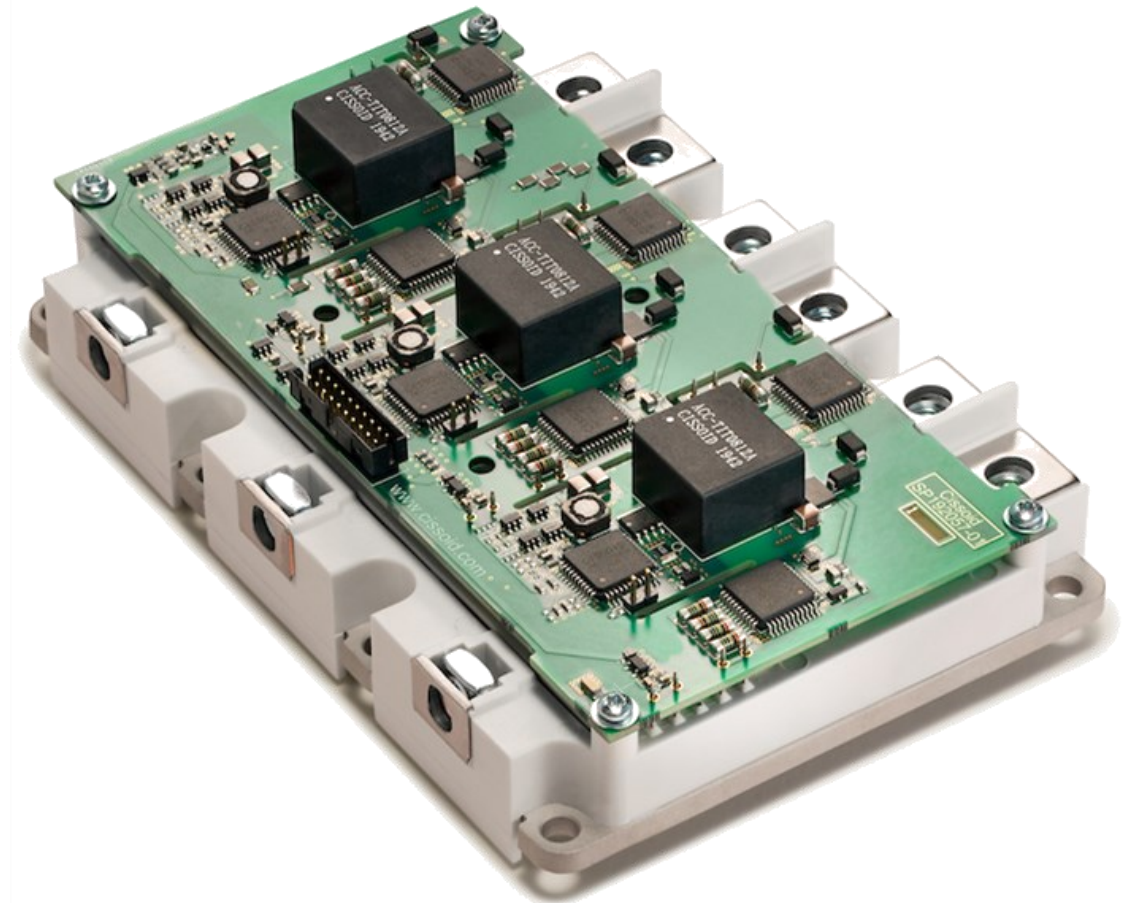
MODULAR 3-PHASE 1200V SiC MOSFET INTELLIGENT POWER MODULE PLATFORM

- Drain-Source breakdown voltage: 1200V

- Max Switching Frequency: 50kHz

- High Isolation Grade: >3.6KVrms

- Baseplate dimensions: 152mm*100mm
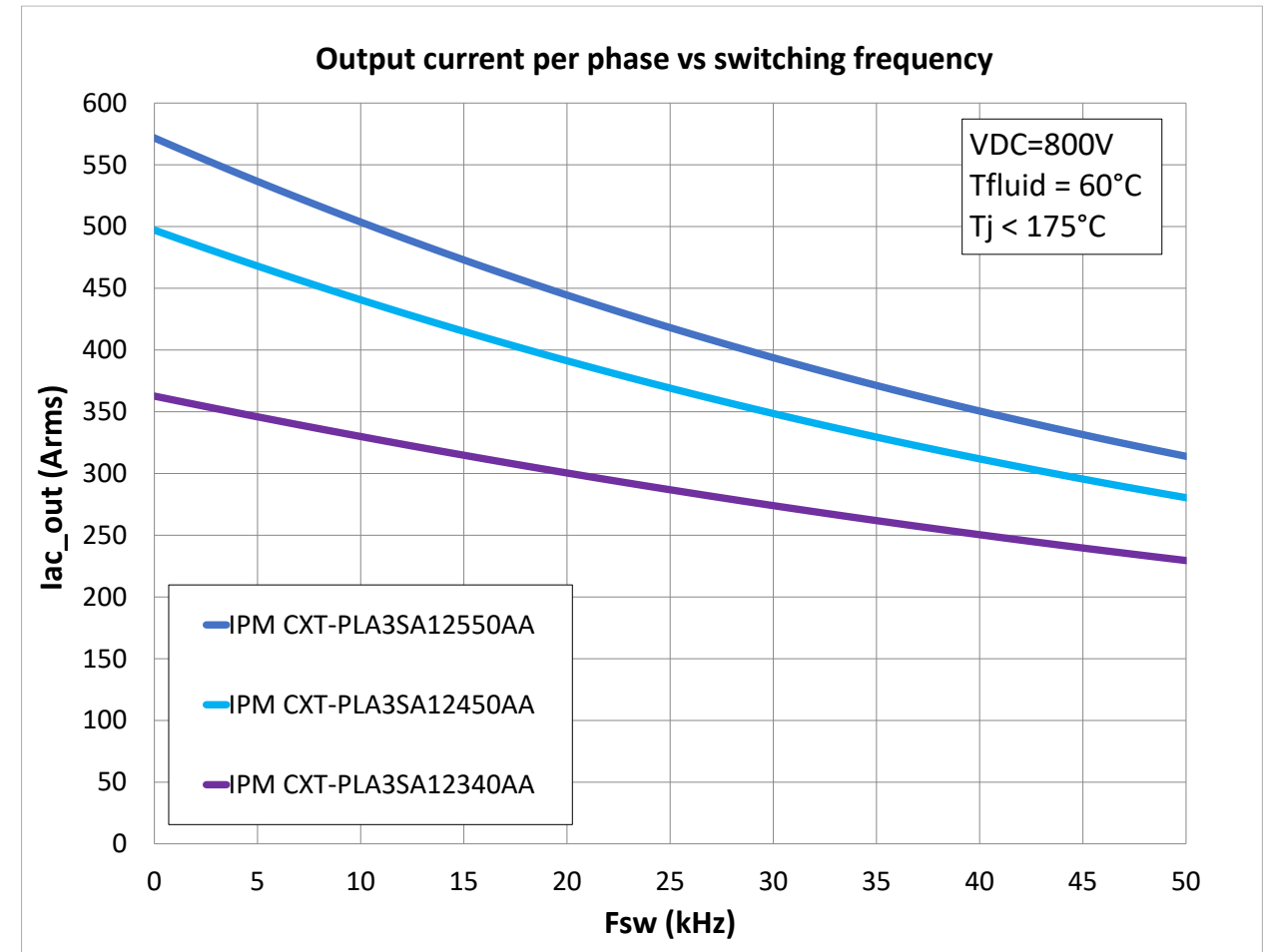
- Lightweight AlSiC Baseplate
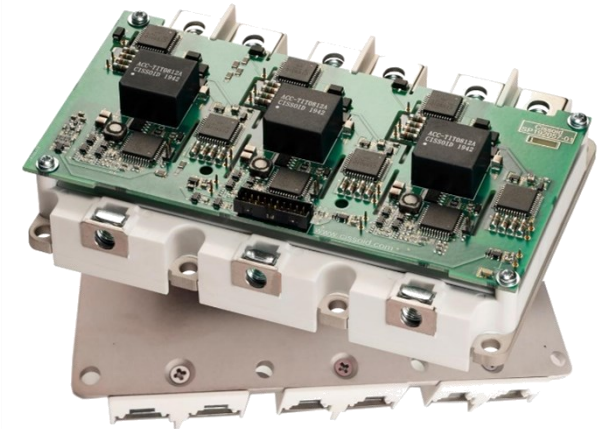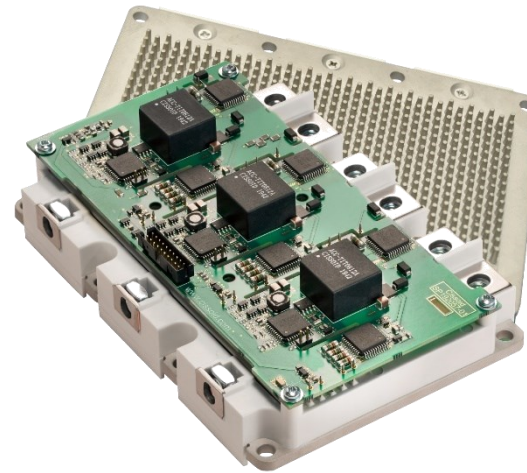
Part Number	Max V_{DS}	Max I_{DC} @ 25°C/90°C	Typ. Ron @25°C/175°C	Eon @300A/600V	Eoff @300A/600V	Baseplate	Rthjc
CXT-PLA3SA12340AA	1200V	340A/260A	4.2mΩ/7.64mΩ	7.48mJ	7.39mJ	Pin fin	0.167°C/W
CXT-PLA3SA12450AA	1200V	450A/350A	3.25mΩ/5.15mΩ	8.42mJ	7.05mJ	Pin fin	0.130°C/W
CXT-PLA3SA12550AA	1200V	550A/400A	2.53mΩ/4.4mΩ	9mJ	7mJ	Pin fin	0.119°C/W
CMT-PLA3SB12340AA	1200V	340A/255A	3.25mΩ/5.15mΩ	8.42mJ	7.05mJ	Flat	0.183°C/W

Modular 3-Phase 1200V SiC MOSFET Intelligent Power Module Platform

Thermally Robust

- Max Junction Temperature of Power Transistors: 175°C

- Lightweight Pin Fin AlSiC, for water-cooling, or flat baseplate

- Junction-to-Fluid Thermal resistance[1]: 0.16°C/W at 10l/min at Flow Rate; 50% ethylene glycol, 50% water, 75°C inflow temperature

- Junction-to-case Thermal resistance[1]: 0.119°C/W

- Temperature robust Gate Driver with Max Ambient Temperature up to 125°C

Note 1: for CXT-PLA3SA12550AA

Output current per phase vs switching frequency

VDC=800V
Tfluid = 60°C
Tj < 175°C

IPM CXT-PLA3SA12550AA
IPM CXT-PLA3SA12450AA
IPM CXT-PLA3SA12340AA

Gate Driver for 3-Phase 1200V SiC MOSFET Intelligent Power Module Platform
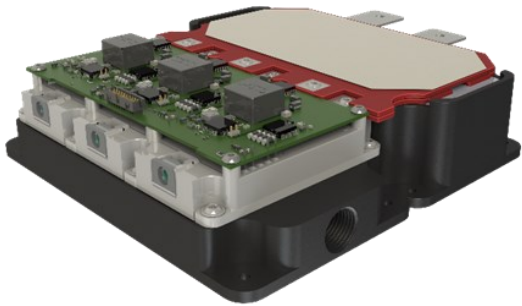
CISSOID
POWER SEMICONDUCTORS

Optimized to drive SiC MOSFETs

- High peak current (>10A) for fast switching

- Robust against high dV/dt (> 50KV/µs)

- High temperature (Tamb>125°C) for high power density

- Accurate gate driver voltages (+/-5%)

- Protection functions

  – UVLO (primary and secondary sides)

  – Desaturation Detection & Soft Shutdown

  – Negative drive & Active Miller Clamp (AMC) for robustness against parasitic turn-On

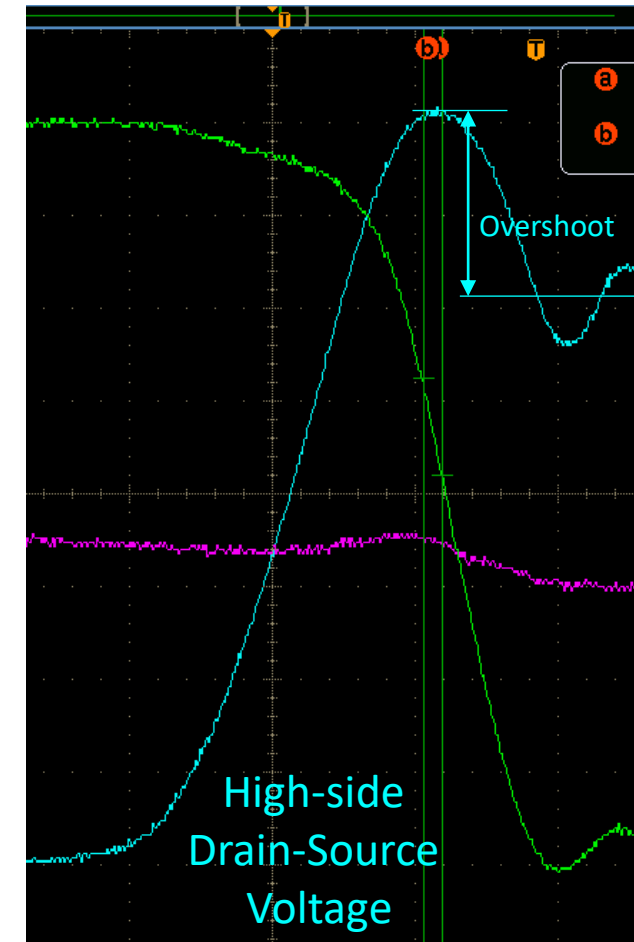 – PWM glitch filter
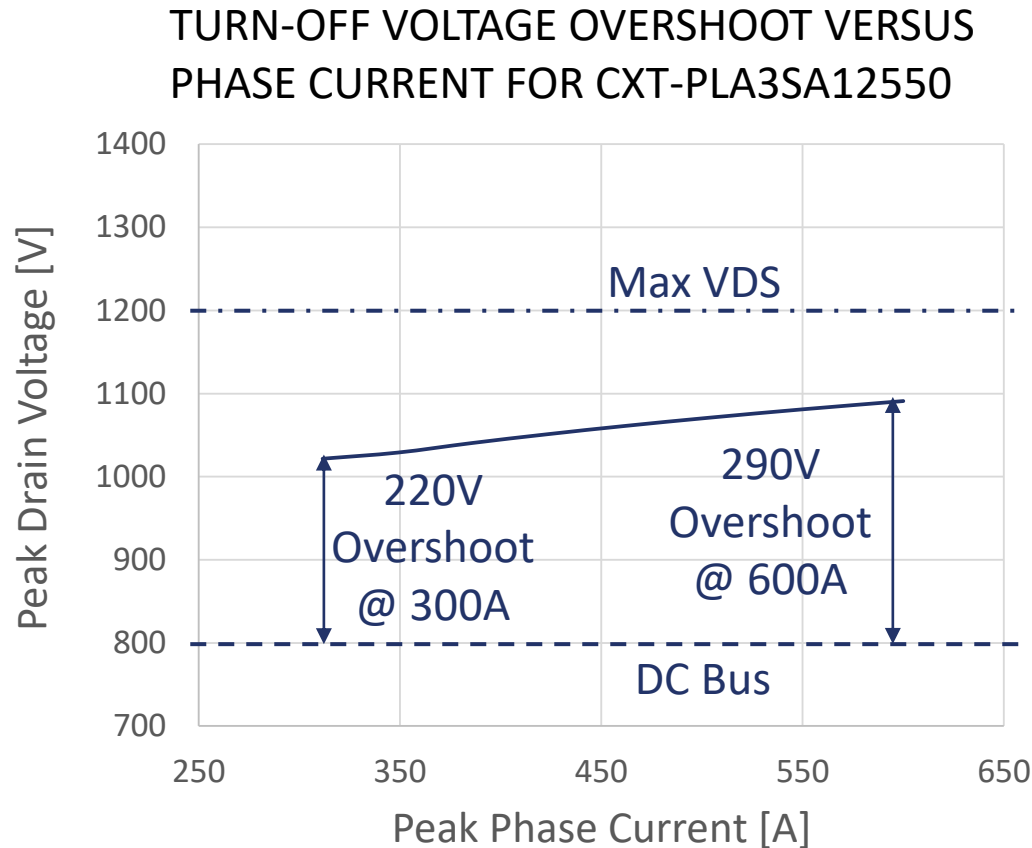
  – PWM anti-overlap protection
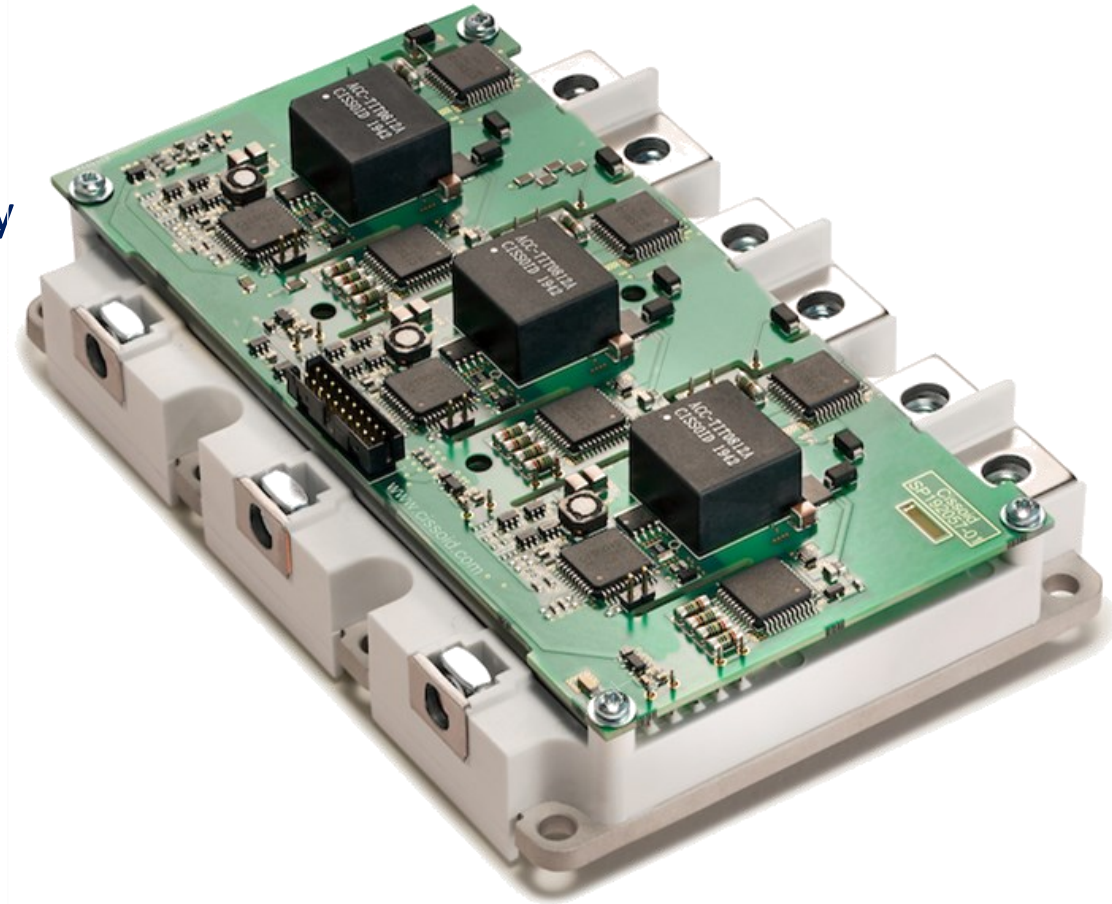
Power Module & gate driver co-design allows best trade-off between switching energies & drain-to-source voltage overshoot

- IPM + companion DC Link capacitor offer a fully characterized switching loop

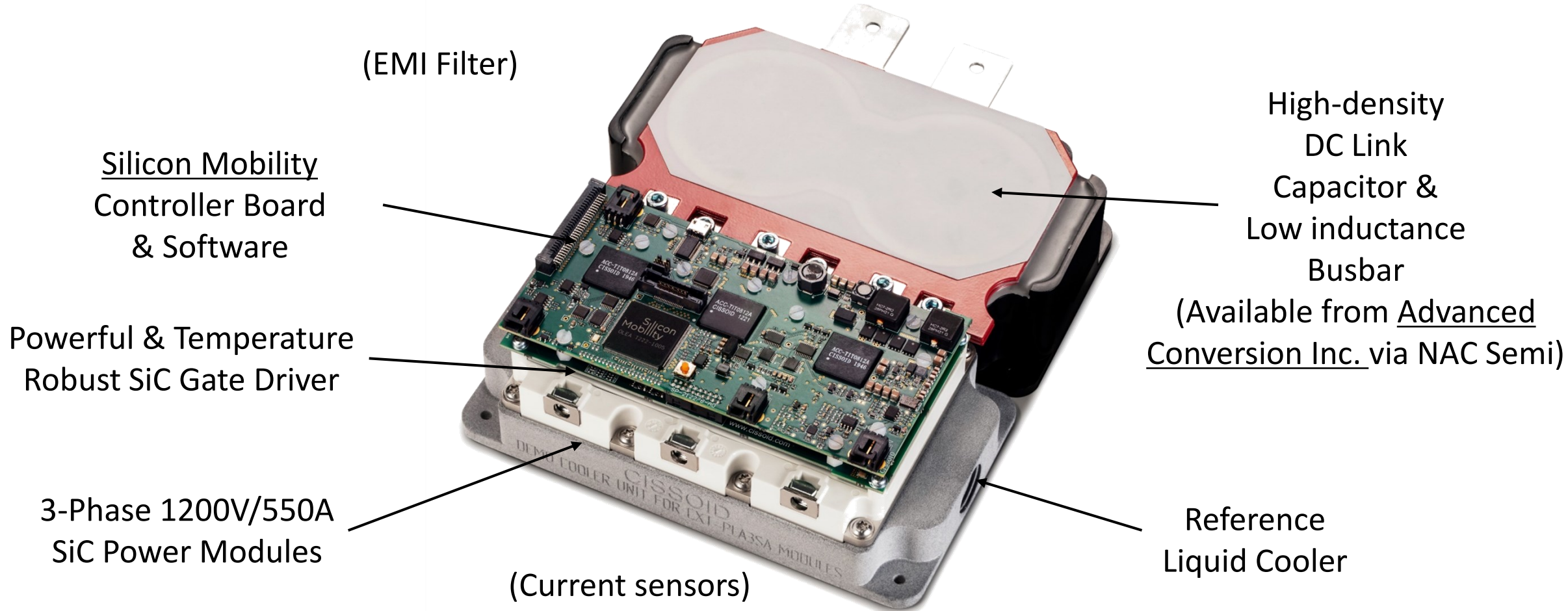- dI/dt and & dV/dt are optimized to support 800V DC bus

TURN-OFF VOLTAGE OVERSHOOT VERSUS PHASE CURRENT FOR CXT-PLA3SA12550

- Max VDS (1200 V dashed line)
- 220V Overshoot @ 300A
- 290V Overshoot @ 600A
- DC Bus (800 V dashed line)

Y-axis: Peak Drain Voltage [V]
X-axis: Peak Phase Current [A]

Overshoot

High-side Drain-Source Voltage

SiC Inverter Design

SiC Inverter Platform
Highly integrated Hardware & Software

Partners' ecosystem speeding up the development of E-Motor Drives

(EMI Filter)

High-density
DC Link
Capacitor &
Low inductance
Busbar
(Available from Advanced
Conversion Inc. via NAC Semi)

Silicon Mobility
Controller Board
& Software

Powerful & Temperature
Robust SiC Gate Driver

3-Phase 1200V/550A
SiC Power Modules

(Current sensors)

Reference
Liquid Cooler

# SiC Inverter Starter Kit
In Partnership with Silicon Mobility

- OLEA® Solution Control Board mechanically & electrically integrated with CISSOID SiC IPMs
  - Based OLEA® T222 FPCU controller chip
  - ISO 26262 ASIL-D Design-Ready Certified
- Interfaces
  - Power module: 3-Phase outputs & 3x2 Power Supply Pins
  - Motor: Resolver, encoder, current/temperature sensors
  - Vehicle: CAN, LIN & Battery supply
  - Developer: SWD (debug) & Trace Port Unit (real-time debug & calibration)
- OLEA® APP INVERTER highly configurable inverter & motor control software supplied by Silicon Mobility
  - Advanced control algorithms for highly energy-efficient systems
  - Closed-loop current control based on Field Oriented Control regulation
  - Frequency scaling SVPWM and DPWM modulation up to 50 kHz with short dead time compensation
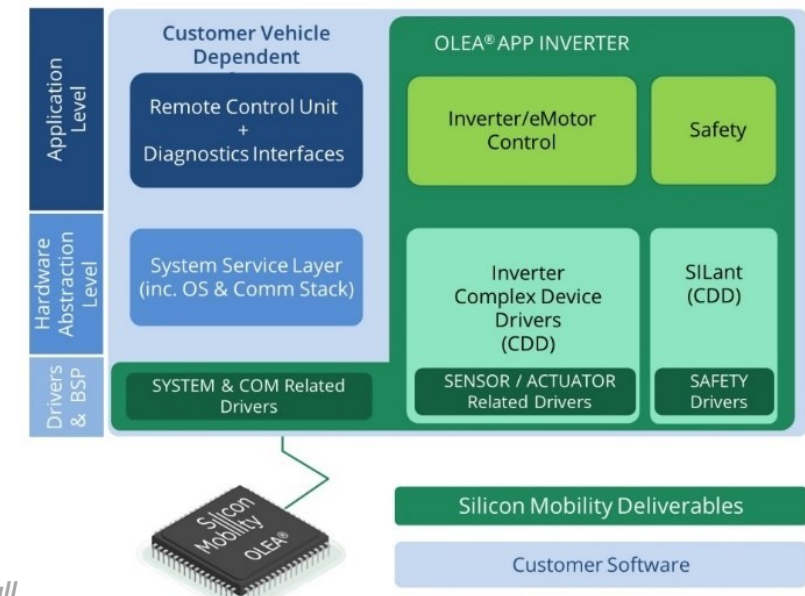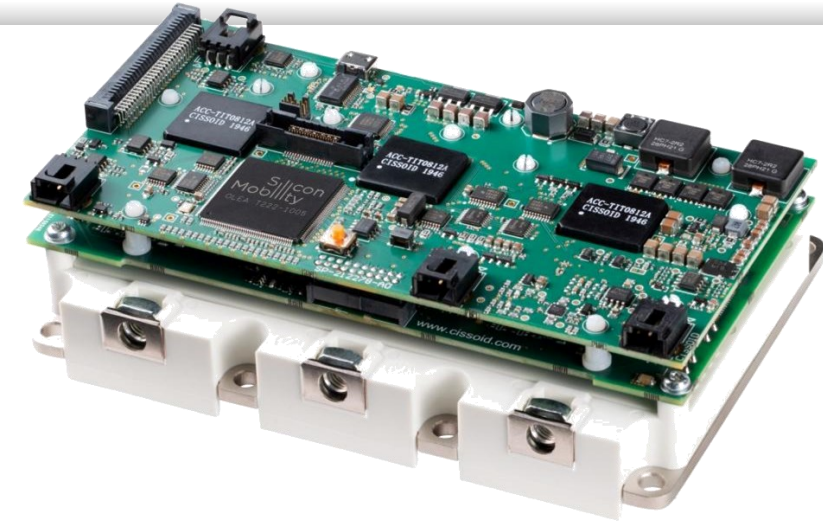
DC Link Capacitor
## In Partnership with Advanced Conversion & NAC Semi

- Mechanically integrated with CISSOID SiC IPM
  - Capacitor range: 135µF to 500µF
  - Voltage range: 500V to 900V
- Integrated capacitor/bus solutions
- High performance capacitor winding elements
- Very low inductance DC link for fast switching with SiC devices
- Capacitor topology enables the best power density
  - High A/µF enables to define µF/kW by control limit and not by capacitor current rating
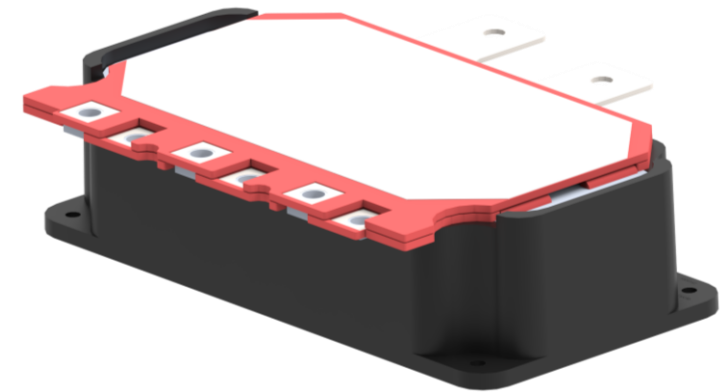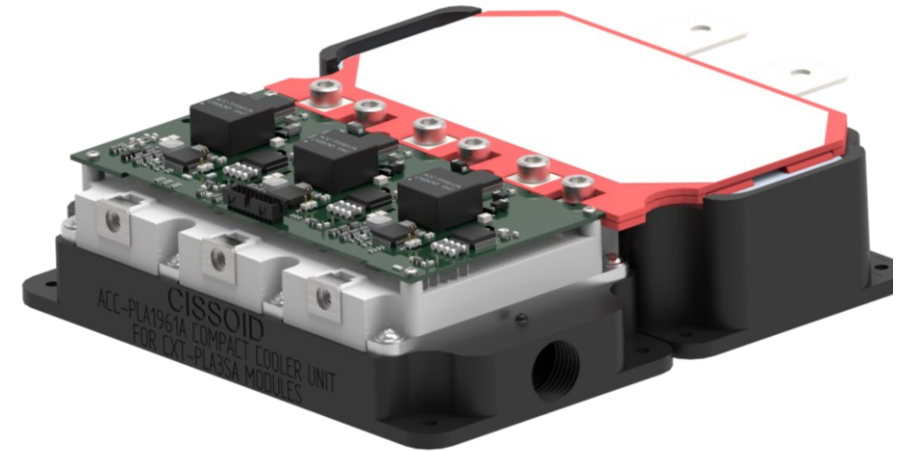
ELECTRICAL & THERMAL MODELLING
LTSPICE MODELS & SIMULATION TESTBENCHES FOR EMC DESIGN

- Transistor-level modelling of SiC MOSFETs

- Behavioral modelling of the gate driver

- Modelling of parasitics

- Modelling of dV/dt, dI/dt and voltage overshoots

- Modelling of SiC MOSFETs On resistance variation with temperature

- Transient thermal modelling with thermal RC network between T_{Fluid} and T_J
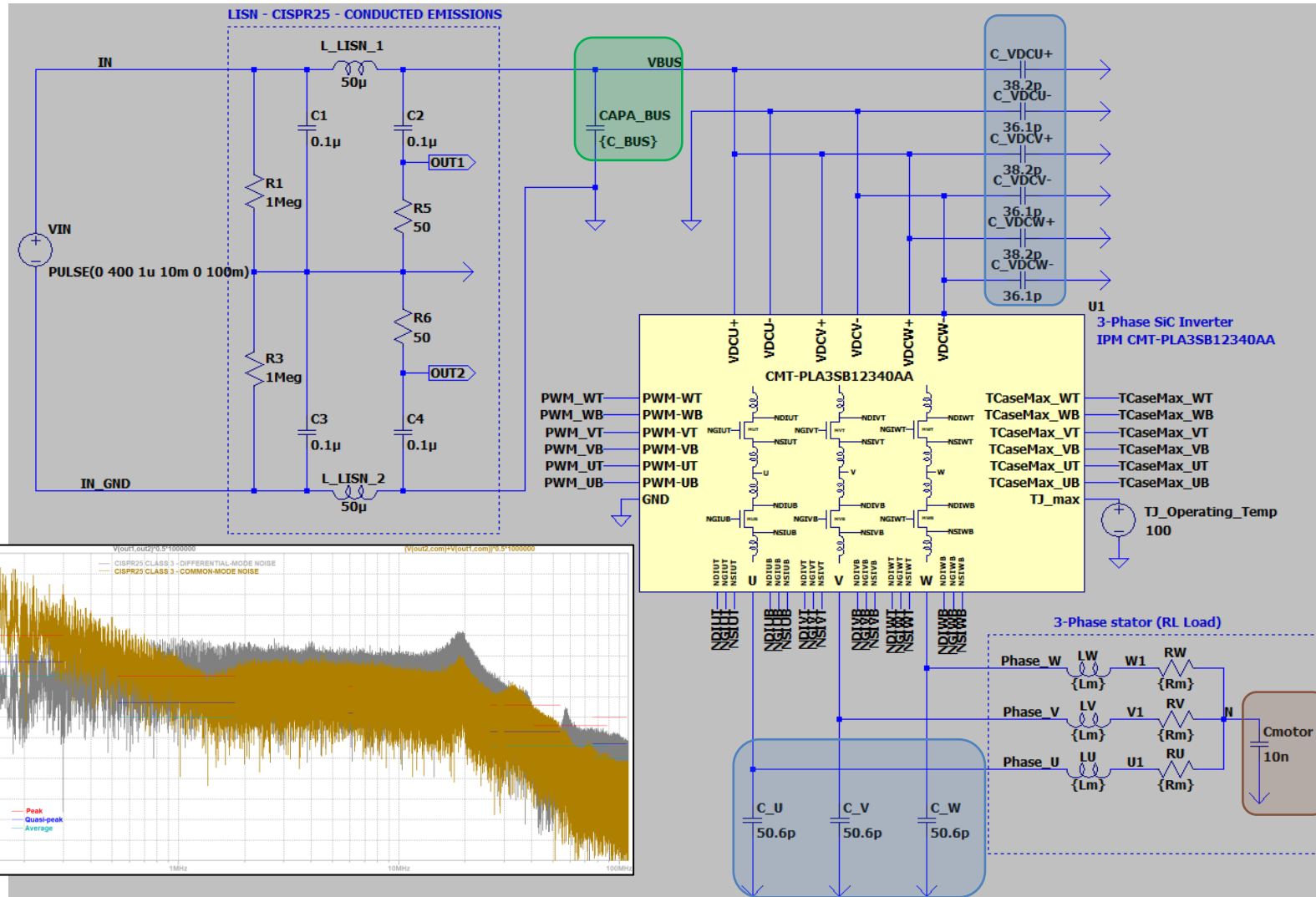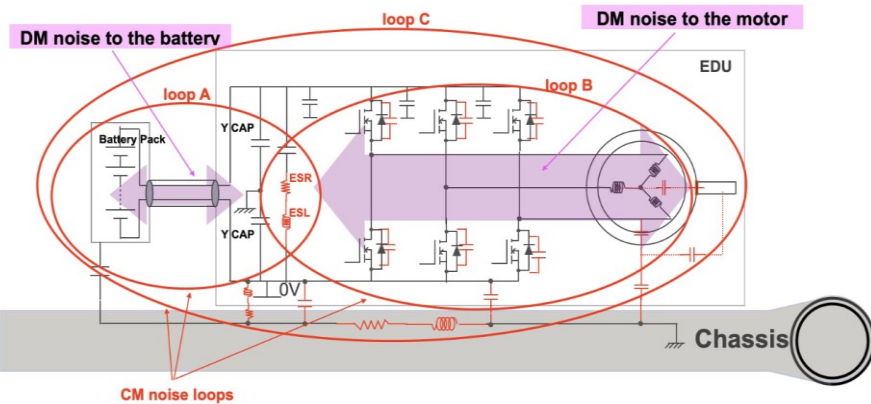
SiC Inverter Reference Design

- Modular design up to 850V/350kW

- 3-Phase 1200V SiC Power Module with integrated Gate Driver Board

- OLEA® T222 FPCU control board

- OLEA® APP INVERTER control software from Silicon Mobility

- DC & Phase current sensors

- 900V/135µF DC Link Capacitor

- TDK CarXield® 900V/400A EMI filter

- DC Bus passive discharge

- Liquid Cooling for power module & EMI filter

SiC Inverter reference Design
OLEA® app Inverter software – Features & APIs

Motor types
- PMSM (Permanent Magnet Synchronous Motor)
- WRSM (Wound Rotor Synchronous Motor)
- Axial/Radial, 3-Phases/6-Phases

Modulation
- SVPWM (Space Vector Pulse Width Modulation)
- DPWM (Discontinuous Pulse Width Modulation)
- Variable switching frequency & Dead-time compensation

Motor position sensors supported
- SIN/COS resolver, AMR-GMR, Hall effect, etc

Motor control
- Flux Weakening management
- Active Discharge
- FOC (Field Oriented Control)
- D/Q inductances LUT
- Torque derating LUT based on Speed/DC-Link and T°
- Slew rate limitation
- Torque/Current/Speed control
- Rotor control
- Clockwise/Anti-clockwise

Motor Control APIs
- to pilot the e-motor with Torque or Speed command
- to manage the control state (Power-up, Init, Standby, Active, Power-down, Power-off)
- to get the motion state (Drive Motion/Braking or Reverse Motion/Braking)

Safety APIs
- to manage the faults/warning such as over/under current/voltage on phases, the over-voltage on DC-Link, the over-temperature on Power Transistor or e-motor
- to get the Safe state

Diagnostics APIs

Calibration/Configuration APIs
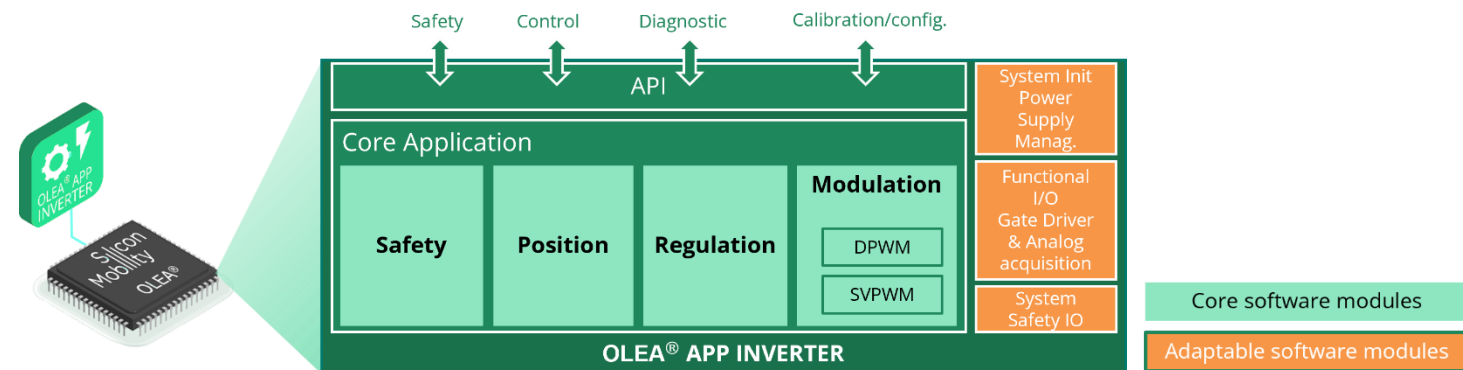
SiC Inverter reference Design
Enabling rapid e-drive evaluation on motor bench

- **Step 1: Configuration of the OLEA® APP INVERTER Software project**
  - According to the e-Motor parameters

- **Step 2: Inverter hardware setup**
  - Motor signal (e.g. resolver, temperature sensor) & ECU/Bench (e.g. CAN, safety) interfaces
  - Power & Cooling interfaces
  - Check that the inverter is functional @ Active state, nominal DC Link value

- **Step 3: System calibration**
  - Open loop mode
  - Current closed-loop mode (position offset calibration)
  - Partial open-loop mode (position offset validation)
  - Current close-loop mode
  - Torque control mode
  - Speed closed-loop mode (speed regulator calibration)

CONCLUSIONS

- A modular hardware and software accelerating the design of SiC Inverters has been presented

- An Intelligent Power Module platform, combining a 3-Phase 1200V SiC power module and its gate driver, facilitates the design of power stage

- Advanced control hardware and software enable fast and safe motor drive

- An ecosystem of partners eases the integration of key inverter elements, as the DC-Link capacitor, current sensors or the EMI filter

- A complete hardware and software SiC inverter reference design makes testing on motor bench possible within a few weeks