SiC Inverter Control Modules & Reference Designs

How to increase efficiency
and accelerate time to market

Mike Sandyck, Marketing Director
CISSOID

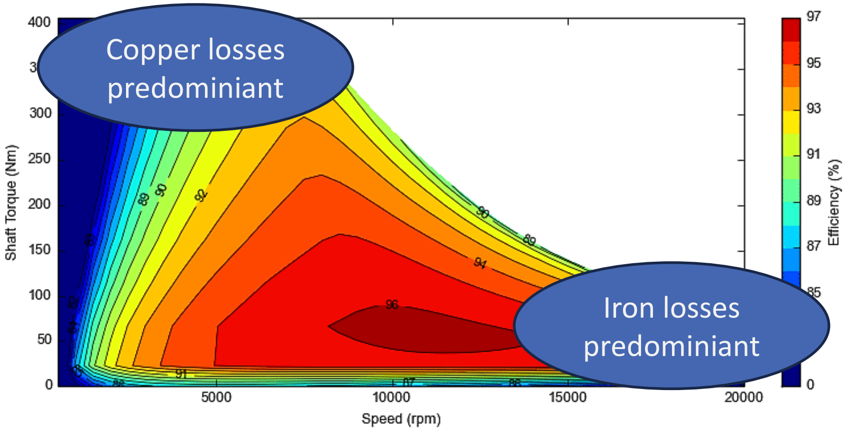
Bodo's Wide Bandgap Event 2024

Making WBG Designs Happen

SiC

WHAT IS THE PROBLEM?

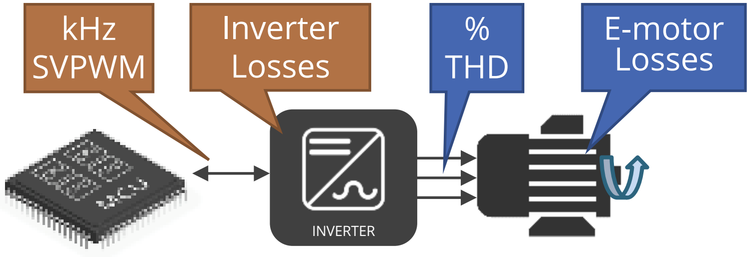
Losses = Efficiency Reduction

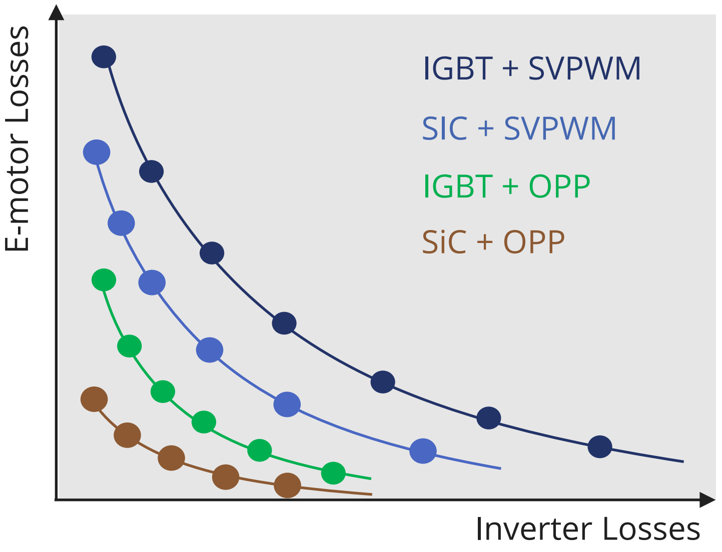


Two major loss locations:

- **Inverter:**
  Switching and conduction losses
- **E-motor:** Iron and copper losses

Losses Reduction = Efficiency Increase





Problem

- With current control solution (SVPWM), reducing the e-motor losses increases the inverter losses and vice versa

Solutions

- Use Wide Band-Gap power switching technology such as SiC or GaN
- Optimize control algorithm and MCU:
  - Dead Time Compensation (DTC)
  - Optimized Pulse Patterns (OPP)

Dead Time Compensation

Simulations In LTspice

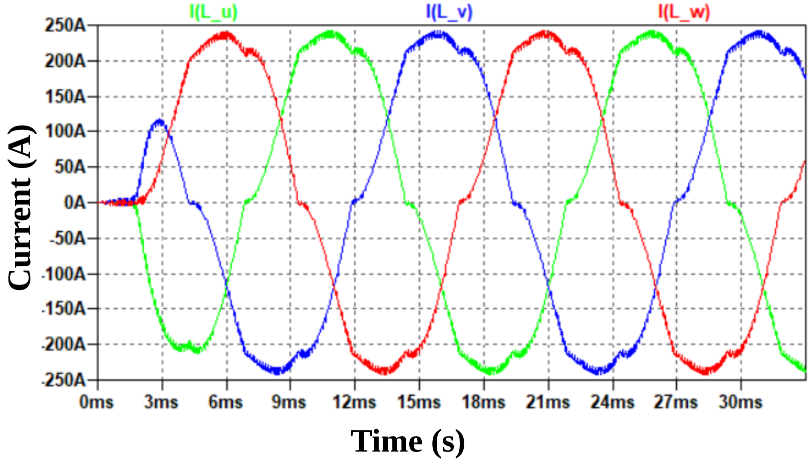
With and Without Dead Time Compensation

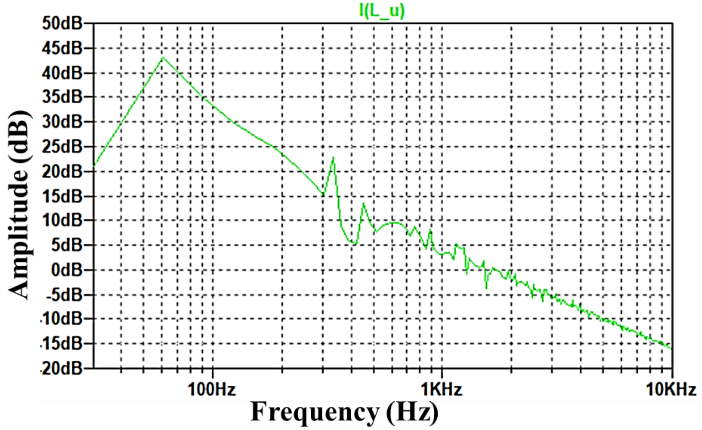
Case Study

Speed = 1000 Rpm, Torque= 50 Nm

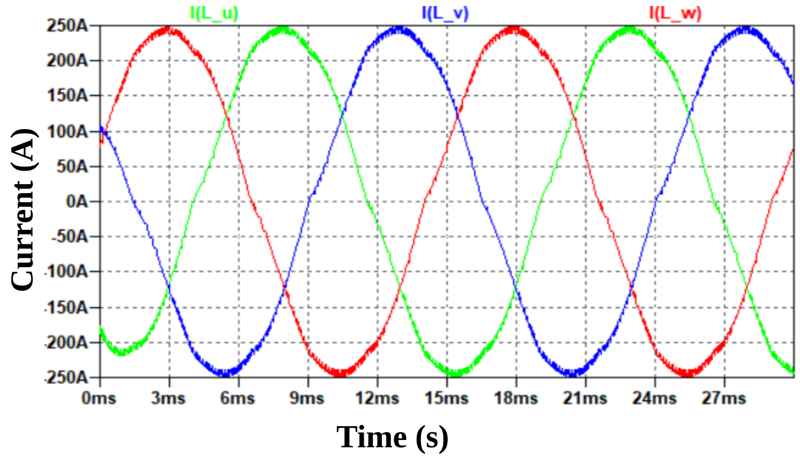
- **SIMULATION PARAMETERS**
  - SPECIFIC INPUT DATA :
    - High Voltage Battery Voltage : 650 V
    - DC-link Capacitor : 320 uF / 750 V
    - ICM CXT-PLA3SA12550AA (Pin Fin) : 1200 V / 550A
    - SVPWM modulation
    - Dead time = 2 µs
    - Fswitching = 16 kHz
  - PMSM CHARACTERISTICS :
    - Number 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

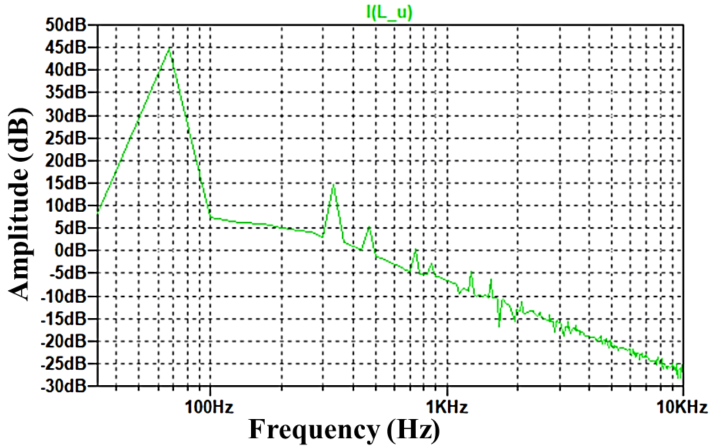
WITHOUT DEAD TIME COMPENSATION





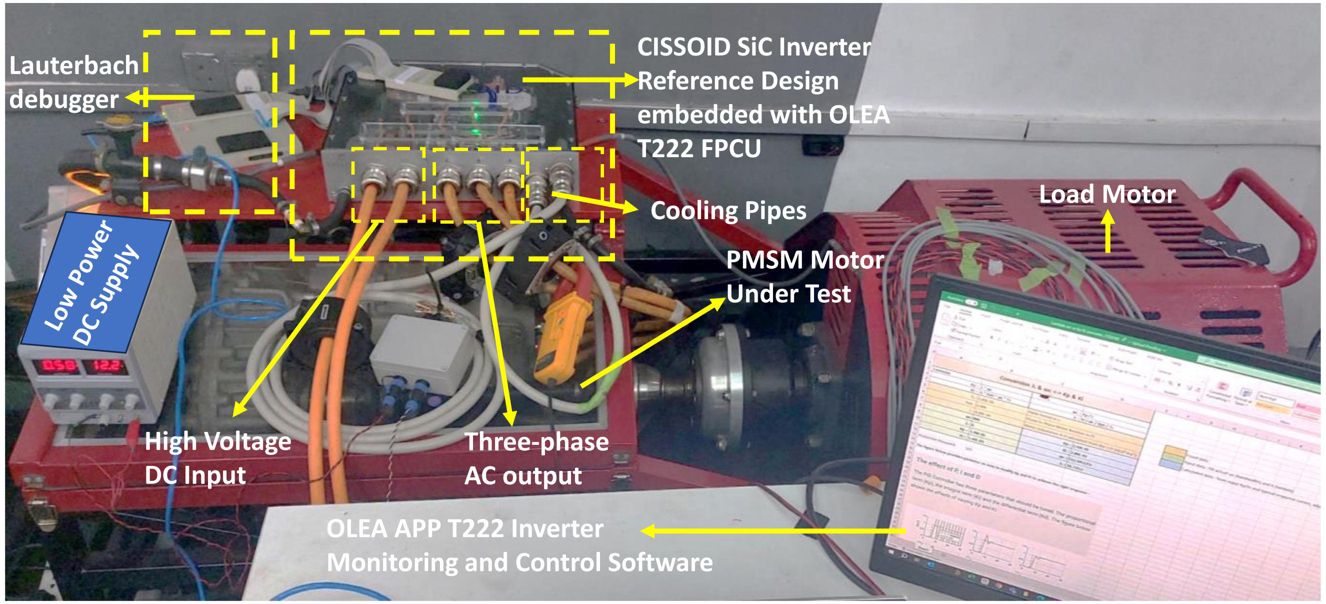
WITH DEAD TIME COMPENSATION





CASE STUDY : AUTOMOTIVE APPLICATION

VSI Rated Parameter(s)	Value
Rated Power of the Inverter	Up to 350 kW
Rated Voltage of the Inverter	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 Rated Parameter(s)	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

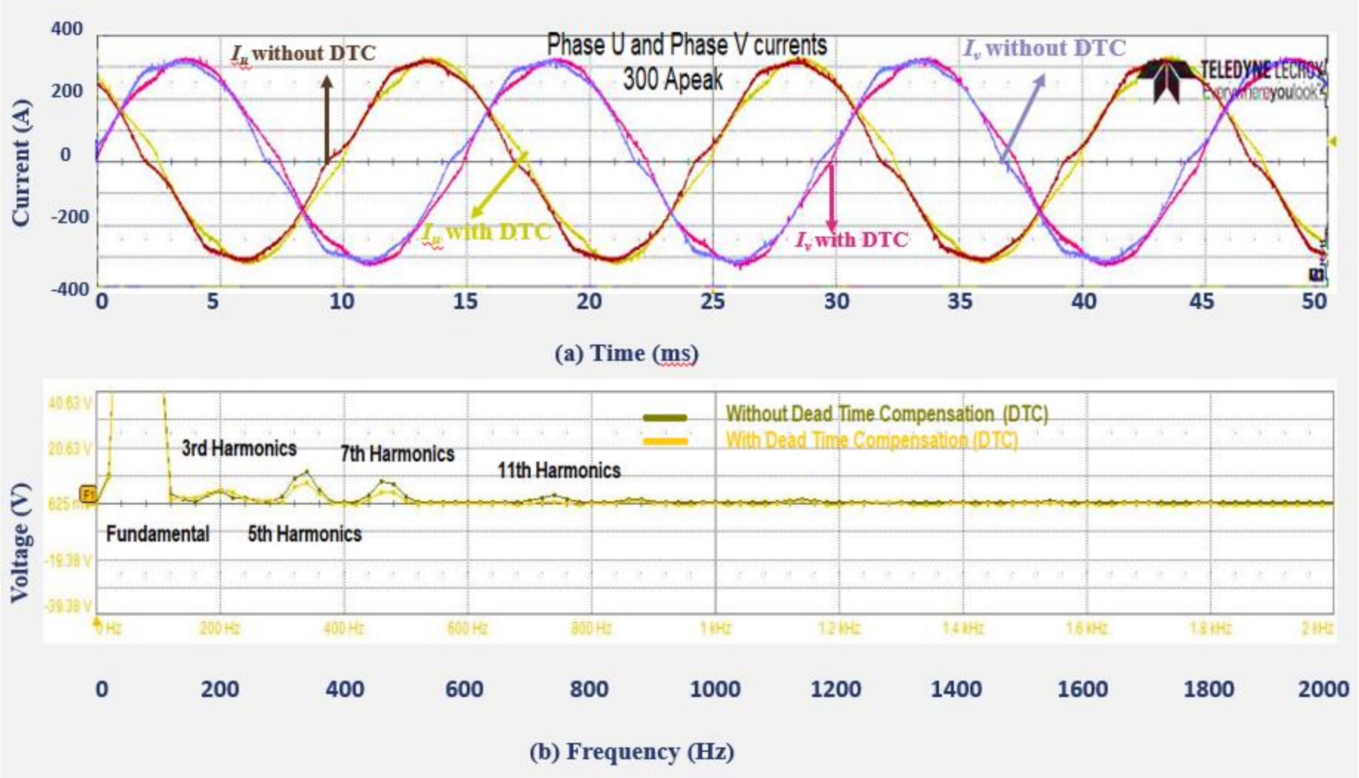


DTC - MOTOR BENCH VS SIMULATIONS

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

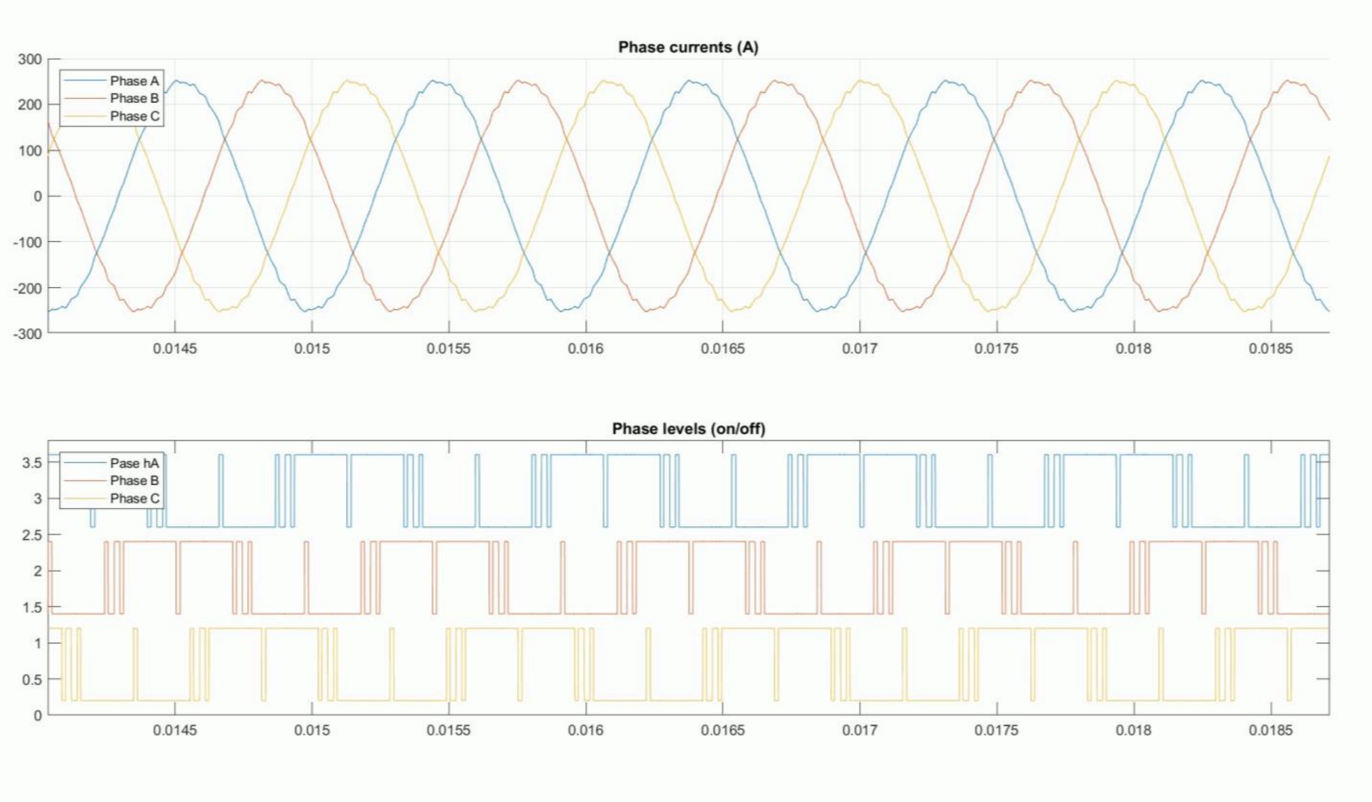
✓ **Phase current THD improved by 4%**

Optimized Pulse Patterns

What are Optimized Pulse Patterns?

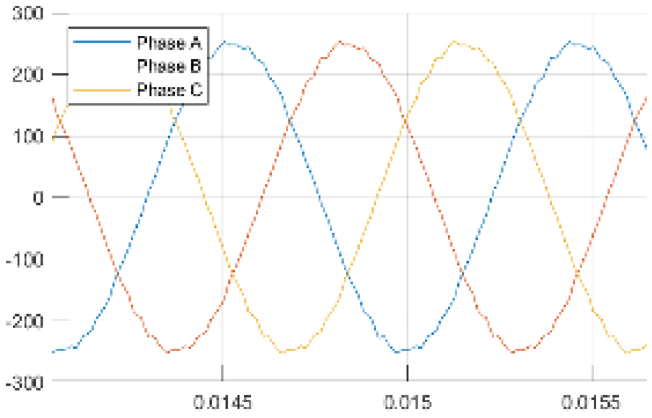
Silicon Mobility
An Intel Company

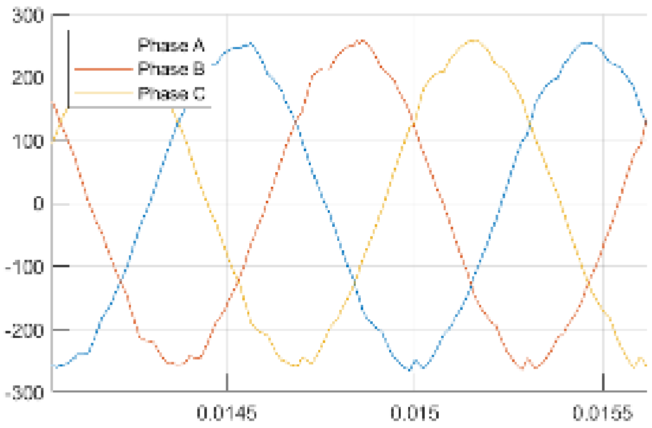
CISSOID
POWER SEMICONDUCTORS



- A control method (or switching modulation) which replaces conventional modulations as SVPWM, DPWM, SIX STEPS, etc.
- The OPP modulation is based on the electrical angle: It is not a time-based modulation such as conventional modulations.
- OPP applies a switching pulse pattern repetitively at each electrical period.
- Switching pulses can be located at any angular position: there is no PWM carrier.
- Full freedom on where to place switching pulses by removing the constraint of the fixed frequency and symmetries on the gate pulses
- OPPs are optimized for a motor speed-torque range.
- OPPs are generated offline in a digital process using tuned models of the inverter and motor

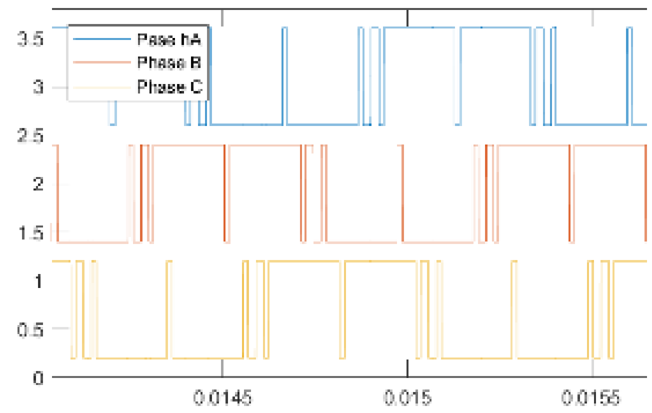
OPP vs SVPWM Gate Control

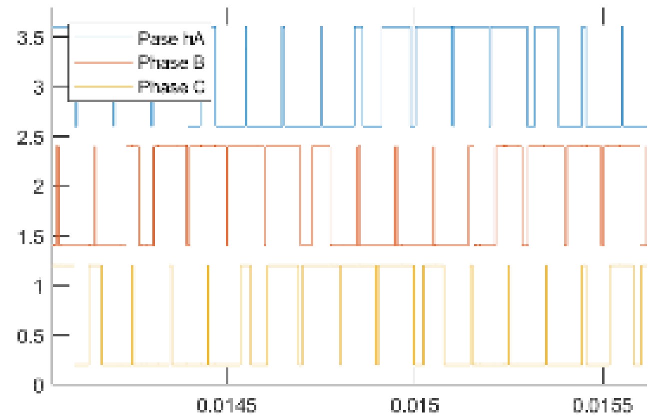




OPP

SVPWM

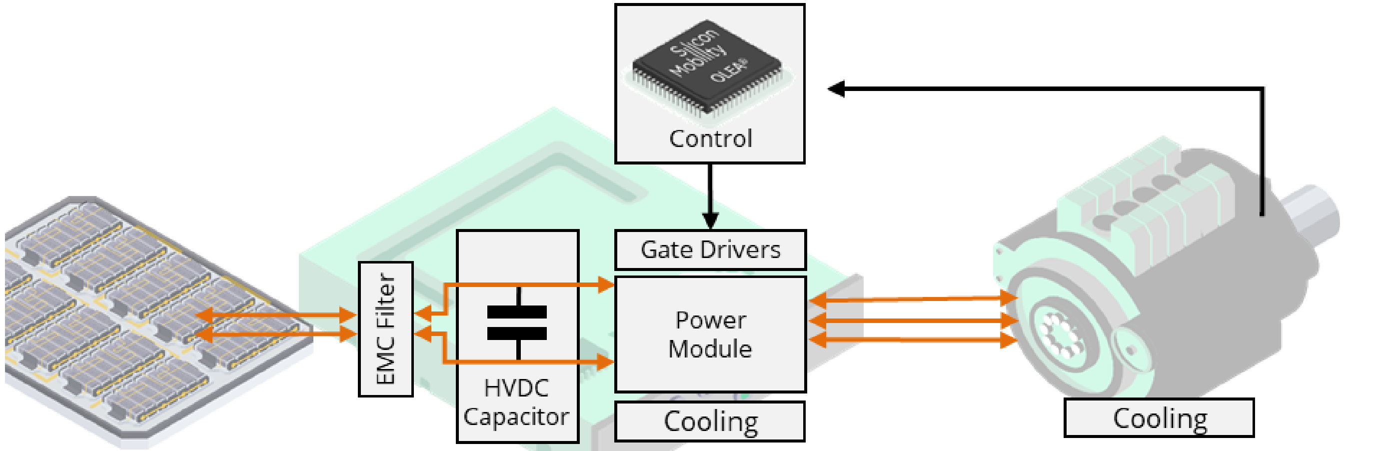




Number of switching pulses and related angle positions are determined to optimize the modulation upon different criteria:

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

OPP BENEFITS



Battery Benefits	Inverter Benefits		Motor Benefits	
Smaller capacity	Lower energy losses	Downsizing of passive components	Lower energy losses	Smaller, higher revving motors
Less volume / weight	Lower cooling demand	Higher power density	Lower NVH	lower mass
			Lower cooling demand	

Vehicle Benefits: less weight & cost

Motor & inverter benefits

- up to 5% points efficiency gain (inverter and 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
- improved, tuneable NVH behaviour

Vehicle benefits

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

CISSOID Solutions

CISSOID's Unique Products

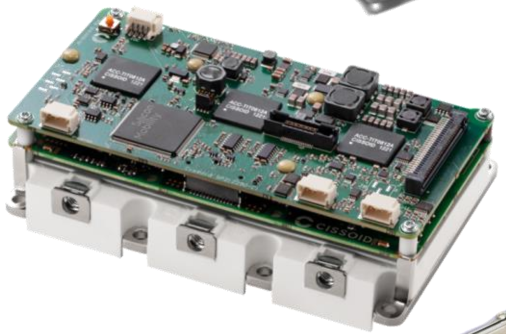
CISSOID
POWER SEMICONDUCTORS

SiC Intelligent Power Modules

- Unique power range of 100 – 350kW
- Single package/footprint
- In-house 2nd generation gate driver chipset
- Stable operation over the complete temperature range
- Full assembly rated to 125°C ambient
- Lightweight (550~590g)

SiC Inverter Control Modules

- Complete HW + customizable SW
- Unique processor reduces fault reaction time to tens of nanoseconds
- Unique dead time compensation SW reduces THD by 4~5%

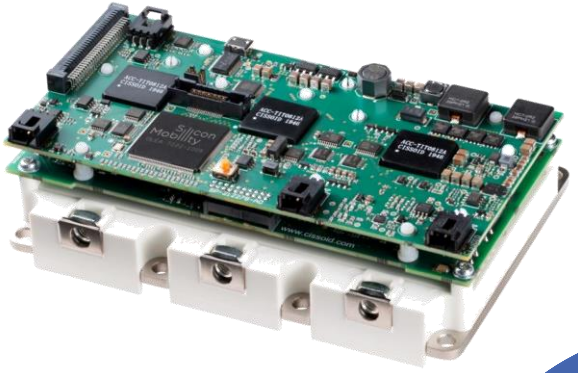


SiC Inverter Reference Designs

- Start testing within days
- Lab version (bench tests) and in-vehicle version (PoC, prototyping, field testing)

Modular SiC Inverter Platform

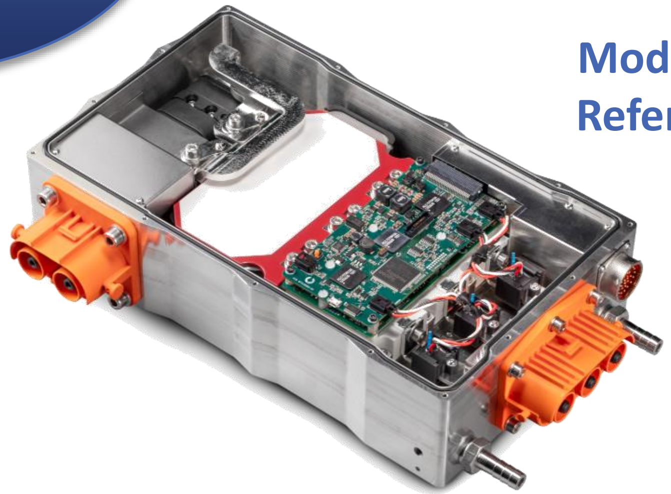
Modular 3-Phase SiC Intelligent Power Module & E-Motor Control Board



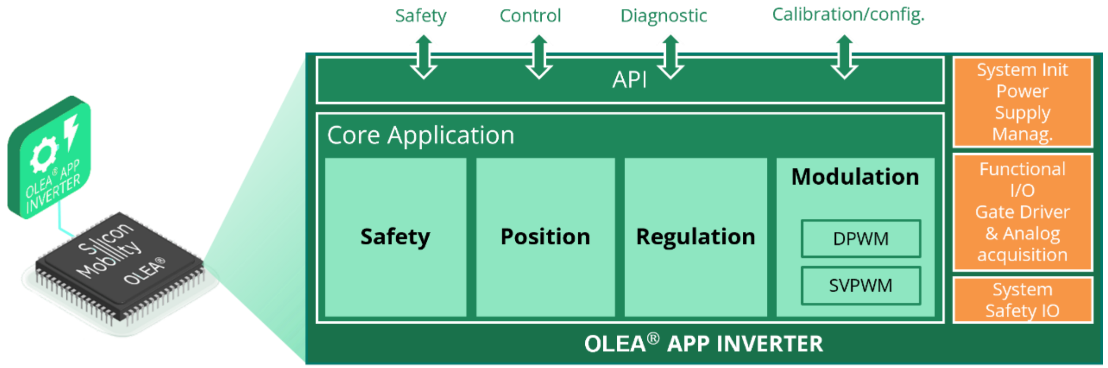
3-Phase 1200V SiC Modular Inverter Platform

Accelerate your Time-to-market

Modular Inverter Reference Design



Configurable OLEA APP® INVERTER E-Motor Control Software



SiC Inverter Reference Designs

CISSOID
POWER SEMICONDUCTORS

- Output power target 100 - 350kW
- Operating bus voltage 100 – 850V
- High power density >50kW/litre
- 3-phase 1200V SiC power module
- Ultra-fast OLEA® T222 FPCU control board
- Customizable OLEA® Inverter software
- DC and 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

Bench-top
version for lab
testing

On-board
version for
in-vehicle testing
(376x220x88)

CISSOID's Unique EV 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

3 100% Modifiable

All 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?

CISSOID
POWER SEMICONDUCTORS

Backup information

13 Years of Silicon Carbide Innovation

CISSOID
POWER SEMICONDUCTORS

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

2024 — SiC Inverter Reference Design Gen 2
Modular HW & SW SiC Inverter Industrialization platform

- SiC Gate Drivers
- Reliable SiC Power Packaging
- SiC Intelligent Power Modules (IPM)
- SiC Inverter Reference designs

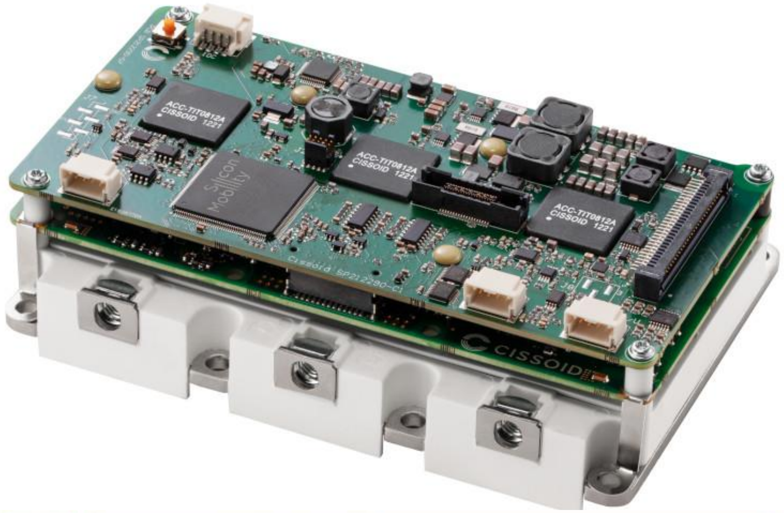
Founded March 2000

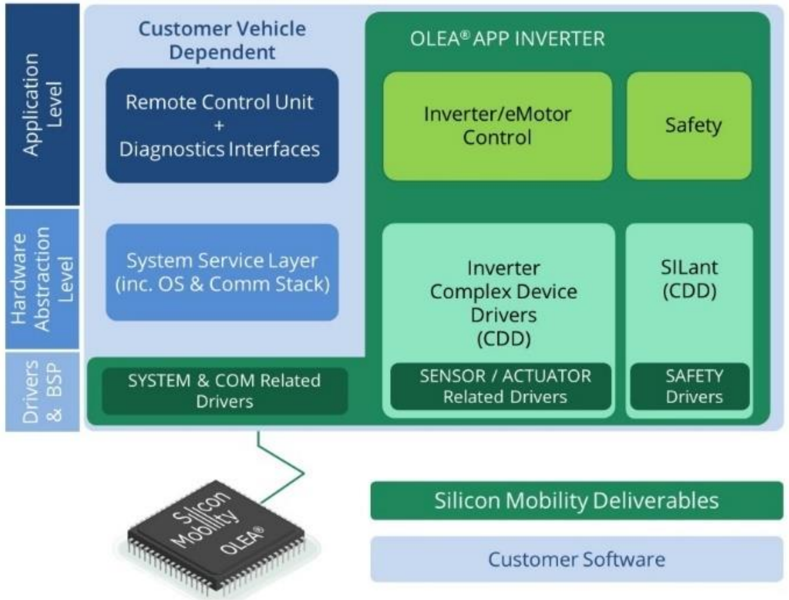
INVERTER CONTROL MODULE (ICM)
IN PARTNERSHIP WITH SILICON MOBILITY

Silicon Mobility An Intel Company

CISSOID POWER SEMICONDUCTORS

- **OLEA® Solution Control Board mechanically & electrically integrated with CISSOID SiC IPMs**
  - Based on OLEA® T222 FPCU controller chip
- **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 (by Silicon Mobility) Highly configurable inverter & motor control software**
  - 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



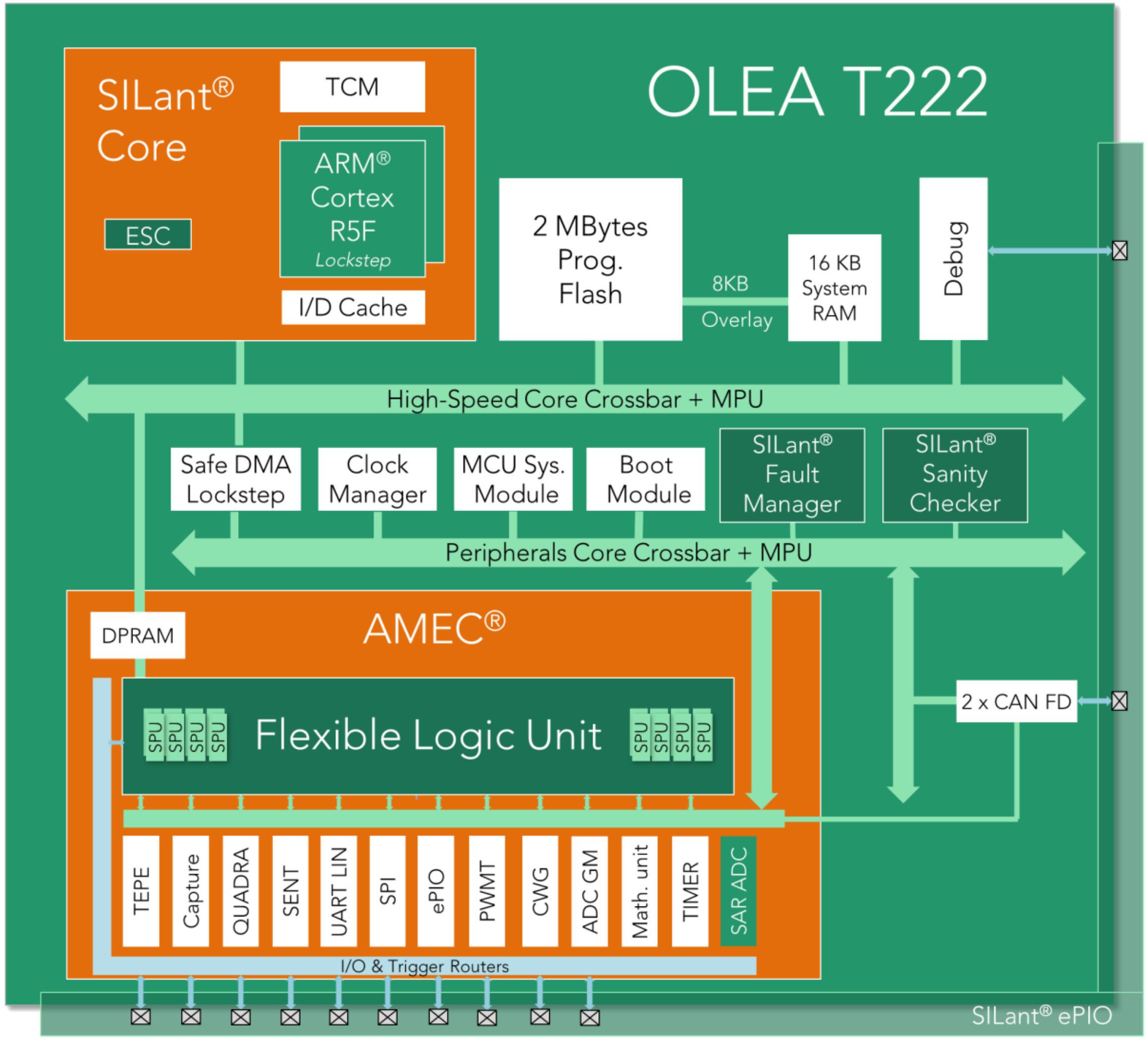


OLEA® T222 PROCESSOR

Dazzling fast real-time processor

System-level fault detection, correction and containment in tens of nanoseconds.

- **Functional Safety Architecture**
  - **SILant Core** - Safety Integrated Level Agent
    Dual 200MHz ARM Cortex R5F in Lockstep
  - Safe DMA transfers with CRC checks
  - Real-time - 100% timing predictability
- **AMEC – Advanced Motor Event Control**
  - HW programmable Flexible Logic Unit
  - Parallel access for acquisition & control
- **Certification**
  - ISO26262 ASIL-D Certified (T222 processor + OLEA SW)
  - AUTOSAR 4.3 (OLEA SW)
  - AEC-Q100 Grade 1 / -40°C to +125°C (T222 processor)
  - ICM: ISO26262 ASIL-C (end 2024), AQG-324 (beginning 2025), ASIL-D (end 2025)



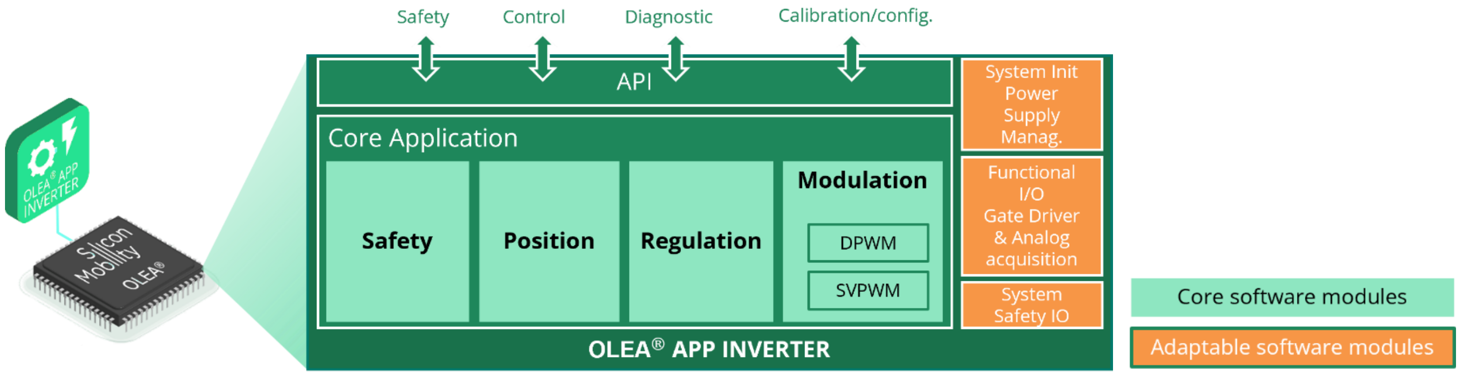
OLEA® APP INVERTER SOFTWARE

Silicon Mobility
An Intel Company

CISSOID
POWER SEMICONDUCTORS

- **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**



OPTIMIZED PULSE PATTERNS (OPP) BASICS

- The OPP modulation is based on the electrical angle, it is not a time-based modulation (such as SVPWM)
- OPP applies a switching pulse pattern repetitively at each electrical period. Phases are shifted by 2π/3 relatively to one another
- Switching pulses can be located at any angular position: there is no PWM carrier
- OPPs are characterized by their modulation ratio and their number of switching angles, while being optimized for a motor speed-torque range
- The modulation ratio is defined as $m = \sqrt{Vd^2 + Vq^2} \ / \ (Vbus/2)$
- OPPs are generated offline in a digital process using models of the inverter and motor
- The pulse patterns optimizations reduce global or independent criteria such as:
  - Inverter and motor losses
  - THD, torque ripple, vibrations

CERTIFICATION & SUPPORT

CISSOID
POWER SEMICONDUCTORS

Certification - Silicon Mobility

- ISO26262 ASIL-D Certified
  (T222 processor + OLEA SW)
- AEC-Q100 Grade 1 / -40°C to +125°C
  (T222 processor)
- AUTOSAR 4.3 (OLEA SW)

Certification - CISSOID

Intelligent Power Module:

- AQG-324 (beginning 2025)

Inverter Control Module:

- ISO26262 ASIL-C (end 2024)
- AQG-324 (beginning 2025)
- ASIL-D (end 2025)

In-house tech support

- Power modules & gate drivers
- Inverter Control Modules
- Reference designs
- Software
- Setup & calibration

