

Integrated packaging allows for improvement in switching characteristics of silicon carbide devices

Cyril BUTTAY¹, Khalil EL FALAH¹, Rémi ROBUTEL¹,
Stanislas HASCOËT¹, Christian MARTIN¹, Bruno ALLARD¹,
Mark JOHNSON²

¹ Laboratoire Ampère, Lyon, France

² University of Nottingham, UK

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Introduction

Analysis of the switching cell

Design improvements

- Integration of the gate driver

- Low inductance packaging

- Integration of common-mode filtering

Conclusion

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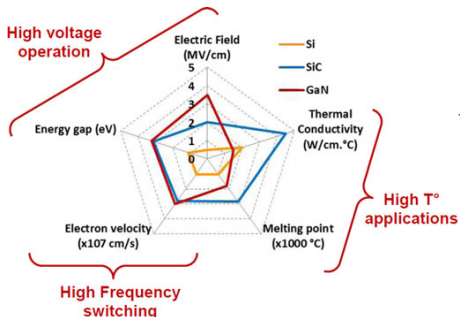
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Conclusion

New components...



- ▶ SiC (and GaN) devices are becoming available;
- ▶ Faster than Si;
- ▶ Can manage higher voltage/current density.

Millán, J. et al. A Survey of Wide Bandgap Power Semiconductor Devices IEEE transactions on Power Electronics, 2014, 29, 2155-2163

... but old issue

- ▶ Circuit parasitics cause:
 - ▶ increase in power dissipation;
 - ▶ EMC issues (ringing, common mode);
 - ▶ Investigated for Si IGBTs and MOSFETs:
 - ▶ Power modules with reduced inductance;
 - ▶ Busbar structures;
 - ▶ Development of cabling modelling tools (Q3D, InCa, ...);
- Faster SiC makes it necessary to go further.

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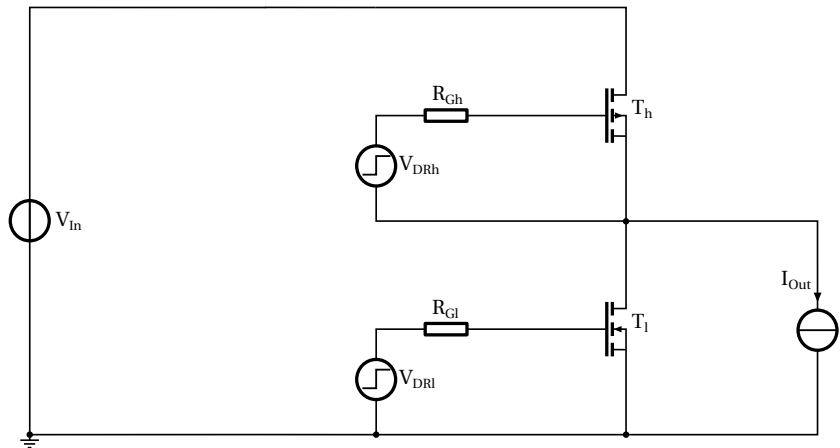
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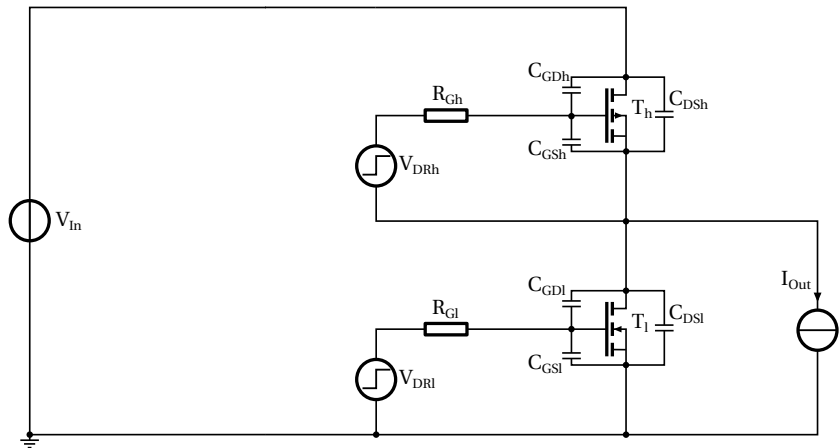
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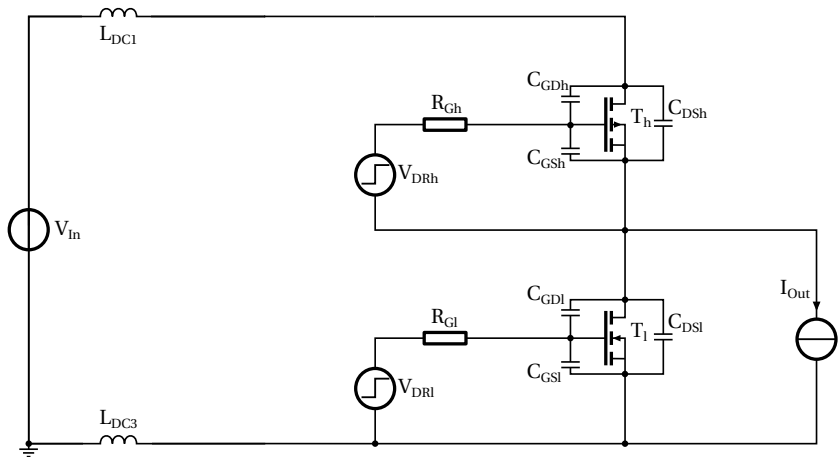
Inverter switching cell



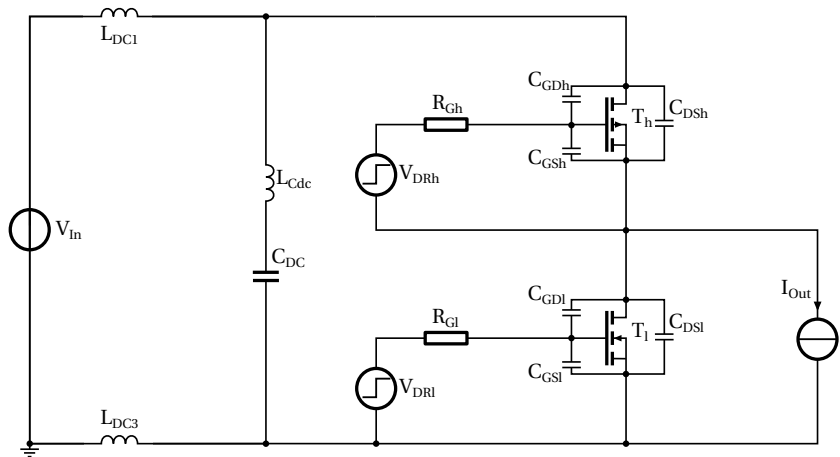
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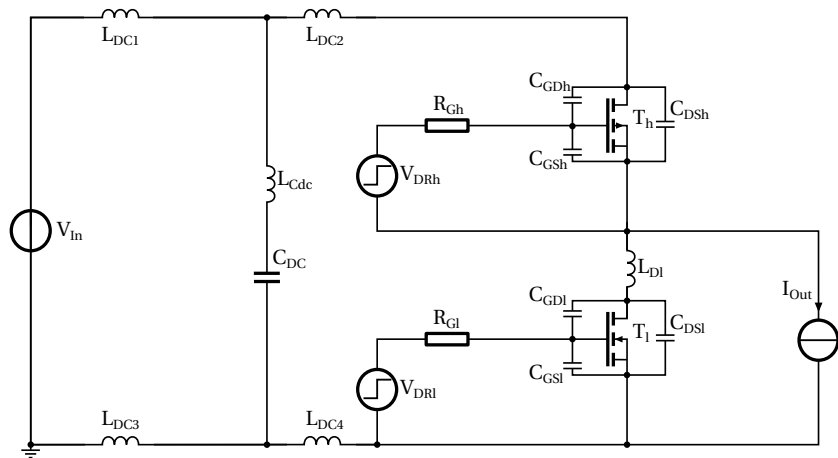
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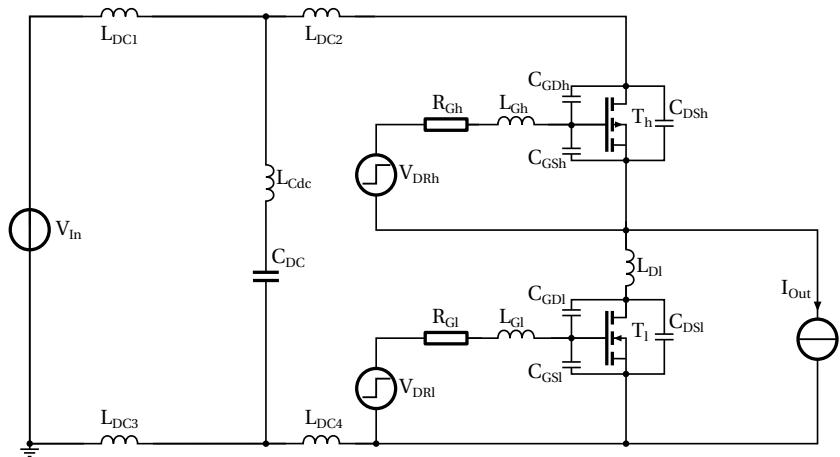
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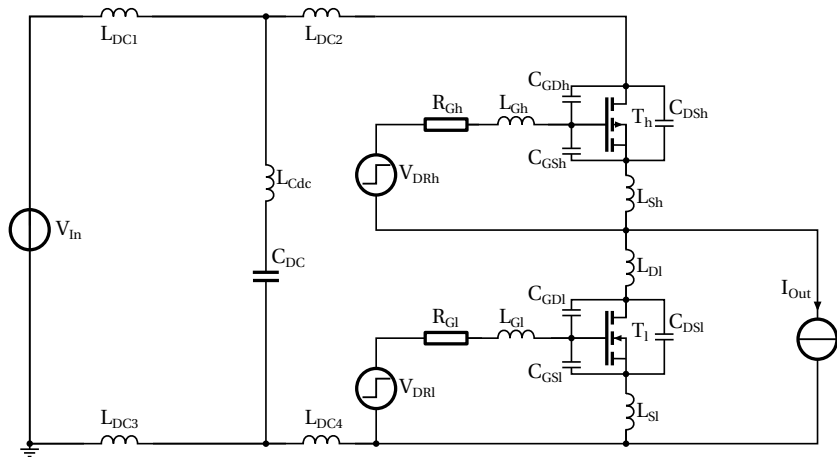
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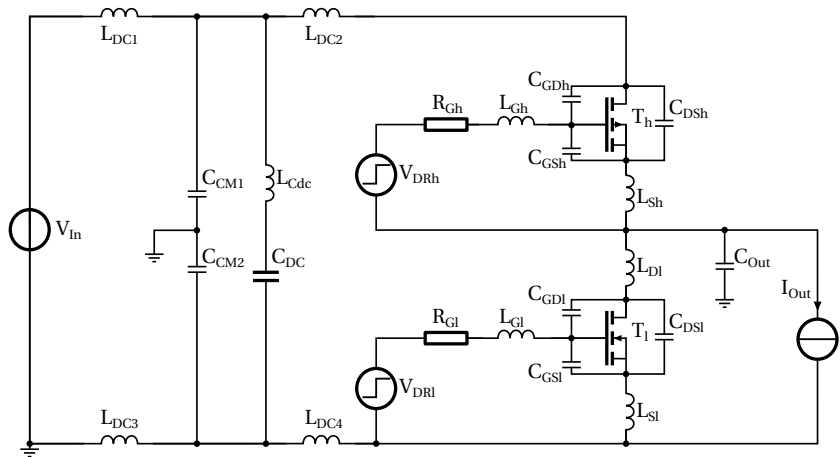
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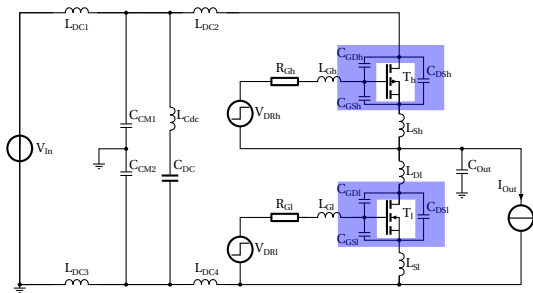
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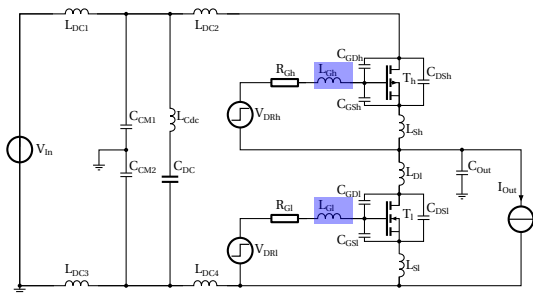


Devices capacitances



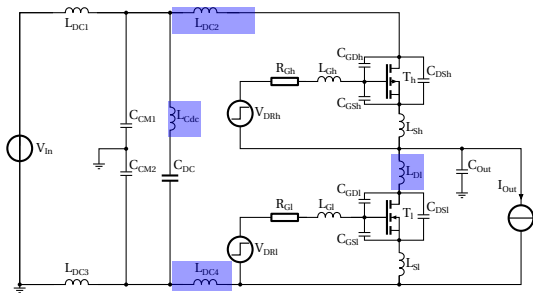
- ▶ From 100s of pF to few nF, but non-linear;
- ▶ Tend to be larger for SiC than for Si;
- ▶ Slow down switching;
- ▶ May oscillate with stray inductances;
- ▶ Increase power dissipation (charge in control and power circuits) .

Gate inductance



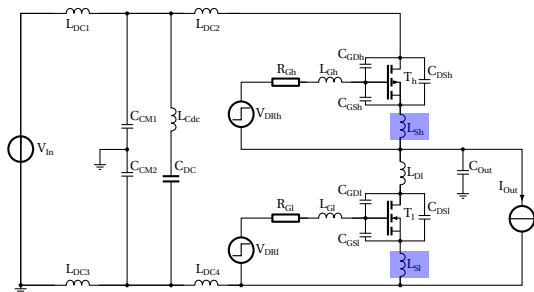
- ▶ Slows down switching;
- ▶ May oscillate with C_{iss} ;
- ▶ May cause spurious turn-ons if impedance is too high;
- ▶ Often large (100 nH) because drivers are kept on separate boards

Drain inductance



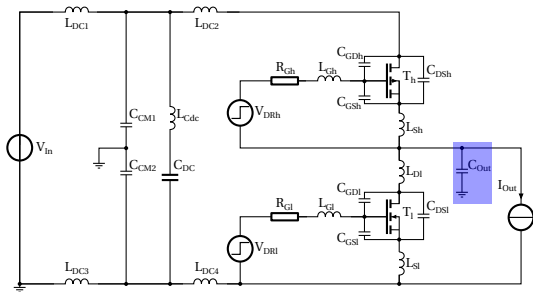
- ▶ The energy stored ($\frac{1}{2}LI^2$) is dissipated in the switches;
- ▶ May oscillate with C_{OSS} , or cause avalanche;
- ▶ Often relatively large because capacitors are kept on separate board.

Source inductance



- ▶ Combines the effects of L_G and L_D ;
- ▶ Introduces a negative feed-back that opposes (slows-down) turn-on and turn-off;
- ▶ Usually small (a few nH), but large consequences due to feed-back;
- ▶ A small value has a damping effect.

Output capacitance



- ▶ Offers an alternative (and un-controlled) path to HF signals;
- ▶ From a few 10s of pF (small copper track on a DBC substrate) up to several nF (load connected through a shielded cable);
- ▶ Requires input filtering.

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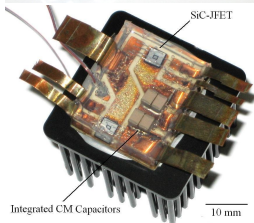
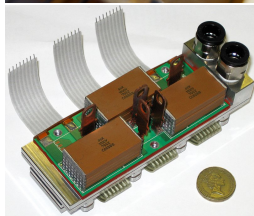
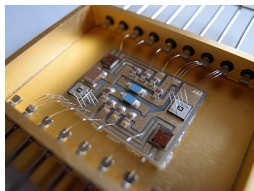
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Design Improvements – Overview

Prototypes designed for high temperature

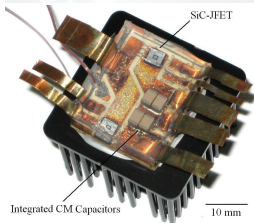
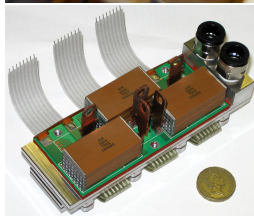
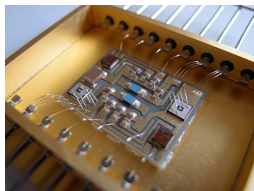
- ▶ Active devices:
 - ▶ SiC power devices;
 - ▶ high temperature control electronics;
 - put control and power on same substrate
- ▶ Sometimes need for efficient Cooling:
 - dual-side cooling (sandwich packaging)
- ▶ Few passive technologies available
 - fast switching for reduced filtering
 - integrated filtering for further reduction



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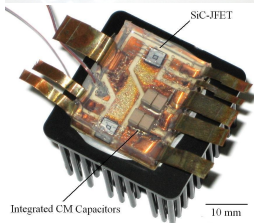
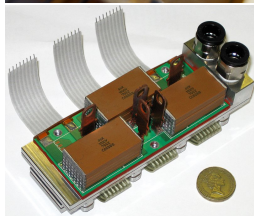
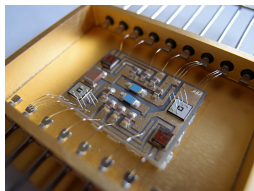
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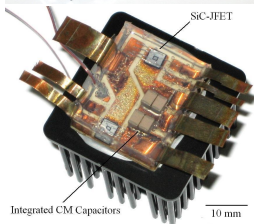
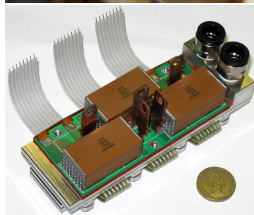
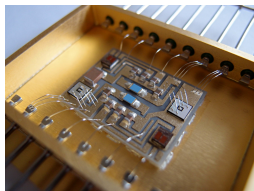


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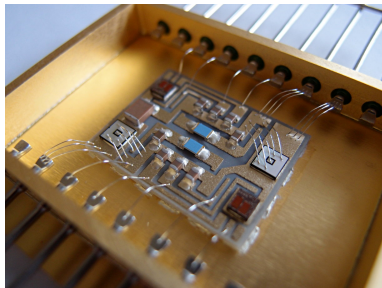
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Fast switching is attractive for high temperature electronics.

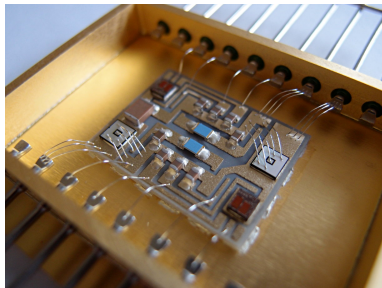


Integration of the gate driver – 1



- ▶ Short control loop;
- ▶ Temperature capability of SOI;
- ▶ High temp.-rated passives (>200 °C);
- ▶ High-temp. packaging solutions.

Integration of the gate driver – 1

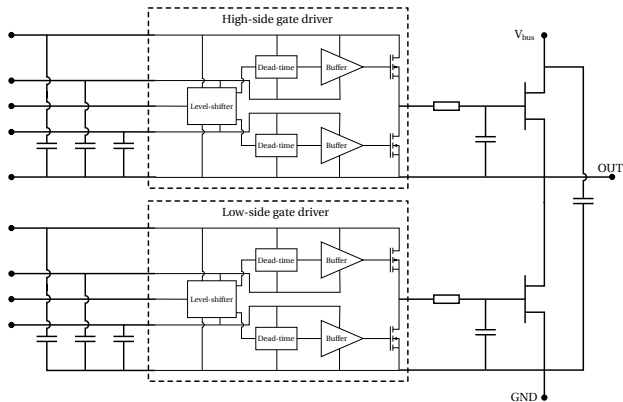


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but some “standard” technologies:

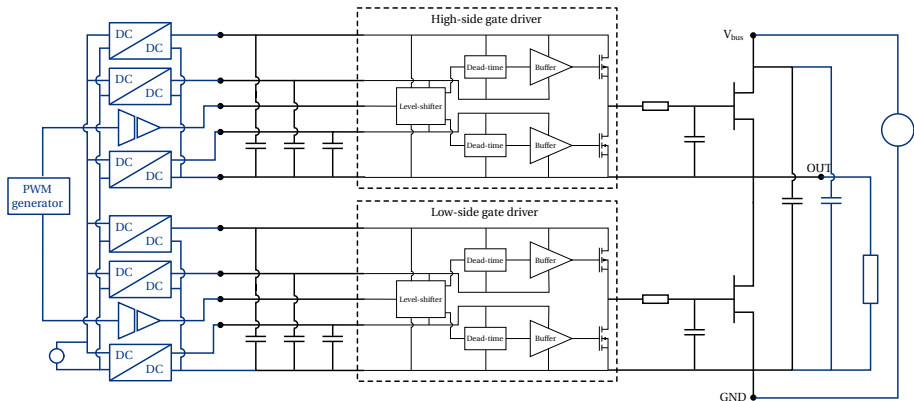
- ▶ Wirebonding;
- ▶ Hermetic case with long leads.

Integration of the gate driver – 2



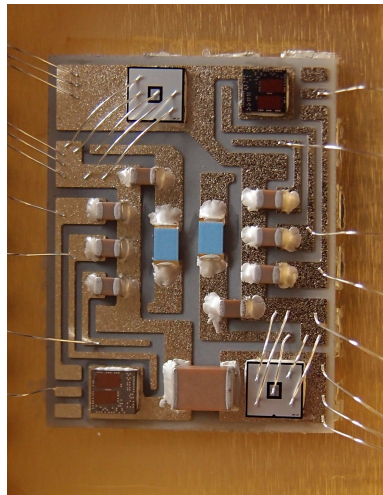
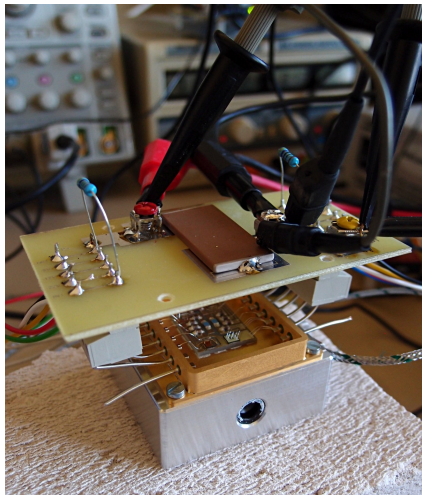
Included: Power devices, small DC decoupling, driver output stage;
External: isolation, signal generation, main DC decoupling.

Integration of the gate driver – 2

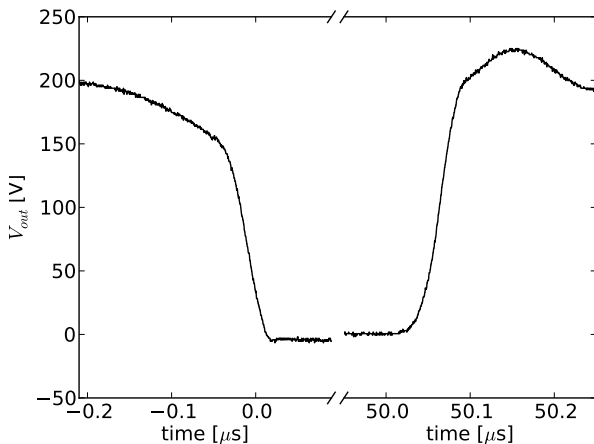


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Integration of the gate driver – 3



Integration of the gate driver – 4



- ▶ Fast rising time (15 ns) with little ringing;
- ▶ Operation proven up to 310°C ambient!

Low inductance packaging – 1



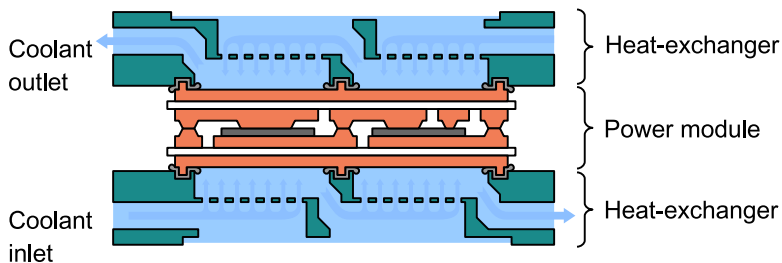
- ▶ Dies soldered to two DBC substrates to form a “sandwich” module;
- ▶ Power module clamped between heat-exchangers;
- ▶ Connection to DC capacitors using a low inductance link (busbar).

Low inductance packaging – 1



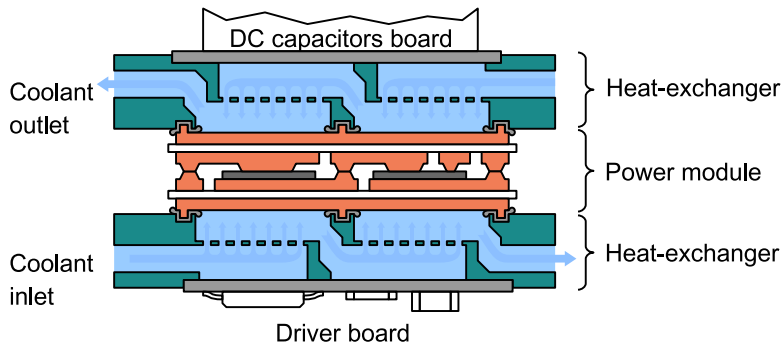
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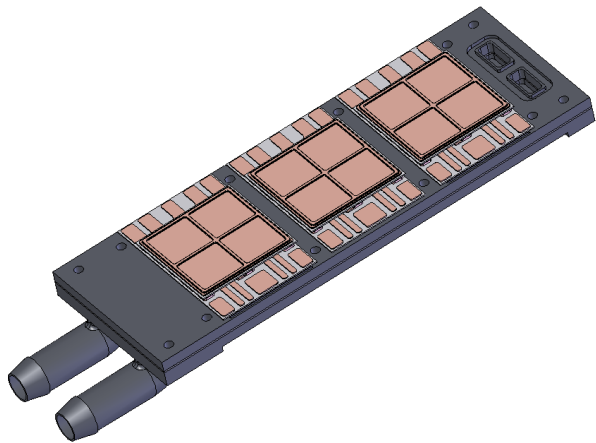
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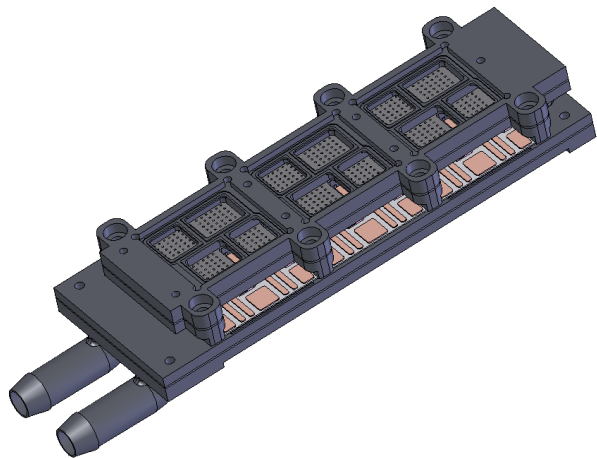
- ▶ “top” heat-exchanger;
- ▶ power modules
- ▶ “bottom” heat-exchanger;
- ▶ driver boards;
- ▶ driver interconnects;
- ▶ driver cover
- ▶ capacitor board;
- ▶ power terminals;
- ▶ busbar;
- ▶ capacitor cover.

Low inductance packaging – 2



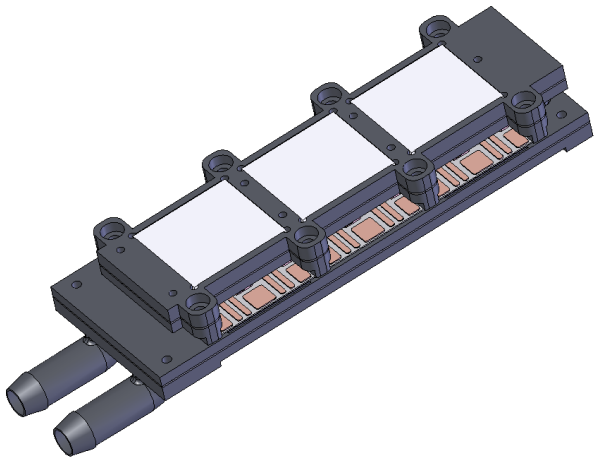
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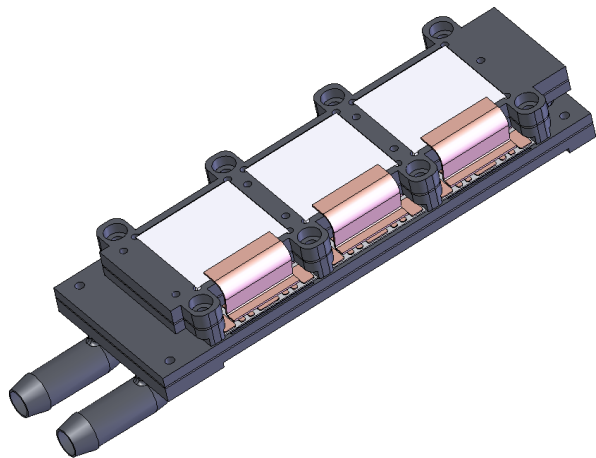
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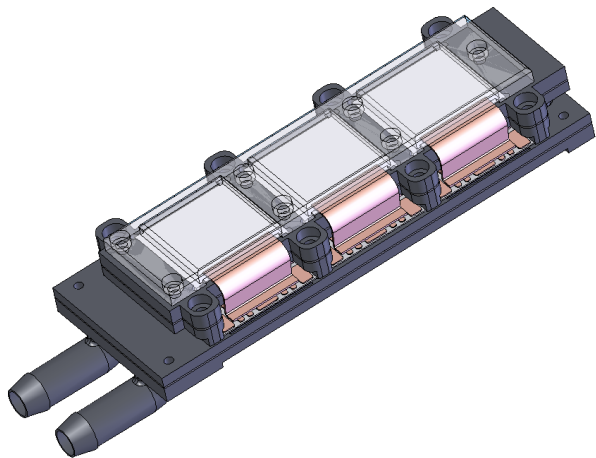
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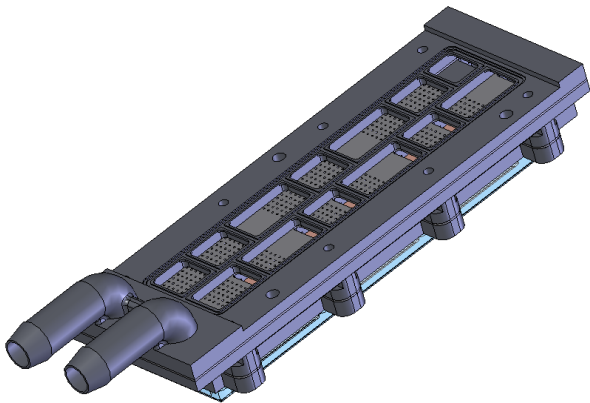
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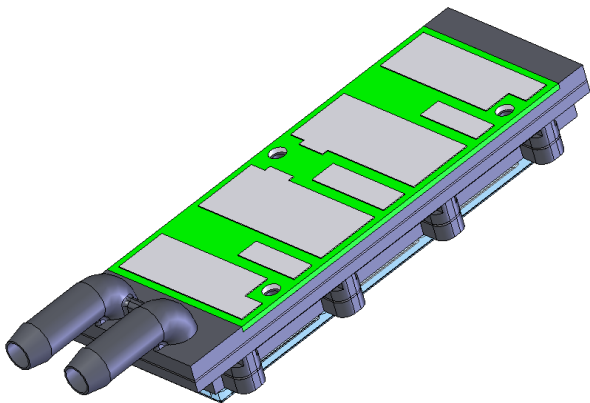
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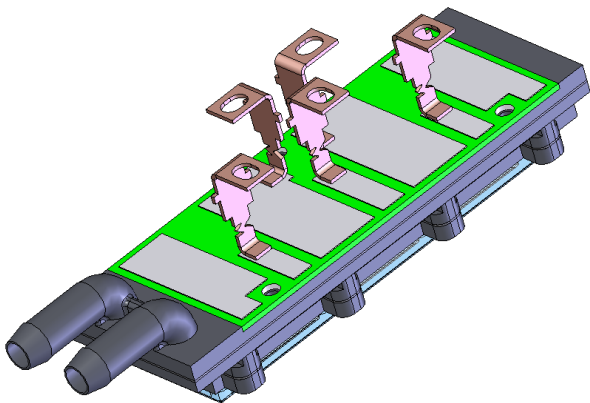
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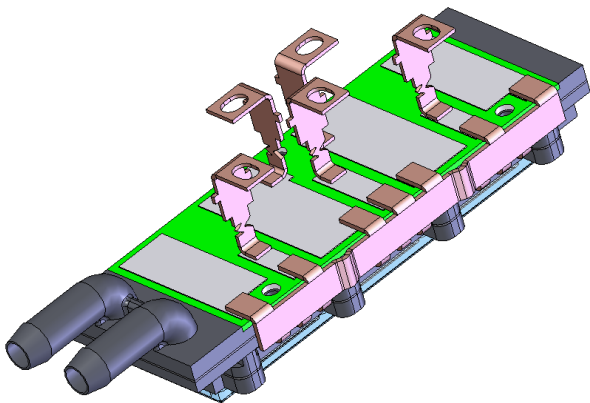
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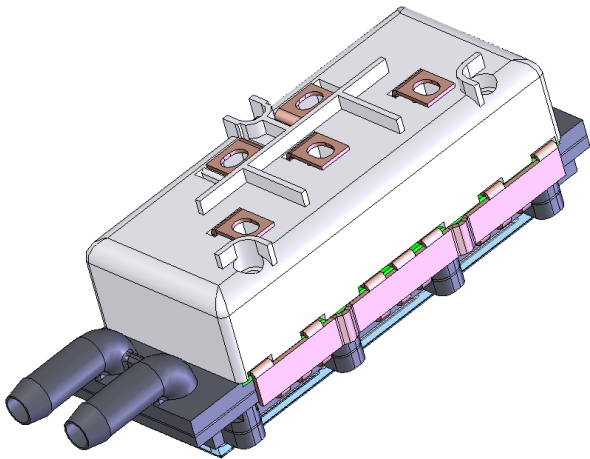
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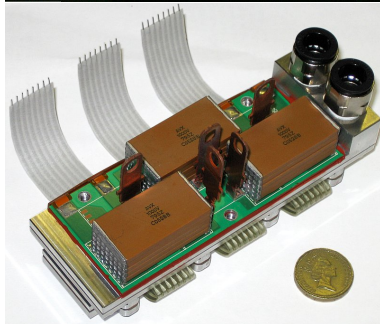
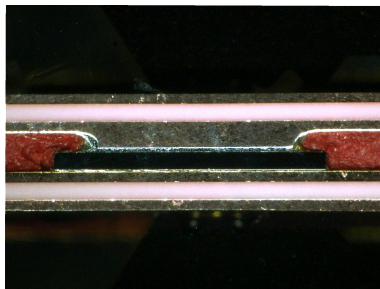
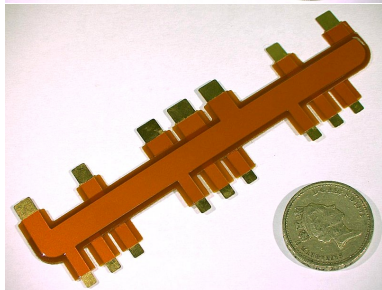
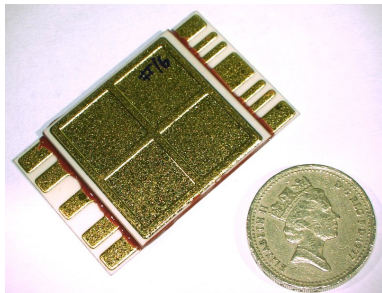
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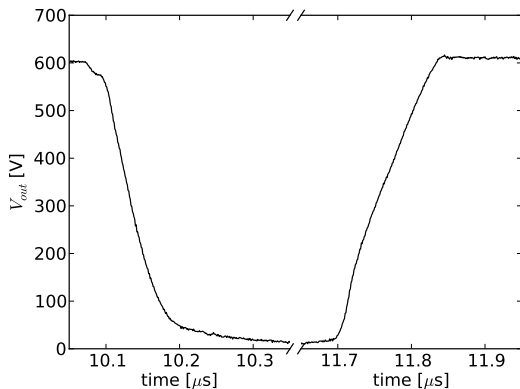


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Low inductance packaging – 3

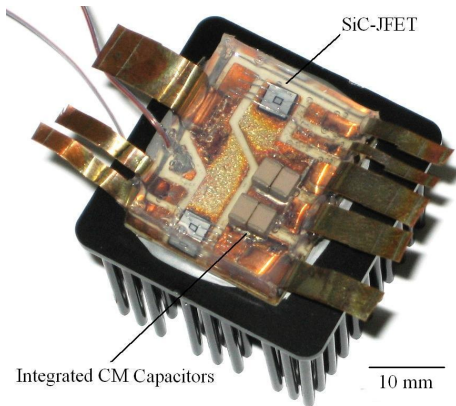


Low inductance packaging – 4



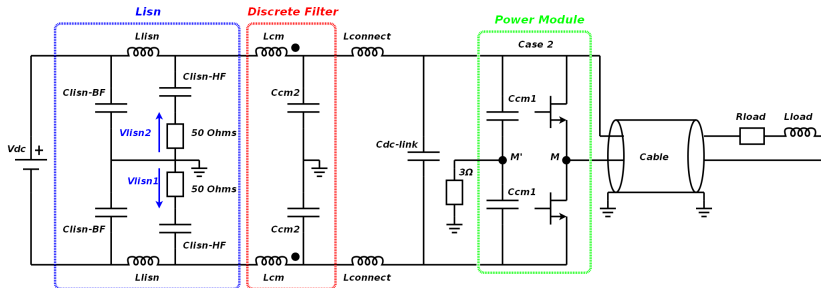
- ▶ Switching speed limited by switches (Si IGBTs, SiC diodes);
- ▶ No ringing measured at the terminals of the modules;
- ▶ DC link inductance estimated at 10 nH.

Integration of common-mode filtering – 1

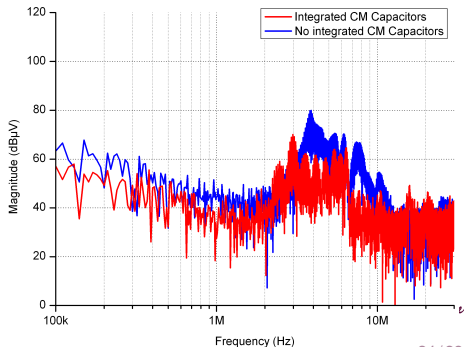


- ▶ Include some common-mode filtering directly inside the power module;
- ▶ Offers a short path to common-mode perturbations;
- ▶ Necessary with fast switching devices.

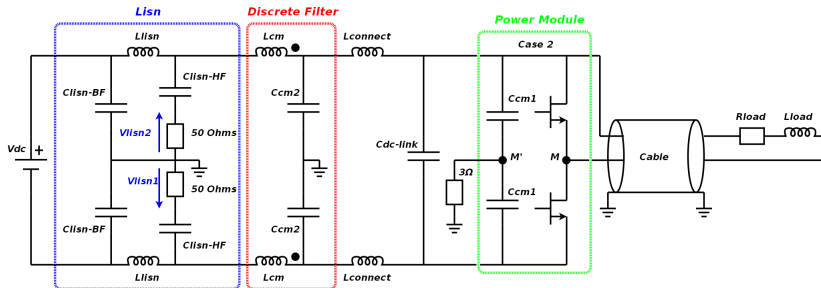
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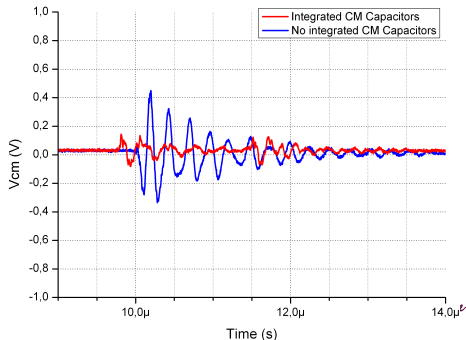
- ▶ 2×6 nF capacitors in the power module;
- ▶ Connected to ground through a damping resistor;
- ▶ External EMC filter for low frequency.



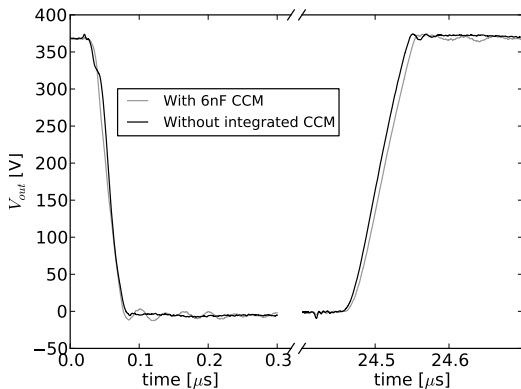
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Integration of common-mode filtering – 3



- Switching speed not altered by integrated common-mode filtering.

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- ▶ Silicon Carbide devices enables faster switches than Si
- ▶ Current packaging technologies must be adapted accordingly
 - ▶ By designing intrinsically-low-inductance packages
 - ▶ By integrating more functions, even with standard technology
- ▶ Boundaries between module and converter less clear
 - ▶ Design must be performed at die level.

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 - ▶ By designing intrinsically-low-inductance packages
 - ▶ Sandwich modules
 - ▶ PCB-embedded circuit
 - ▶ Interconnects with laminated busbars
 - ▶ By integrating more functions, even with standard technology
 - ▶ Filtering and decoupling
 - ▶ Gate drives close to the devices
- ▶ Boundaries between module and converter less clear
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 - ▶ interconnects with laminated busbars
 - ▶ By integrating more functions, even with standard technology
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Thank you for your attention,

cyril.buttay@insa-lyon.fr

