Common-mode challenges in high-frequency switching converters

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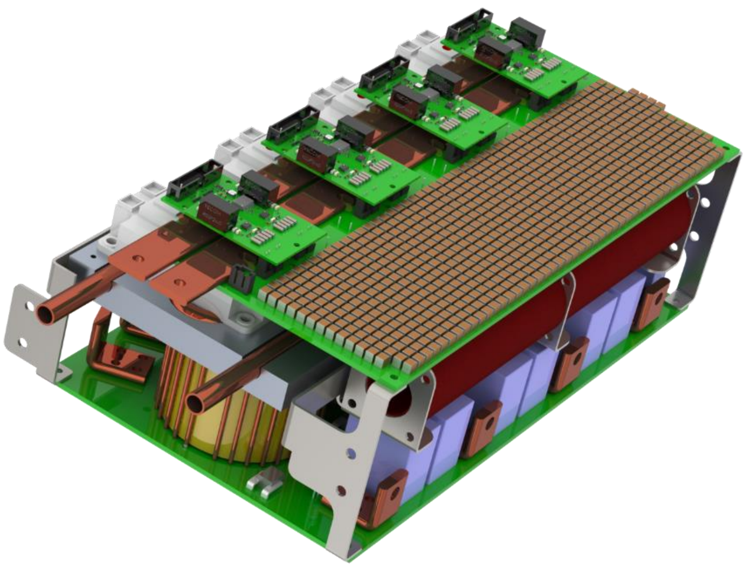
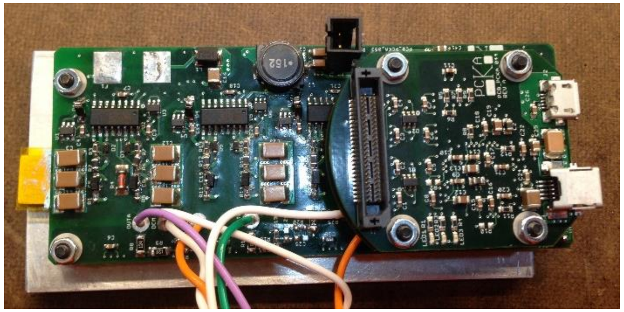
Overview

- Transient voltages in wide-bandgap converters
- Gate drive dV/dt immunity and latch-up
- Electromagnetic interference
- Common-mode management solutions



62 kVA SiC Inverter with integrated CM/DM filtering



7.2 kVA GaN Inverter

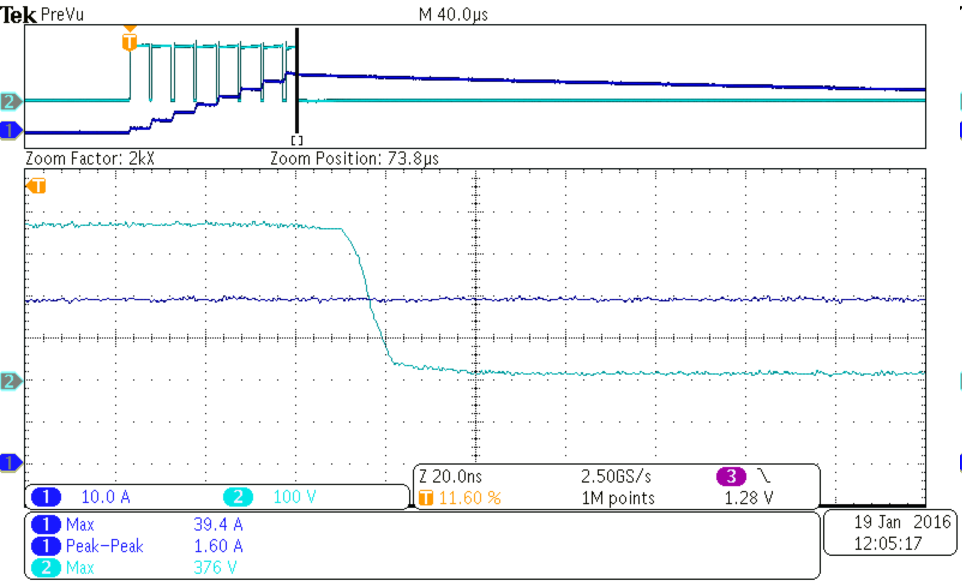
Switching device commutation speed

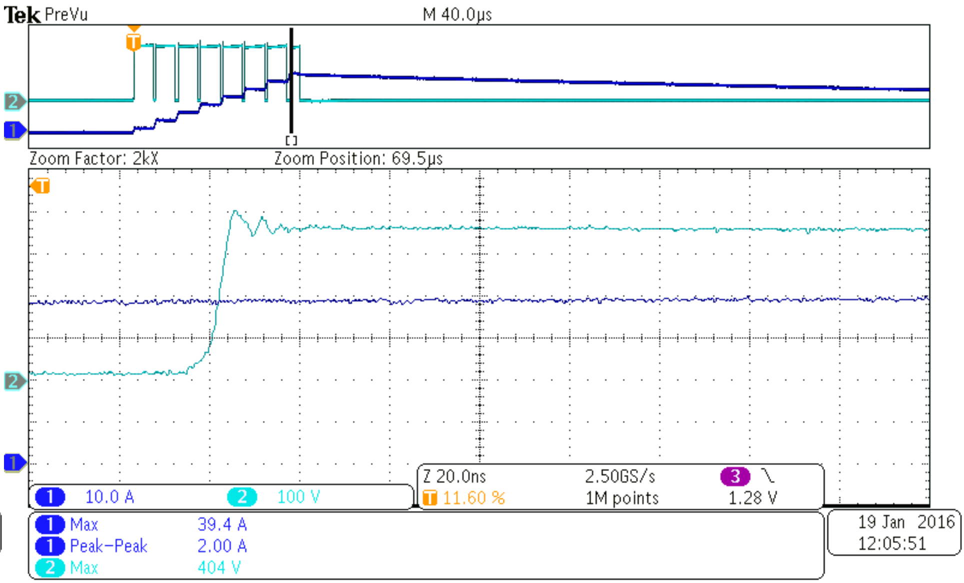
- The commercial availability of wide-bandgap GaN and SiC semiconductors presents new challenges to designers of power electronic equipment.

Device Technology	Rise/Fall Times	Typical dV/dt	Typical Applications
HV IGBT gen 3 (6500V)	400 - 500 ns	9 V/ns	Medium-voltage inverter topologies
LV IGBT gen 4 (1200V)	50 - 160 ns	12 V/ns	Low-voltage inverters and medium-voltage multilevel topologies
Si MOSFET CoolMOS (600 V)	15 - 30 ns	20 V/ns	Low-voltage inverters and dc/dc converters
SiC MOSFET (1200 V)	30 - 70 ns	20 V/ns	Low-voltage inverters
GaN HEMT FET (650 V)	5 - 10 ns	75 V/ns	Low-voltage inverters and dc/dc converters

Switching transients in GaN inverters

- GaN devices in particular have extremely high dV/dt
- Capable of commutating 375 V in 5-10 ns, leading to 75 V/ns transitions
- Even a 5 pF parasitic capacitance will conduct 375 mA, more than enough to cause latching in many CMOS circuits
- In addition to functional failures, increased common-mode circulation creates challenges for EMI management (typical resonant frequencies >150 Mhz)





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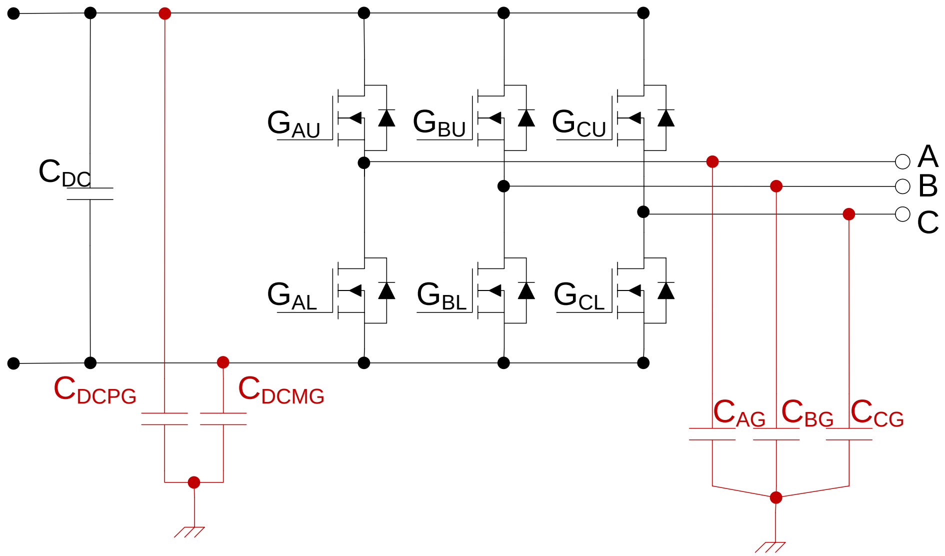
Gate-drive dV/dt immunity

- Most commercially available gate drive ICs are unable to handle the dV/dt of GaN devices with only a few devices being capable of handling 50-100 V/ns during a dynamic switching edge
- Physical circuit layout is equally important to selection of IC
- Any resonance in the parasitic common-mode capacitances can exacerbate the dV/dt seen by the driver insulation system
- Several vendors are indicating new families of 200 V/ns drivers directed at GaN application, some have begun to arrive on the market

Supplier	Part #	CMTI (DV/DT)	Type
Texas Instruments	LM5113	50 V/ns	GaN FET driver
Texas Instruments	ISO5451	50 V/ns	SiC FET / Si IGBT driver with desat detection
Infineon	1ED020I12	50 V/ns	Si IGBT Driver with desat detection
Analog Devices	ADUM3223	25-50 V/ns	Si/GaN FET driver
Silicon Labs	Si8273	200-400 V/ns	SiC / GaN FET driver

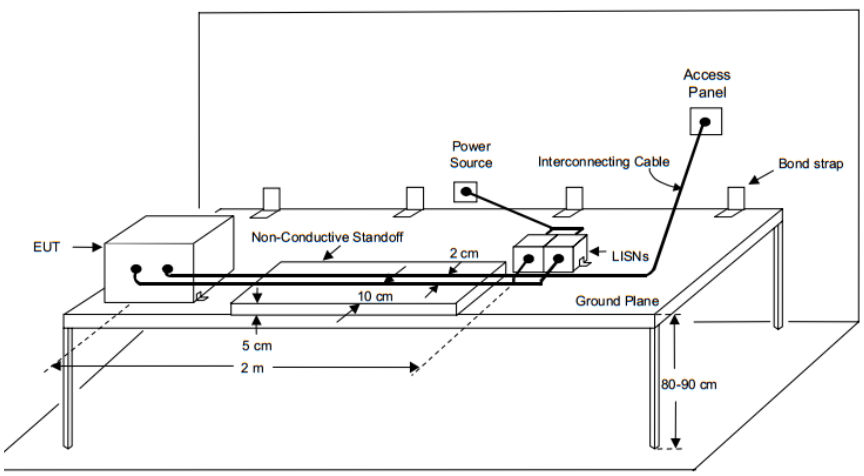
Parasitic CM elements

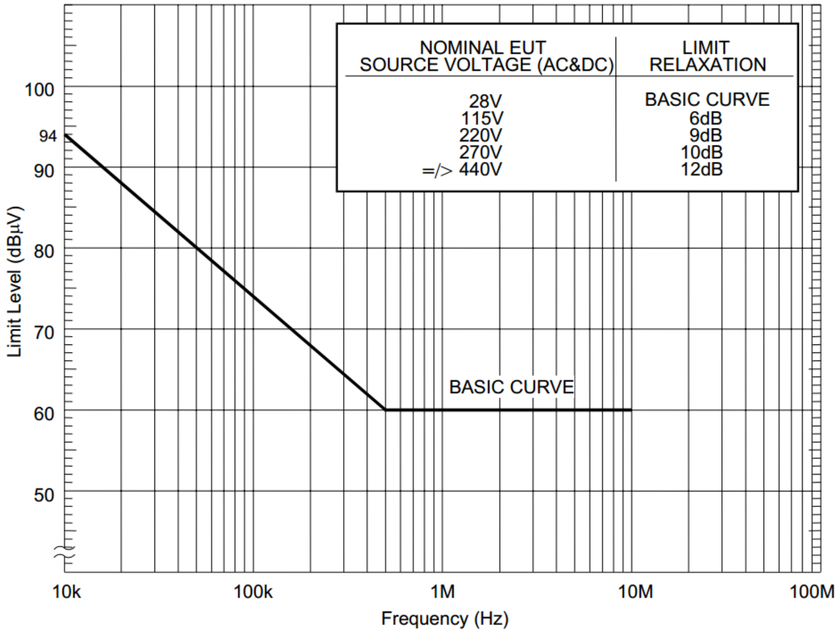
- Power-circuit parasitic elements cause internal circulating currents due to dV/dt
- In many cases these capacitances are directly tied to the cooling isolation barrier, and thus have large area and small distance making very effective capacitors
- The example shown is a simple inverter topology, but the same is true for multilevel and cascade H-Bridge switching circuits



Impact on EMI compliance

- Common-mode currents have high-frequency characteristic and must be managed to prevent EMI. High switching edge rates make this far more critical.
- Grid equipment is generally exempt from FCC standards, though distributed generation inverters generally fall under FCC Part 15B Class B residential standards.
- Example shown is MIL-STD-461F CE102, though other EMI standards have similar requirements

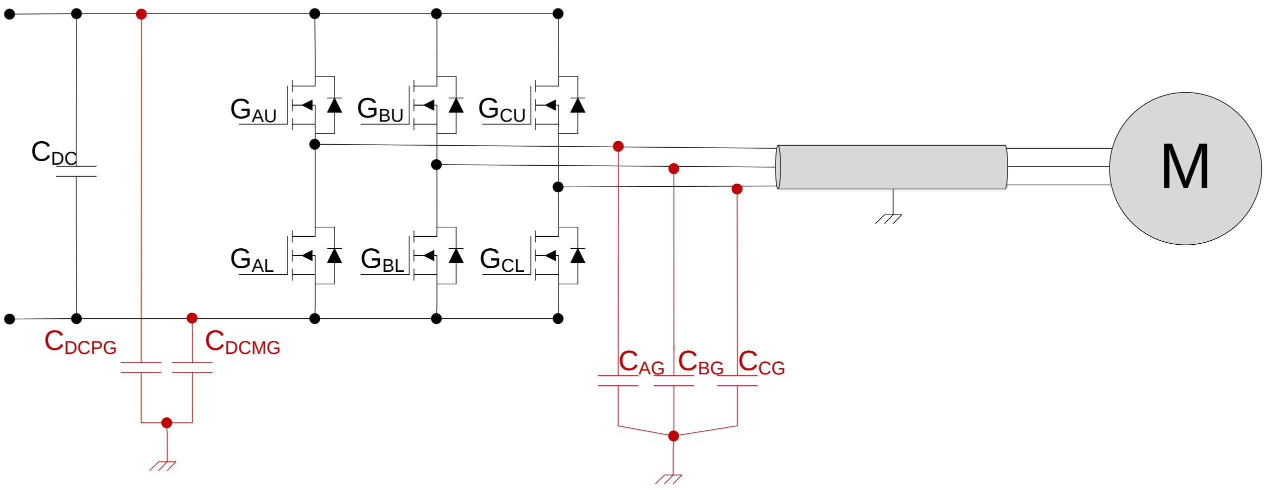




Common-mode currents are a main contributor to EMI compliance issues

Common-mode in motor drives

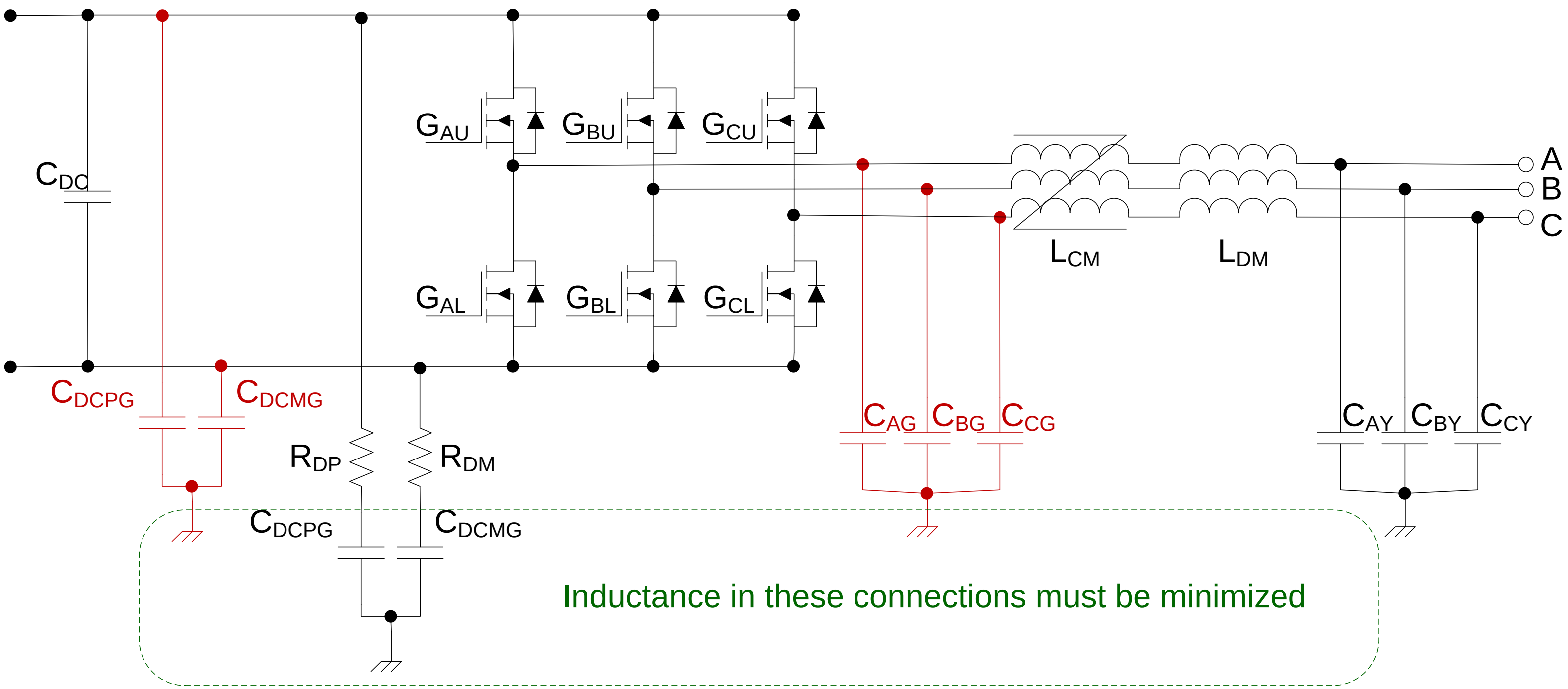
- dV/dt at output of inverter causes reflections in long cables
- The reflection is dependent on the relationship between resonant frequency of the cable, which depends on length
- Wide-bandwidth converters have the capability of exciting much shorter cables than traditional inverters if left un-filtered.
- Traditional damped-LC dV/dt control filters increase the phase-ground capacitance and therefore can increase local CM current if a choke is not present



Common-mode issues in motor drives lead to insulation and motor bearing failure

Basic CM filtering elements

- High switching frequency enables use of reasonably sized CM choke
- Addition of Y-capacitors causes the need for differential-mode inductors, creating a full DM+CM sinusoidal filter
- Damping resistors may be required grounding capacitors to damp internal resonance



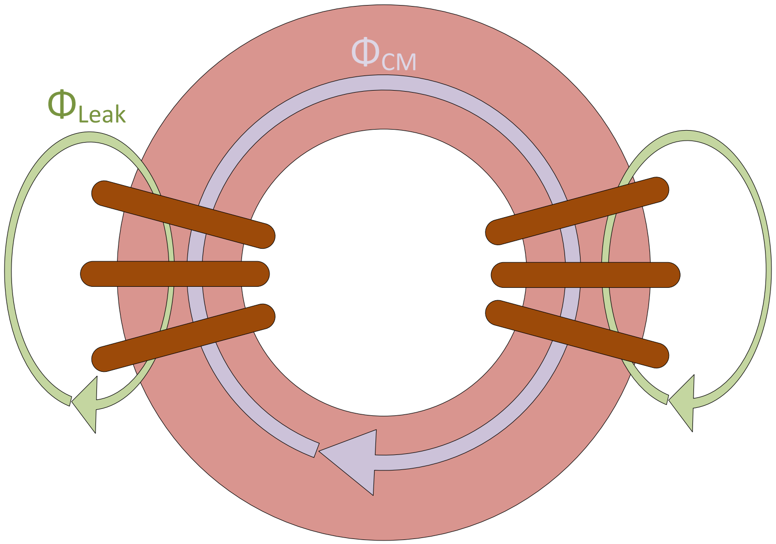
Effects of CM choke leakage inductance

- Reduced-inductance CM choke is required due to high switching frequency, but ratio of CM inductance to leakage inductance can become important
- Differential currents are several orders of magnitude larger than CM currents
- Nominally flux is canceled between turns, but leakage presents a flux contribution from the DM current, which contributes to core saturation

$$L_\sigma \cong 2.5\mu_o N_L^2 \frac{A_e}{l_{\text{eff}}} \left(\frac{l_e}{2} \sqrt{\frac{\pi}{A_e}} \right)^{1.45}$$

$$l_{\text{eff}} = \sqrt{\frac{OD^2}{\sqrt{2}} \left(\frac{\theta}{4} + 1 + \sin\frac{\theta}{2} \right)^2 + ID^2 \left(\frac{\theta}{4} - 1 + \sin\frac{\theta}{2} \right)^2}$$

[1] Heldwein, M.L. et al, "The Three-Phase Common-Mode Inductor: Modeling and Design Issues" in IEEE Trans. Industrial Electronics, vol 58, No 8, Aug 2011, pp 3264-3274



Leakage flux contributes to saturation

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Conclusions and discussion

- Wide-bandgap switching speed creates new challenges for PEL designers to manage common-mode currents
- Commercially available gate-drivers are evolving to cope with the dV/dt requirement
- Power stage common-mode currents often require design of filter components and resonance control integral to the power electronic module
- System-level CM management is necessary even for testing basic functionality

Questions?