A PCB BASED PACKAGE AND 3D ASSEMBLY FOR HIGH POWER DENSITY CONVERTERS

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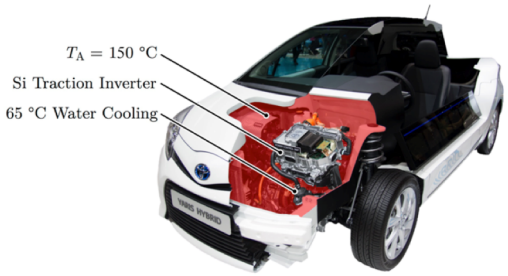
Content

- Context
- State of the art
- Power switching cell description
- Characterization results
- Use case example
- Conclusion

Context

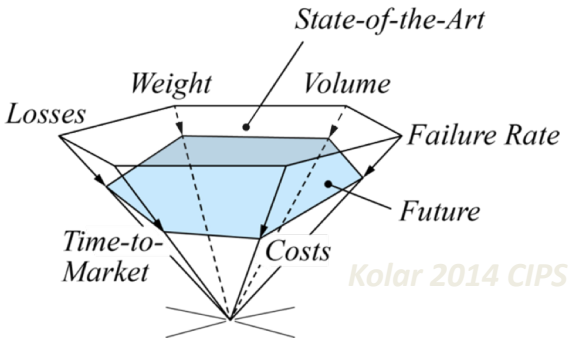
- Volumetric power density increase is a major trend in power electronics. Today, it is strongly driven by the electrification of vehicles.



Toyota Yaris 2015

- Wide band gap devices are offering a good opportunity for higher power density
  - Faster switching for smaller passive components
  - Lower losses for smaller cooling systems

- Using the complete potential of wide band-gap devices require a suitable packaging
  - Better usage of space → less air volume
  - Better interconnection for faster operation → smaller passives
  - Superior thermal performance → smaller heat sink
  - Reasonable cost → mass production

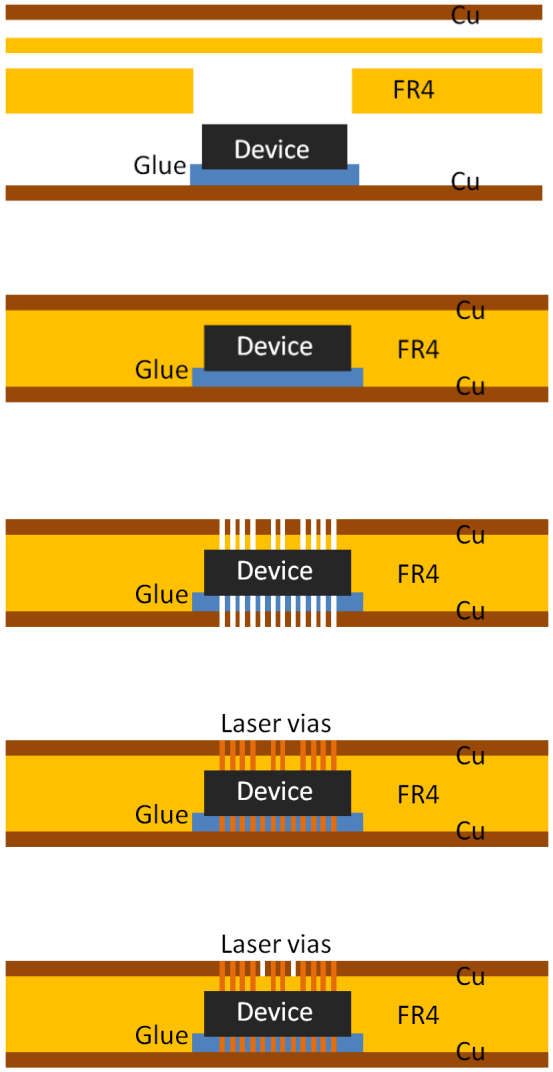


Kolar 2014 CIPS

- Objectives of this project
  - Switching cell suitable for SiC MOSFETs
  - Stand alone power switching cell
  - Easily modified according to power rating
  - Switching cell can be used for modular converters

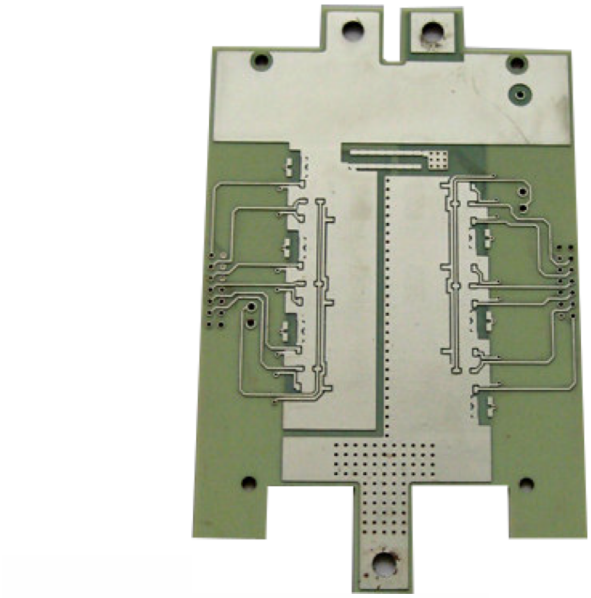
Context

- Power device embedding in PCB offers an opportunity to fulfill all the requirements for wide band-gap device packaging
- Process example (other processes exist) :
  - Glue the device on copper sheet
  - Cut FR4 sheets to create cavities with the same size of the dies and insert dies
  - Laser drill in order to expose the device pads (copper finish is required on the device pads)
  - Copper filling of the drills to make electrical and thermal connection
  - Structure the copper for a desired layout
  - Other PCB process
- PCB embedded package :
  - Shorter connection to the device
  - Less interconnection layers in the application
  - Mature and cost-controlled technology
  - Better usage of space and smaller footprint
  - Heterogonous integration
  - PCB design tools



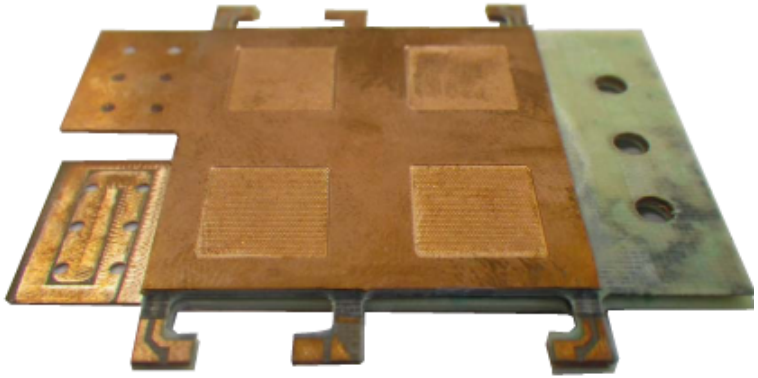
State of the art

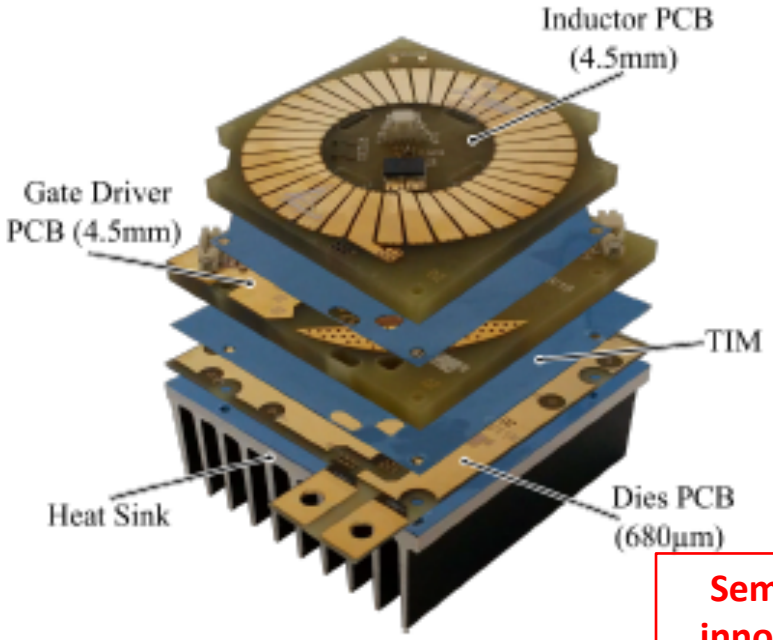
- [Hoene, and al. 2013]
  - Bus Cap on the top
  - Current sensor
  - Die embedded in the PCB



- Hi-Level Project Demonstrator
  - 10 kW and 50 kW demonstrators
  - Integration of passive and active parts
  - Die embedded in the PCB

State of the art



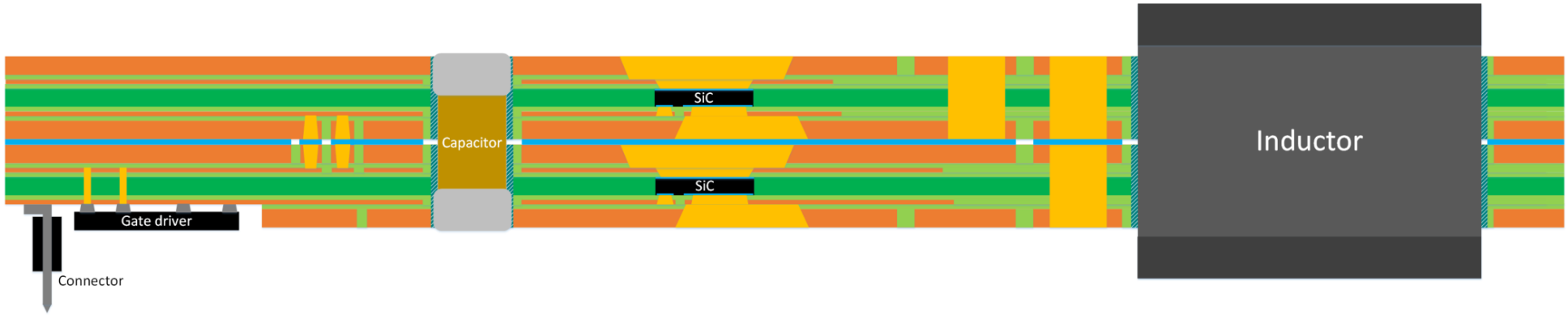


Semikron innovation award 2019

- [Regnat, and al. 2016]
  - Bus Cap on the edge
  - 3D Die embedded in the PCB

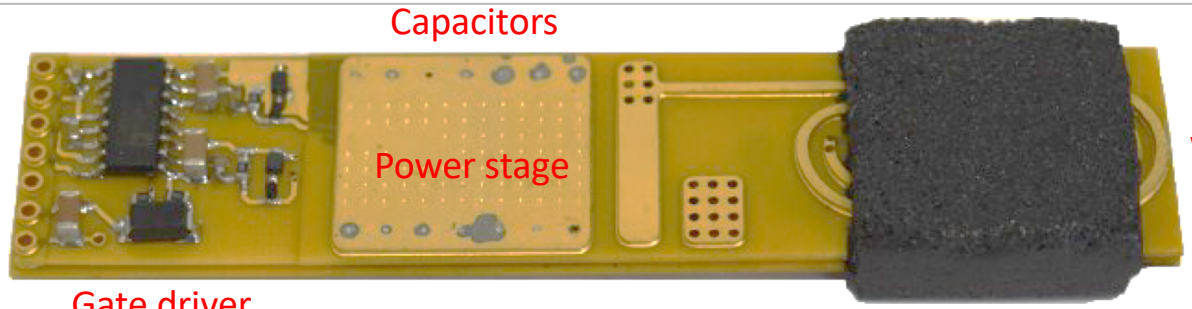
- [Caillaud, and al. 2019]
  - Die embedded in the PCB
  - Bus Cap and gate driver embedded
  - Inductor EMI filter embedded
  - 3.3 KW demonstrator

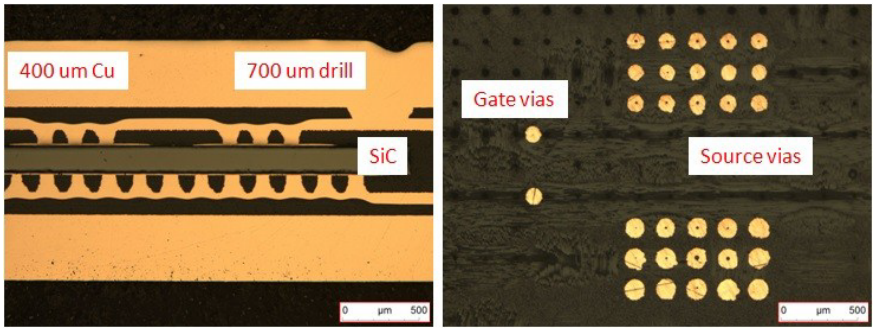
Power switching cell description



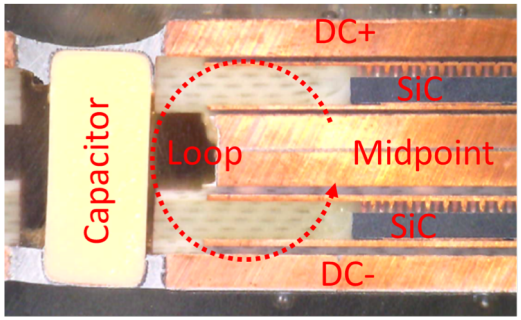
- Power stage in 3D configuration and vertical bypass capacitors
- Gate driving circuit in order to have a shorter gate connection
- Embedded switching node and shielded by DC+/DC- for less radiated EM noise
- The module has two copper thicknesses:
  - 4 x 400 µm for better thermal performance and high current carrying capabilities
  - 4 x 400 µm are also used to make the turns of the output reactor
  - 4 x 35 µm in order to access the gate pad with laser vias with high precision
  - 35 µm is also used in order to solder the gate driving circuit
- Soft compound magnetic material for a low temperature process compatible with PCB material

Manufacturing output

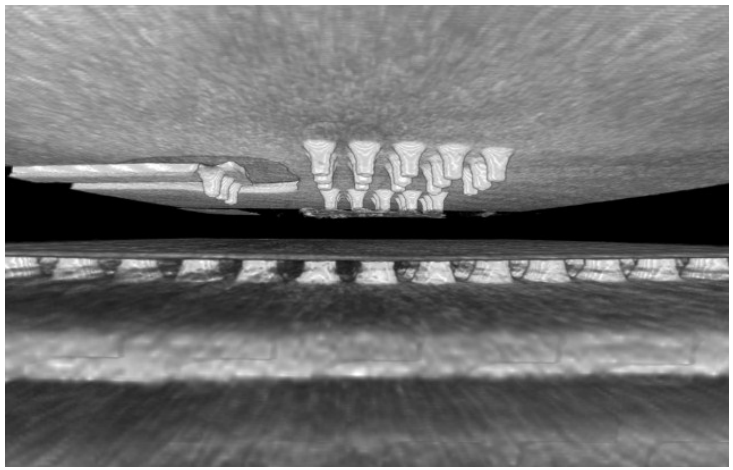


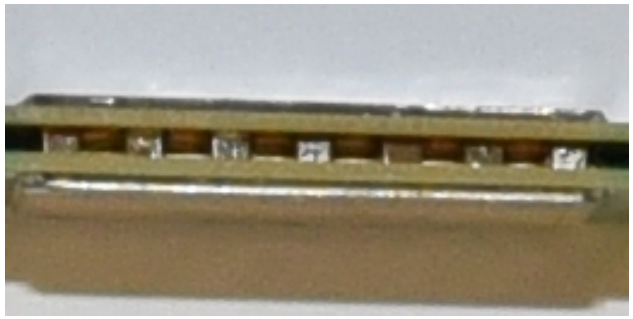


Embedded power device



3D power stage

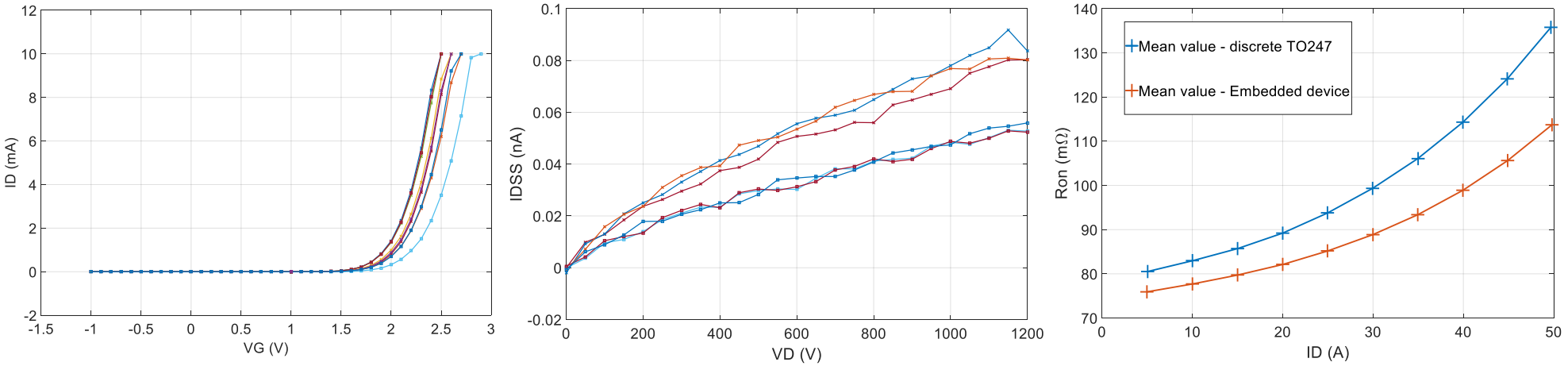




Vertical capacitor

Electrical measurements

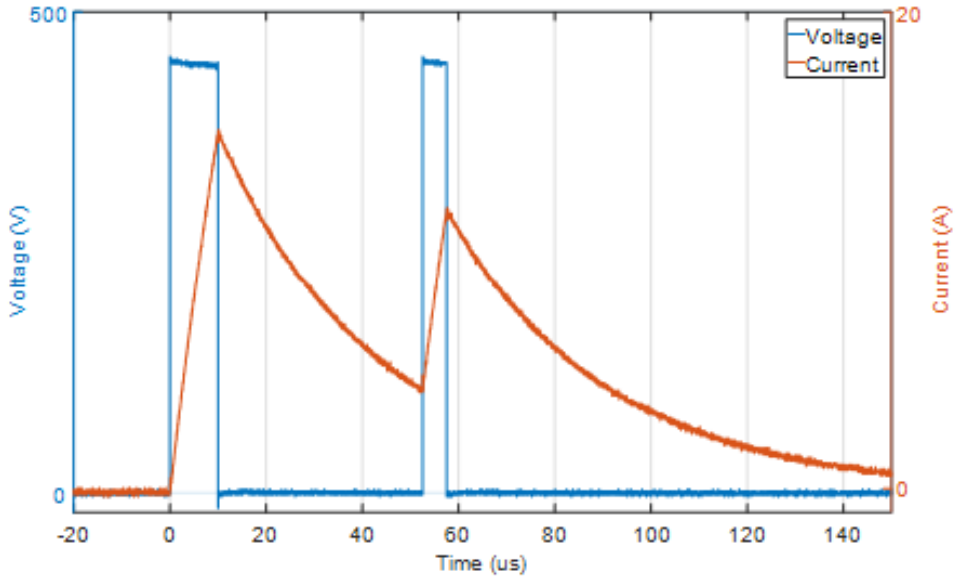
- Static electrical measurement using Keysight curve tracer in order to evaluate impact of the embedding process on the die electrical
- I_D (V_G) ; I_{DSS} (V_{DS}) and R_{ON} (I_D) are measured
- V_{th} and I_{DSS} are in the datasheet range respectively. (V_{th} [2 ; 4] ; I_{DSS} < 1 µm)
- According to the R_{ON} graph, the embedded module has 5 mΩ less resistance compared to a TO247.

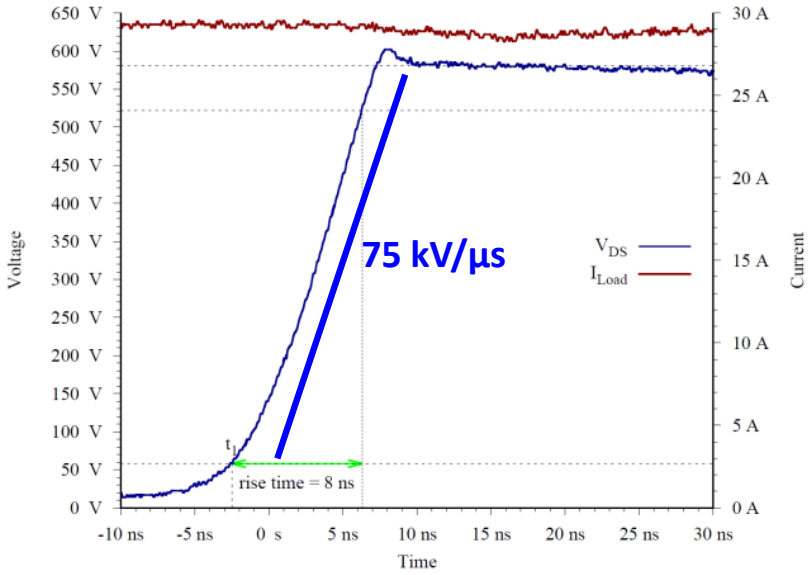


- Vertical SiC power devices are embedded successfully in the PCB substrate with 400 um thick copper

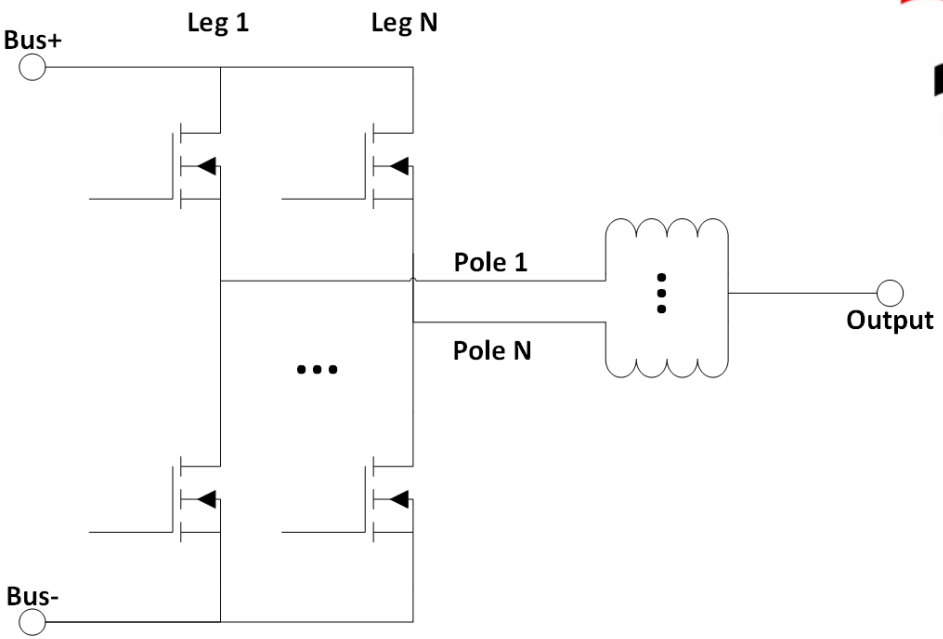
Switching test

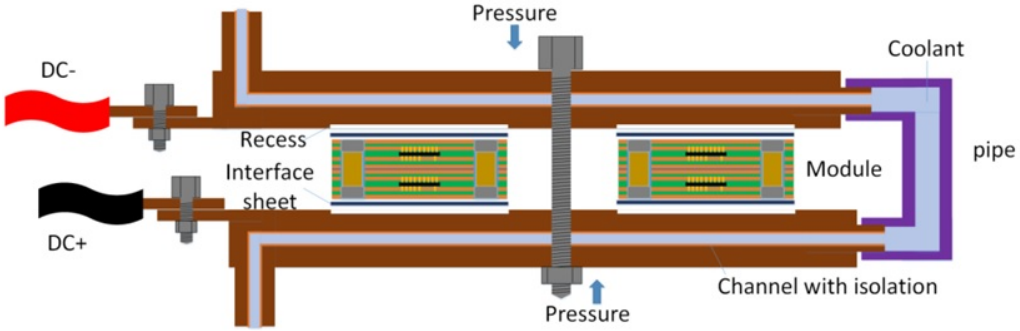
- Double pulse test with an inductive load is done on the embedded module to evaluate its switching behavior
- The double pulse test is successful with ON/OFF switching on the top/bottom switches and conduction of the body diode
- The cell is able to switch very fast (8 ns) thanks to it's sub-nH loop inductance and the very short gate connection for a small gate loop inductance
- Complete absence of ringing or overshoot can be seen on the switching edge even with vey fast switching

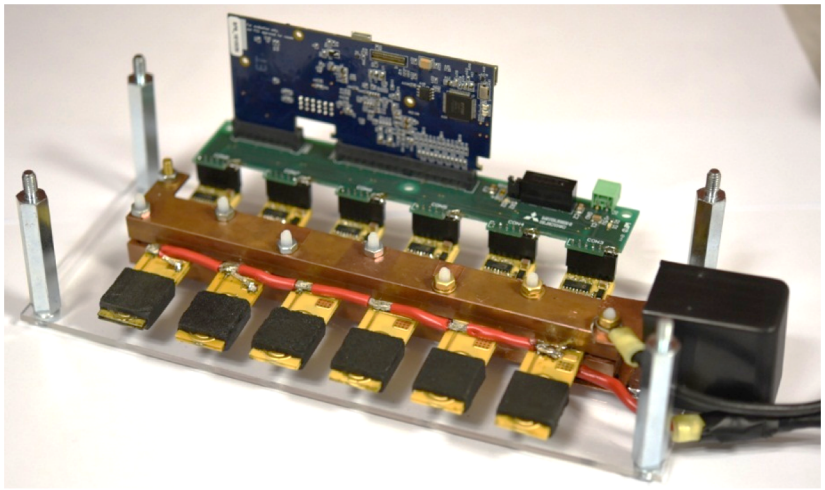




Use case example

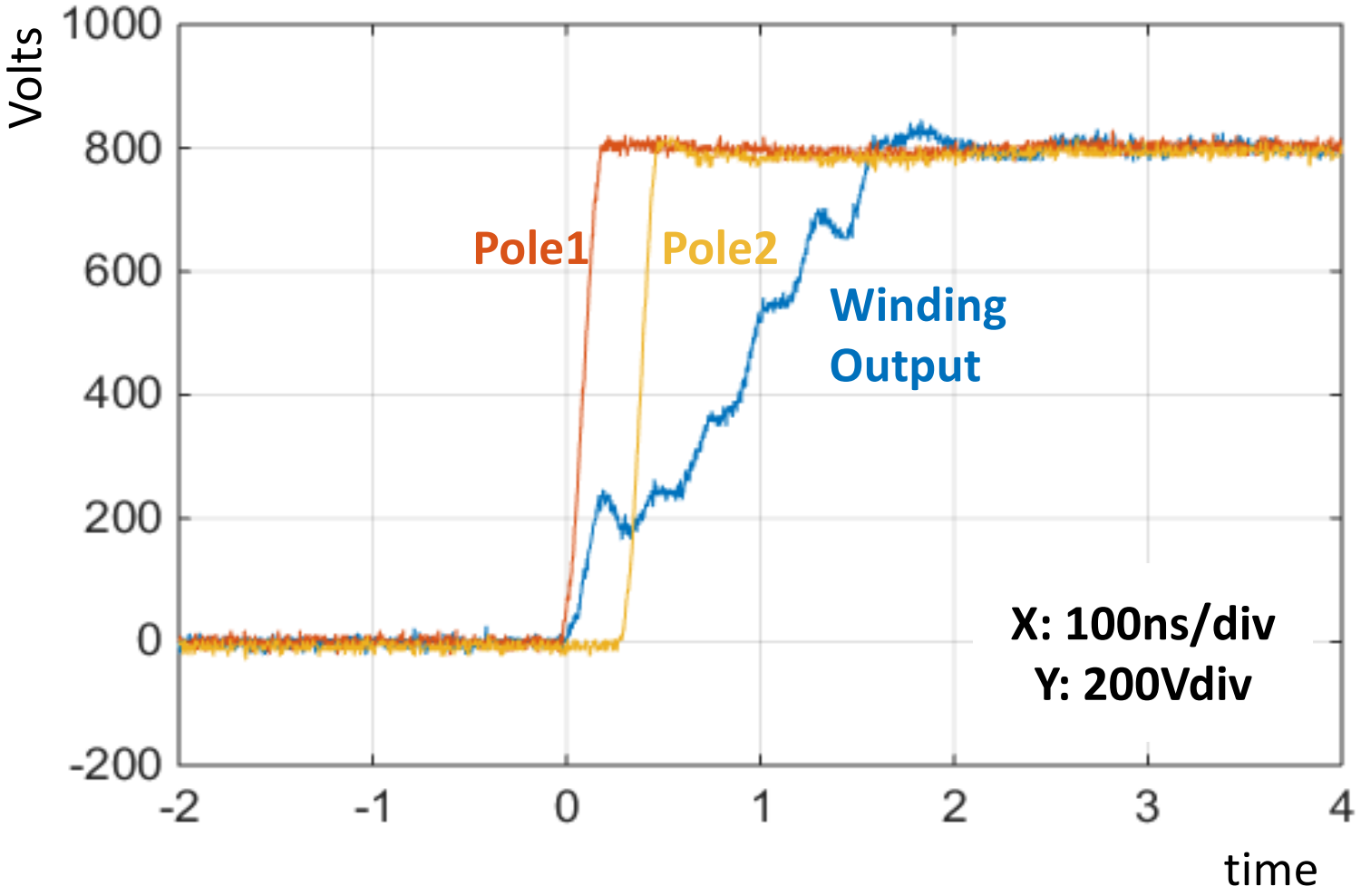






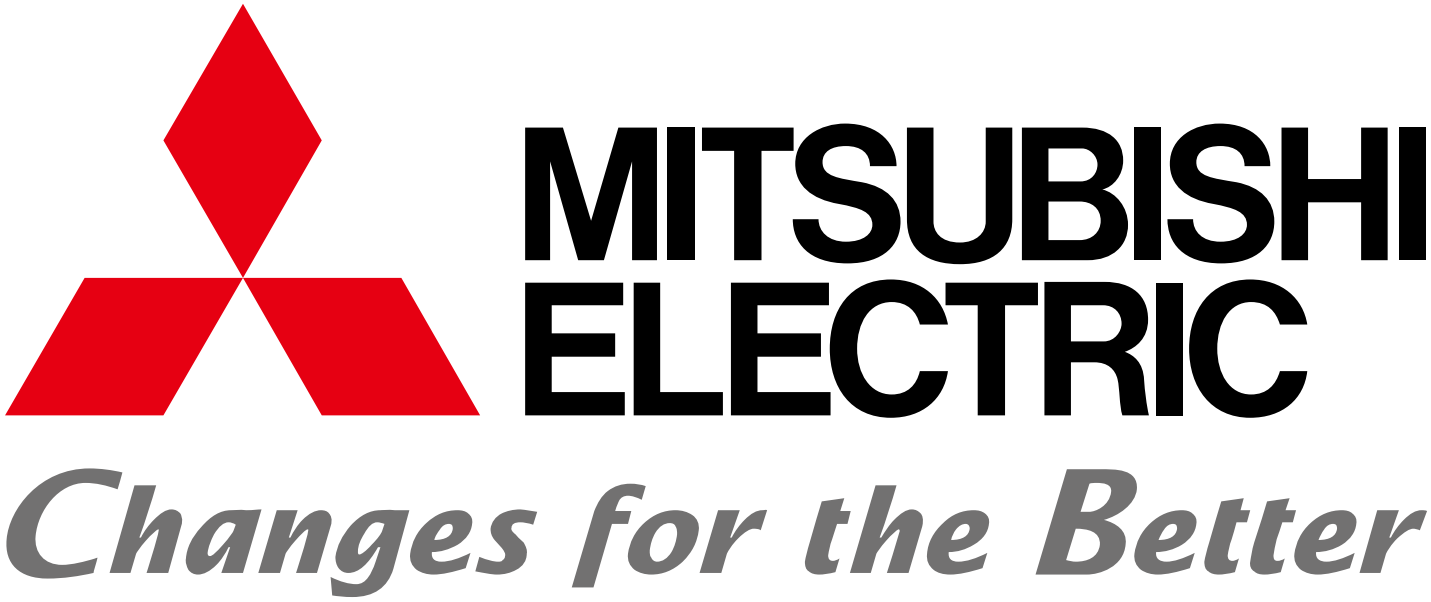
- High dV/dt provoke a degradation of the motor winding isolation
- Staved-off power switching can be used to reduce dV/dt on the motor winding
- Fast switching transitions at the module level and slower switching at output level
- Six parallelized power switching cell for 7 levels staggered switching edge

Results



Conclusion

- A 3D power switching cell is designed and manufactured
- It is suitable for the wide band-gap devices and for modular converters
- The electrical characterization shows a successful embedding of the power devices in the PCB substrate
- Double pulse test shows a very clean switching behavior of the switching cell with a total absence of ringing or overshoot
- A staved-off switching is presented as example of the module utilization
- It shows a slow switching at the output even with very fast switching at the module level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