CISSOID
POWER SEMICONDUCTORS

SiC Inverter Platform Webinar

27 February 2025

INTRODUCTION

Agenda

- SiC Intelligent Power Modules & Inverter Control Modules
- Modular SiC Inverter Platform (+ Software)
- SiC Inverter Reference Designs

- Case studies:
  - Dead Time Compensation & Optimized Pulse Patterns
  - Reduction of noise & vibration results
  - Efficiencies achieved

- Q&A

Presenters

Pierre Delatte
Chief Technology Officer

Mike Sandyck
Marketing Director

CISSOID AT A GLANCE

Silicon Carbide Innovation since 2011

CISSOID
POWER SEMICONDUCTORS

2000
CISSOID SA Founded
Founded in Belgium
July 2000

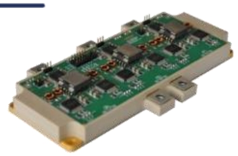
2011
1st SiC Gate Driver ICs
High Temperature
Chipset

2013
225°C SiC MOSFET Discrete
10A/1200V SiC MOSFET
in TO-257 package

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

2015
SiC Gate Driver ICs - Gen2
2nd Generation of
Chipset

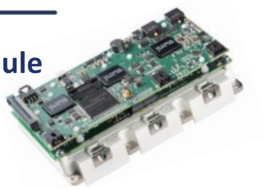
2016
1st SiC MOSFET IPM
3-Phase 1200V/200A
SiC IPM for Aerospace



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 Intelligent Power Module

2022
Inverter Control Module
OLEA T222 based
Inverter Control Board



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

2024
2nd Gen SiC Inverter Reference Design
Modular HW & SW
SiC Inverter ***industrialization*** platform

Q1 2025
Functional Safety Certification
3-Phase 1200V IPM & ICM
ISO26262 ASIL-C level

ISO 26262

Q2 2025
AQG324 Certification
Intelligent Power Modules &
Inverter Control Modules

ECPE

SiC Hi-Rel Packaging & Gate Drivers | SiC Intelligent Power Modules | SiC Inverter Solutions & Control Software

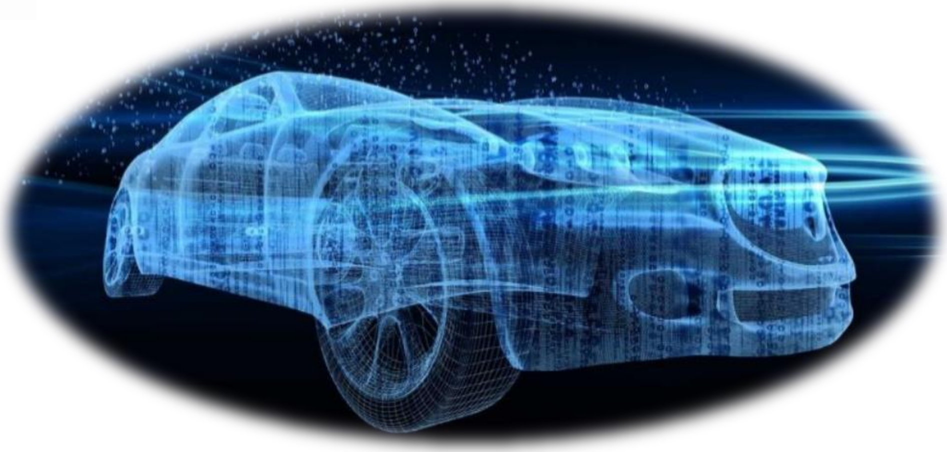
GLOBAL ELECTRIFICATION IS CREATING MULTIPLE OPPORTUNITIES FOR SiC BESIDES MAINSTREAM EVs

CISSOID
POWER SEMICONDUCTORS

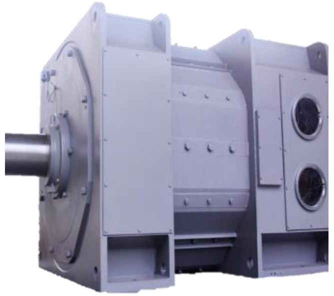
Heavy duty vehicles

E-Boats

E-Aviation



E-Busses



Industrial motor control

Autonomous vehicles

EV Supercars

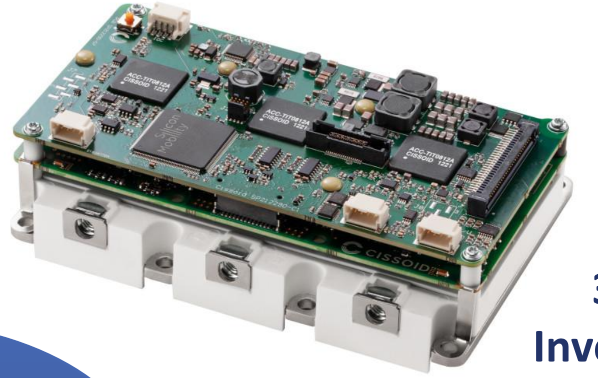
E-Trucks

A Unique Modular SiC Inverter Platform

Based on a suite of Hardware & Software Products

CISSOID
POWER SEMICONDUCTORS

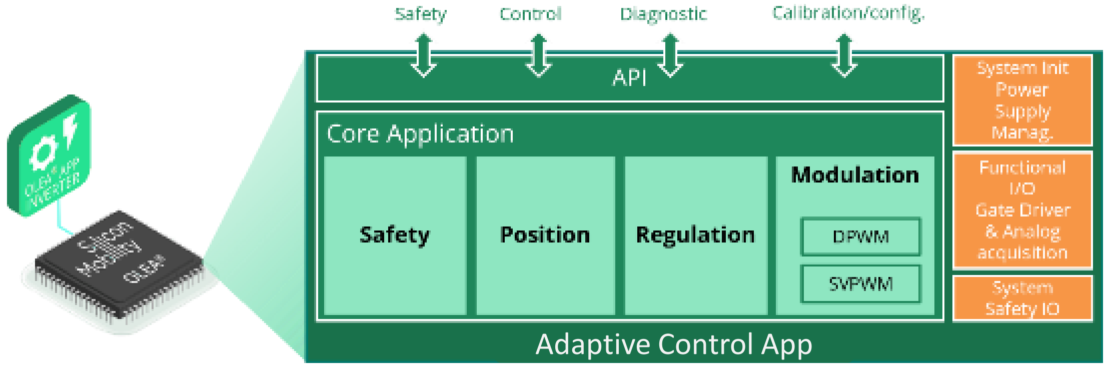
3-Phase 1200V/340A-550A SiC Intelligent Power Module (IPM)

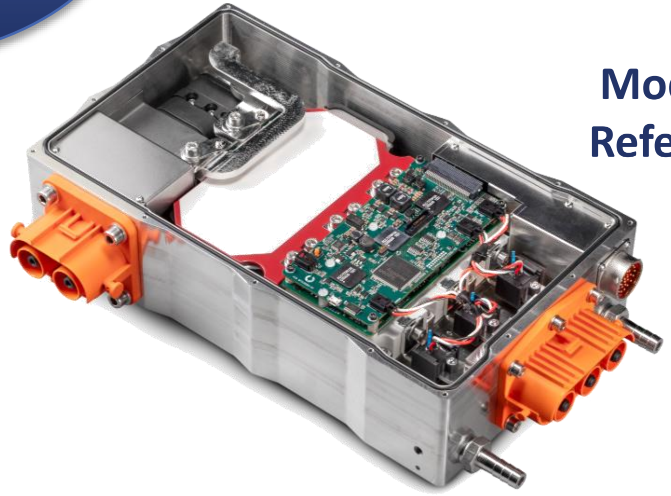


3-Phase 1200V SiC Inverter Control Module (ICM)

Accelerate your Time-to-market

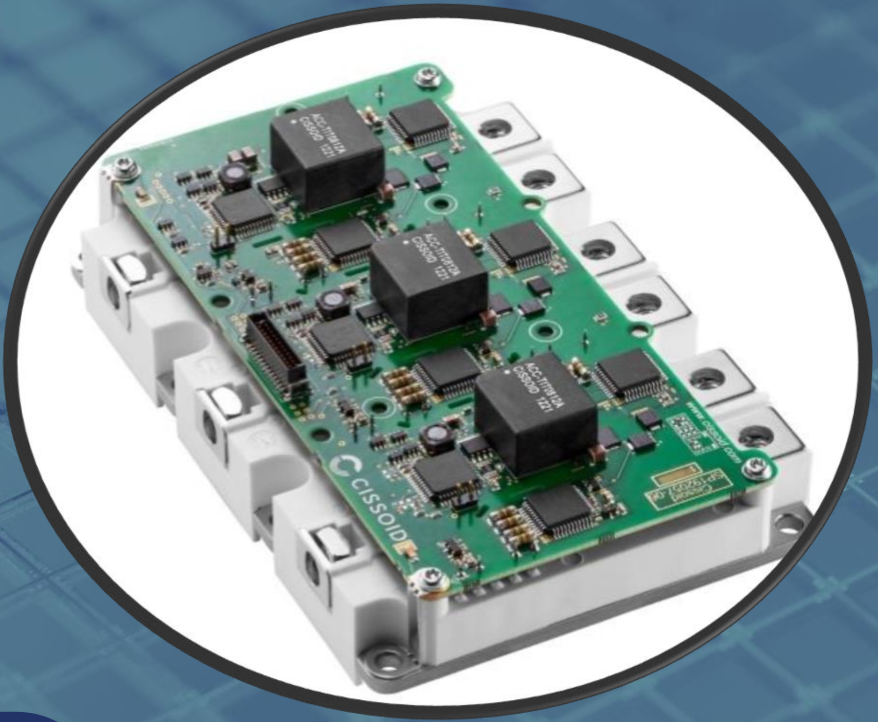
Functionally Safe E-Motor Control Hardware & Software from Intel Automotive





Modular Inverter Reference Designs

CISSOID
POWER SEMICONDUCTORS

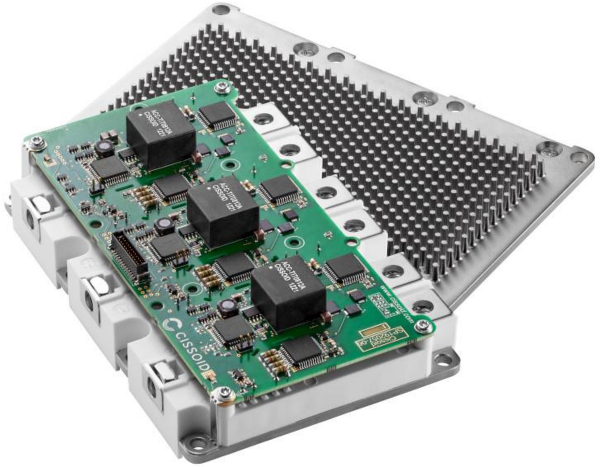


SiC Intelligent Power Module

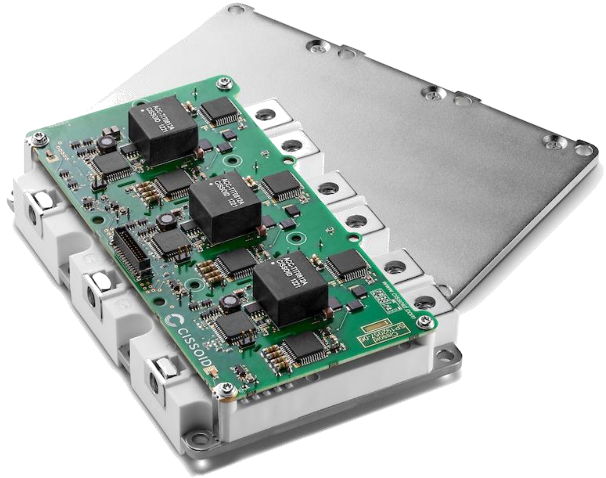
3-Phase 1200V SiC MOSFET
Intelligent Power Modules (IPM)

CISSOID
POWER SEMICONDUCTORS

- Drain-Source breakdown voltage: **1200V**
- Low On-Resistance: **2.53mΩ** to **4.2mΩ**
- Max Continuous Current: **340A$_{RMS}$** to **550A$_{RMS}$**
- Max Switching Frequency: **50kHz**
- High Isolation Grade: **>3.6KVrms**
- Low Switching Energies
- Extended Operating Temperature
- Lightweight AlSiC baseplate: **550 - 590g**



Pin Fin (liquid cooling)

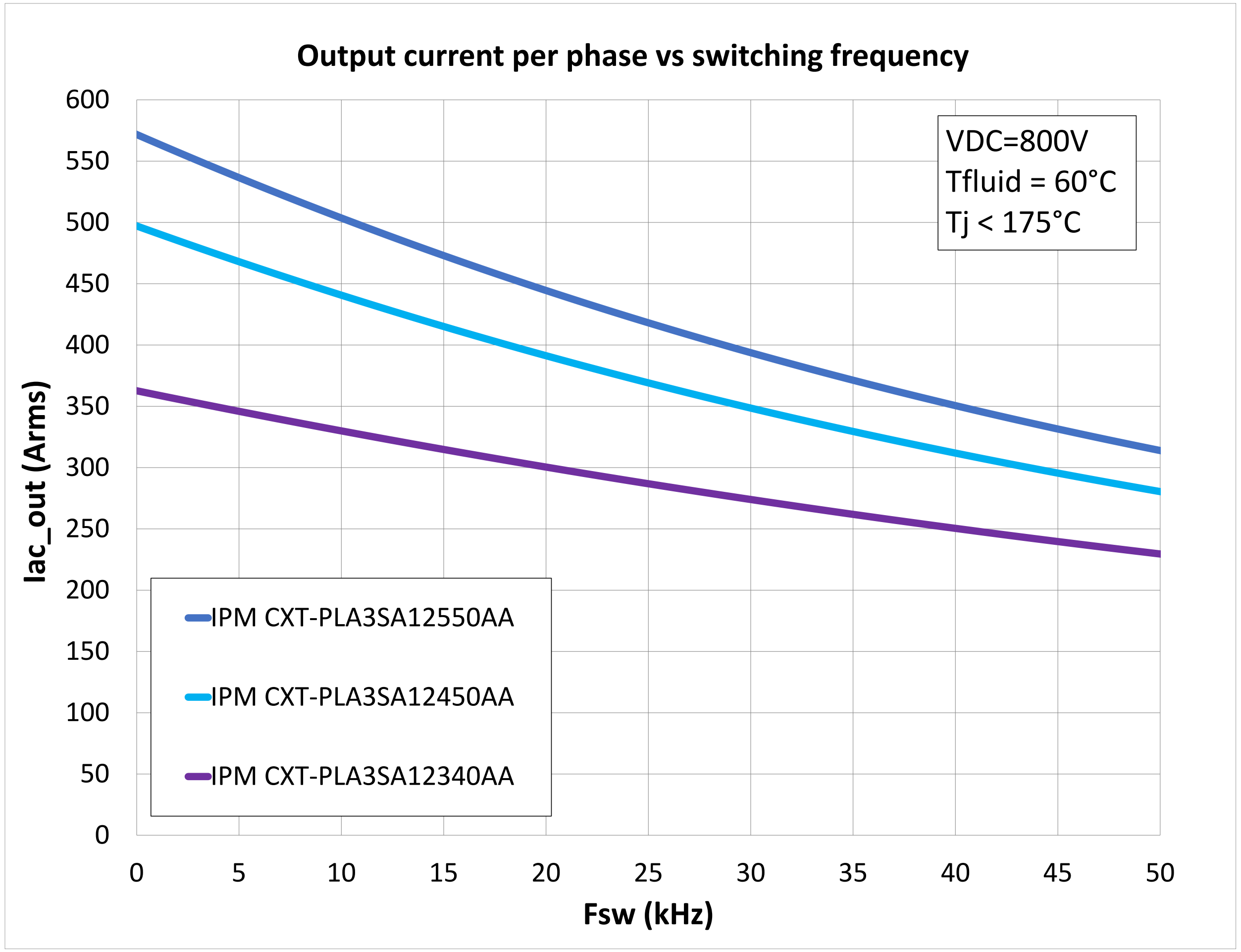


Flat baseplate

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

THERMALLY ROBUST IPMs

- **Max junction temperature** of power transistors: **175°C**
- **Junction-to-Fluid** thermal resistance[1]: **0.16°C/W** at 10l/min 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 board with **Max Ambient Temperature up to 125°C**



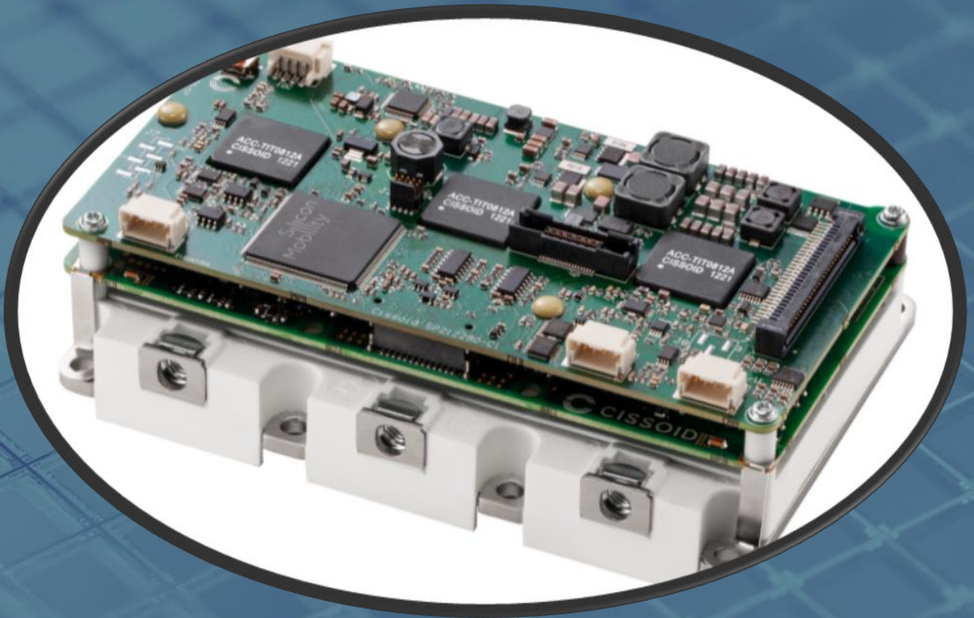
Note 1 : for CXT-PLA3SA12550AA

SiC Gate Drivers – Gen2

Optimized to drive SiC MOSFETs

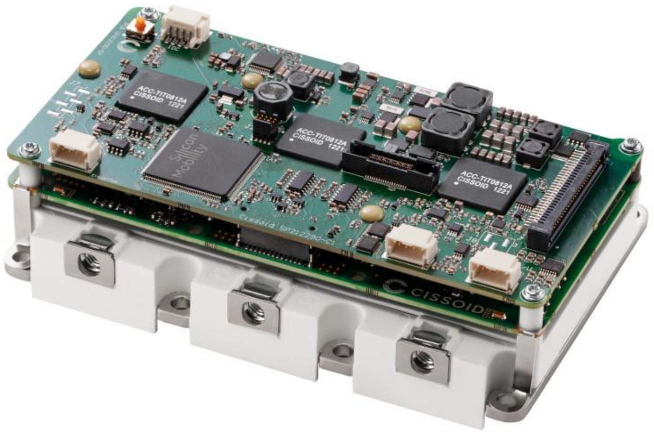
- High peak current for fast switching: **> 10A**
- Robust against high dV/dt: **> 50kV/µs**
- High temperature for high power density: **T_{amb} > 125°C**
- Accurate gate driver voltages: **< +/-5%**
- Protection functions
  - UVLO (primary and secondary sides)
  - Desaturation Detection & Soft Shutdown
  - Negative drive & Active Miller Clamp (AMC) for robustness against parasitic turn-On
  - PWM glitch filter
  - PWM anti-overlap protection

SiC Inverter Control Module



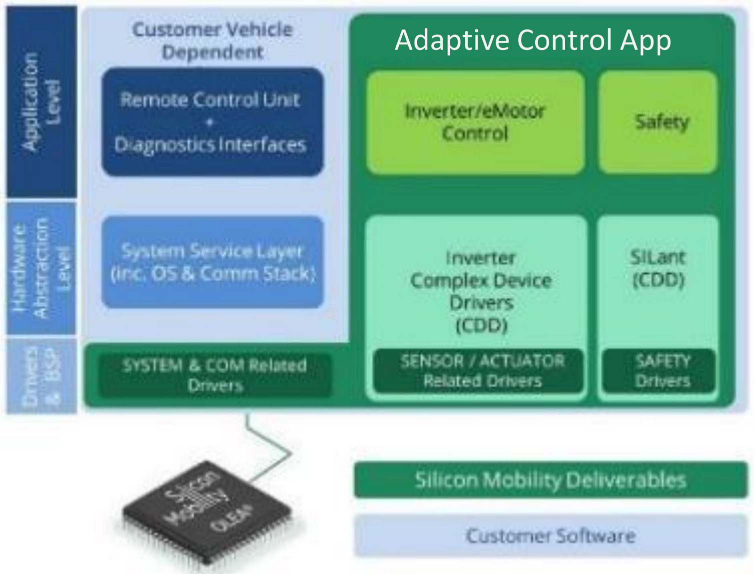
SiC Inverter Control Module (ICM)

- **Control Board** mechanically & electrically integrated with the SiC IPM based on **Adaptive Control Unit (ACU) T222** by **Intel Automotive**



- **ICM Interfaces**
  - Power module: 3-Phase outputs & 3x2 Power Supply Pins
  - Motor: Position Sensor (Resolver, Sin/Cos), current/temperature sensors
  - Vehicle: CAN & Battery supply
  - Developer: SWD (debug) & Trace Port Unit (real-time debug & calibration)

- **Adaptive Control App (ACA) by Intel Automotive**
  - Highly configurable inverter & motor control software
  - Advanced control algorithms for highly energy-efficient systems
  - Closed-loop current control based on Field Oriented Control regulation
  - SVPWM and DPWM modulation up to 50 kHz or Optimized Pulse Patterns

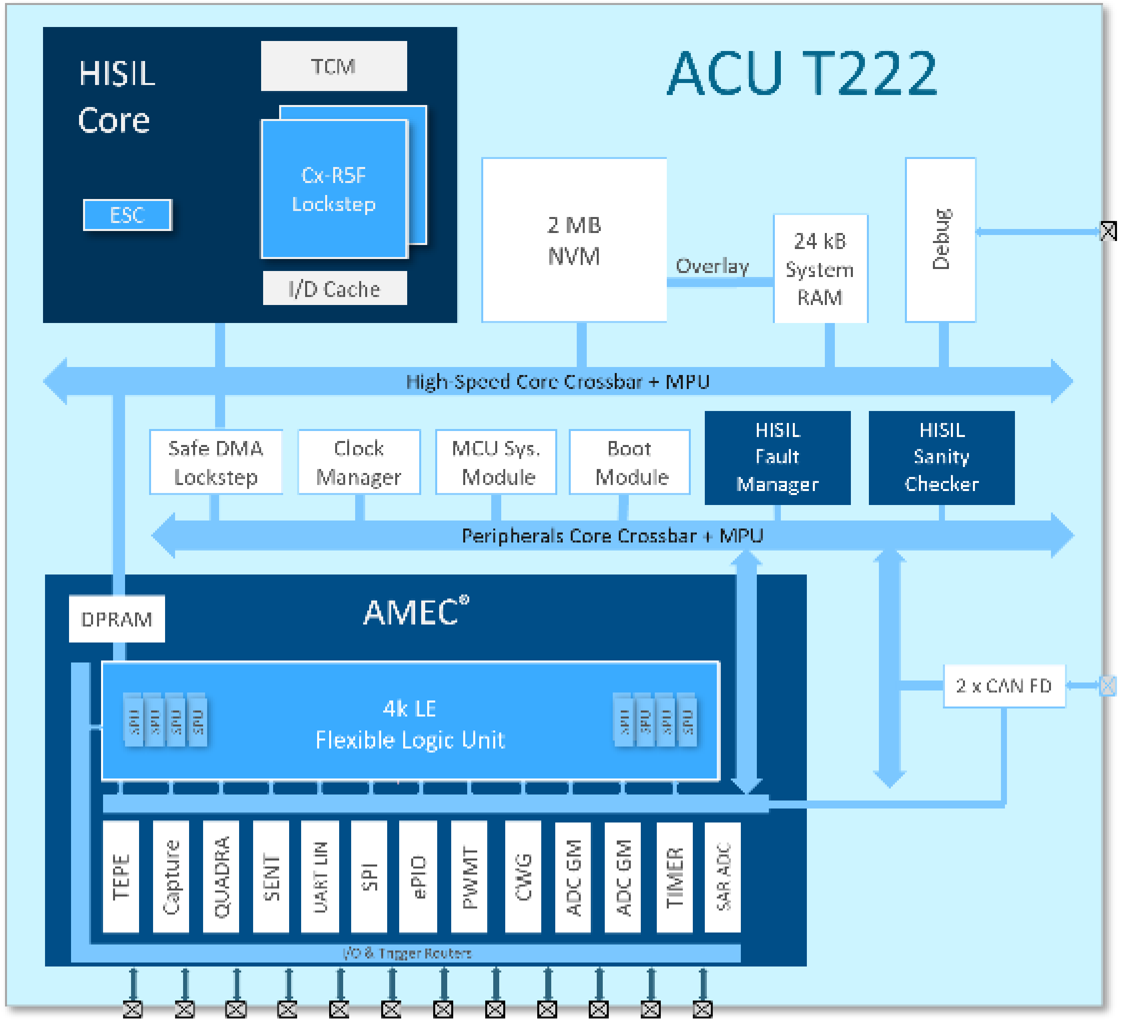


ADAPTIVE CONTROL UNIT (ACU) T222

- **Ultra-fast real-time processor by Intel Automotive**
  System-level fault detection, correction and containment in tens of nanoseconds
  - **40x faster processing compared to standard MCUs**
  - **1000x faster fault detection compared to standard solutions**
  - **Real-time - 100% timing predictability**

- **HISIL Core – Functional Safety Integrated**
  - Dual 200MHz ARM Cortex R5F in Lockstep
  - Safe DMA transfers with CRC checks

- **AMEC – Advanced Motor Event Control**
  - HW programmable Flexible Logic Unit
    - 4560 Programmable Logic Elements
    - 20x 24-bit Signal Processing Units
  - Parallel access for acquisition & control

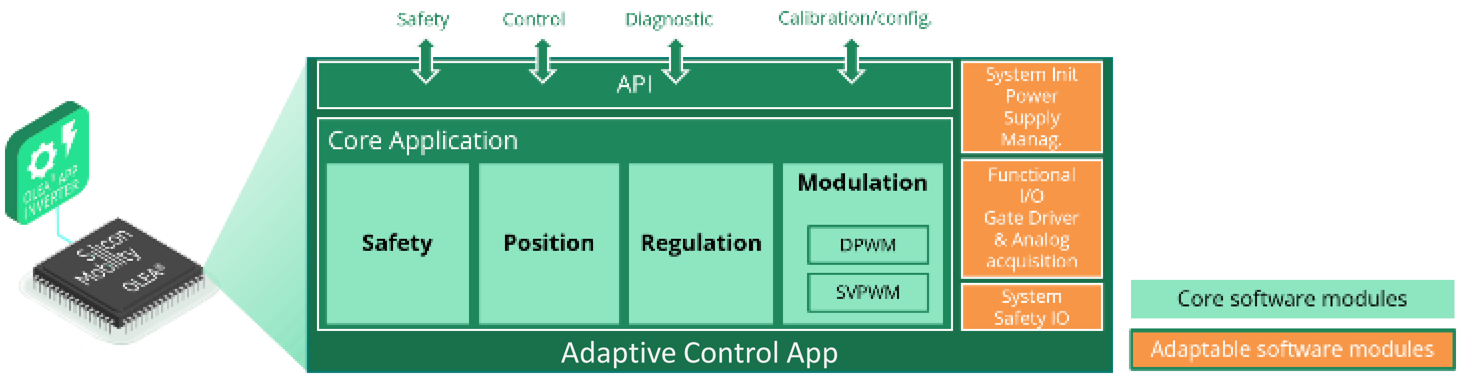


HISIL = Hardware Integrated Safety Integrity Level

Adaptive Control App (ACA)

- **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 algorithms**
  - Flux Weakening management
  - 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**



Certification & Availability

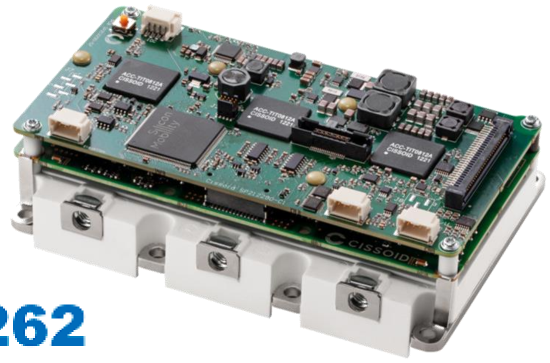
CISSOID
POWER SEMICONDUCTORS

INTEL/Silicon Mobility Certification

- **MCU: T222 Adaptive Control Unit (ACU)**
  - AEC-Q100 Grade 1 (-40°C to +125°C)
  - ISO26262 ASIL-D Certified
- **SW: Adaptive Control App (ACA)**
  - ISO26262 ASIL-D Certified
  - AUTOSAR 4.3

ICM Certification

- ISO26262 ASIL-C Ready (Q1 2025)
- AQG-324 (Q2 2025)
- ISO26262 ASIL-C Certified (Q3 2025)

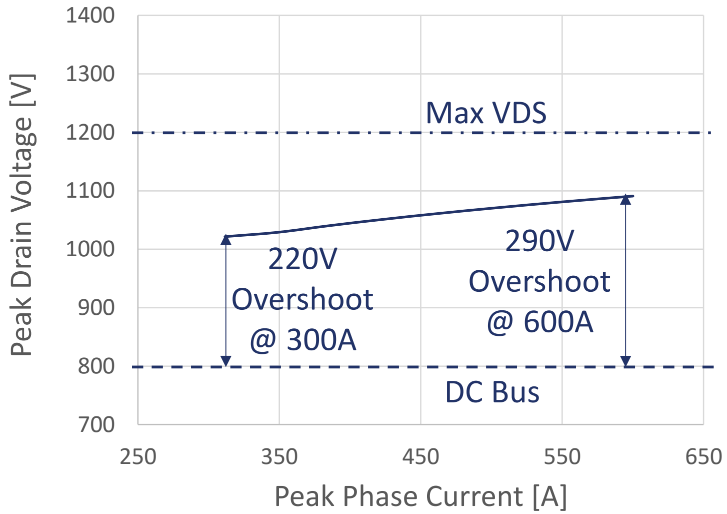


ISO 26262

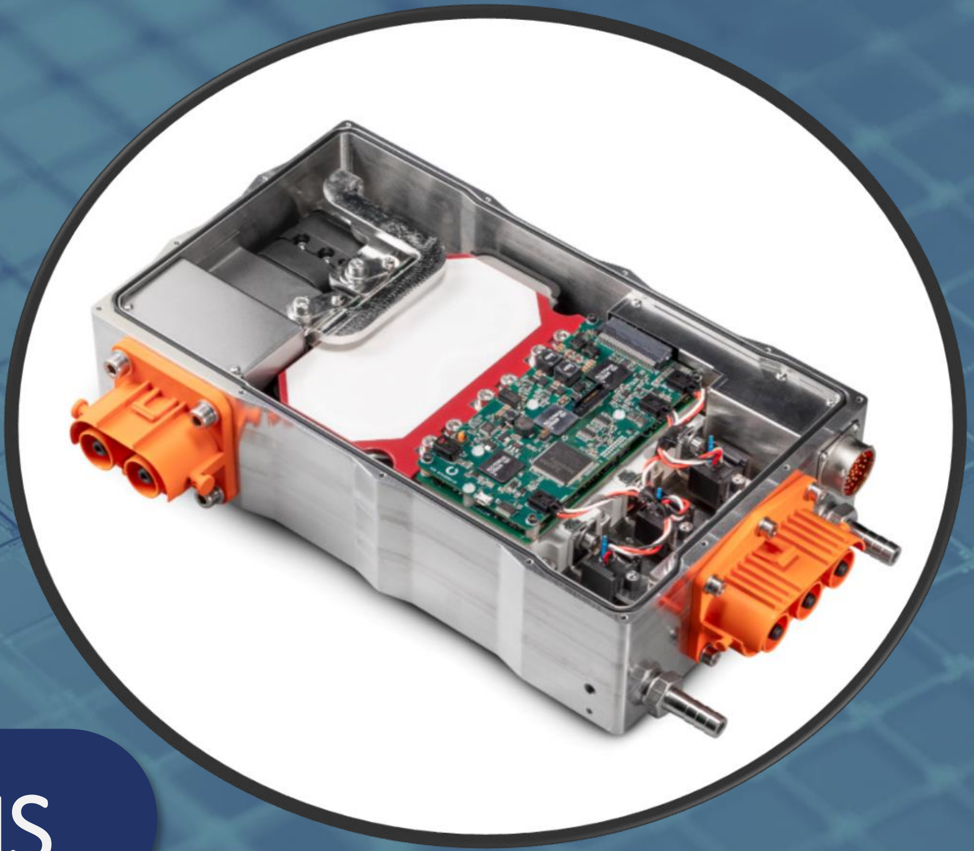
Ordering References	Max Output Power	Max Phase Current	Base-plate
CXT-ICM3SA12340AAA	305kW	$295A_{RMS}$	Pin fin
CXT-ICM3SA12450AAA	405kW	$390A_{RMS}$	Pin fin
CXT-ICM3SA12550AAA	475kW	$460A_{RMS}$	Pin fin
CXT-ICM3SB12340AAA	330kW	$320A_{RMS}$	Flat

SiC Inverter Platform

- **Companion DC Link Capacitors for IPMs/ICMs**
  in partnership with Advanced Conversion
  - Capacitor range: 135µF to 500µF
  - Voltage range: 500V to 900V
  - Total loop inductance (IPM + Cap) : <18nH
  - High temperature dielectric : > 125°C
- **Power module, gate driver & DC Link Capacitor**
  - Fully characterized switching loop
  - dI/dt and & dV/dt optimized to support 800V DC bus
  - Best trade-off between switching energies & drain-to-source voltage overshoot
- **3D-printed Reference Coolers**
  - With & without pressure sensors

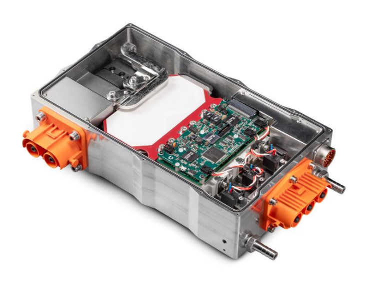


SiC Inverter Reference Designs



SiC Inverter Reference Designs

- **Accelerating** SiC inverters design
- Modular design around CISSOID ICMs
- Supporting high voltage/power designs
- **Open Bill-of-Material** (BOM) & step files
- Embedding Intel Adaptive Control App ISO-26262 ASIL-D Software
- **Setup & calibration in less than a week** on a motor bench

SiC Inverter Reference Designs	Bench-top 	On-board 
For lab & bench testing	✓	
For in-vehicle testing		✓
Easy access to • All sub-components • Measurement points • Connectors	✓	
Compact design		✓
Extensive EMC shielding		✓
Hermetically sealed		✓
Vibration resistant		✓

Bench-Top SiC Inverter Reference Design

CISSOID
POWER SEMICONDUCTORS

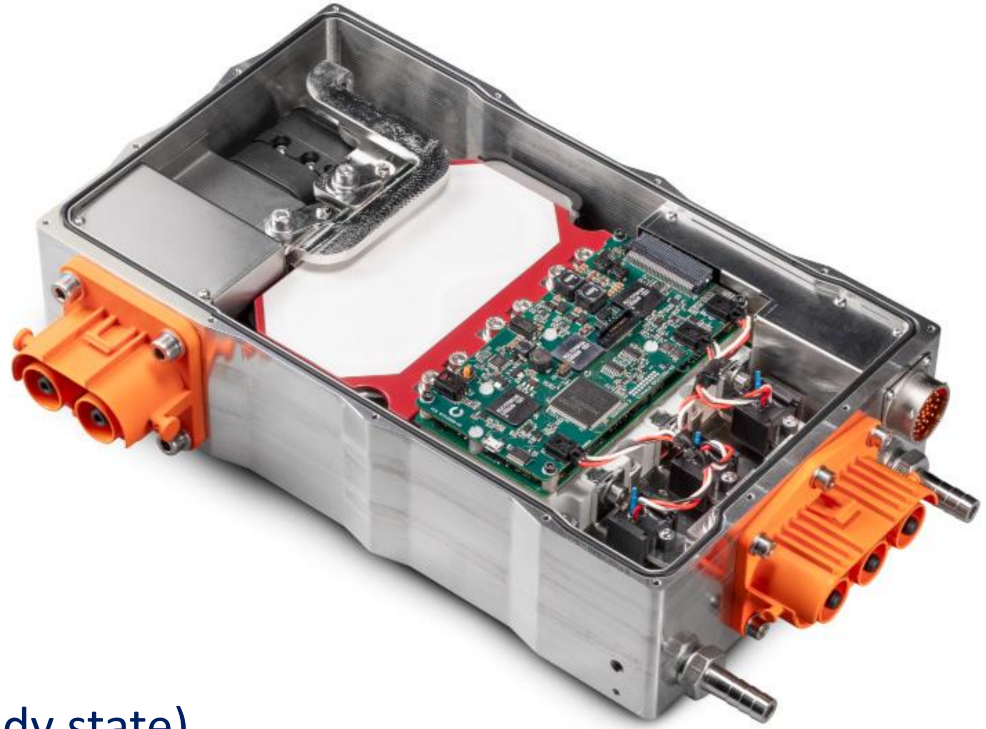
- Modular design up to 850V/330kW (peak, 60s)
- 3-Phase 1200V SiC Inverter Control Module
- **INTEL Adaptive Control Unit (HW) & App (SW)**
- DC & Phase current sensors
- High temperature DC Link capacitor
- **TDK CarXield® 900V/400A EMC filter**
- DC bus passive discharge
- **Liquid cooling** for power module & EMC filter

Reference	Description
EVK-PLA1050B-74	650 V_{DC} / 275 A_{RMS} / 150 kW
EVK-PLA1050B-76	650 V_{DC} / 400 A_{RMS} / 250 kW
EVK-PLA1050B-94	800 V_{DC} / 275 A_{RMS} / 200 kW
EVK-PLA1050B-96	800 V_{DC} / 400 A_{RMS} / 300 kW (includes DC link capacitor top cooling)

ON-BOARD SIC INVERTER REFERENCE DESIGN

Key characteristics

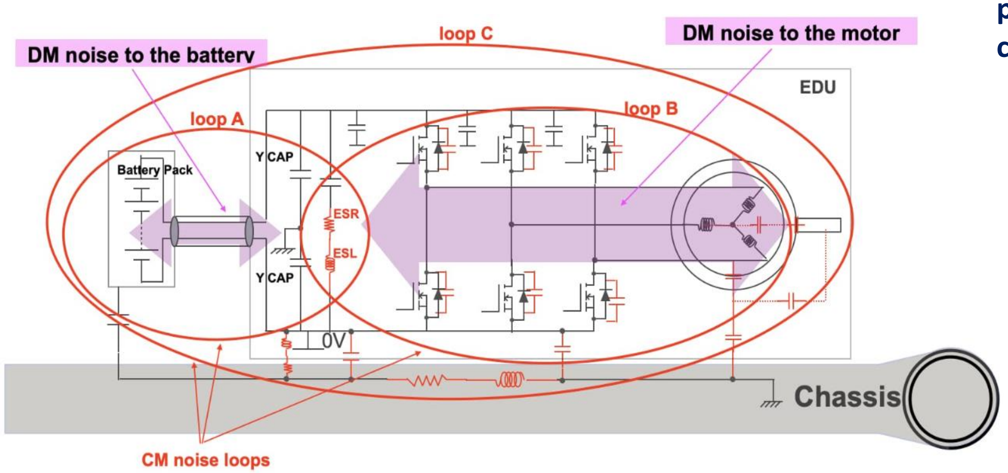
- Output power (peak, 60s): **up to 350kW**
- DC bus voltage : 100V – 850V
- Max Phase Current (steady State) : 250A_{RMS}
  (limit = Amphenol HVSL1 connector)
- Max Phase Current (peak, 60s) : **600A_{PEAK}**
- Output Frequency : 100 – 2000Hz
- PWM frequency : **up to 50kHz**
  (power derating from 20-50kHz)
- Dimensions: 381 x 220 x 90 mm (6.73Litre)
- High power density : **52kW/litre** (peak, 60s) – 36 kW/L (steady state)

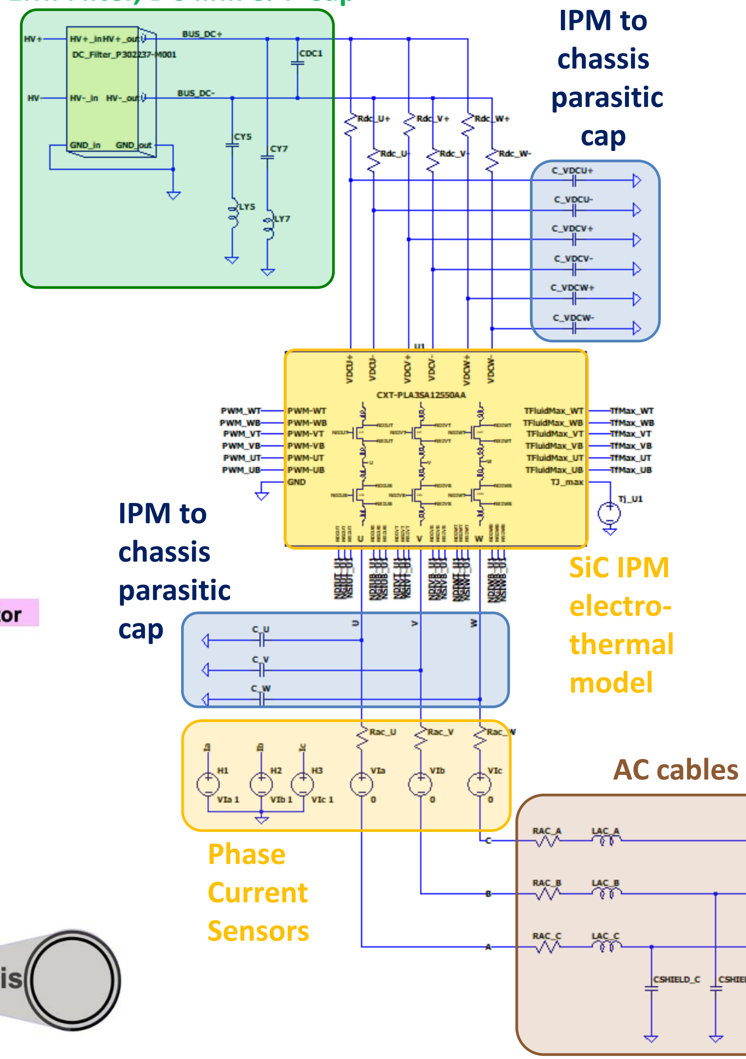


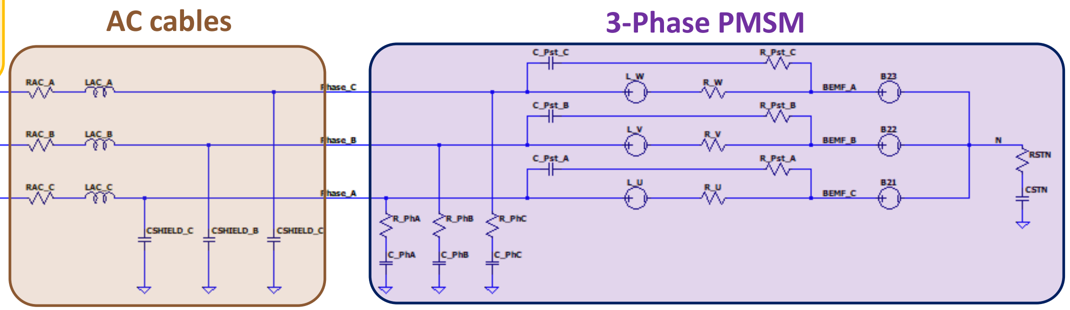
ELECTRICAL & THERMAL MODELLING

INVERTER MODEL & SIMULATION TEST BENCH FOR EMC DESIGN

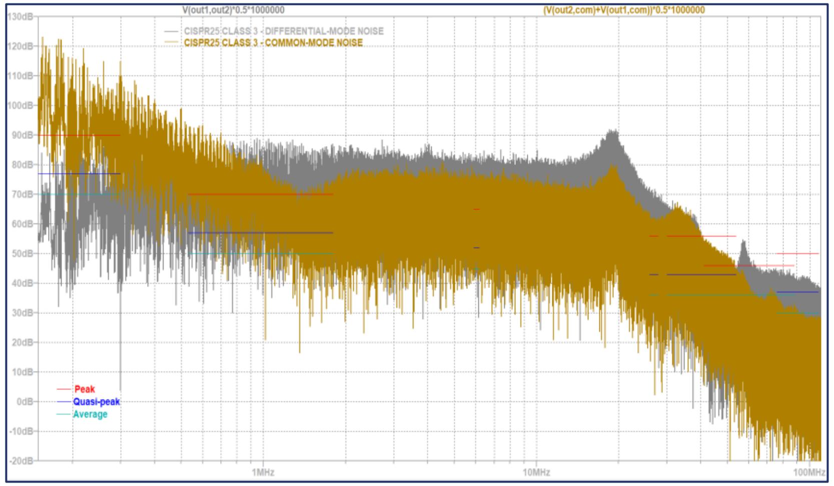
- Transistor-level modelling of SiC MOSFETs
- Behavioral modelling of the gate driver
- **Modelling of parasitics**
- **Modelling of dV/dt, dI/dt and voltage overshoots**
- Modelling of SiC MOSFETs On resistance variation with temperature
- Transient thermal modelling with thermal RC network between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







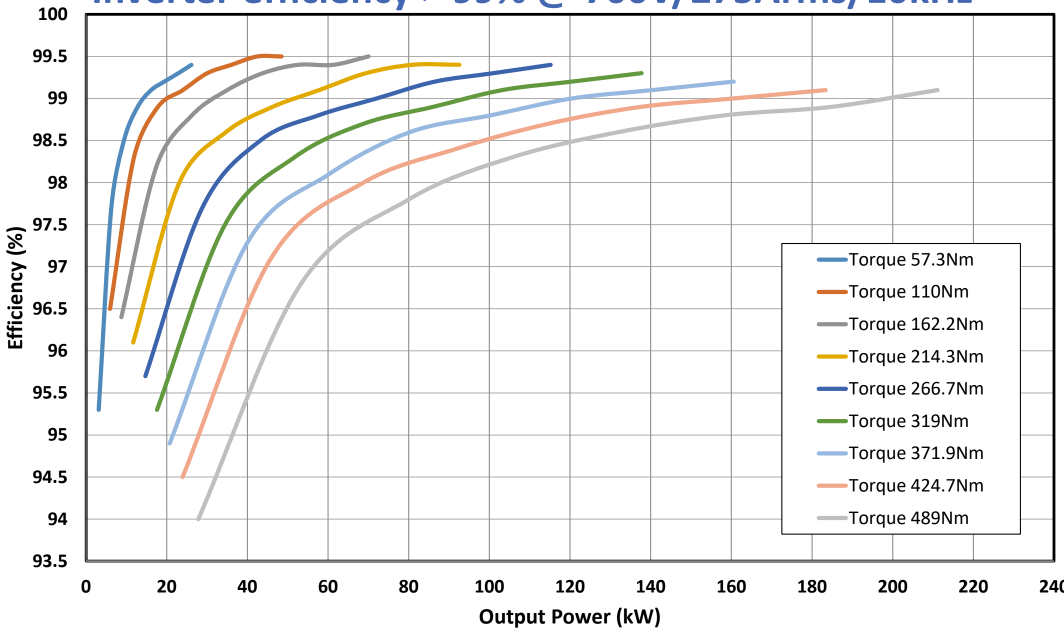
Differential / Common-mode noise & CISPR25 limits



FAST E-DRIVE EVALUATION @ MOTOR BENCH

- **Step 1: Adaptive Control App software project configuration**
  - According to the e-Motor parameters
- **Step 2: Inverter/motor 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)
- **Step 4: Inverter & motor drive characterization**

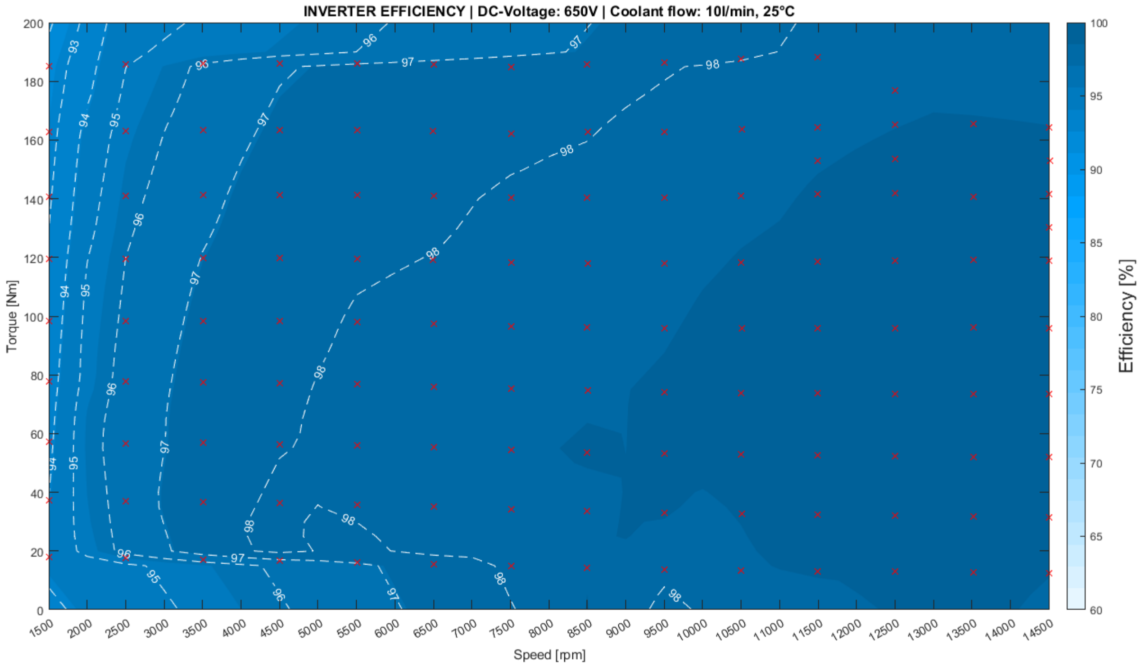
Inverter efficiency > 99% @ 700V/275Arms/10kHz



SiC versus IGBT Efficiency

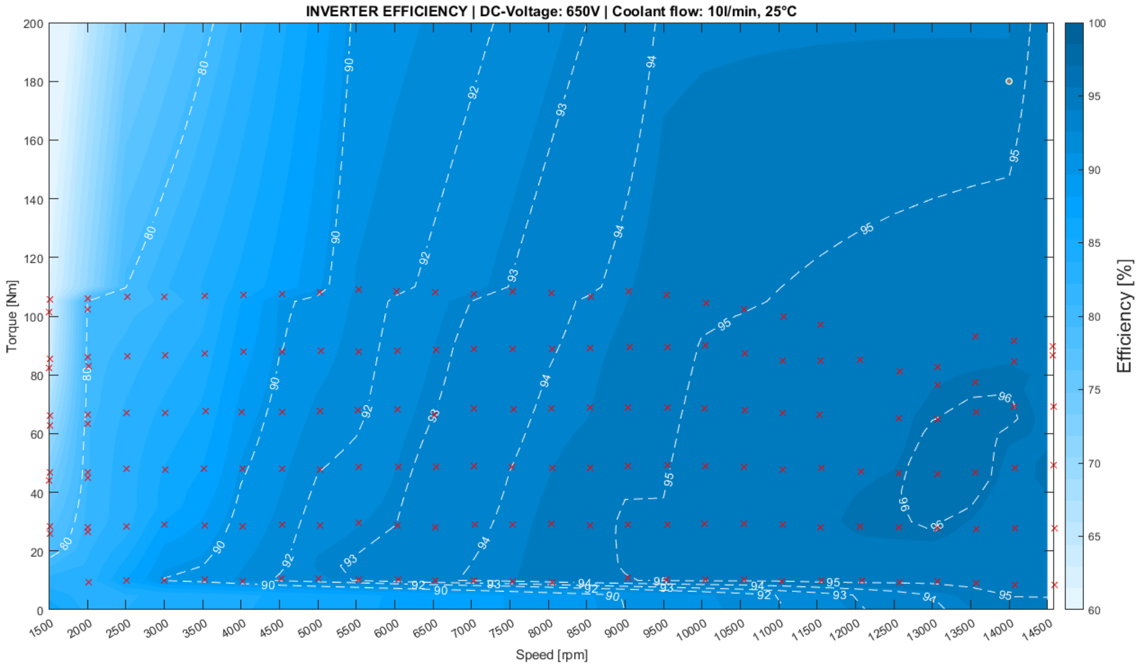
CISSOID SiC Inverter Ref Design @650V

- Max speed: 14500rpm
- Max torque: 190Nm
- Peak output power: 260kW (13500rpm)
- **Peak efficiency: 98.9%**



IGBT inverter @650V

- Max speed: 14500rpm
- Max torque: 120Nm
- Peak output power: 120kW (11500rpm)
- **Peak efficiency: 96.6%**



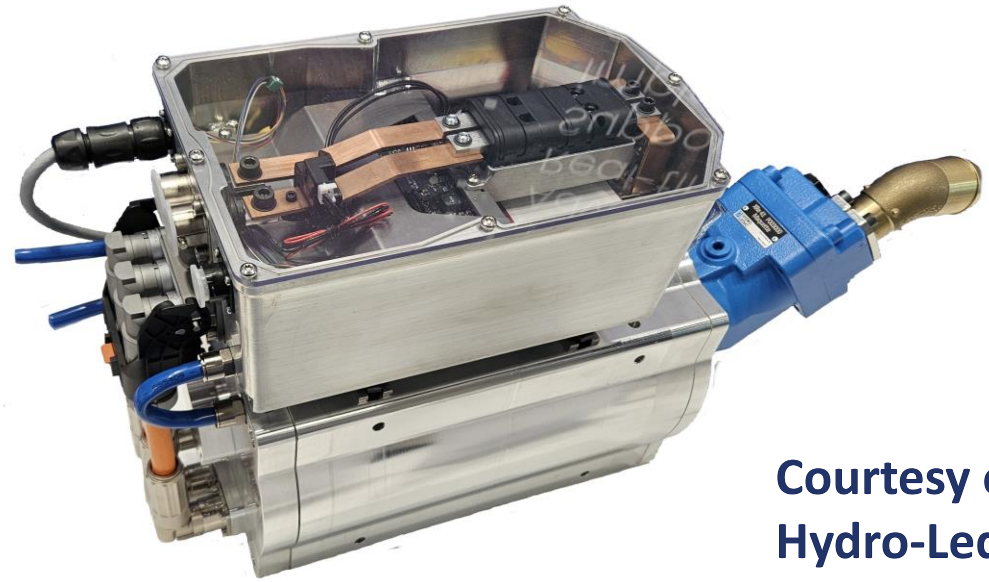
SiC Inverter maintains high efficiency even at low torque & speed !

Use Case - Electric Power Take Off (ePTO)

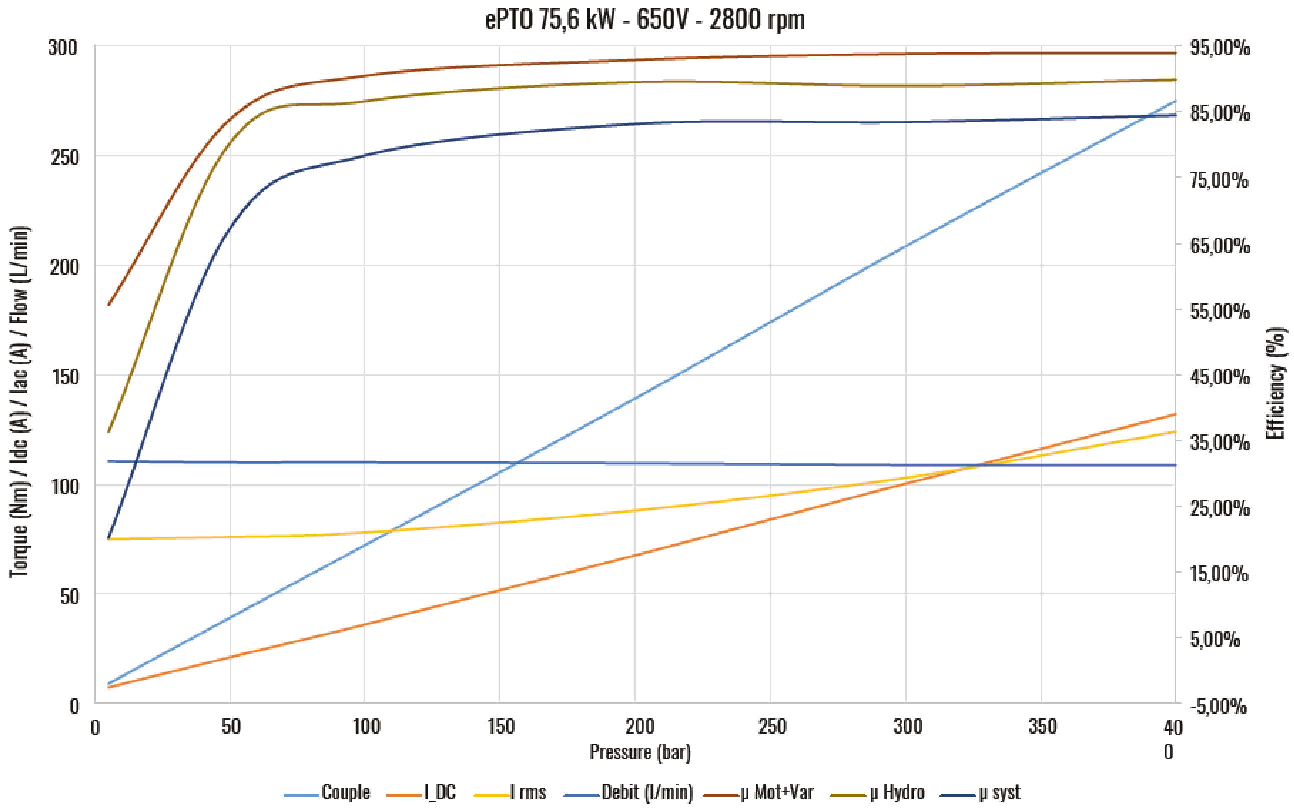
Electrification of hydraulic pump

76kW / 650V / 2800rpm

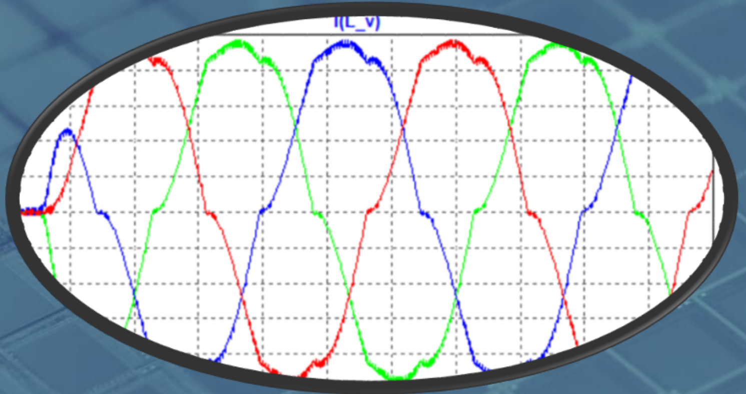
- e-motor + inverter = 94% efficiency
- hydraulic pump = 89% efficiency
- system efficiency = 84%



Courtesy of Hydro-Leduc

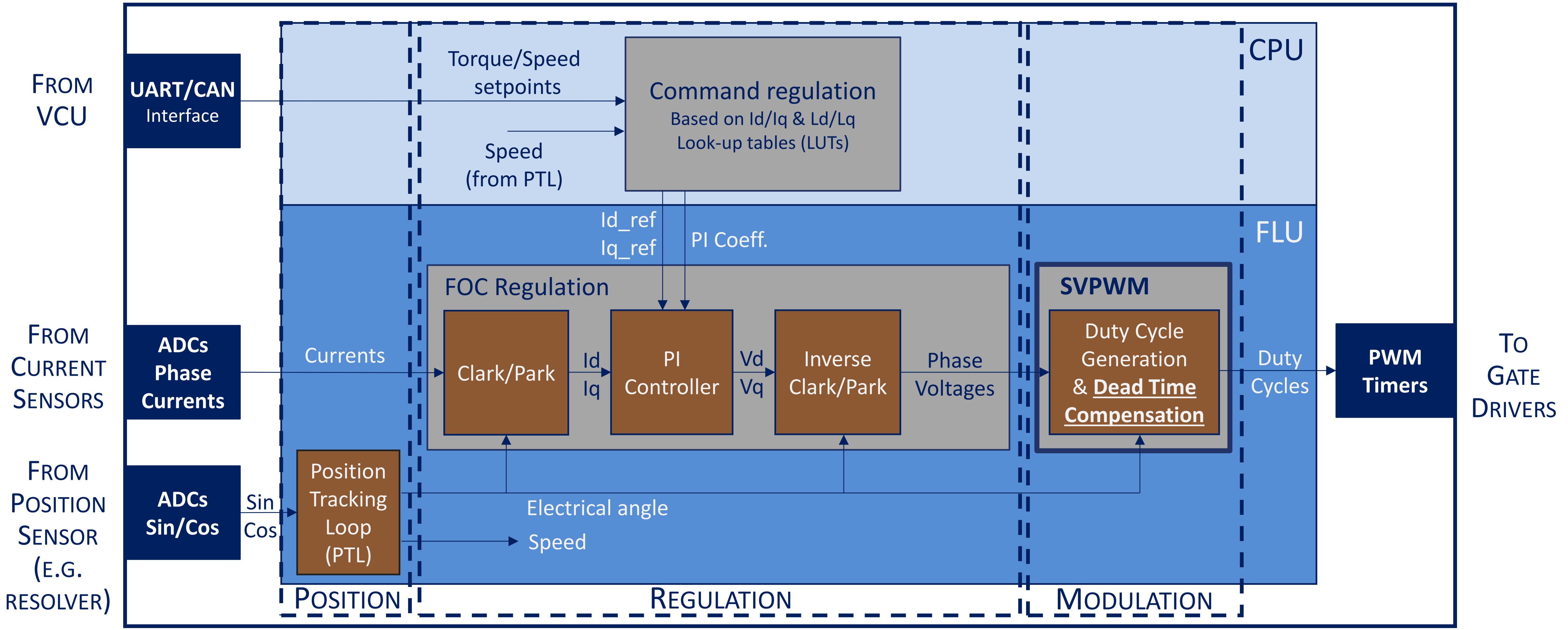


Dead Time Compensation



Dead Time Compensation (DTC)

Part of Intel Adaptive Control App SVPWM module



Dead Time Compensation (DTC)

- Duty Cycle correction to **compensate the effects of the dead time**
  - Fundamental output voltage loss
  - Low-Frequency Harmonics (5^{th}, 7^{th}, 11^{th})
  - Output current and torque ripples
- Compensation $\propto$ V_{DC}, $F_{switching}$, Dead time, MOSFET t_{on} & t_{off} times
- **Case study**[1]: SiC Inverter + PMSM

Inverter Parameters	Value
Inverter Control Module	CXT-ICM3SA12550AAA
Rated Inverter Power	Up to 350 kW
Rated Inverter Voltage	Up to 850 V
Rated Voltage of IPM	1200 V
Rated Current of IPM	550 A
SiC MOSFET Turn-on time T_{on}	(97+102)= 199 ns
SiC MOSFET Turn-off time T_{on}	(276+52)= 328 ns

PMSM Motor Parameters	Value
Rated Power	260 kW
Rated Torque	180 Nm
Rated Speed	14000 RPM
Number of pole pairs	4
Switching Frequency F_s	12 kHz, 16kHz
User-defined Dead time T_d	2 µs
DC Bus Voltage V_{dc}	650 V

[1] T. Bonnin, M. Nasir, P. Delatte, M. El Mokadem, “Implementation and Validation of a Simplified Dead Time Compensation Scheme for a High-Power Space Vector Controlled SiC Inverter PMSM Drive”, 2024 IEEE Workshop on **Control and Modelling for Power Electronics** (COMPEL)

SIMULATIONS IN LTSPICE
WITH AND WITHOUT DEAD TIME COMPENSATION

Silicon Mobility An Intel Company

CISSOID POWER SEMICONDUCTORS

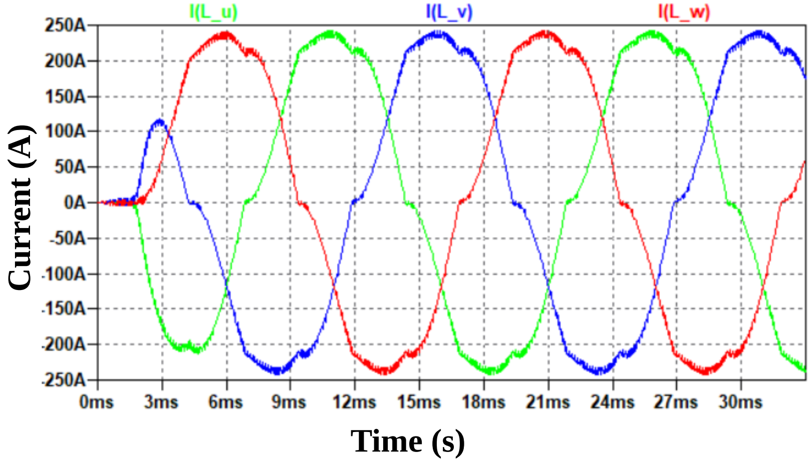
Case Study

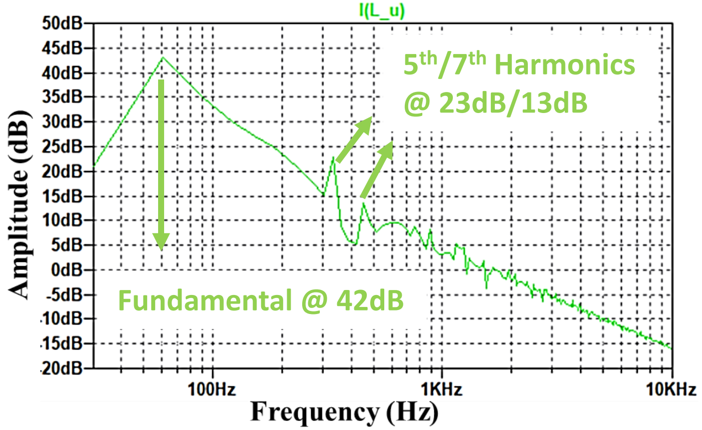
Speed = 1000 Rpm, Torque= 50 Nm

SIMULATION PARAMETERS

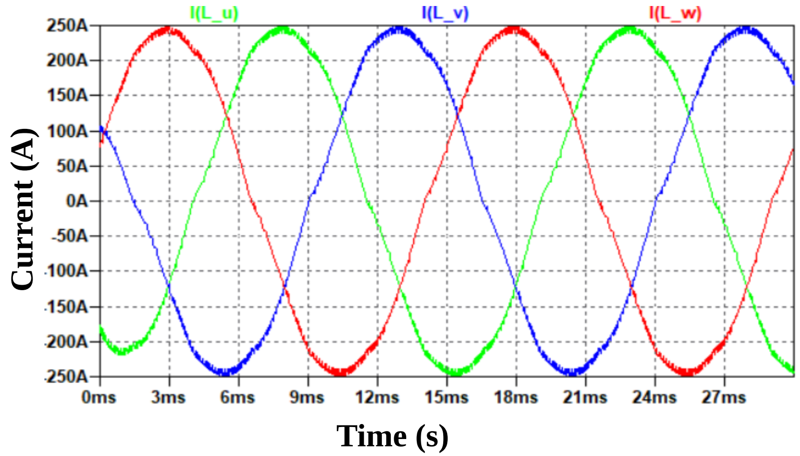
- SPECIFIC INPUT DATA
  - High Voltage Battery Voltage : 650 V
  - DC-link Capacitor : 320 uF / 750 V
  - ICM CXT-PLA3SA12550AA : 1200 V / 550A
  - SVPWM modulation
  - Dead time = 2 µs
  - Fswitching = 16 kHz
- PMSM CHARACTERISTICS
  - Number of pole pairs : 4
  - Flux linkage : 0.048 Wb
  - D-axis inductance : 55 µH
  - Q-axis inductance : 150 µH
  - Stator self-inductance : 160 µH
  - Stator self-resistance : 0.008 Ω

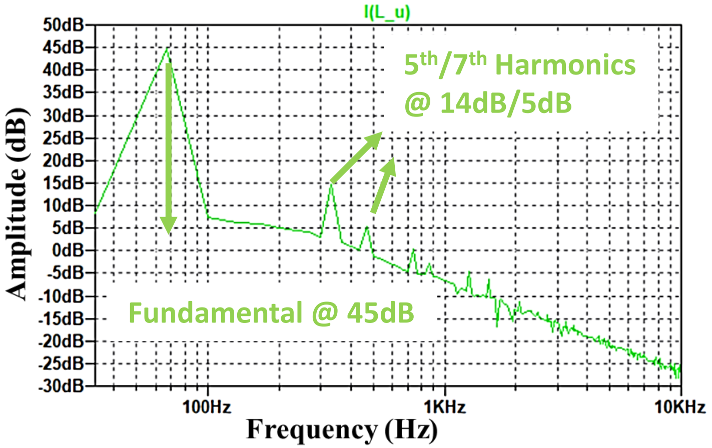
WITHOUT DEAD TIME COMPENSATION





WITH DEAD TIME COMPENSATION

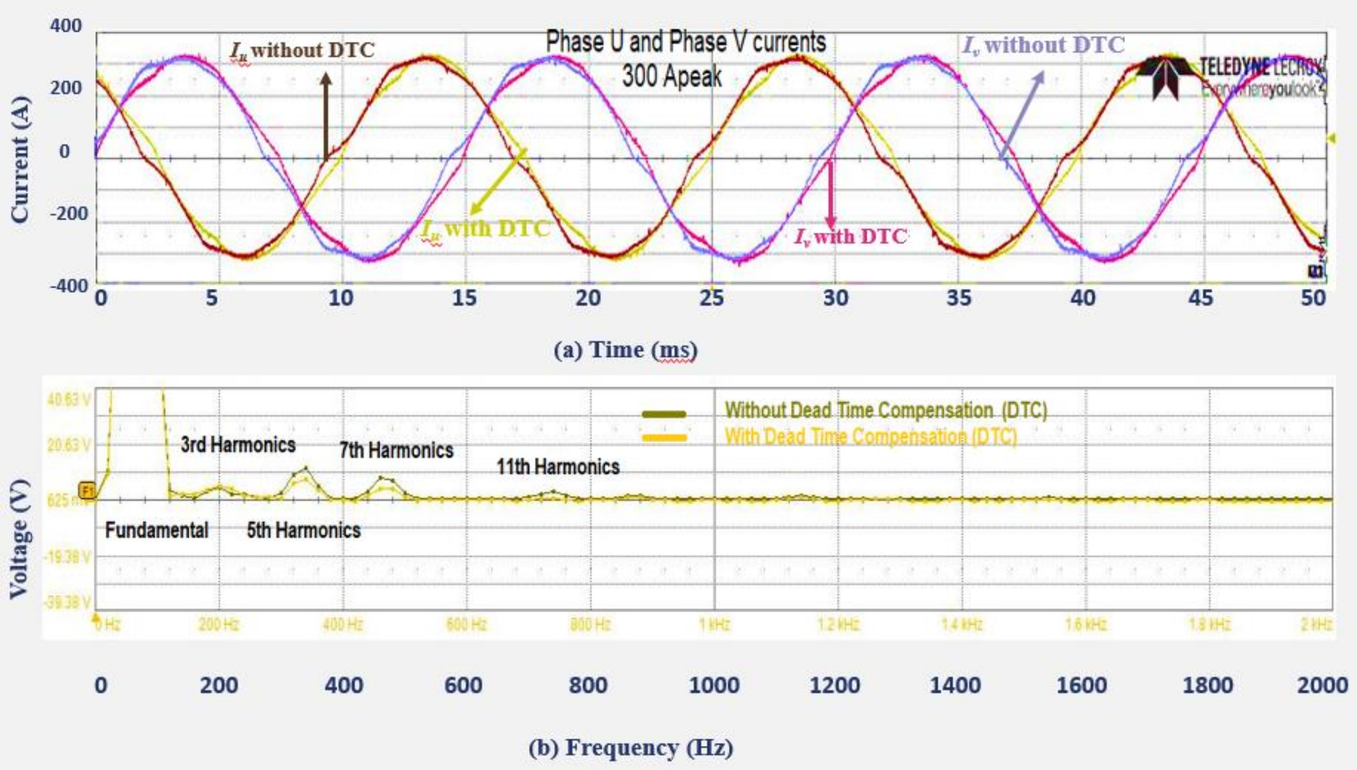


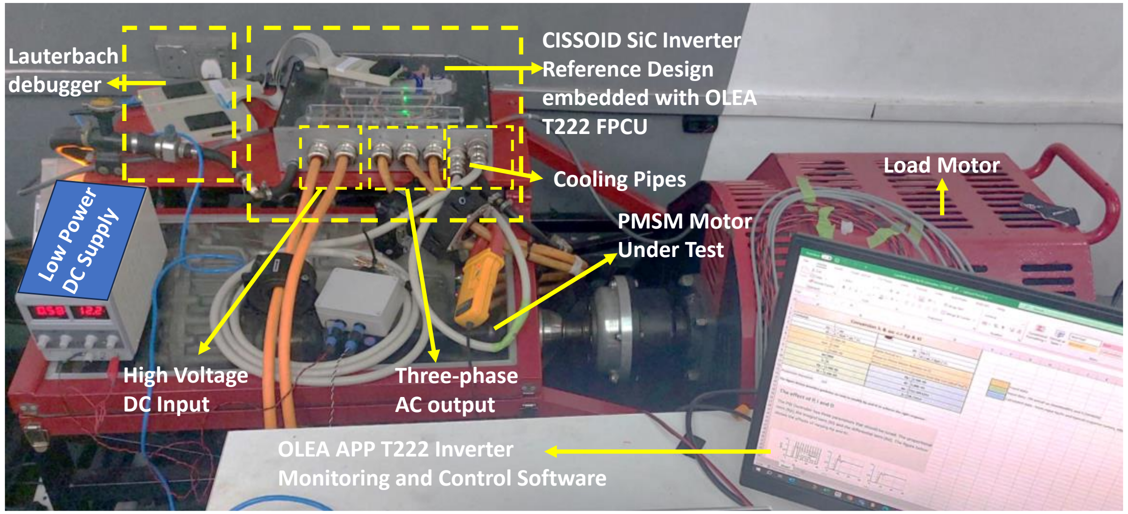


DTC - Motor Bench vs Simulations

Case Study: Speed = 1000 Rpm, Torque= 50 Nm

MOTOR BENCH DATA



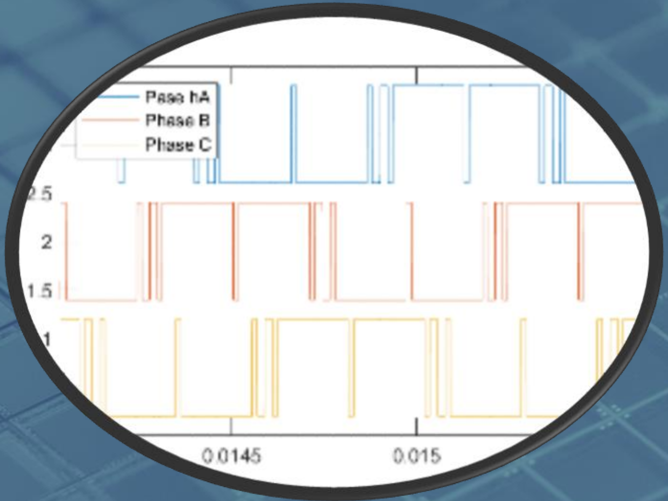


COMPARATIVE ANALYSIS

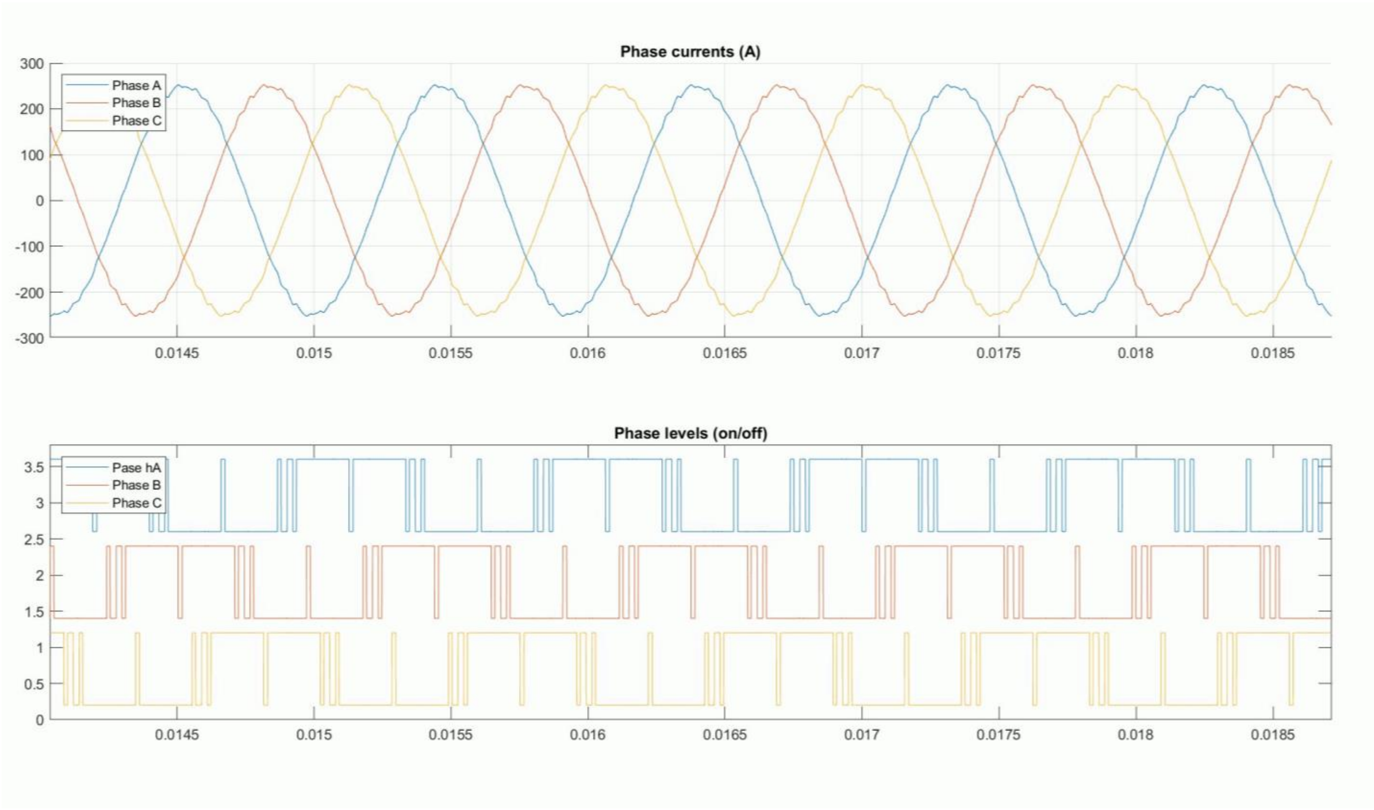
	I_u FFT (simulations)				I_u FFT (motor bench)			
	Fund. Normalized (%)	5th Normalized (%)	7th Normalized (%)	THD (%)	Fund. Normalized (%)	5th Normalized (%)	7th Normalized (%)	THD (%)
W/O DTC	100	6.2	3.2	7.3	100	8.9	5.4	7.8
With DTC	101.4	2.6	1.2	3.1	101	5.4	2.8	4.7
Improv.(%)	1.4	59	63	4.2	1	39	48	3.1

Improvement in phase current THD thanks to DTC demonstrated both in simulations and on the bench !

Optimized Pulse Patterns



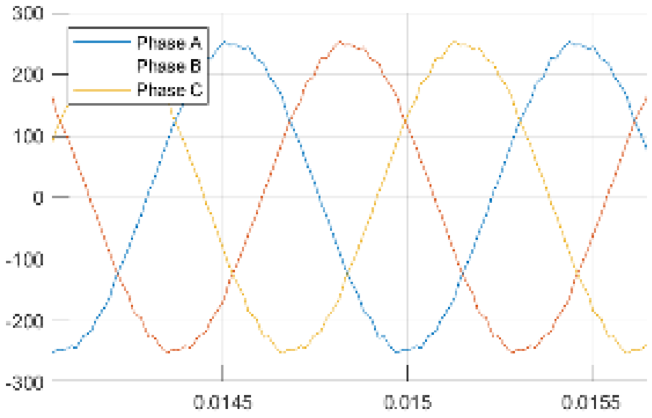
OPTIMIZED PULSE PATTERNS



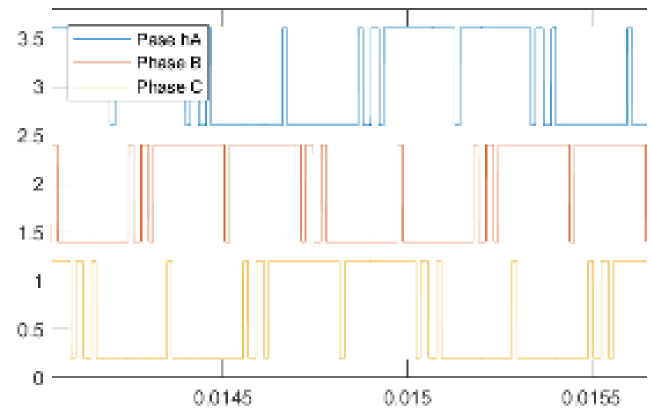
- A control method replacing conventional modulations as SVPWM, DPWM, SIX STEPS, etc.
- Based on the electrical angle: **Not time-based as SVPWM modulation**
- OPP applies a switching pulse pattern repetitively at each electrical period.
- No PWM carrier : **full freedom to locate switching pulses** at any angular position.
- Optimized for a motor speed-torque range.
- OPPs are generated offline in a digital process using tuned models of the inverter and motor

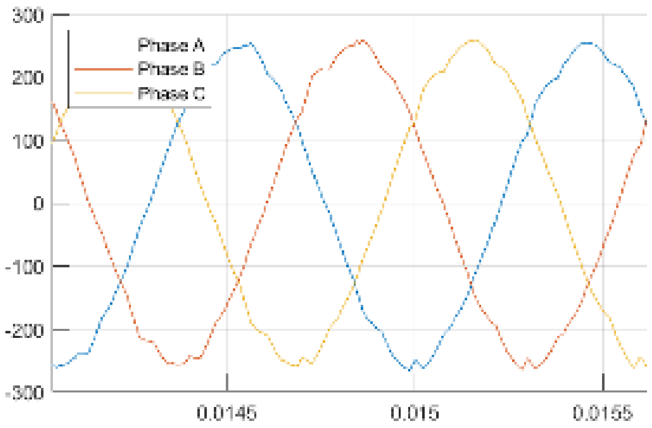
CISSOID's SiC Inverter solutions offer a ready-to-use hardware platform for Intel Automotive's Adaptive Control App (ACA) and its high-performance OPP modulation

OPP vs SVPWM Gate Control

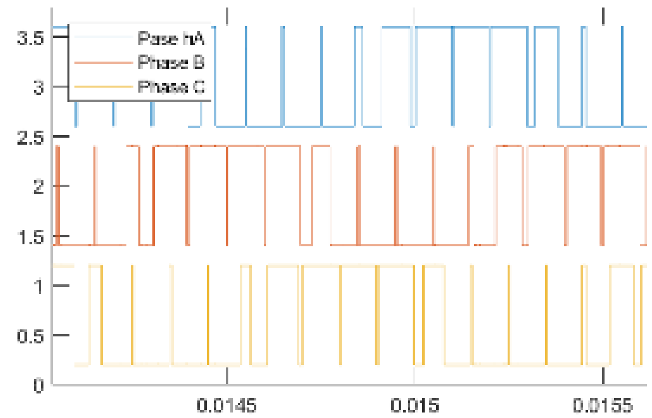


OPP





SVPWM



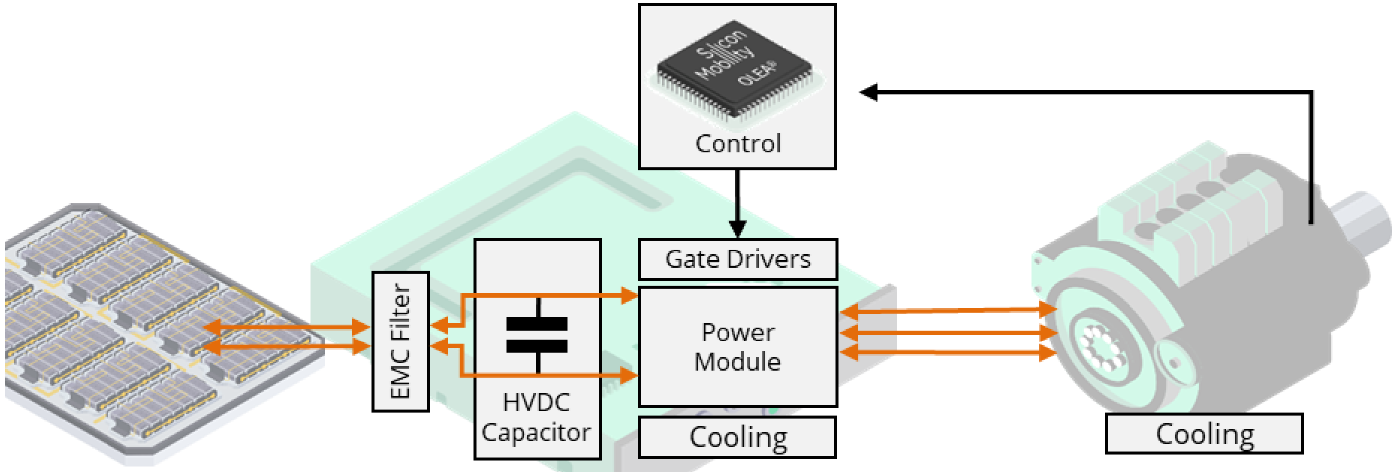
Number of switching pulses and related angle positions are determined to optimize the modulation **upon different criteria**:

- Inverter losses
- E-motor losses
- Total Harmonic Distortion (THD)
- Noise, Vibration and Harshness (NVH)
- Current ripple

OPP BENEFITS

Silicon Mobility
An Intel Company

CISSOID
POWER SEMICONDUCTORS



Battery Benefits
- Smaller capacity
- Less volume / weight

Inverter Benefits
- Lower energy losses
- Downsizing of passive components
- Lower cooling demand
- Higher power density

Motor Benefits
- Lower energy losses
- Smaller, higher revving motors
- Lower NVH
- lower mass
- Lower cooling demand

Vehicle Benefits: less weight & cost

Motor & inverter benefits

- **Up to 5% efficiency gain** (inverter & motor) at critical load points
- Control of electrical machines revving supporting **100.000 rpm and above**
- **20% higher torque** out of the same motor or 20% lower battery voltage by extended overmodulation
- Tuneable, **Improved NVH** behaviour

Vehicle benefits

- Cost & weight savings by **motor downsizing**
- Cost & weight savings by **DC-Link capacitor downsizing** by 2 and reducing by 40% the peak cooling demands (Inverter)
- Cost & weight savings from **lower battery voltage** or higher power/peak torque out of the same motor
- Cost & weight savings from **lower sound-insulation** requirements

SUMMARY

Unique Inverter Solutions

CISSOID POWER SEMICONDUCTORS

1 Modular & open platform

Footprint-compatible power modules make it easy to vary up and down in power range, according to the needs across vehicle families. Controller solutions can be provided or swapped for in-house developments.

2 Easy, proven solution

A proven design, tested across a wide range of use cases, up and running within days

3 Highly Modifiable

Most parts of the design, from the semiconductor components to the software and the mechanical design, can be adapted to the application's needs.

4 Components to Software

Single supplier from individual components over control boards to motor control software and reference designs

5 Single Point of Contact

Single point of contact for technical support on hardware and software

CISSOID

POWER SEMICONDUCTORS

QUESTIONS?

SALES@CISSOID.COM

WWW.CISSOID.COM