CISSOID

POWER SEMICONDUCTORS

SiC Intelligent Power Modules, a system approach that lowers the barrier to entry of SiC in niche e-mobility applications

Pierre Delatte, CTO, CISSOID

Power Electronics International Conference,
Brussels, 18-19 April 2023

CISSOID

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

12 Years of Innovation in SiC Gate Drivers & Power Modules

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2011 — 1st SiC Gate Driver ICs
High Temperature Gate Driver Chipset

2013 — 225°C discrete SiC MOSFET
10A/1200V SiC MOSFET in TO-257

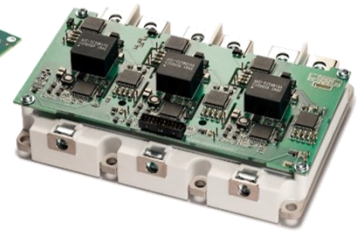
2015 — 225°C SiC MOSFET Module
Dual 30A/1200V SiC MOSFET

2015 — 2nd Gen SiC Gate Driver ICs
2nd Generation Gate Driver Chipset

2016 — 1st SiC MOSFET IPM
3-Phase 1200V/200A SiC IPM for Aerospace

2019 — 125°C SiC Gate Driver Board
For 62mm & XM3 SiC MOSFET Power Modules

2020 — SiC MOSFET IPM For E-Mobility
3-Phase 1200V/450A SiC IPM for E-Mobility



2023 — SiC Inverter Reference Design
Modular HW & SW SiC Inverter development platform

SiC Gate Drivers

Reliable SiC Power Packaging

SiC Intelligent Power Modules (IPM)

GLOBAL ELECTRIFICATION IS CREATING MULTIPLE OPPORTUNITIES FOR SiC BESIDES MAINSTREAM EVs

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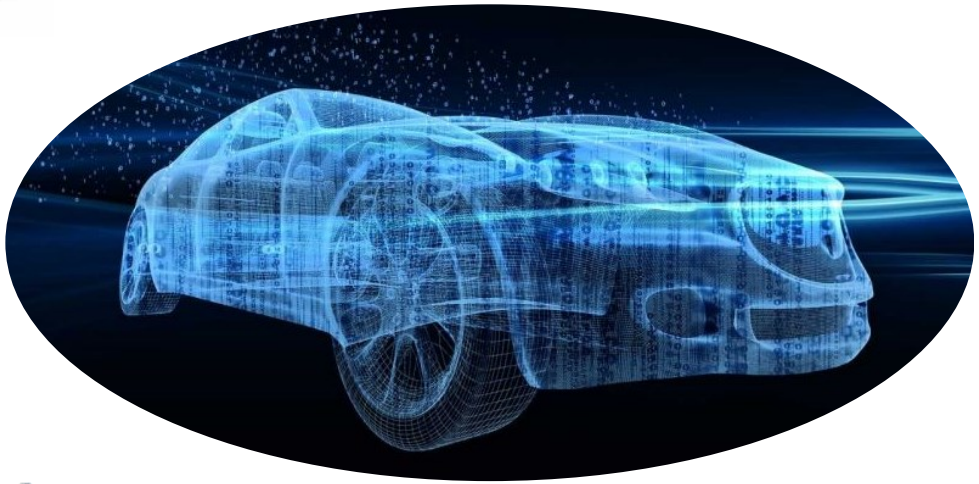
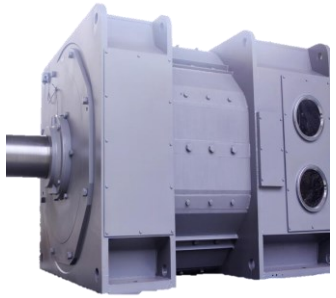
Heavy machines

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

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- 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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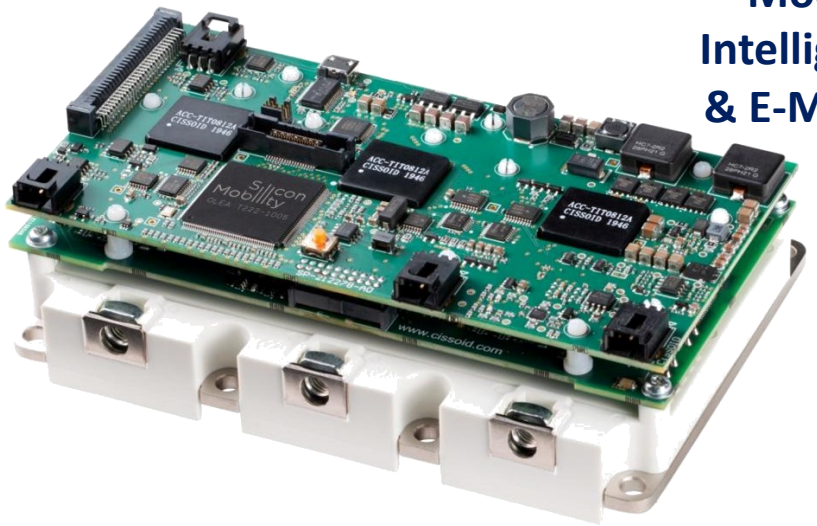
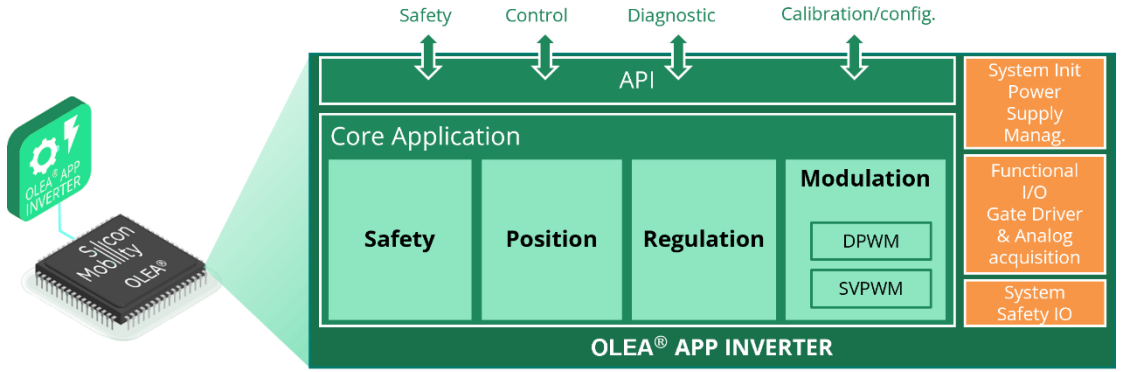
Modular 3-Phase SiC Intelligent Power Module & E-Motor Control Board



Configurable OLEA APP® INVERTER E-Motor Control Software



SiC Inverter Reference Design

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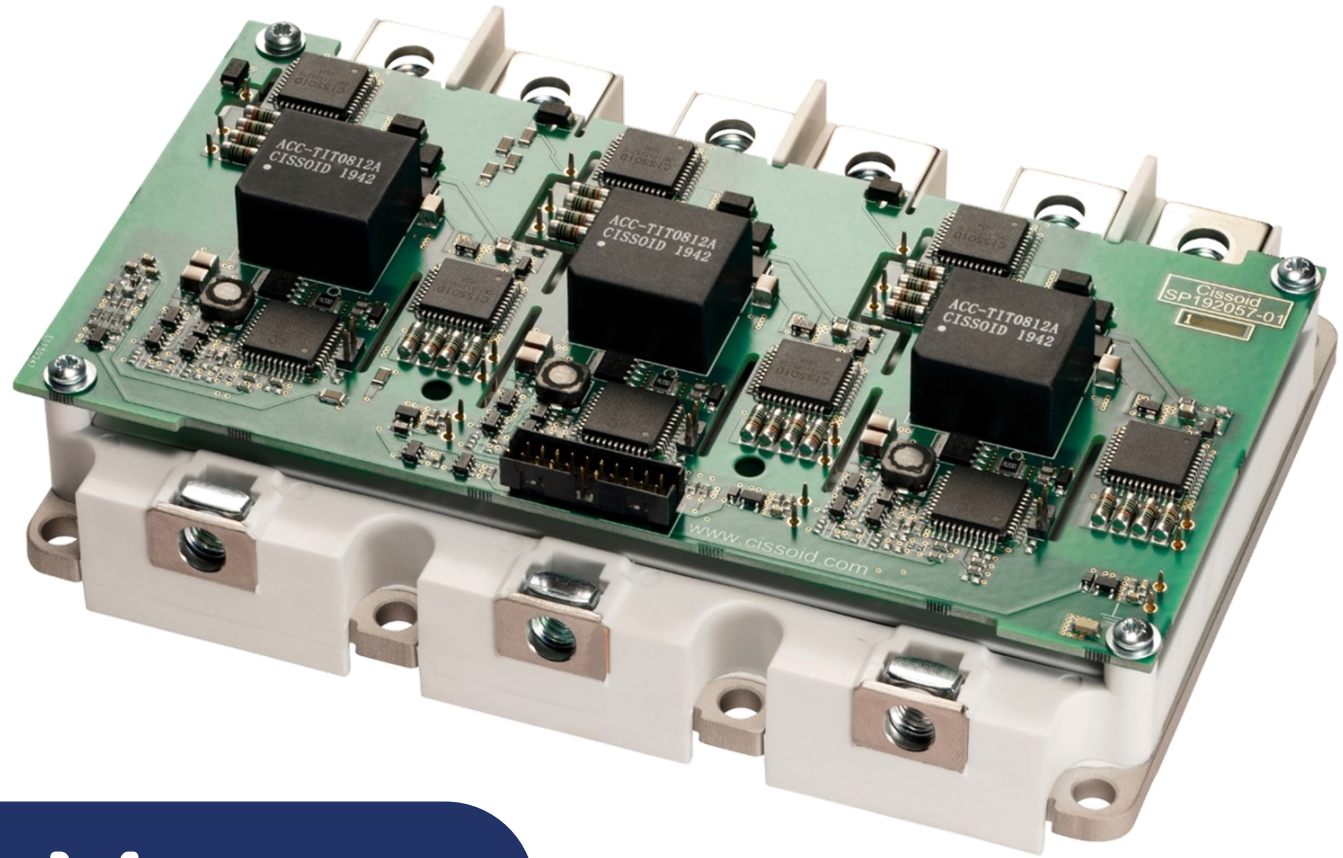

SiC Intelligent Power Module

MODULAR 3-PHASE 1200V SIC MOSFET INTELLIGENT POWER MODULE PLATFORM

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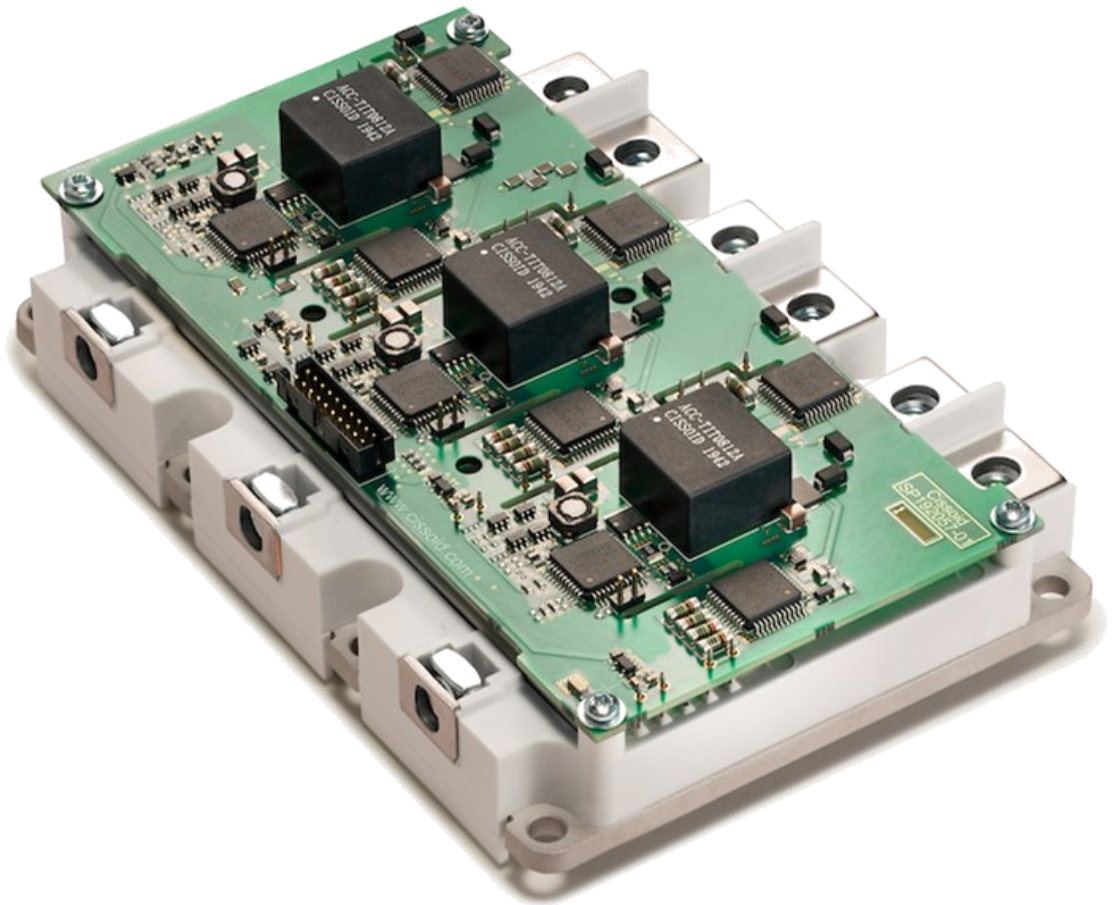
- Highly Integrated & **Modular** SiC Power Module **platform** with SiC-Optimized Gate Driver
- Drastically shortening the design cycle of SiC-based inverters or power converters
- Drain-Source breakdown voltage: 1200V
- Low On-Resistance: 2.53mΩ to 4.2mΩ
- Max Continuous Current: 340A to 550A
- Low 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

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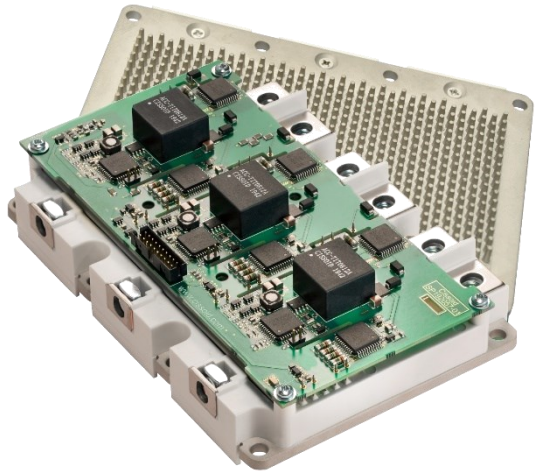
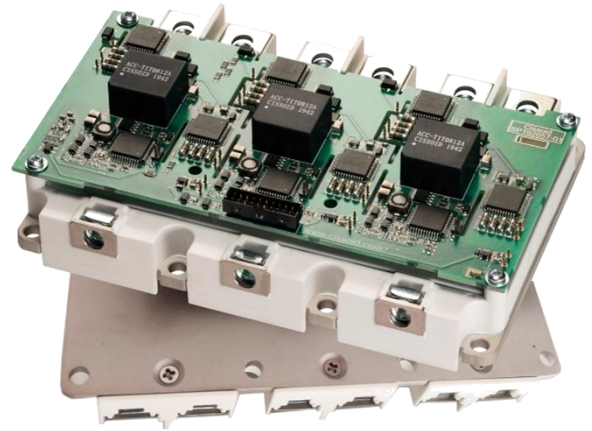
- Drain-Source breakdown voltage: 1200V
- Max Switching Frequency: 50kHz
- High Isolation Grade: >3.6KVrms
- Baseplate dimensions: 152mm*100mm
- Lightweight AlSiC Baseplate





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

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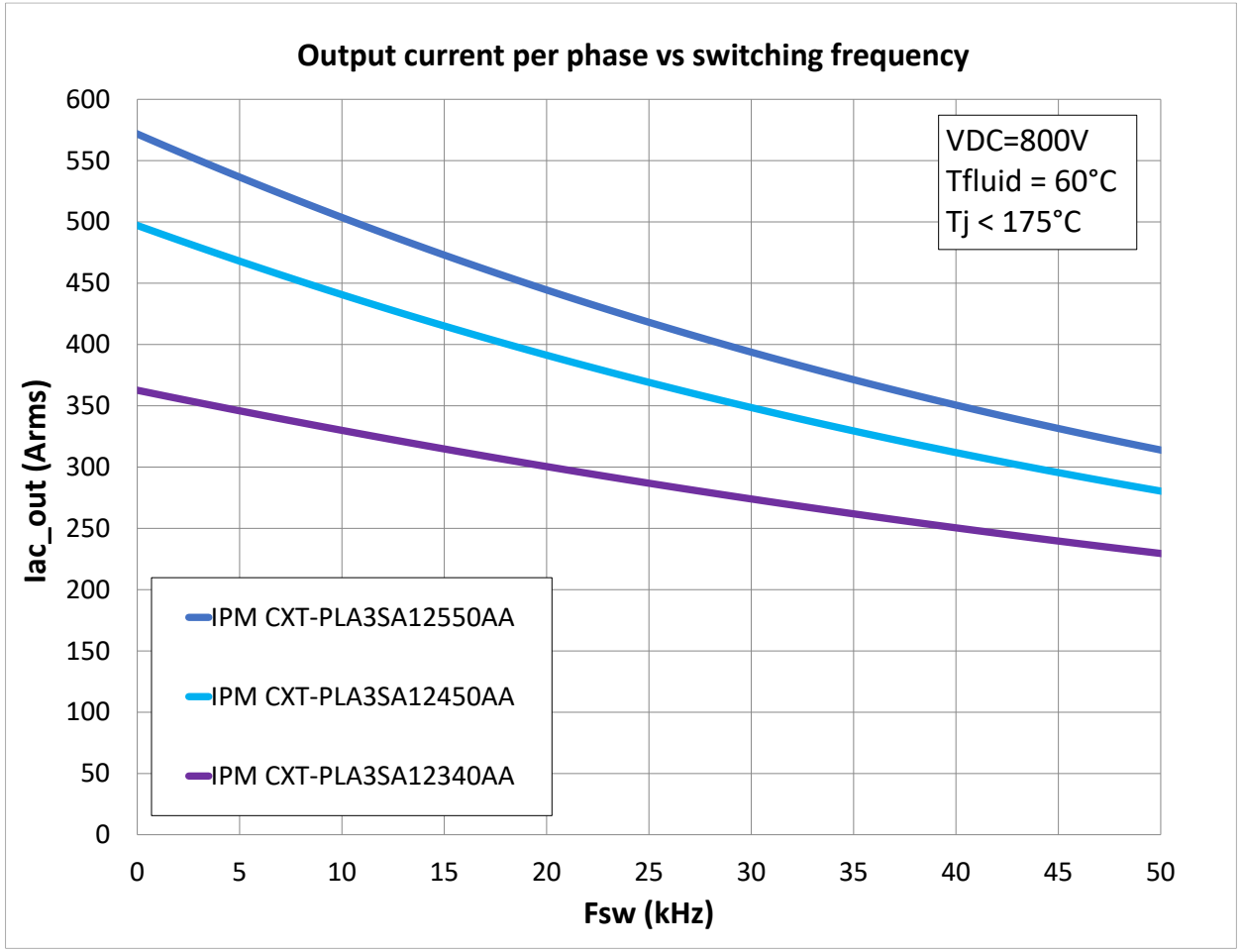
- Thermally Robust
  - Max Junction Temperature of Power Transistors: 175°C
  - Lightweight Pin Fin AlSiC, for water-cooling, or flat baseplate
  - Junction-to-Fluid Thermal resistance[1]: 0.16°C/W at 10l/min at Flow Rate; 50% ethylene glycol, 50% water, 75°C inflow temperature
  - Junction-to-case Thermal resistance[1]: 0.119°C/W
  - Temperature robust Gate Driver with Max Ambient Temperature up to 125°C



Note 1: for CXT-PLA3SA12550AA

GATE DRIVER FOR 3-PHASE 1200V SIC MOSFET INTELLIGENT POWER MODULE PLATFORM

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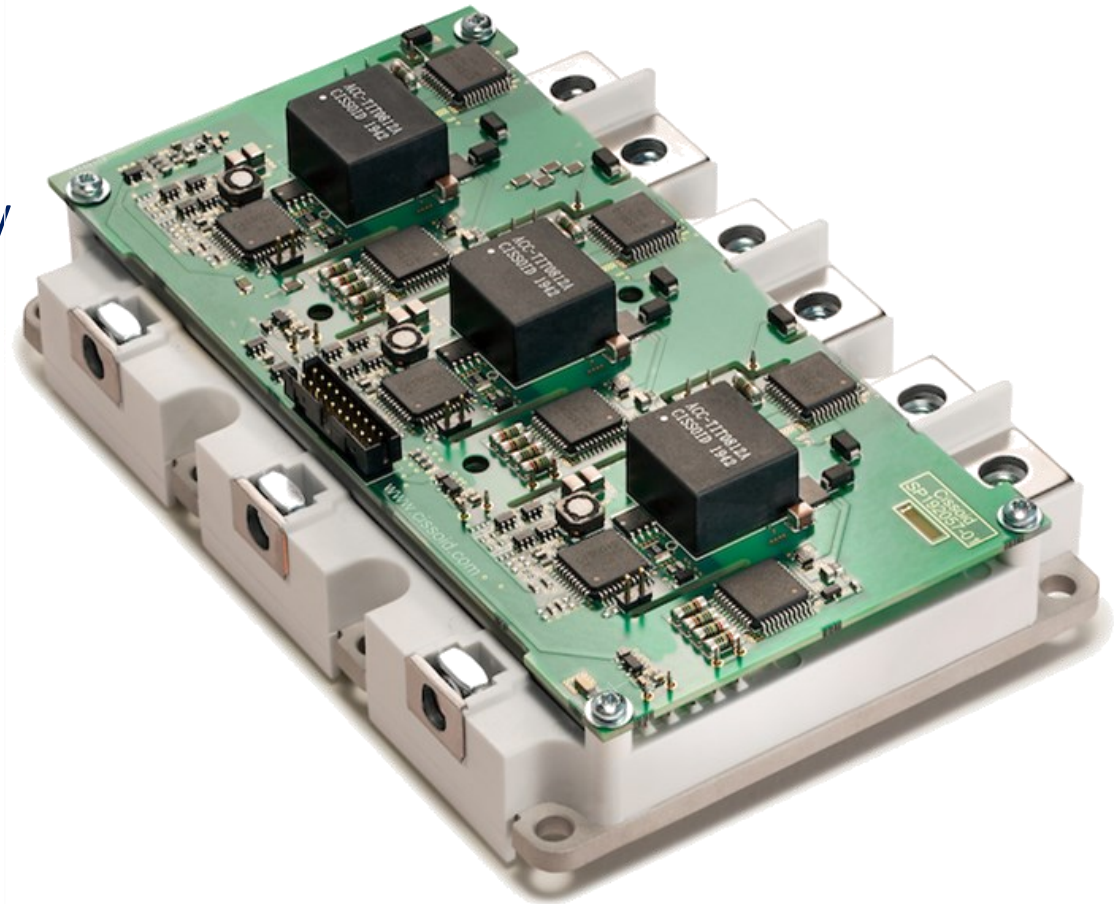
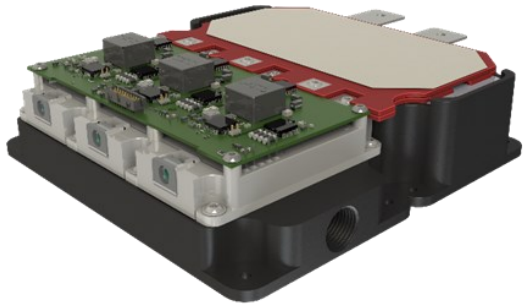
Optimized to drive SiC MOSFETs

- 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

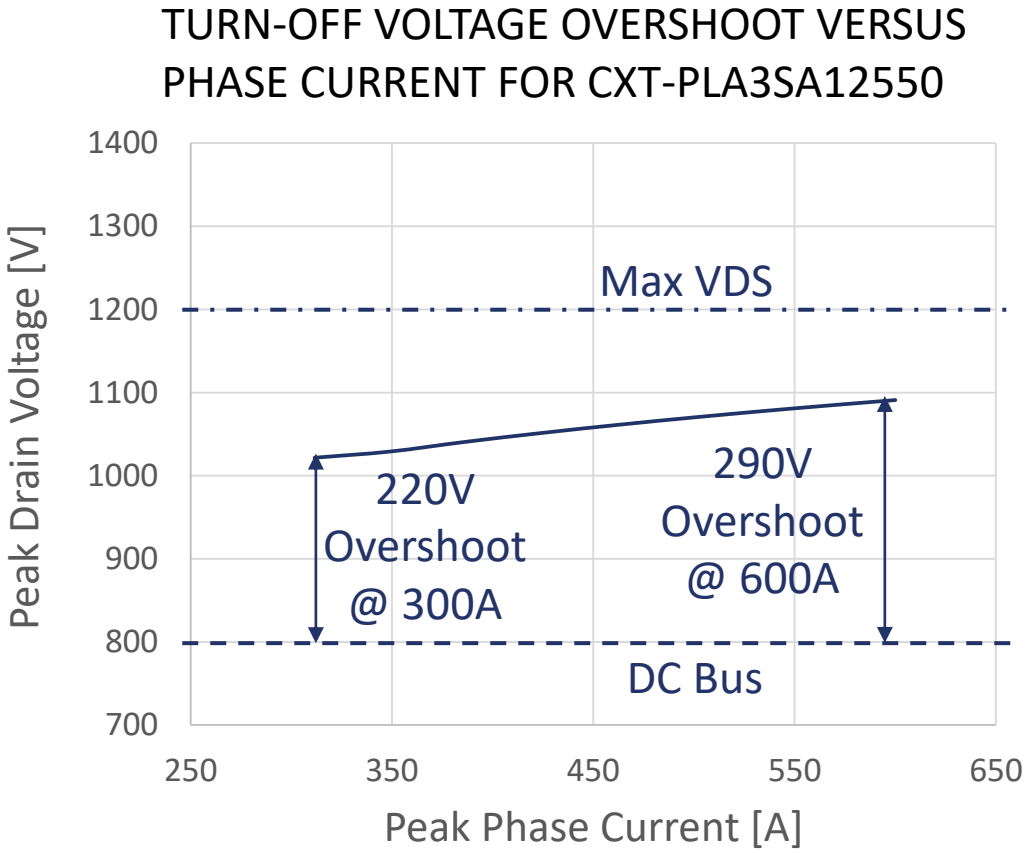


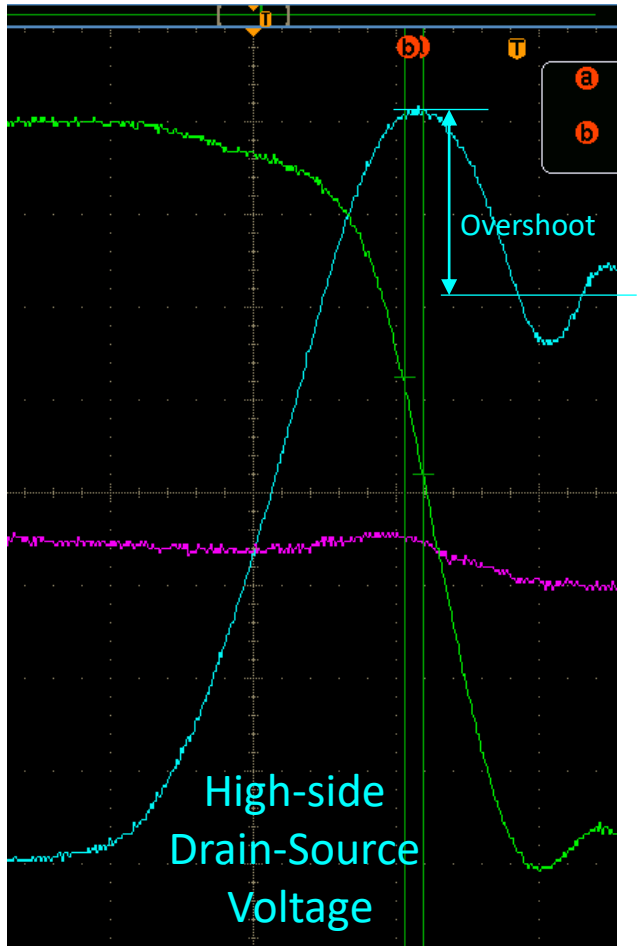
Power Module & gate driver co-design allows best trade-off between switching energies & drain-to-source voltage overshoot

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



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





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SiC Inverter Design

SiC Inverter Platform
Highly integrated Hardware & Software

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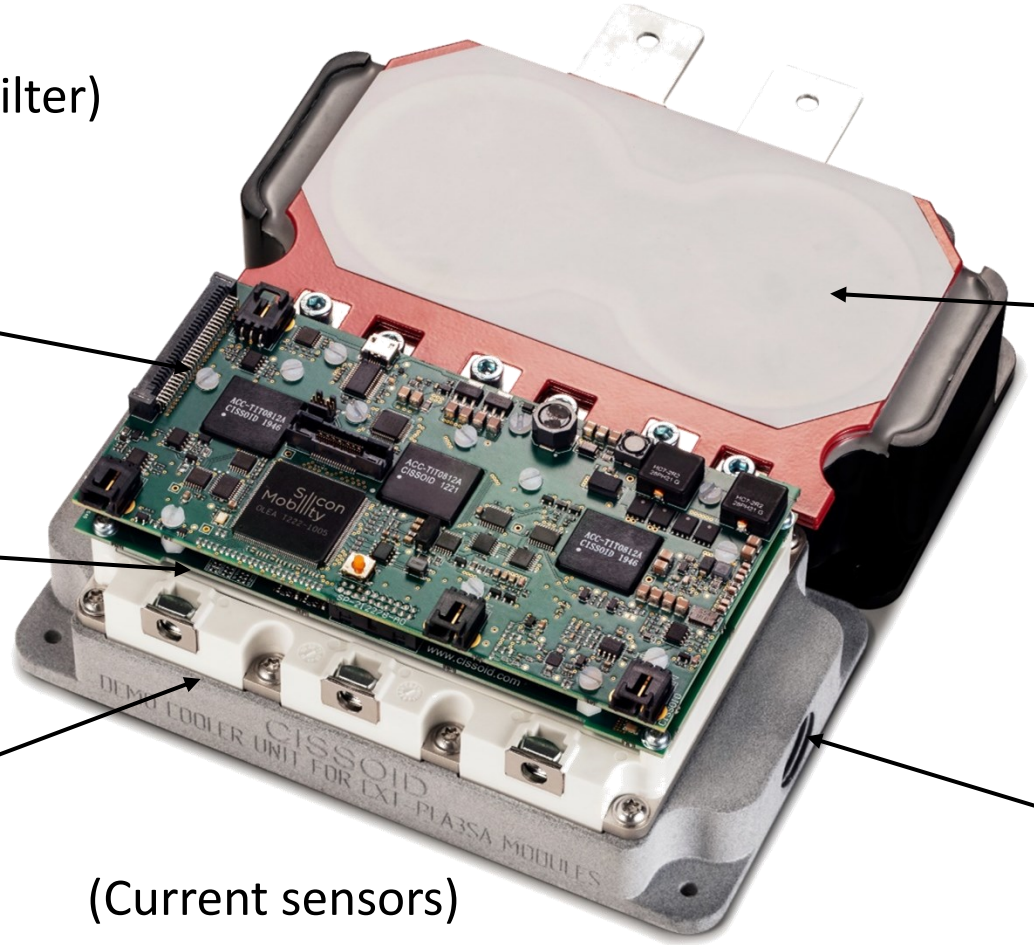
Partners' ecosystem speeding up the development of E-Motor Drives

(EMI Filter)

Silicon Mobility
Controller Board
& Software

Powerful & Temperature
Robust SiC Gate Driver

3-Phase 1200V/550A
SiC Power Modules



(Current sensors)

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

Reference
Liquid Cooler

SiC Inverter Starter Kit

In Partnership with Silicon Mobility

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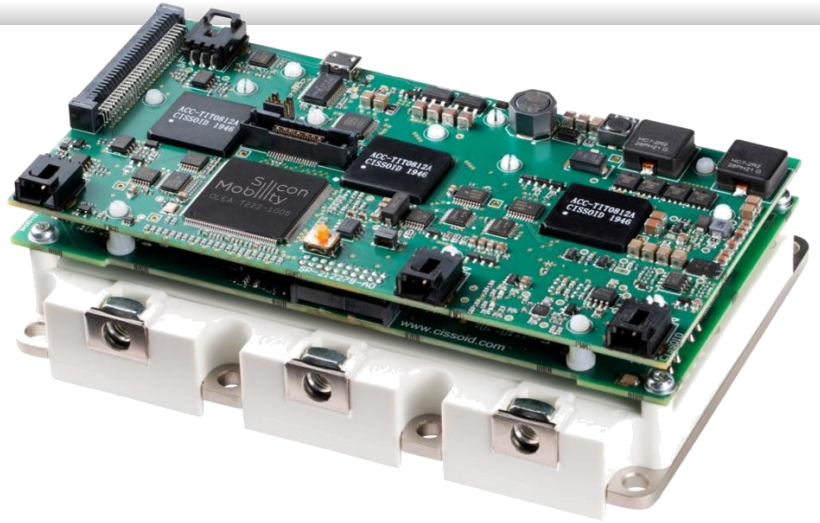
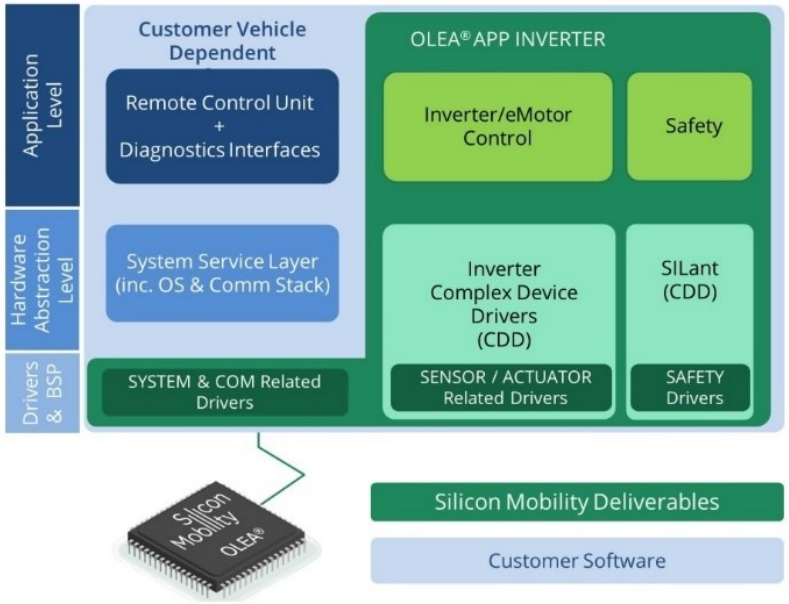
- OLEA® Solution Control Board mechanically & electrically integrated with CISSOID SiC IPMs
  - Based OLEA® T222 FPCU controller chip
  - ISO 26262 ASIL-D Design-Ready Certified
- Interfaces
  - Power module: 3-Phase outputs & 3x2 Power Supply Pins
  - Motor: Resolver, encoder, current/temperature sensors
  - 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

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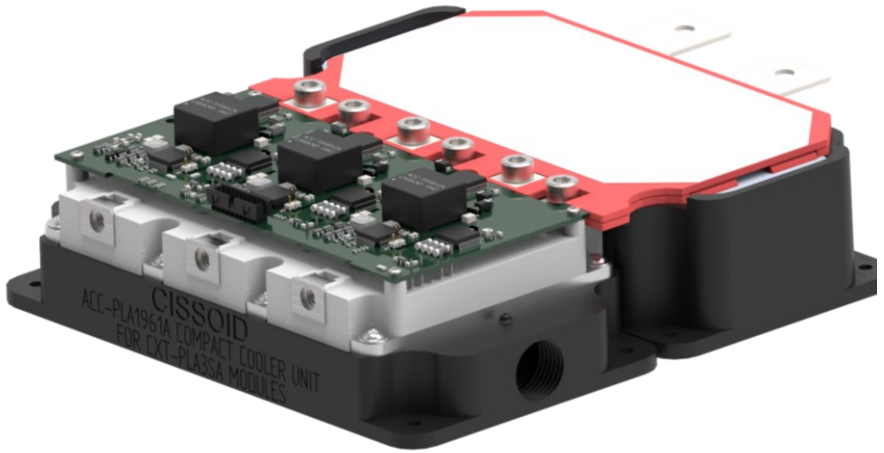
- Mechanically integrated with CISSOID SiC IPM
  - Capacitor range: 135µF to 500µF
  - Voltage range: 500V to 900V
- Integrated capacitor/bus solutions
- High performance capacitor winding elements
- Very low inductance DC link for fast switching with SiC devices
- Capacitor topology enables the best 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

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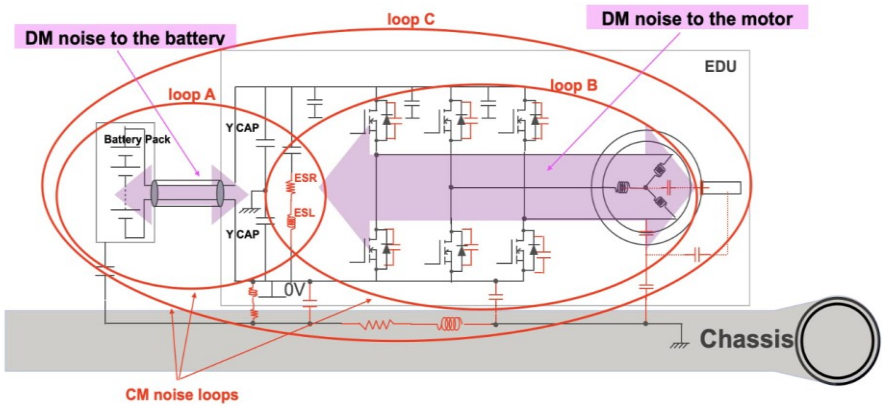
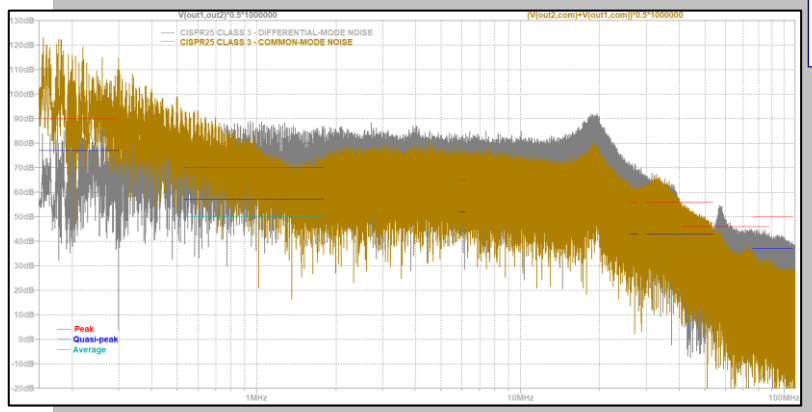
- Transistor-level modelling of SiC MOSFETs
- Behavioral modelling of the gate driver
- Modelling of parasitics
- Modelling of dV/dt, dI/dt and voltage overshoots
- Modelling of SiC MOSFETs On resistance variation with temperature
- Transient thermal modelling with thermal RC network between T_{Fluid} 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

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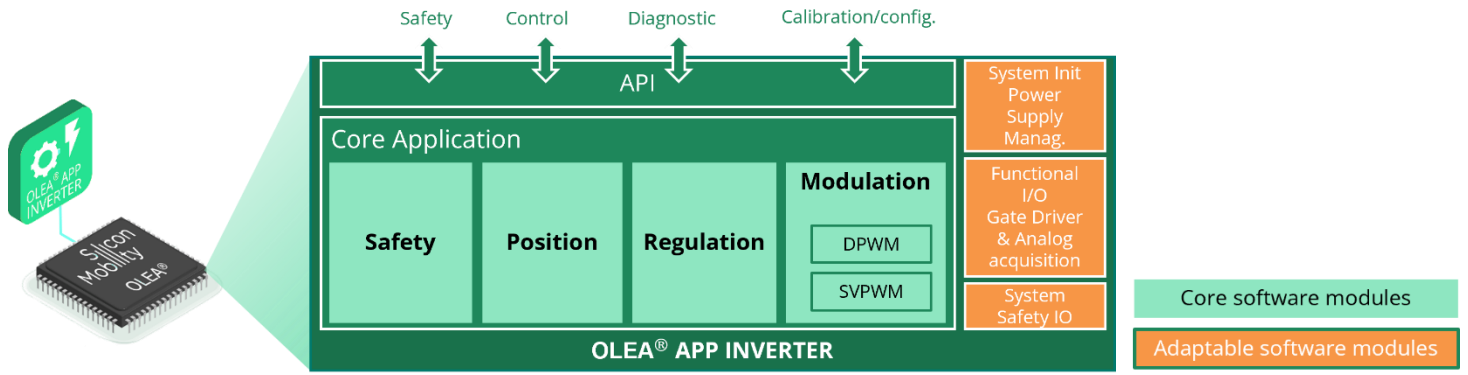
- **Motor types**
  - PMSM (Permanent Magnet Synchronous Motor)
  - WRSM (Wound Rotor Synchronous Motor)
  - Axial/Radial, 3-Phases/6-Phases
- **Modulation**
  - SVPWM (Space Vector Pulse Width Modulation)
  - DPWM (Discontinuous Pulse Width Modulation)
  - Variable switching frequency & Dead-time compensation
- **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

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- 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

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