DIDIMO: dual inverter for automotive applications and preliminary evaluation from a reliability and safety viewpoint

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7th European Expert Workshop on Reliability of Electronics and Smart Systems
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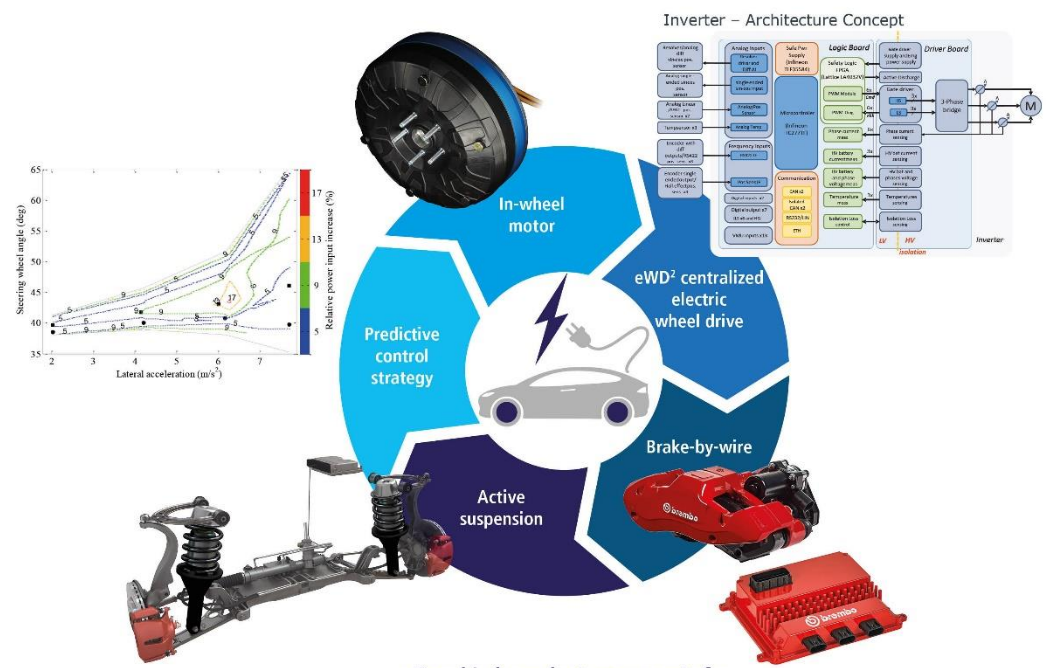
Contents

- EVC1000 at a glance
- A composable and modular dual-inverter architecture
- Reliability, criticality and functional safety preliminary analysis
- Design, development and realization
- Next steps and conclusions

The EVC1000 project at a glance (1/4)

- The EVC1000 project (Electric vehicles components for 1000km daily trips) will focus on innovative “corner concept”. More specifically, the consortium will develop:

- **New components for in-wheel powertrains**: i) Efficient, scalable, reliable, low-cost and production-ready **in-wheel motors** suitable for a wide range of torque and power levels]; and ii) **compact centralised drive for in-wheel motor axles**, based on **Silicon Carbide** technology, targeting superior levels of **functional integration** and **failsafe operation**



• Brand-independent components for next generation electrified vehicles

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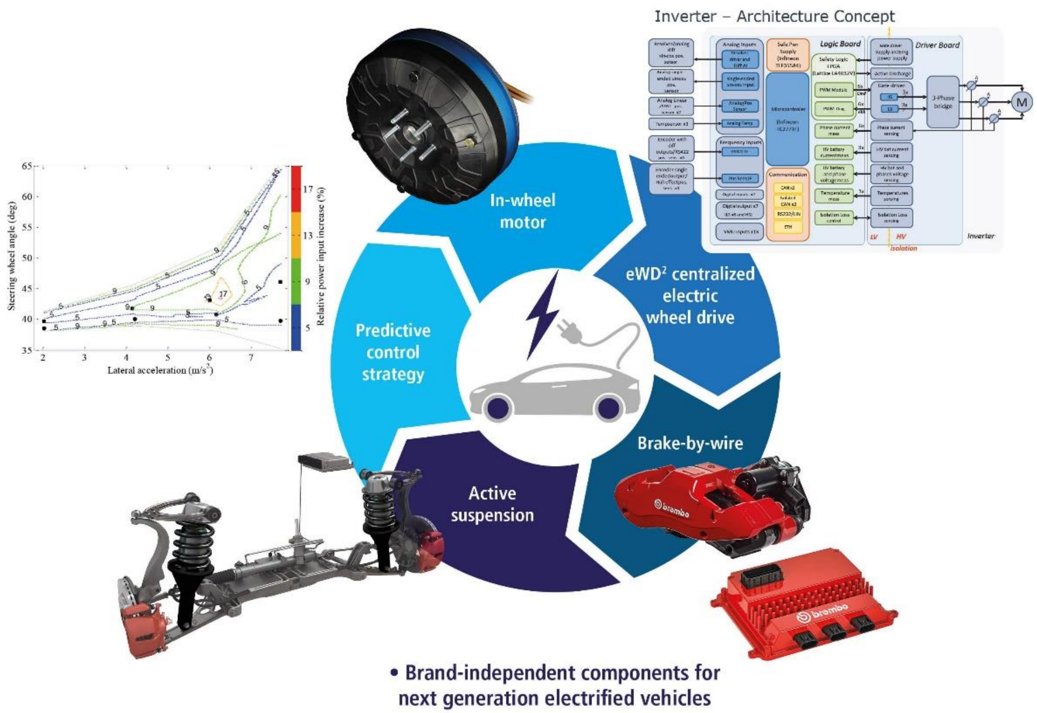
The EVC1000 project at a glance (2/4)

- The EVC1000 project (Electric vehicles components for 1000km daily trips) will focus on innovative “corner concept”. More specifically, the consortium will develop:
- **New components for electrified chassis control with in-wheel motors**: i) **Brake-by-wire** system, consisting of front electro-hydraulic brakes and rear electro-mechanical brakes for seamless brake blending, high regeneration capability and enhanced anti-lock braking system performance; and ii) **Electro-magnetic and electro-pneumatic suspension actuators**, targeting increased comfort and EV efficiency, e.g., through the optimal control of the ride height depending on the driving conditions.



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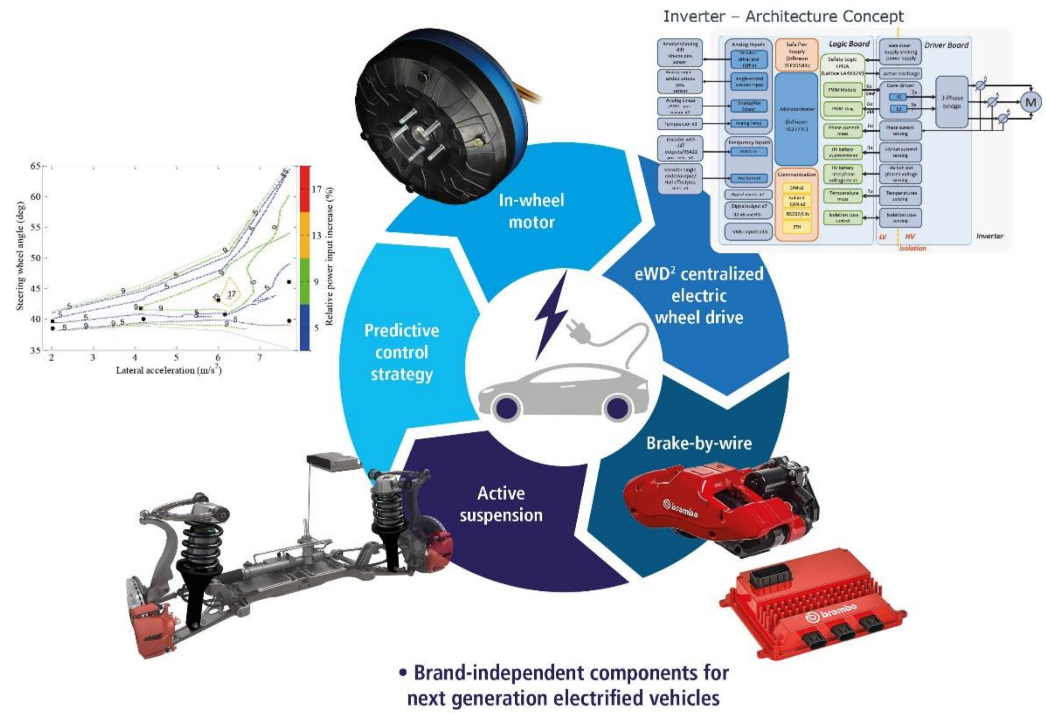
The EVC1000 project at a glance (3/4)

- The EVC1000 project (Electric vehicles components for 1000km daily trips) will focus on innovative "corner concept". More specifically, the consortium will develop:
- **Controllers** for the **novel components** and **new functionalities**, exploiting the benefits of **functional integration**, vehicle connectivity and driving automation for advanced energy management, based on the results of previous projects and initiatives.



Contents

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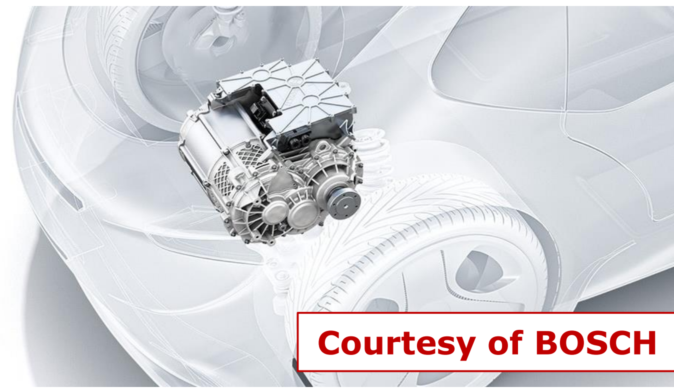
Integration of e-drivetrain components

- In electro-mobility there are several attempts **aiming at the functional integration of the electric drivetrain components to reduce dimensions and mass, while improving performance and safety**

- For instance, the eAxle is a compact, cost-attractive electric drive solution for battery-electric vehicles and hybrid applications. The electric motor, power electronics and transmission are combined in a compact unit directly powering the vehicle's axle.



Courtesy of BOSCH

- Another viable option is the functional integration of the electric drivetrains through the combination of in-wheel motor technology and automotive power electronics. A **centralised electric wheel drive**, **controlling the two motors of the same axle**, perfectly matches the in-wheel layout.

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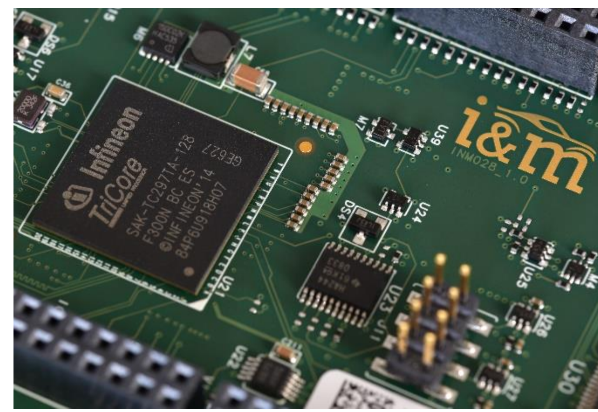
DIDIMO: a composable and modular dual-inverter architecture

EVC1000

- **The most relevant characteristic of the proposed Dual Inverter (namely DIDIMO (*))**, **is the functional integration at the vehicle level.**

  In fact, several functionalities have been incorporated into a single mechanical package.

- The DIDIMO architecture is modular and composable: it is based on a state-of-art automotive multicore microcontroller and the power stage can accommodate either standard MOSFETs or SiC devices thus covering different power ratings and DC link voltages.



- The proposed architecture is protected through patent.

(*) Didimo stems from the greek name *Didymos*, based on the adjective δίδυμος (*didumos*, *didymos*, "dual", "twin")

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DIDIMO: main characteristics

The main electrical characteristics of the DIDIMO family, describing the 48V and the high power platforms, are provided below:

	48 V Platform		High Power Platform	
Maximum peak phase current (10s)	500	A_{rms}	500	A_{rms}
Continuous phase current	230	A_{rms}	230	A_{rms}
Input DC link voltage range	36 to 54	V	up to 600	V
Maximum peak input power (10s)	2x 22	kW	2x 125	kW
Continuous input power	2x 10.5	kW	2x 65	kW
Switching frequency	Up to 20	kHz	Up to 40	kHz

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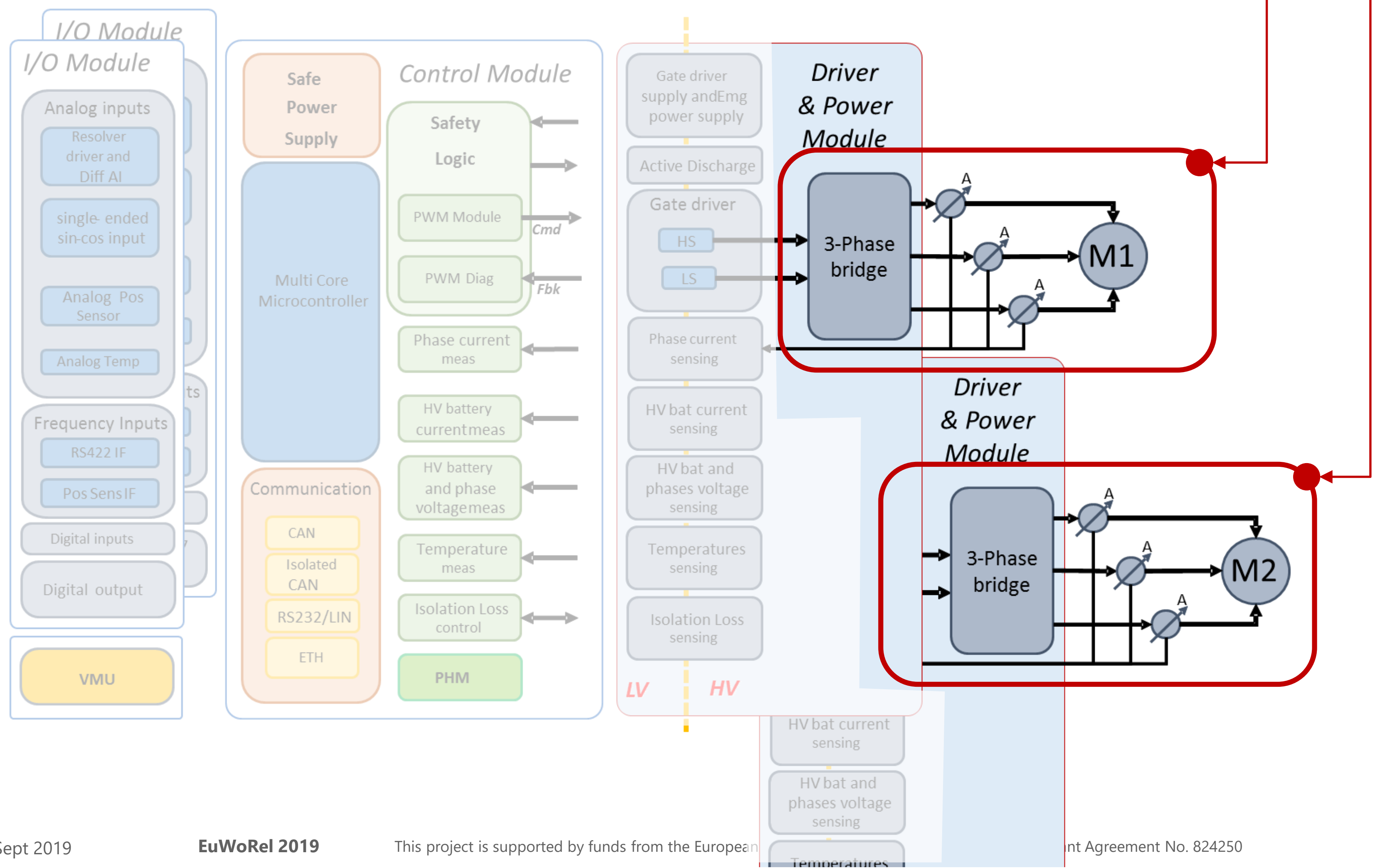
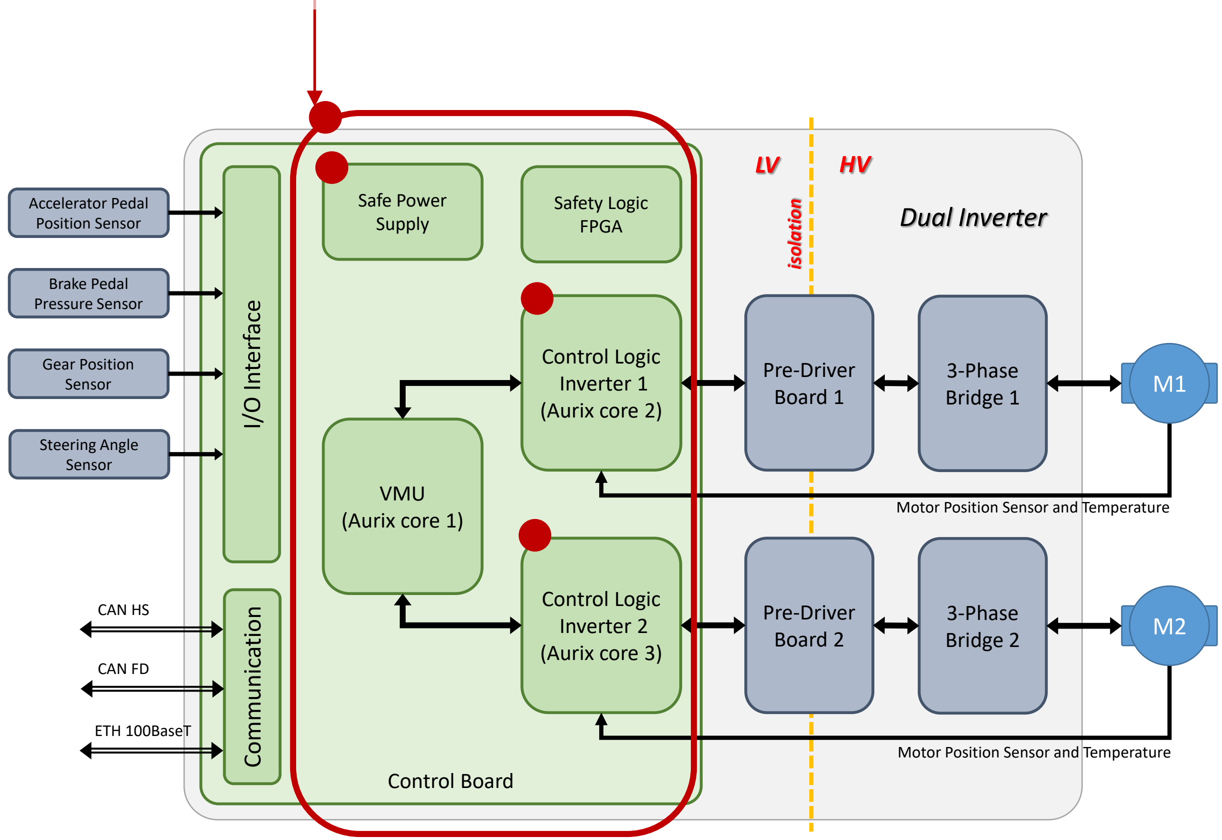
DIDIMO: functional integration (1/7)

The e-drive can manage either two multi-phase electrical motors or one complex multi-phase for automotive applications.



DIDIMO: functional integration (2/7)

The combination of the AURIX microcontroller and its safe power supply TLF35584 supports applications up to ASIL-D as a SEooC, mainly thanks to the lockstep implementation of one of the AURIX cores and a challenge-response safety watchdog integrated in the TLF35584.



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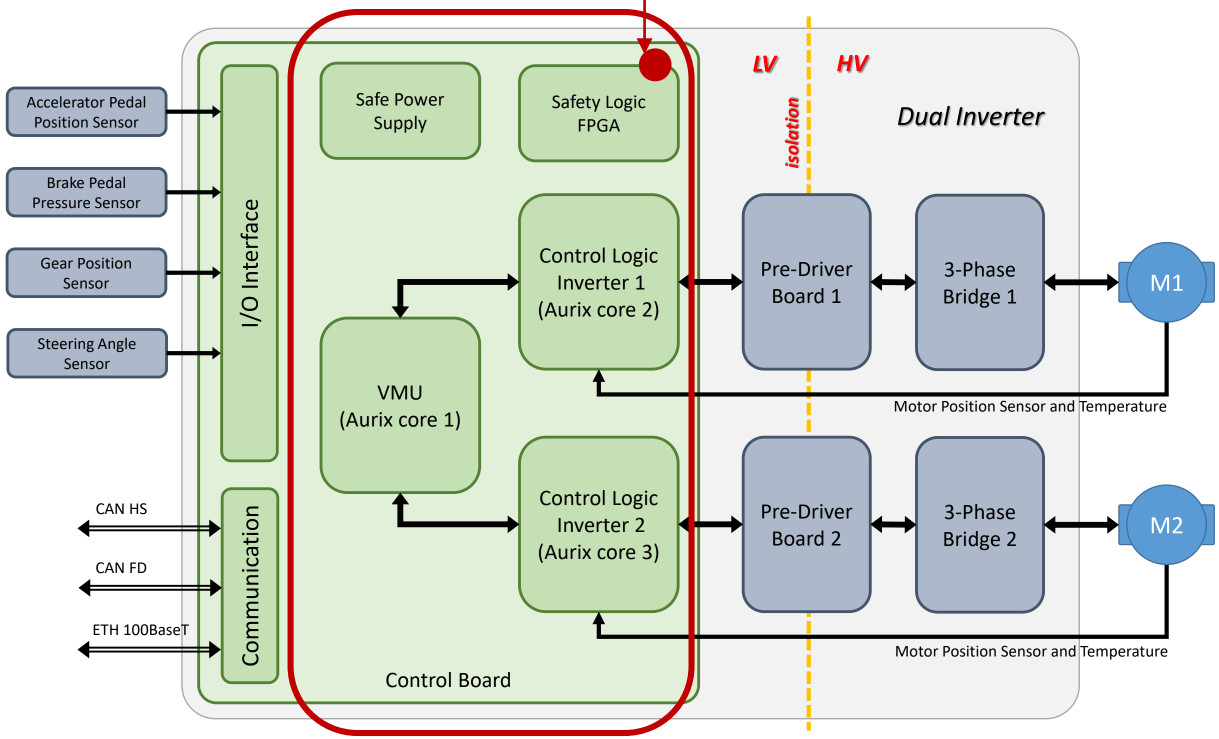
DIDIMO: functional integration (3/7)

A dedicated Safety Logic Module (SLM), based on FPGA, is responsible for actuating recovery functions without microcontroller intervention, setting the system in a safe state and preventing damage to power electronics.



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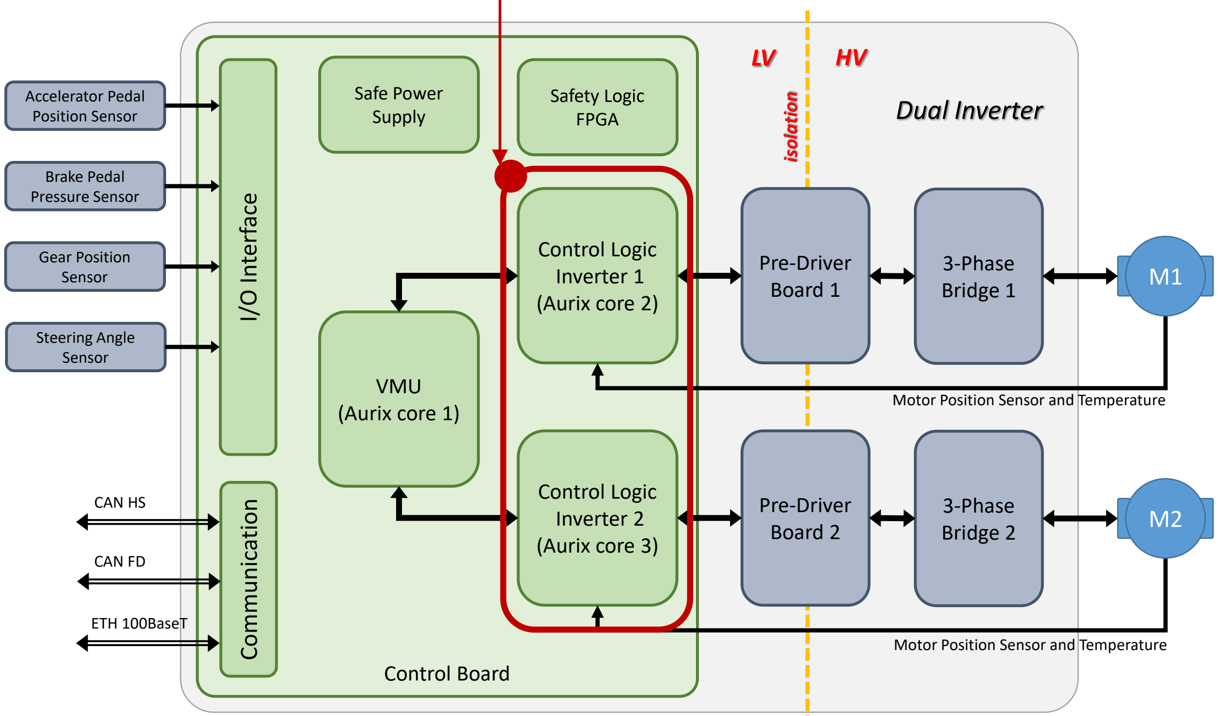
DIDIMO: functional integration (4/7)

Two of the AURIX cores are dedicated to motor control, performing both PWM command generation and acquisition of motor signals (phase-current/voltage, fault information).



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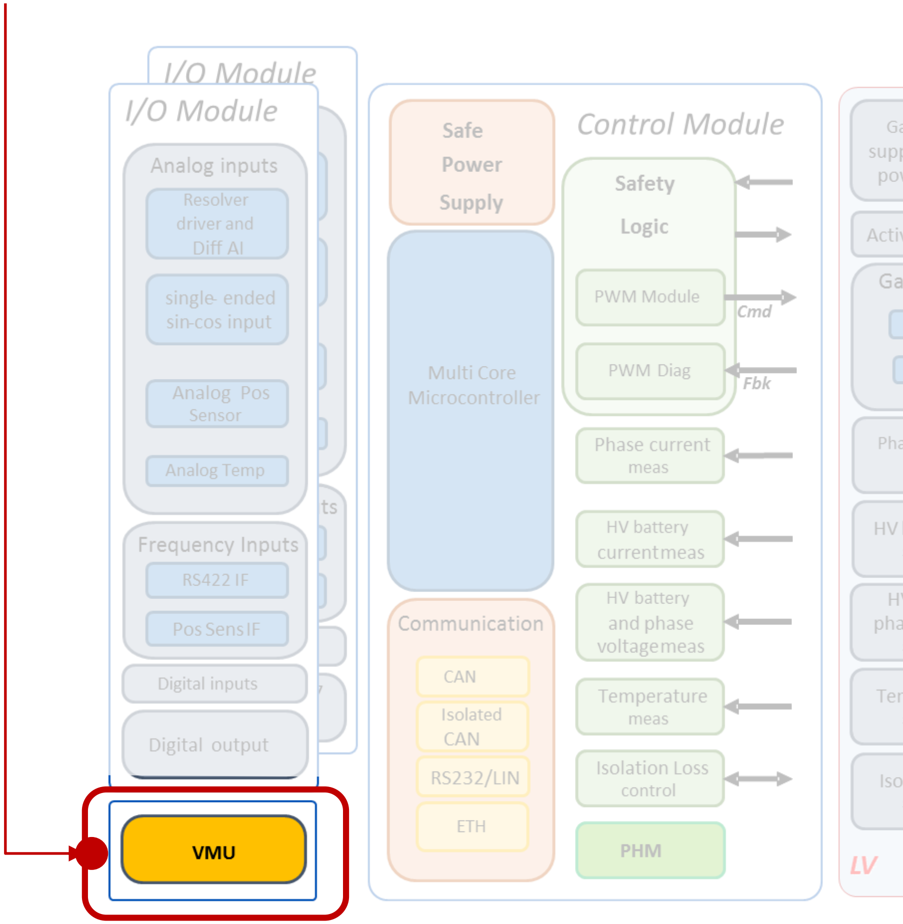
DIDIMO: functional integration (5/7)

The third AURIX core implements a Vehicle Management Unit (VMU).

The VMU acquires inputs from the driver (such as **accelerator pedal, brake pedal, steering angle, drive mode selection**) and coordinating the two motors through torque vectoring strategies.

The VMU integrates a **redundant internal inertial platform** (3-axis accelerometer plus 3-axis gyroscope), which will allow the safe integration of advanced vehicle dynamic functions.



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Contents

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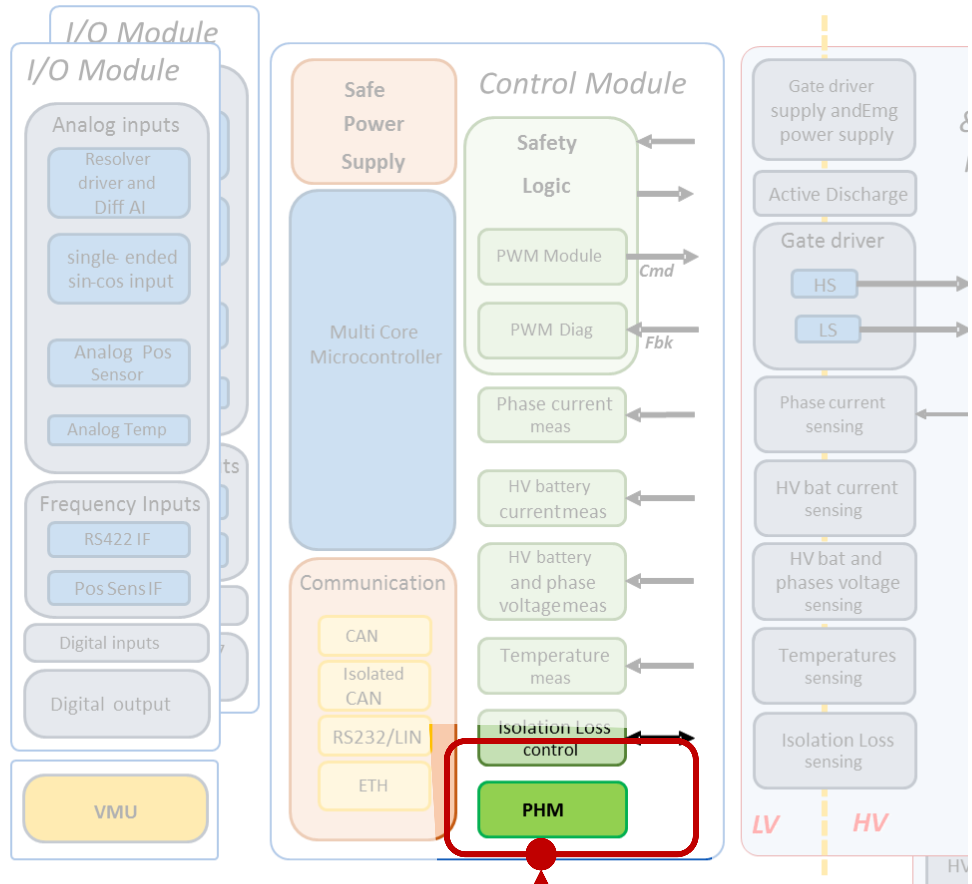
DIDIMO: Implementation of Prognostic and Health Monitoring methodology (1/3)

An active **Prognostic and Health Monitoring** (PHM) scheme, will be implemented. HW mechanisms will recognise the onset of degradation, and estimate the **remaining useful life** (RUL), i.e., the time until the degradation leads to out-of-specification behaviour.



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DIDIMO: Implementation of Prognostic and Health Monitoring methodology (2/3)

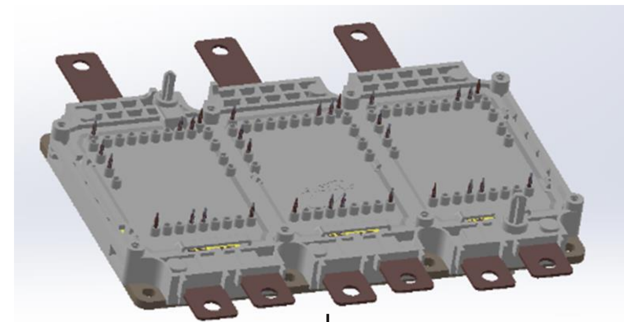
A formal methodology for the lifetime assessment of DIDIMO will be defined in cooperation with FhG (ref. dr. A.Otto, dr. E. Kaulfersch).

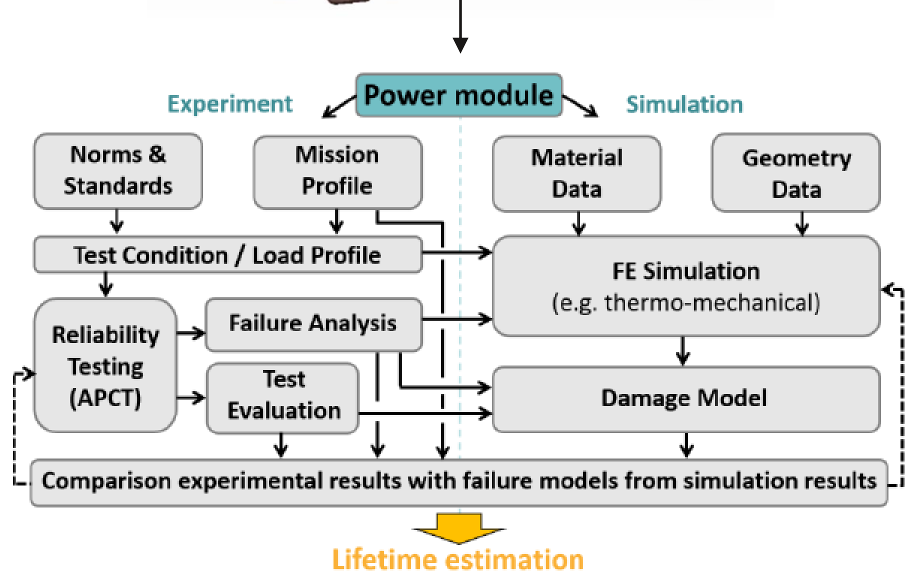
In particular the focus will be on:

i. Determination of the **'Physics of Failure'** (PoF) for all essential failure modes and interactions.

ii. **PoF based DfX** (Design for X = reliability, testing, manufacturing, etc.) quantification schemes.

iii. **Methods and strategies for field data collection and Prognostic Health Monitoring** (PHM).





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DIDIMO: Implementation of Prognostic and Health Monitoring methodology (3/3)

In particular the investigations will be focused on the main controller board as well as on the driver boards of the dual inverter.

- In the first step, a warpage measurements for different temperature profiles and different frame conditions is accomplished (e.g. bare PCB board, PCB board with soldered components and PCB board with soldered components and fixed within the inverter) and will be combined with FE simulations.
- Consequently an FE model calibrated with the warpage analyses is developed to investigate thermo-mechanical stresses and hence to provide design guidelines to reduce them within the PCBs and components.
- In parallel, the identification of different canary structures (e.g. SMD devices with partially reduces solder widths) to realize an early failure indication is performed.
- Then the canary structures will be placed in the control / driver boards.

With the results of the mentioned warpage and of the canary structure investigations it will be possible to correlate the (pre-defined) lifetime of the canary structures (=failure indicator) with the lifetime of the whole PCB board.

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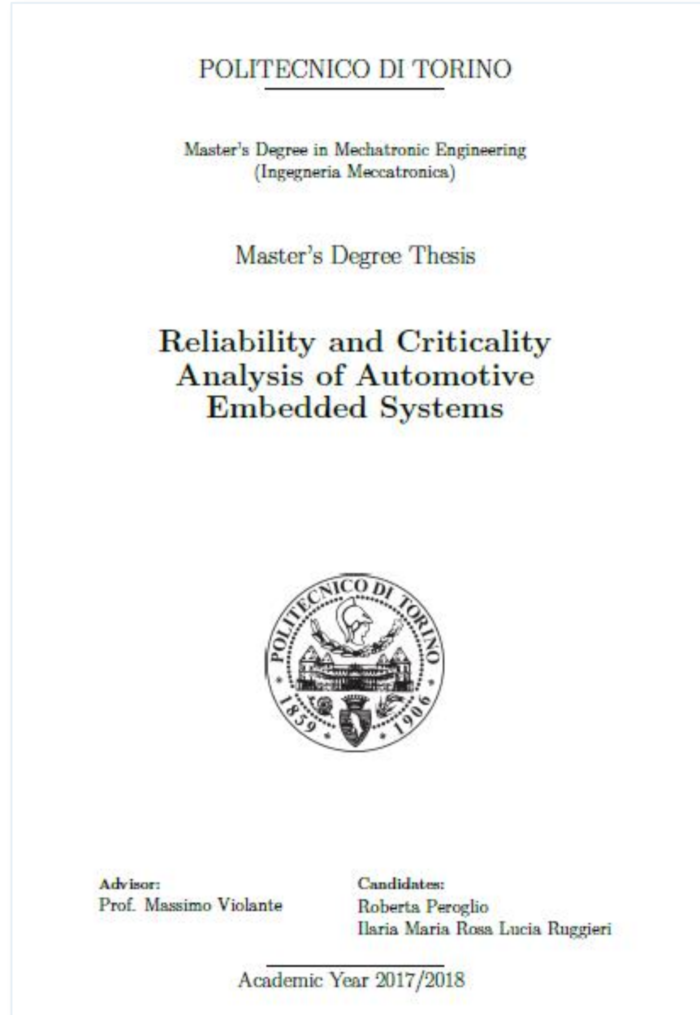
DIDIMO: reliability and criticality analysis (1/2)

Due to rather complex architecture of the dual inverter (more than 1100 components) and the request to deal with safety applications, such as controlling the e-traction motors of a vehicle, two different design methodologies have been applied, namely FIDES and FMECA (Failure Modes, Effects and Criticality Analysis).

In particular a reliability and criticality preliminary analysis has been performed on the logic board of the dual inverter, which has a high level of complexity.


POLITECNICO DI TORINO

Master's Degree in Mechatronic Engineering
(Ingegneria Meccatronica)

Master's Degree Thesis

Reliability and Criticality Analysis of Automotive Embedded Systems

Advisor:
Prof. Massimo Violante

Candidates:
Roberta Peroglio
Ilaria Maria Rosa Lucia Ruggieri

Academic Year 2017/2018

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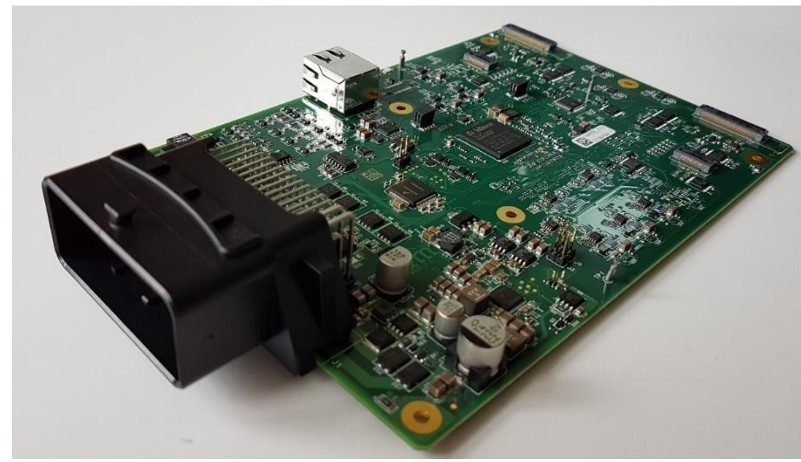
DIDIMO: reliability and criticality analysis (2/2)

Hazard Analysis and Risk Assessment:

Stating the conditions that could lead to an undesired event and deduce the acceptability of the risk of the event happening (risk is the combination of probability of the event happening and the gravity of the consequences).



Automotive Safety Integrity Level (ISO 26262)

It takes into account severity of possible negative events, exposure to hazardous situations and controllability of the consequences. ASIL determines the coverage that the system must achieve in order to prevent negative consequences in case of failure: the higher the ASIL rating, the better the coverage must be.

Safety goals

The goals stated about the system in order to achieve safety depending on the analysis of the risk and the coverage previously performed.

Component	Failuremode	α	Effect on thesystem	λ	λ α
Capacitor C3	SC	0,49	PosSensB-EncB1_IFdoesn't work	1,117196885	0,547426474
	OC	0,22	No effect	1,117196885	0,245783315
	ChangingValue	0,29	No effect	1,117196885	0,323987097
IC U44	Notworking	1	No output	5,453355594	5,453355594
Diode,Rectifier DD2	SC	0,51	Possible overload onMicrocontroller	0,114514973	0,058402636
	OC	0,29	Nooutput:Microcontrollerdoesn't work	0,114514973	0,033209342
	ParameterChange	0,2	Possible overload onMicrocontroller	0,114514973	0,022902995
Oscillator Y3	OC	0,89	No clock	22,4743014	20,00212824
	NoOscillation	0,11	No clock	22,4743014	2,472173154

Failure Modes, Effects and Criticality Analysis (FMECA)

Each component is analysed for its functions, interfaces, operational modes and interdependencies, its failure modes and failure rates are identified, the effects on the system and on the environment are analysed and the coverage is obtained.

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Contents

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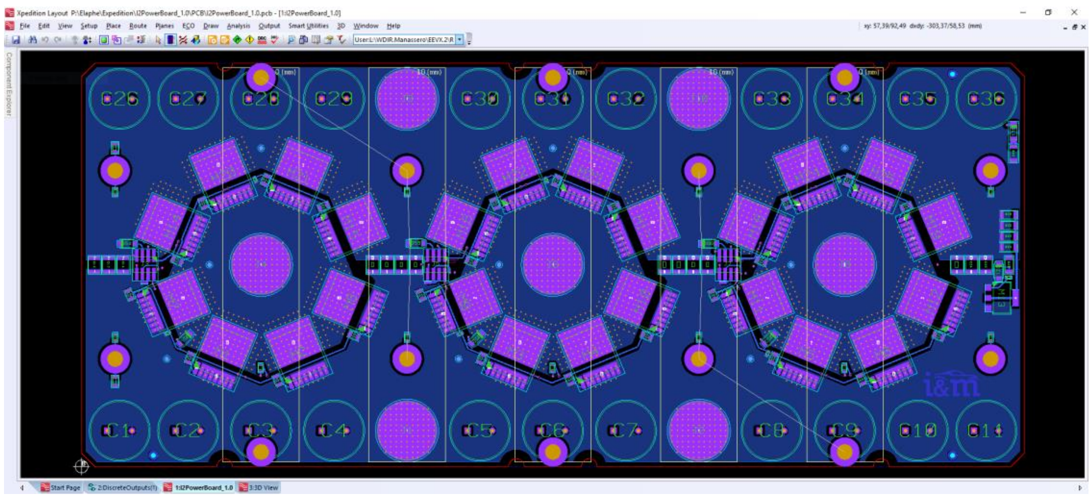
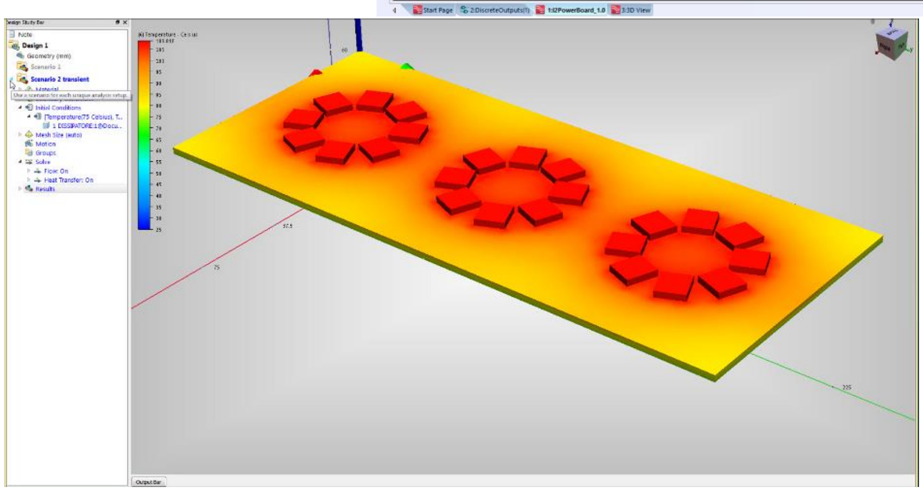
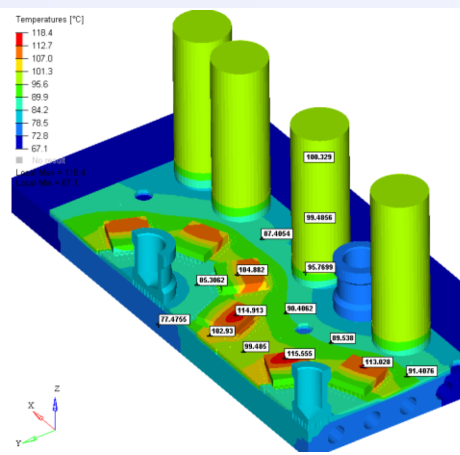
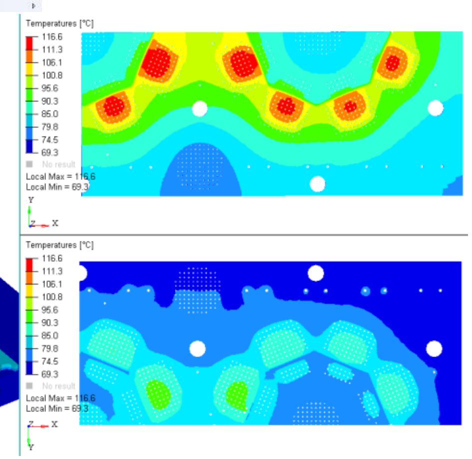
DIDIMO: design and development

- The design of DIDIMO is supported by CAD/CAE tools and simulation.









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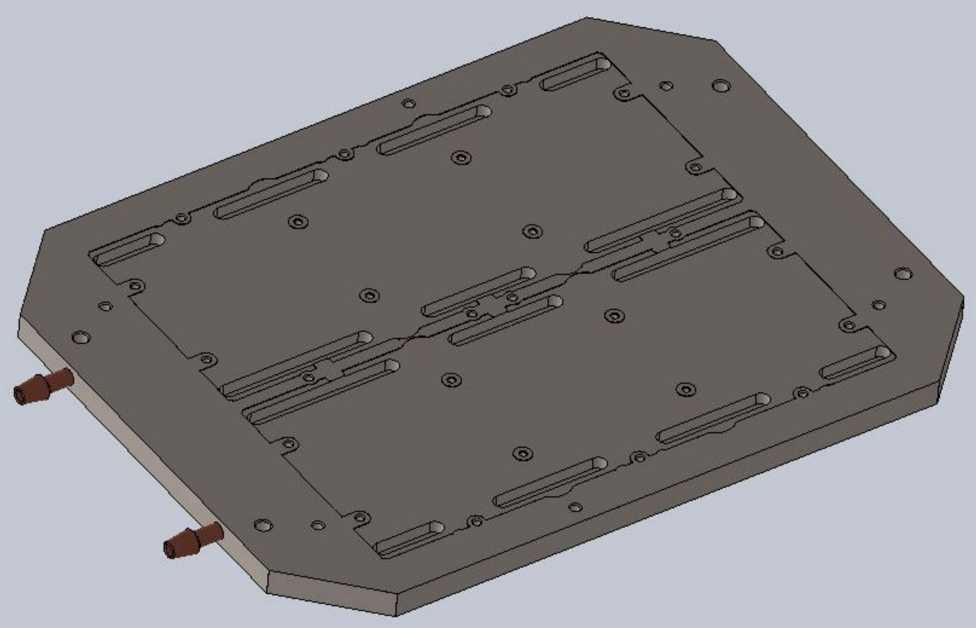
DIDIMO: 48V version (1/8)



Baseplate and heatsink

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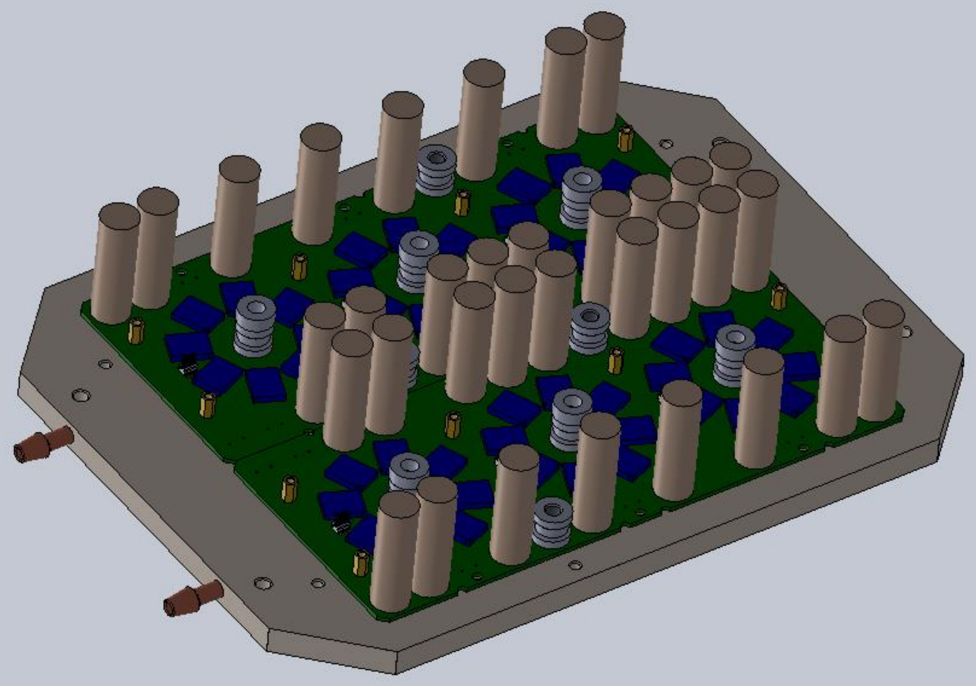
DIDIMO: 48V version (2/8)



Power stage

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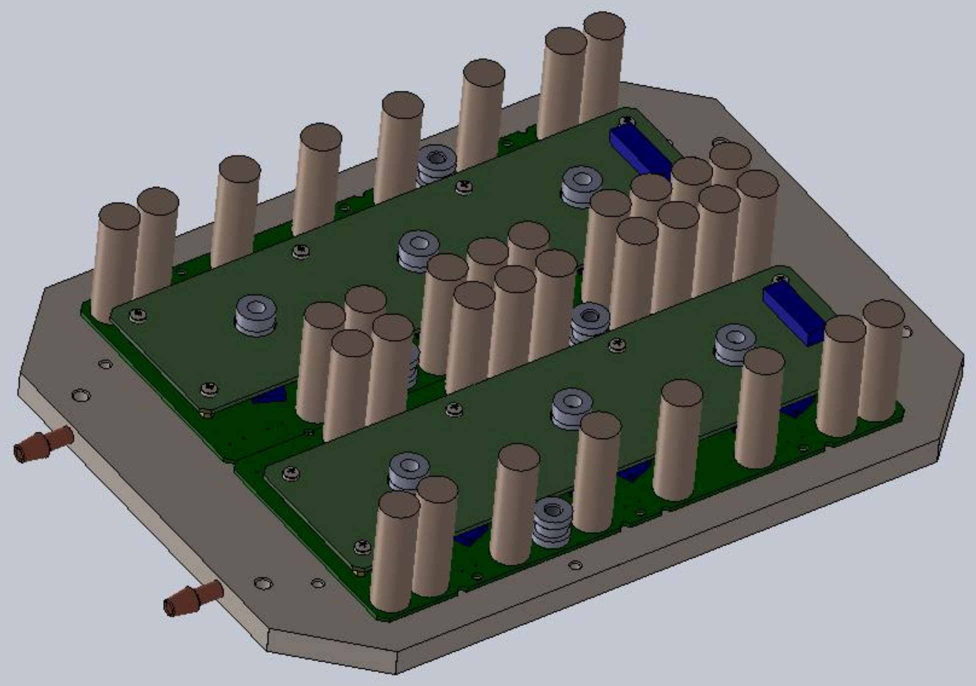
DIDIMO: 48V version (3/8)



Pre driver board

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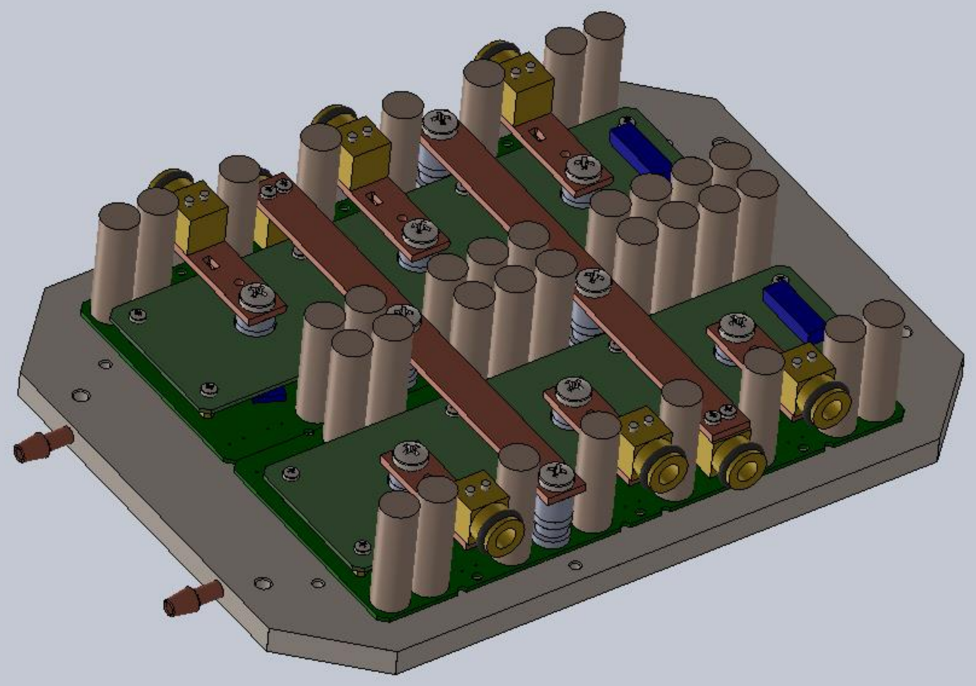
DIDIMO: 48V version (4/8)



Bus bars and spacers

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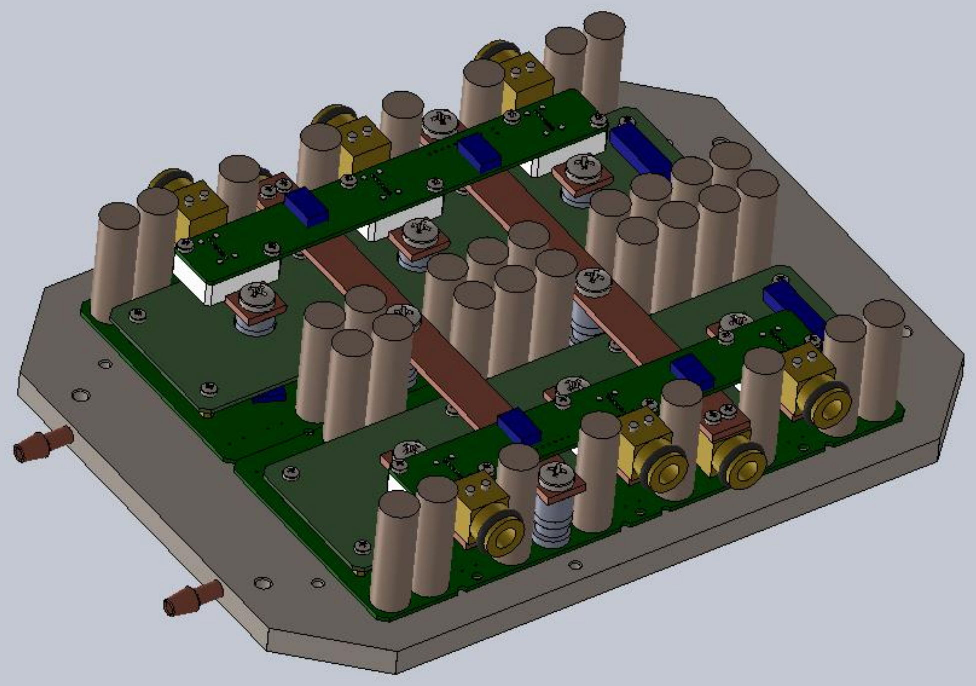
DIDIMO: 48V version (5/8)



IFX current sensors and control board

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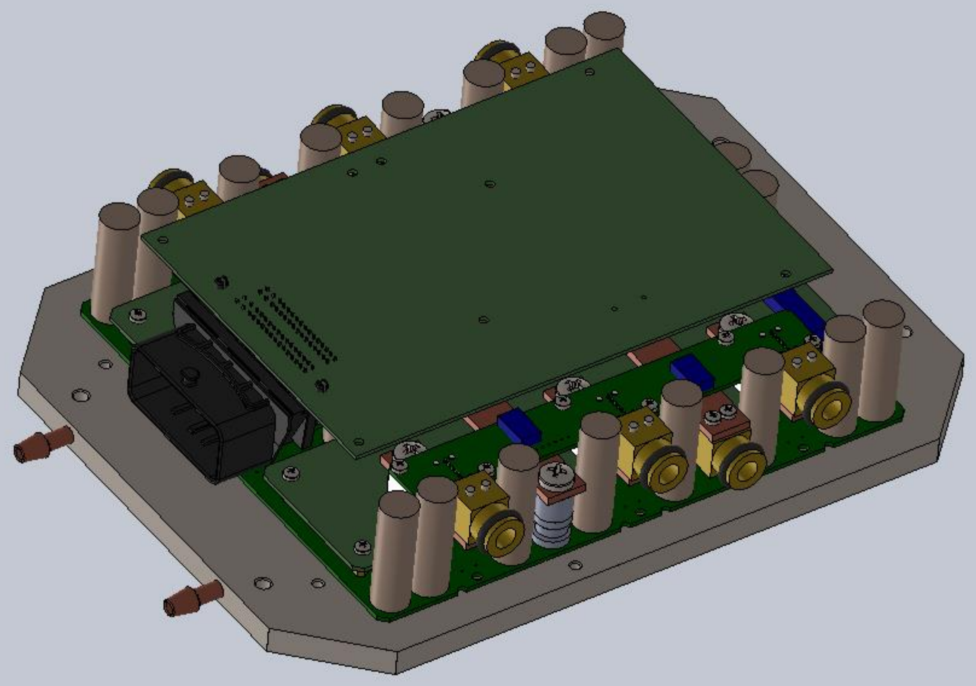
DIDIMO: 48V version (6/8)



Control board

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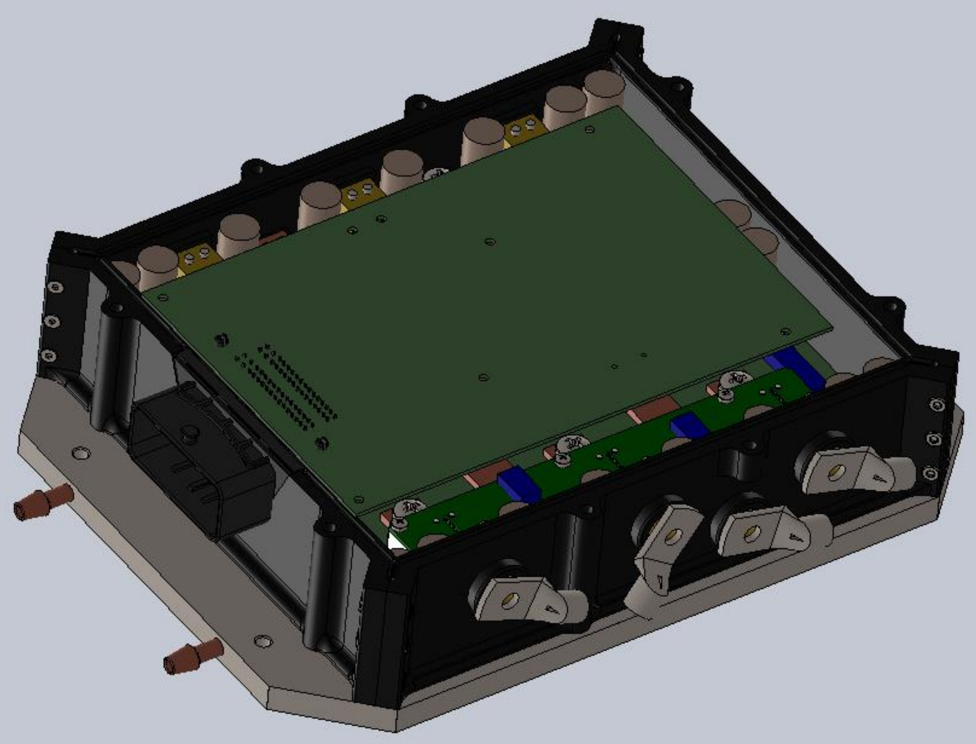
DIDIMO: 48V version (7/8)



Side walls

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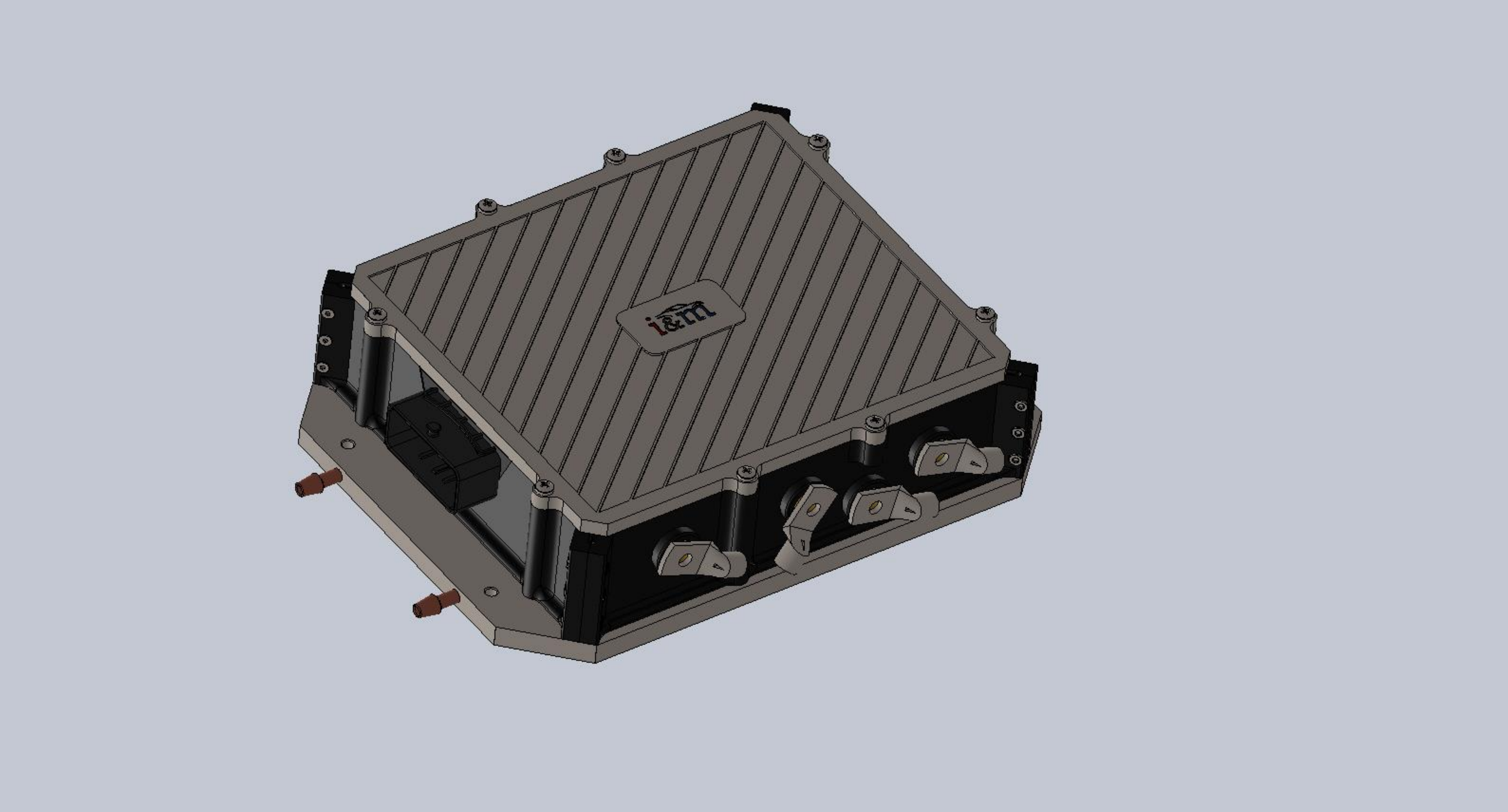
DIDIMO: 48V version (8/8)



Top cover

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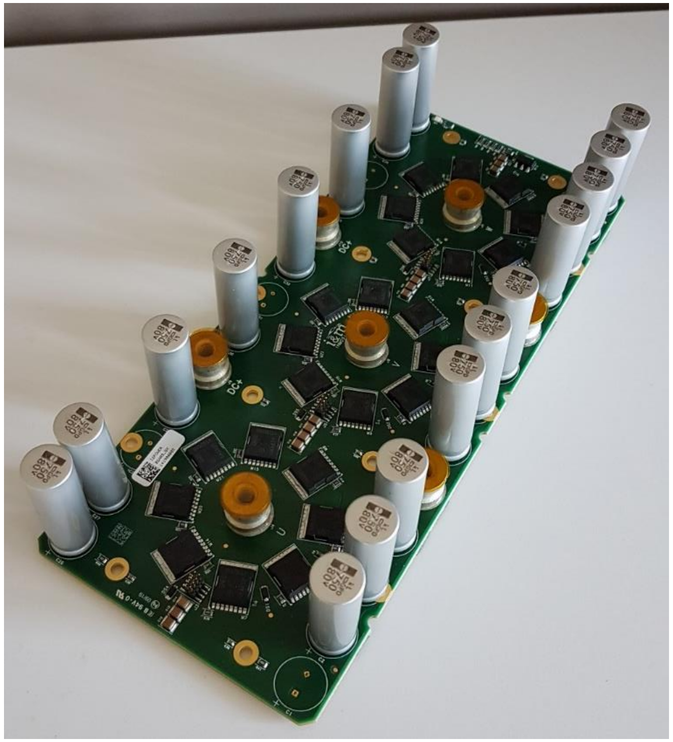
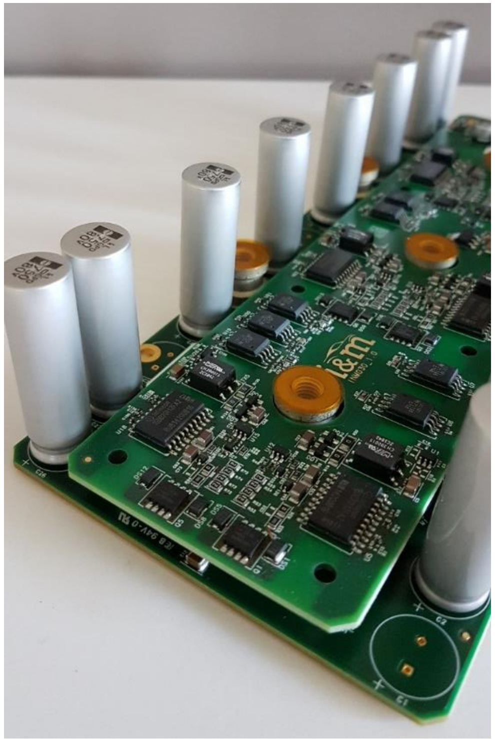
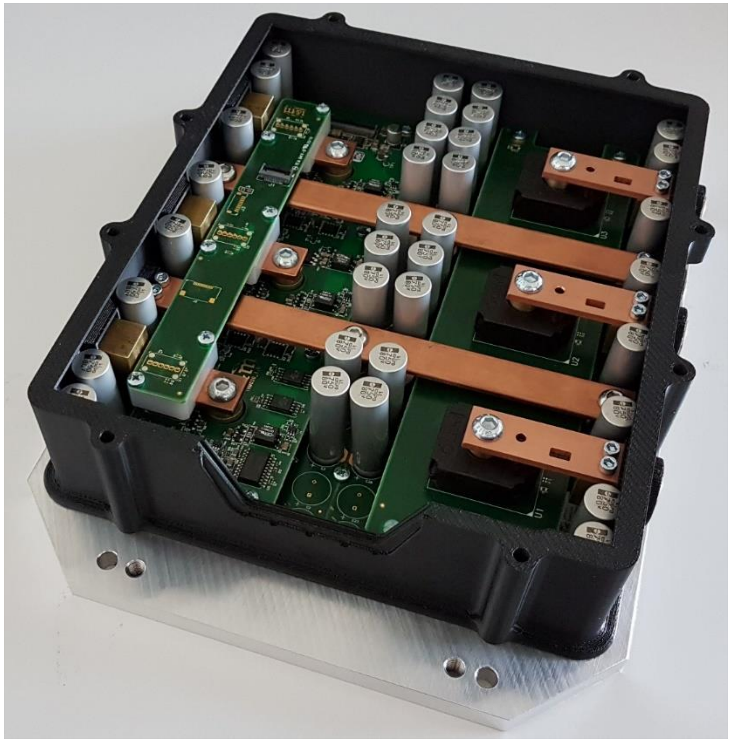
DIDIMO: prototype realisation







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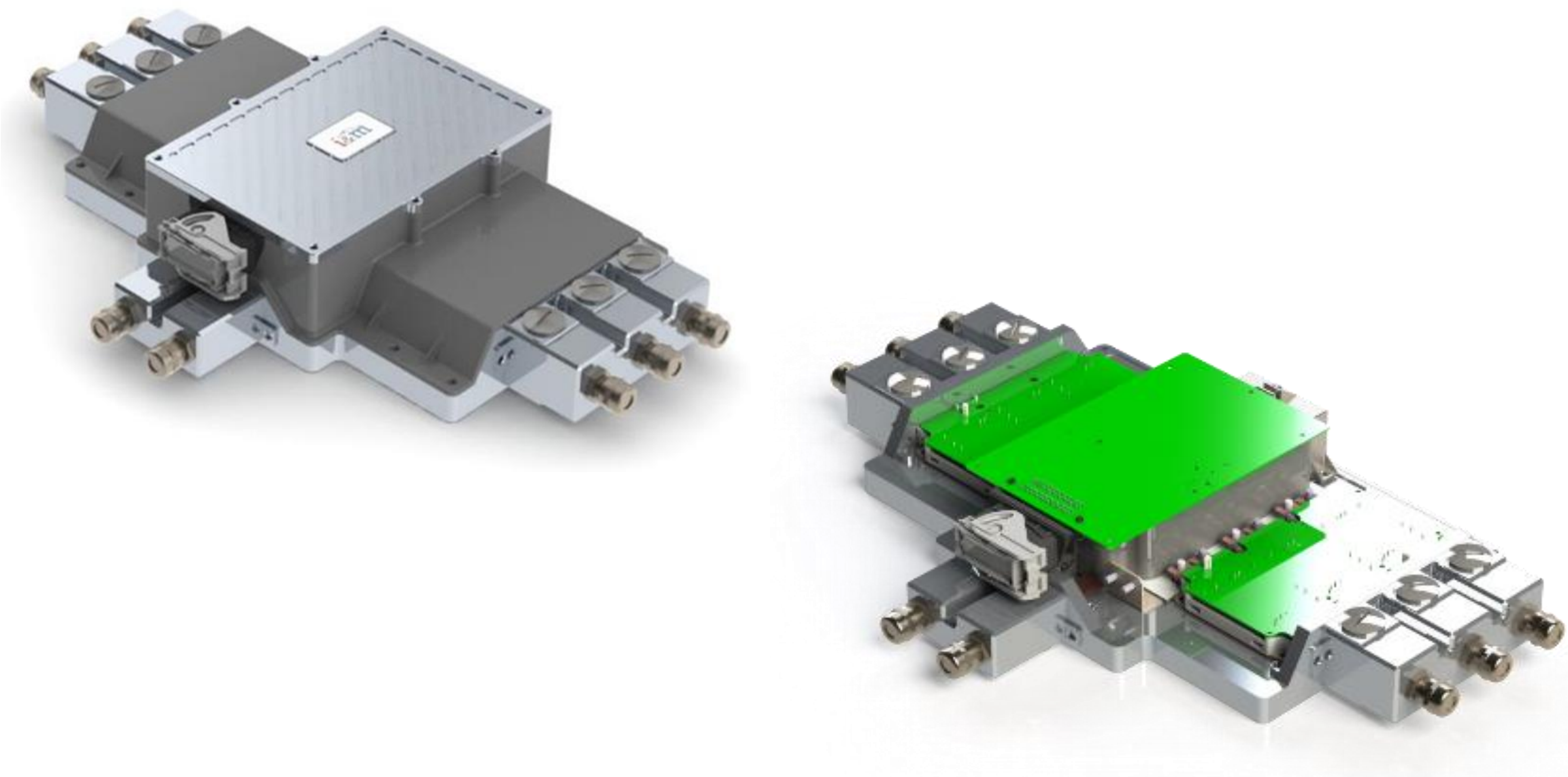
DIDIMO: high power version with SiC



Contents

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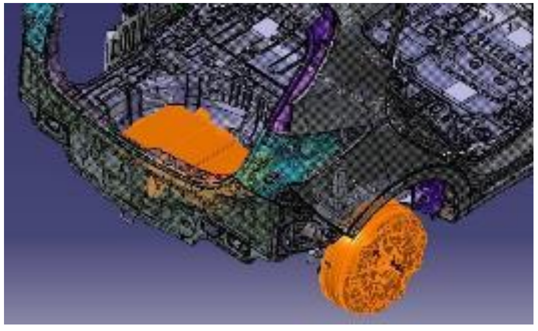
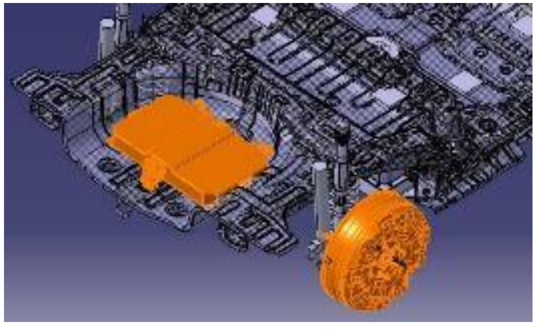
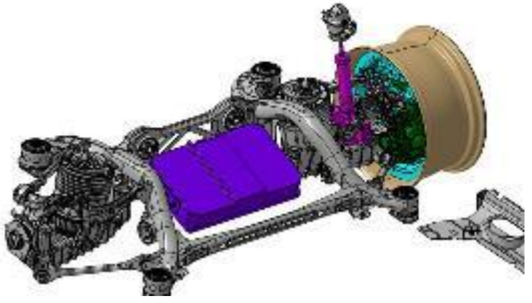
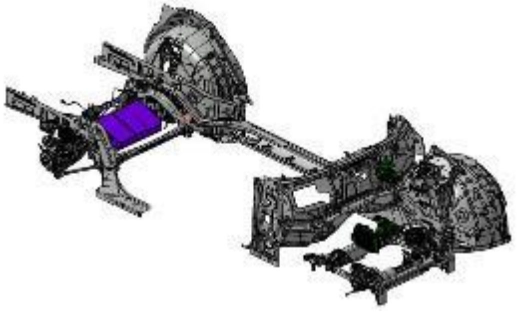
Next steps and conclusions

- The high power version is under development, with particular respect to the power stage based on SiC devices. The prototype will be available in Q1/2020 for the validation phase in the lab.
- Innovative solutions about PHM will be investigated and implemented on the dual inverter.
- The integration on the vehicles will follow, including a comprehensive test in realistic use cases.









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EVC1000

Thank you for your attention!

Riccardo Groppo

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Berlin, 30.09.2019

European Commission

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HORIZON 2020
THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION