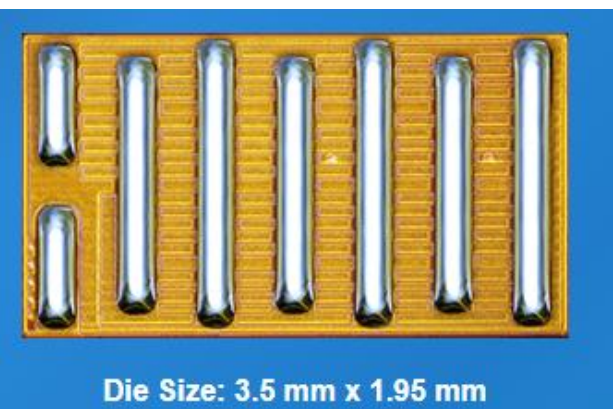


Research context and motivation

- The context of the research activity is the use of Gallium Nitride wide bandgap semiconductor transistors and integrated circuits in motor drive applications ranging from 0.1 to 100 kW. Applications may include electrical mobility, automated warehouses, collaborative robots and heavyweight lifter systems.
- The aim of the research is to find the most competitive and advanced solutions in terms of topology, component counts, reliability, lifetime, power density and weight. Particular attention is given to simplified thermal solutions and multi-level topologies.
- The research work is carried out in a multidisciplinary environment inside the Power Electronics Innovation Center of Politecnico di Torino under the supervision of EPC Italy.

EPC2206

V_{DS} , 80 V
 $R_{DS(on)}$, 3.6 m Ω
 I_D , 60 A
 Pulsed I_D , 215 A



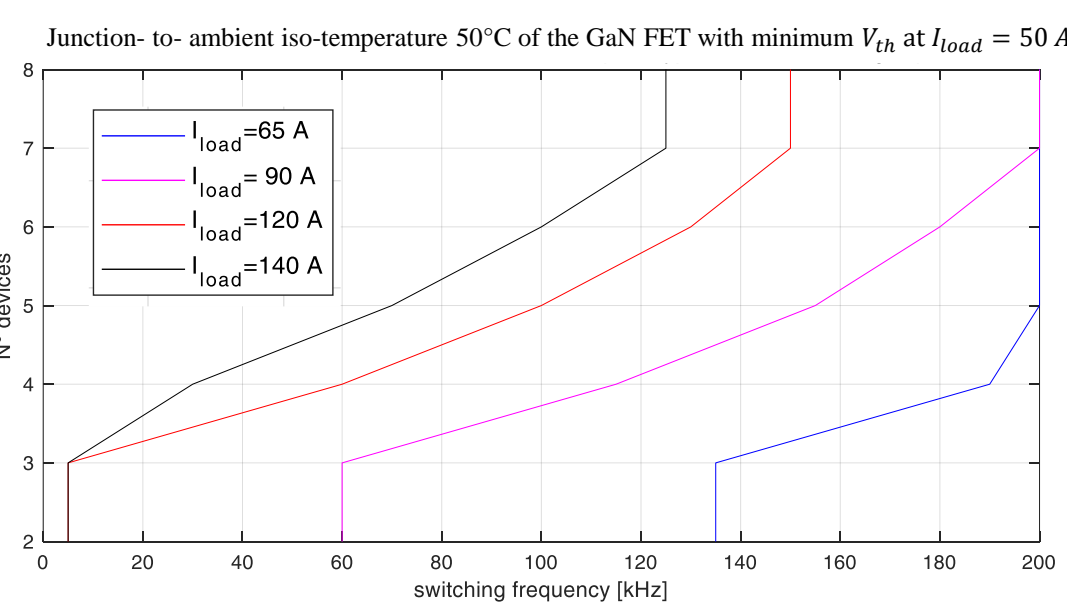
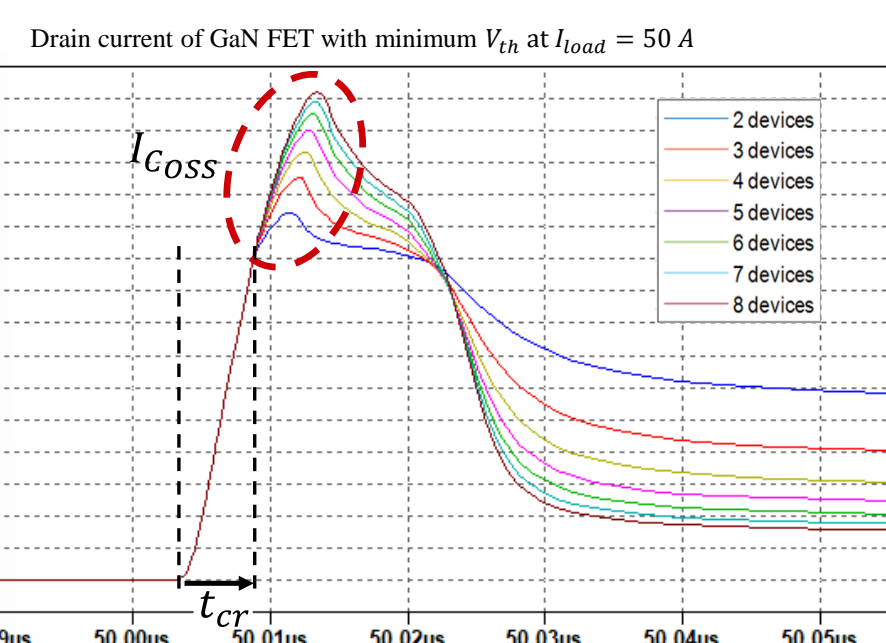
Die Size: 3.5 mm x 1.95 mm

Addressed research questions/problems

- The efficiency and power density improvement of power switching converters play a crucial role in energy conversion. In the field of motor control, this requires an increase in the converter switching frequency together with a reduction in the switching legs' dead time. The state of the art in power converter is based on devices as IGBT and MOSFET. GaN devices have appeared in the switching device arena in recent years and feature much more favorable static and dynamic characteristics compared to pure Si devices.
- Parallel connection of GaN FETs increases the current capability of the power converter but the design of the PCB layout is challenging.
- GaN FETs devices are relatively recently introduced in the wide-band-gap semiconductor (WBG) power electronics market. For this cause, the models available are not numerous and still in development.

Adopted methodologies

- LTspice simulations have been carried out in order to understand the effects on current, voltage caused by parasitic impedances.
- Peak current and thermal response when connecting in parallel more GaN FETs have been investigated. The PCB topology with its parasitic impedances has proven to cause voltage ringing on the devices and an unequal subdivision of the load current between them. Moreover, the threshold voltage has proven to be the most problematic parametric spread for parallel connection of GaN FETs. Current peak and junction heating make the device with lower threshold voltage the most stressed. Remaining below a certain switching frequency and using an appropriate number of devices is mandatory.

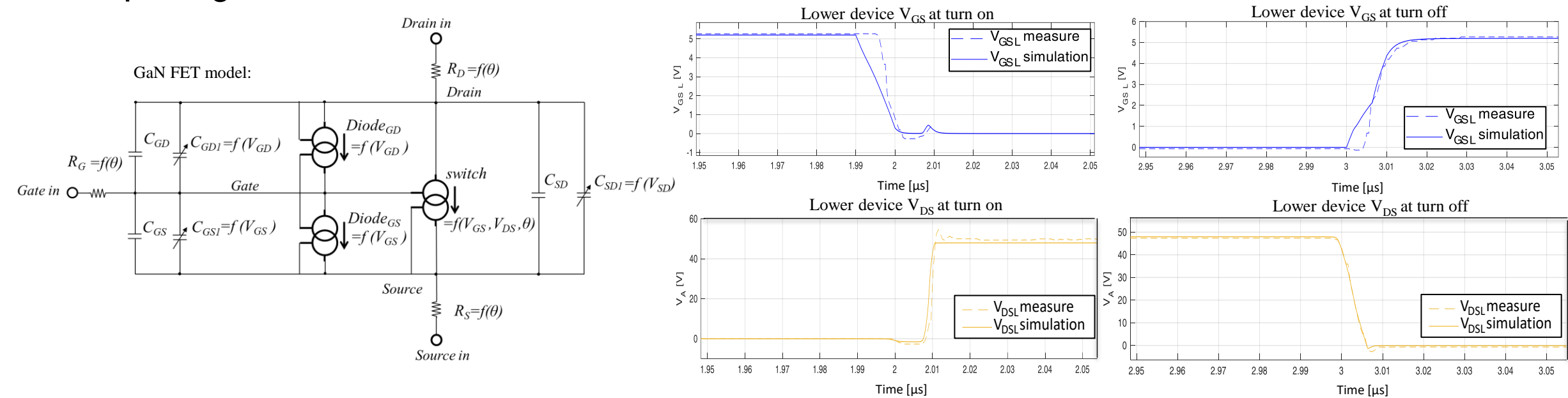


Submitted and published works

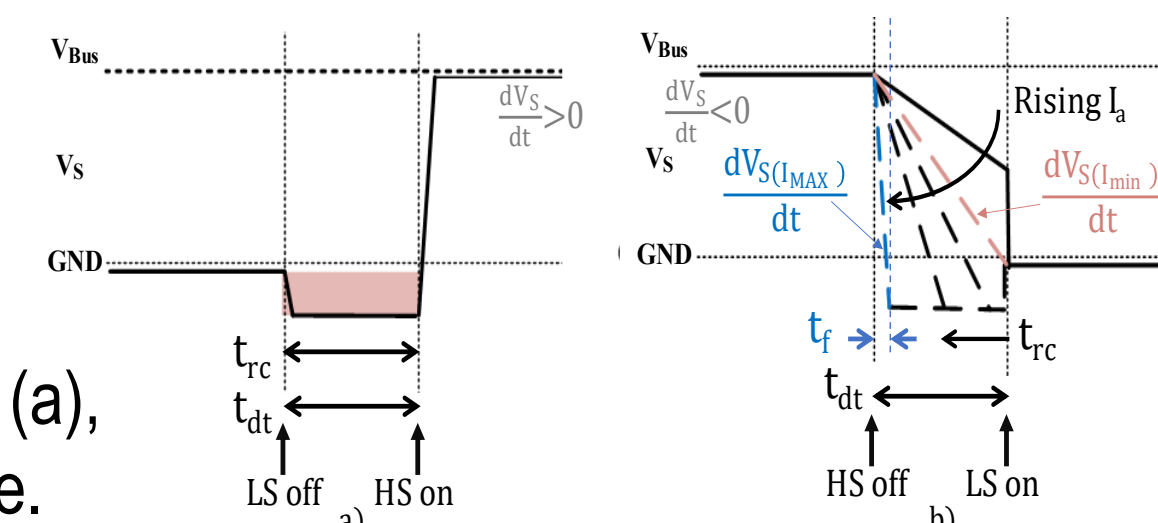
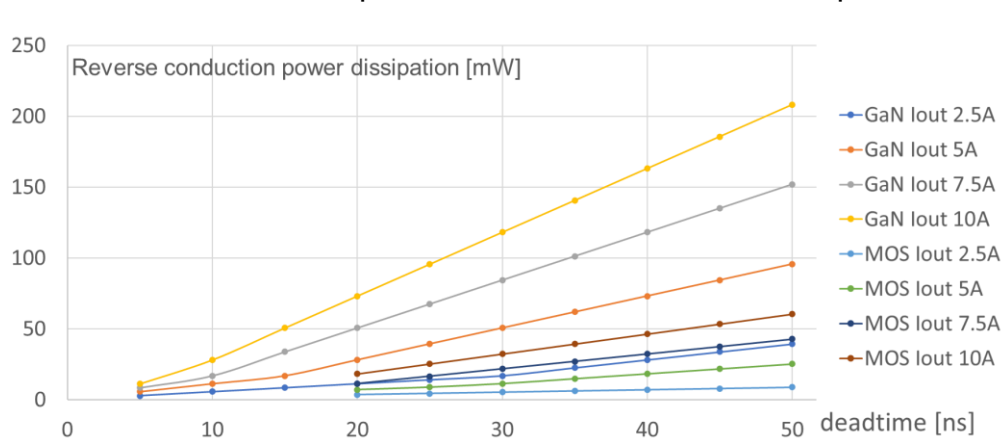
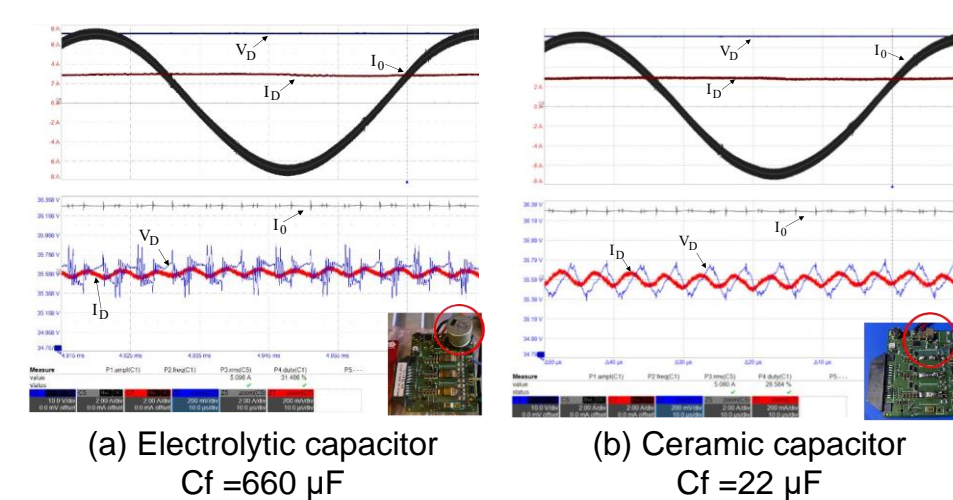
- S. Musumeci, M. Palma, F. Mandrile and V. Barba, "Low-Voltage GaN Based Inverter for Power Steering Application," AEIT International Conference on Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE), 2021, pp. 1-6
- M. Palma, S. Musumeci, F. Mandrile and V. Barba, "GaN Devices for Motor Drive Applications," IEEE 8th Workshop on Wide Bandgap Power Devices and Applications (WIPDA), 2021, pp. 146-151
- S. Musumeci, F. Mandrile, V. Barba, and M. Palma, "Low-Voltage GaN FETs in Motor Control Application; Issues and Advantages: A Review," Energies, 2021, 14 no. 19
- M. Palma, S. Musumeci, F. Mandrile and V. Barba, "Experimental Evaluation of Dead-Time Reverse Conduction Losses in Motor Drives Applications," PCIM Europe, Nuremberg, Germany, 2022
- V. Barba, S. Musumeci, M. Palma and R. Bojoi, "Maximum Peak Current and Junction-to-Ambient delta-temperature Investigation in GaN FETs Parallel Connection", GaN Marathon 2022, Venice, Italy, 2022
- V. Barba, S. Musumeci, L. Solimene, C. S. Ragusa, M. Palma and R. Bojoi, "Modelling and Experimental Validation of GaN Based Power Converter for LED Driver", 22nd annual conference of the International Conference on Environmental and Electrical Engineering (EEEIC 2022), Prague, Czech Republic, 2022
- S. Musumeci, V. Barba, F. Scrimizzi, C. Mistretta, "Advanced Low-Voltage System-in-Package Half-Bridge MOSFET with Added Protection Features", EPE ECCE EUROPE 2022, Hannover, Germany, 2022
- S. Musumeci, V. Barba and M. Palma, "GaN-Based Low-Voltage Inverter for Electric Scooter Drive System", it will appear on AEIT2022 International Annual Conference, Rome, Italy, 2022
- S. Musumeci, V. Barba, F. Mandrile, R. Bojoi and M. Palma, "Dead Time Reverse Conduction Investigation in GaN-Based Inverter for Motor Drives", it will appear on 48th Annual Conference of the Industrial Electronics Society IECON 2022 Conference, Bruxelles, Belgium, 2022

Novel contributions

- The model of the GaN FET has been built. It comes from the base model of a typical MOSFET and it is a modified property. Non-linear capacitance characteristics of GaN FET devices are modelled using semi-empirical fits to measured capacitance vs voltage data. The drain current value is modelled by a controlled current source as function of the gate voltage (V_{GS}), the output drain-source voltage (V_{DS}) and the temperature (θ). The model can represent also the reverse conduction operation. The model has been validated by comparing the simulation waveforms with those of a GaN based Buck converter.

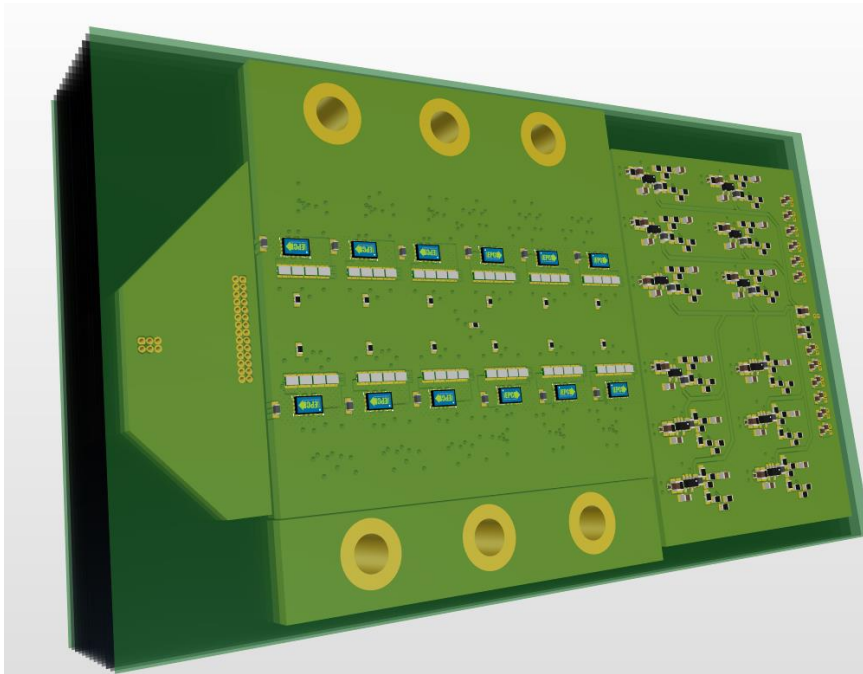


- The increasing switching frequency using GaN FETs allows to reduce the input filter size. In this way, is possible to use only the more reliable ceramic or tantalum capacitors rather than the electrolytic ones.
- The decrease in dead time is a consequence of the zero reverse recovery charge and it leads to a sinusoidal current of the motor closer to the ideal one. This lowers the motor losses and makes the torque constant closer to the theoretical one.
- In inverter leg supplying sinusoidal current, GaN FET reverse conduction behave differently depending on the current amplitude and sign and the voltage slope sign. When the device turns-on with positive current (a), reverse recovery always lasts as the dead time. When the device turns-off with positive current (b), reverse recovery is present only for high current magnitude. The dual behaviour happens with negative current values.



Future work

- Design of a board with GaN FETs connected in parallel is in progress for investigating the reliability of thermal and electrical limits.
- Design of a board for validating the GaN FET model also for thermal behaviour.
- Implementation of a dead time reduction strategy for GaN-based inverter in motor drive system aiming to reduce reverse conduction losses.



List of attended classes

- 02LWHRV – Communication (13/11/2021, 1, SS)
- 01DMJRV – Design Thinking, Processes and Methods (26/04/2022, 0.4, SS)
- 01SHMRV – Entrepreneurial Finance (14/11/2021, 1, SS)
- 01LXBRW – Life Cycle Assessment (LCA) (20/06/2022, 5, HS)
- 01DOPRO – Marine Energy (18/05/2022, 4, HS)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (04/11/2021, 1, SS)
- 01RGRV – Optimization methods for engineering problems (07/06/2022, 6, HS)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/04/2022, 6, HS)
- 08IXTRV – Project management (20/11/2021, 1, SS)
- 01RISRV – Public speaking (13/11/2021, 1, SS)
- 01SYBRV – Research integrity (09/11/2021, 1, SS)
- 01SWQRV – Responsible research and innovation... (09/11/2021, 1, SS)
- 01TSLRO – Soluzioni innovative per veicoli elettrici e/o ibridi (31/03/2022, 3, HS)
- 02RHORV – The new Internet Society... (13/11/2021, 1, SS)
- 01SWPRV – Time management (09/11/2021, 1, SS)
- 01QORRV – Writing Scientific Papers in English (16/06/2022, 3, HS)