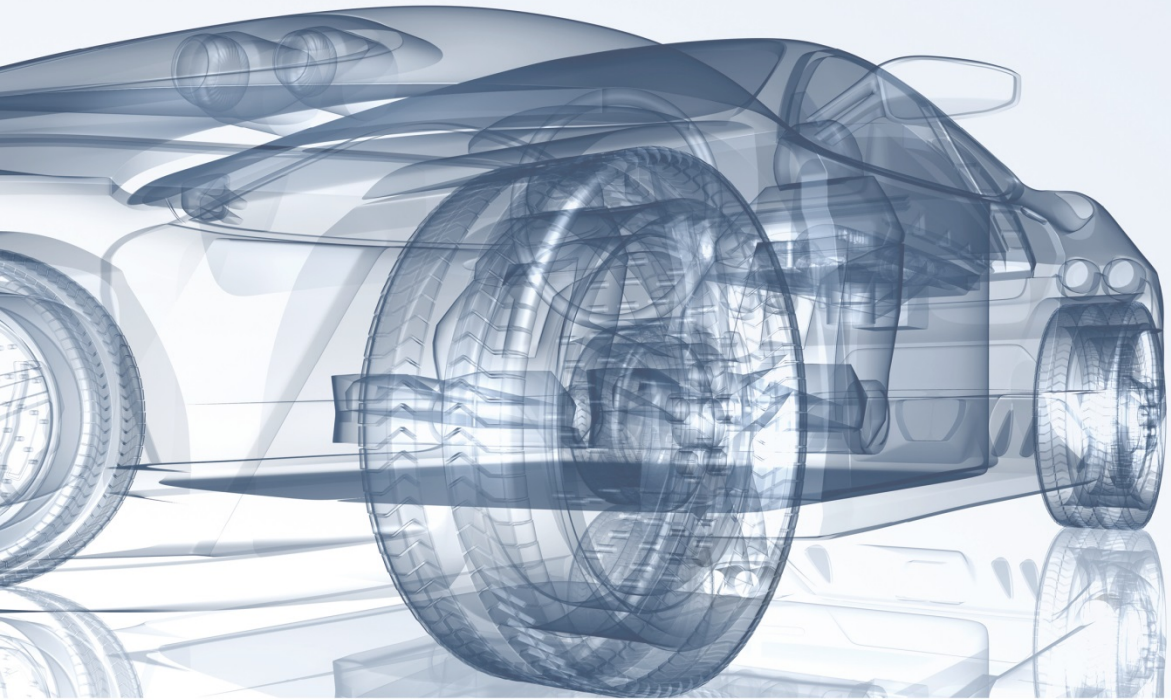
evs 30



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Low inductive power module design for tractive systems

Stuttgart, 09.10.2017

Agenda

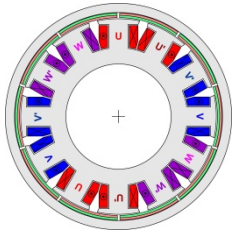
- Motivation
- Module Design
- Stray Inductance Determination
- Switching behavior of new modules compared to reference
- Conclusion

Motivation

Very low inductance (e.g. some kinds of fractional slot winding machines)

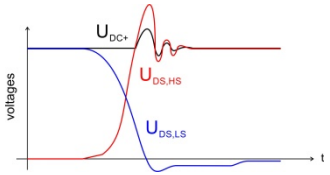
Modern electric traction motors

Special motor designs with high number of poles



Power electronics requirements:

- significantly higher switching frequencies (30-100kHz)
- improved switching behavior



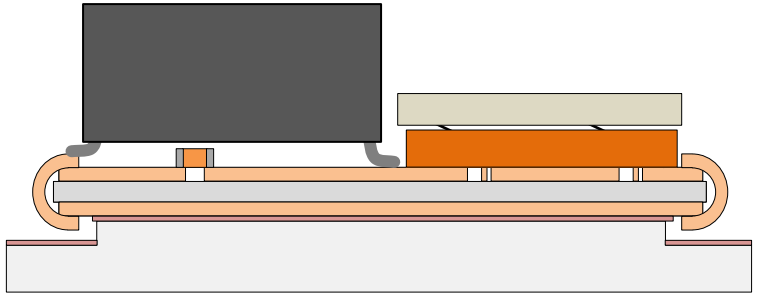
Novel low inductive module design

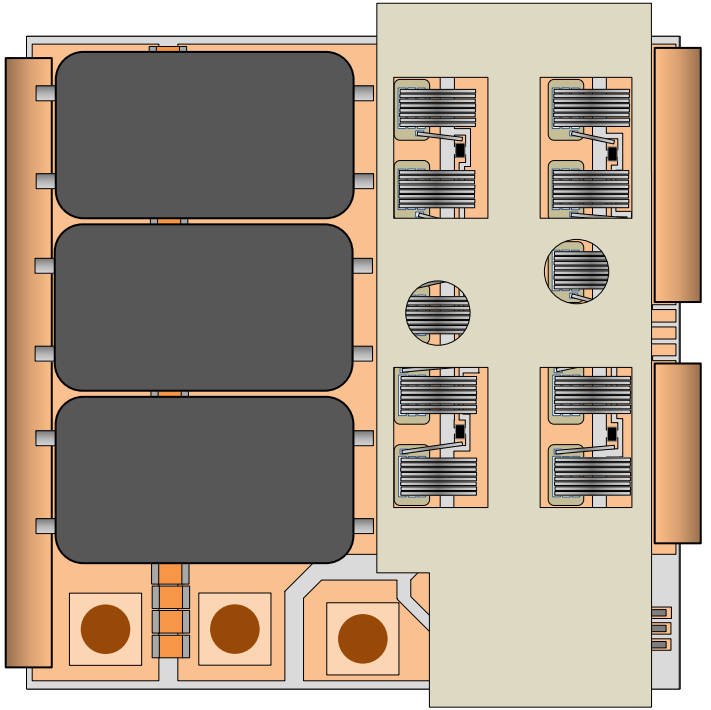
Si | SiC hybrid | full SiC

The switching behavior and switching speed of a hard-switching two-level inverter should be improved by optimization of the power module design (module stray inductance).

Module Design

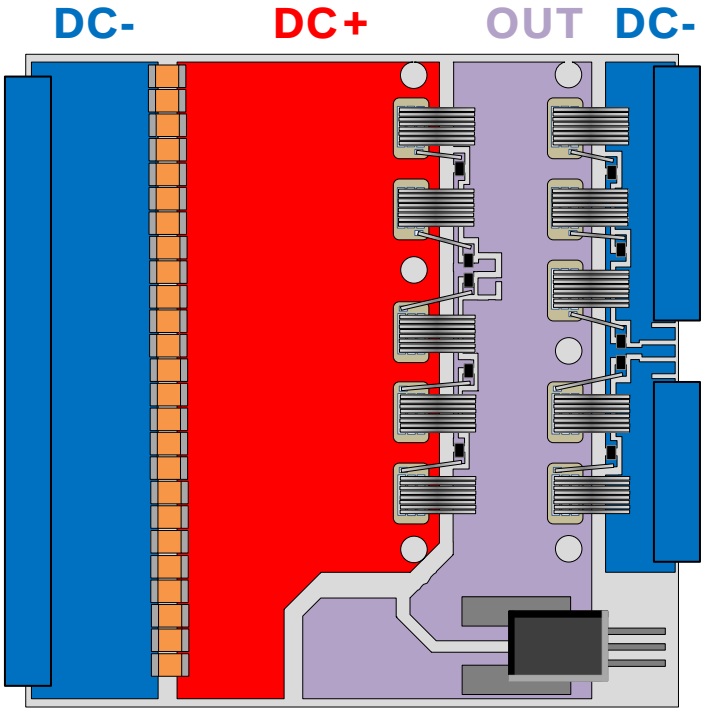
- AlN-DCB
- coplanar design
- SiC-Mosfet Dies (or IGBT/Si-/SiC-Diodes)
- Optional: ceramic capacitors
- Integrated DC-link capacitors
- additional insulation layer necessary
- 3D printed press down frame

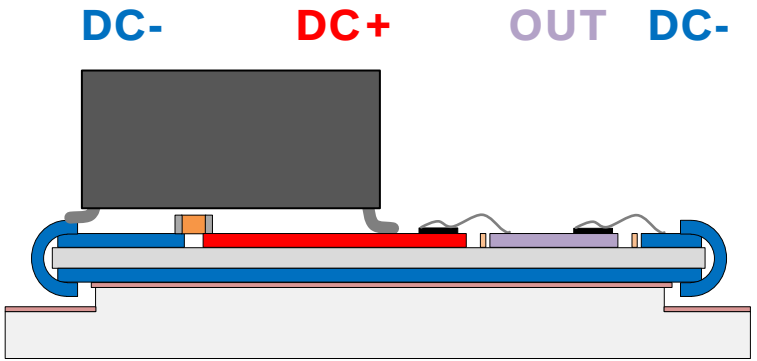




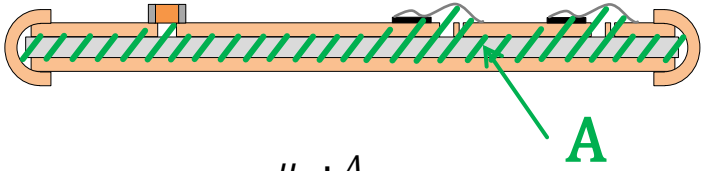
Module Design

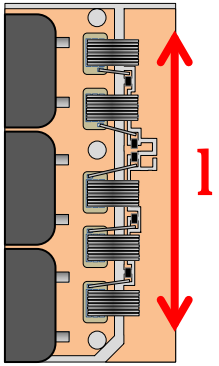
- Electric Potentials





Stray Inductance



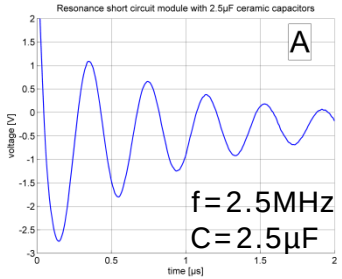


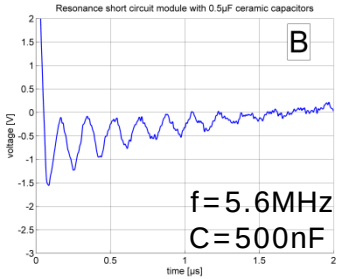
- Calculation
  - Formula for inductance of long air coil $L_\sigma = \frac{\mu_0 \cdot A}{l}$
  - Result: **1.35 nH** (module only)

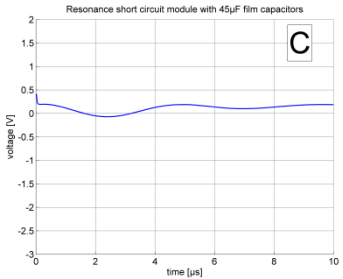
- Measurement
  - Stray inductance

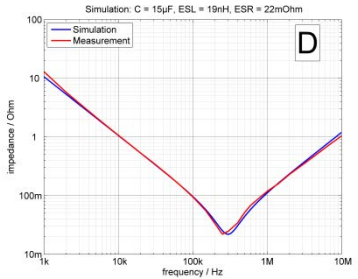
$$L_\sigma = \frac{1}{4\pi^2 \cdot f^2 \cdot C}$$

  - Results:
  - module + film capacitors: **7.65nH**
  - module + film + ceramic: **1.6nH**
  - module only: **1.35nH**



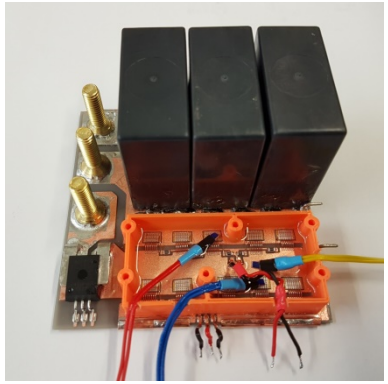


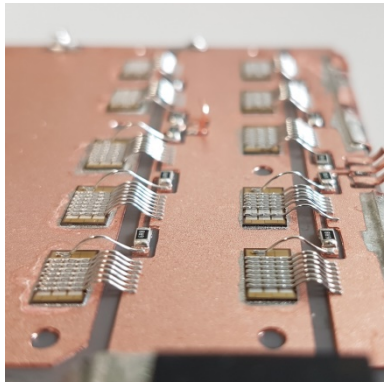




Comparison of switching behavior

- Novel power modules





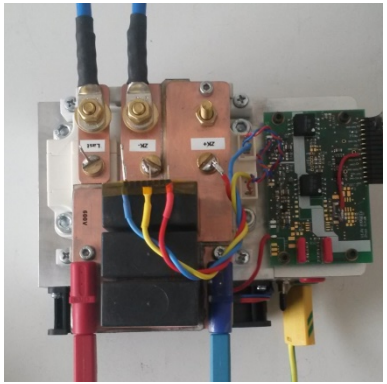
LinkPack
7.65 nH
(film Cap)

LinkPack
1.6 nH
(film&cera Cap)

VS.

Reference
25-30 nH
(optimized
DC-link setup)

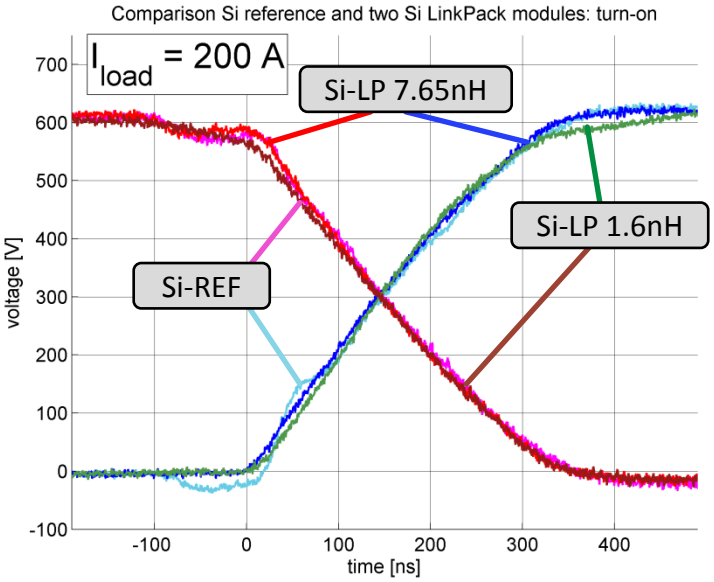
- Conventional power modules with optimized DC-link setup

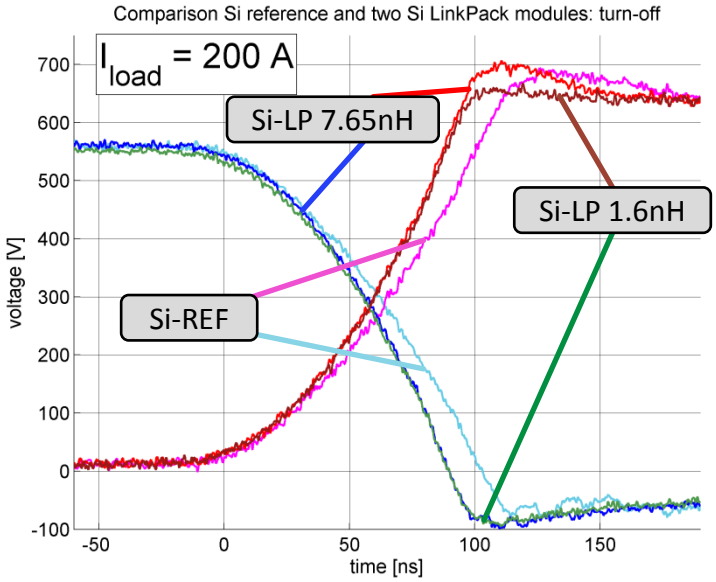


Si | SiC hybrid | full SiC

Switching behavior – Si modules

600V / 200A / R_G 5.5Ω: high & low side voltages





Si-REF: t_{on}=450ns | Si-LP7.65: t_{on}=450ns | Si-LP1.6: t_{on}=450ns

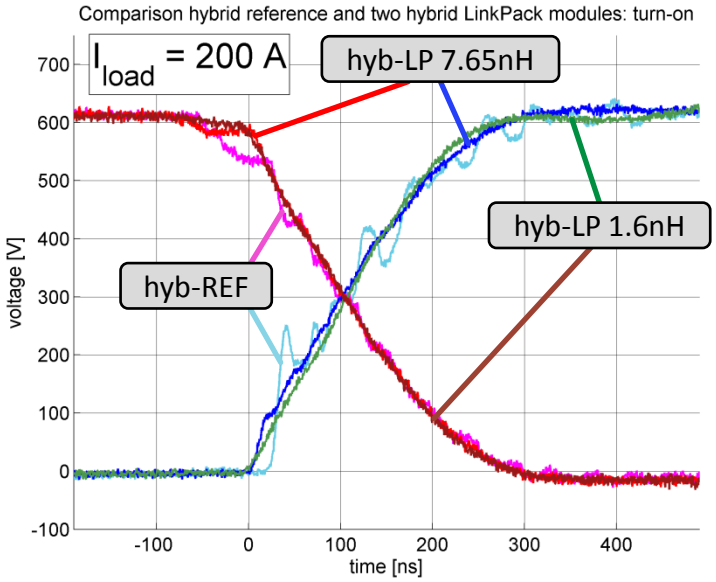
Si-REF: t_{off}=110ns | Si-LP7.65: t_{off}=100ns | Si-LP1.6: t_{off}=100ns

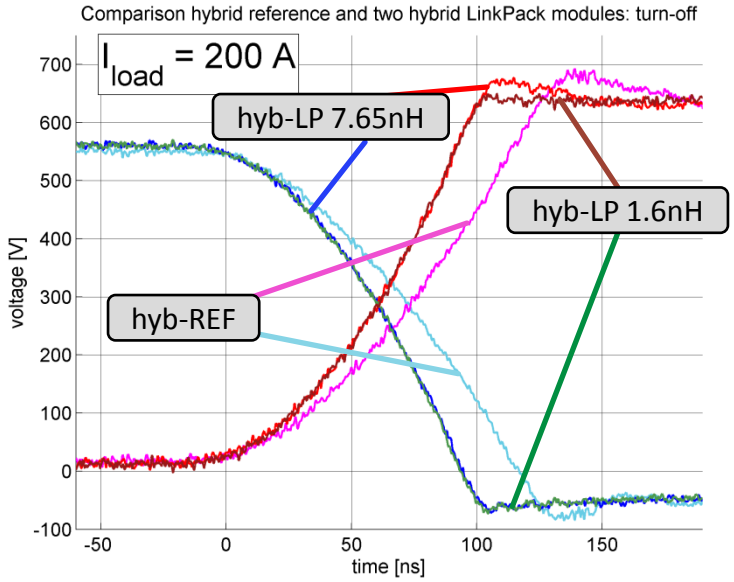
low side		high side	
LP 7.65nH		LP 7.65nH	
LP 1.6nH		LP 1.6nH	
reference		reference	

U_{OV}	
LP 7.65nH	120 V
LP 1.6nH	80 V
reference	110 V

Switching behavior – SiC hybrid modules

600V / 200A / R_G 5.5Ω: high & low side voltages





hyb-REF: t_{on}=370ns | hyb-LP7.65: t_{on}=370ns | hyb-LP1.6: t_{on}=370ns

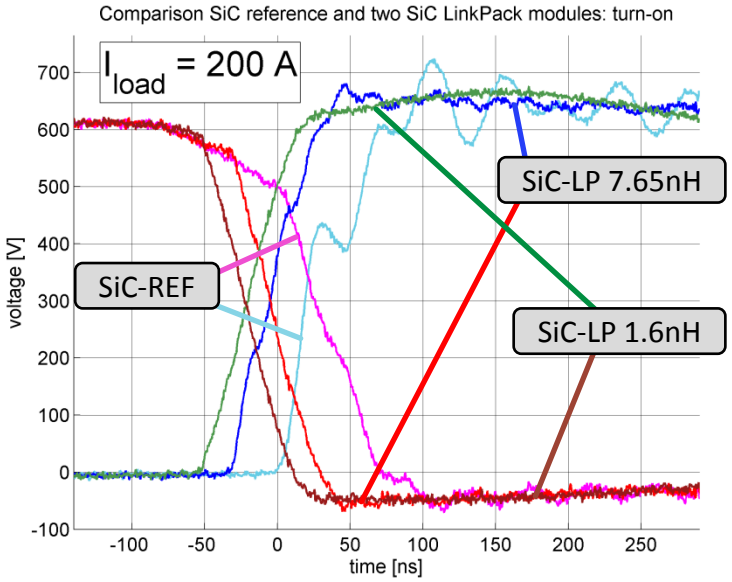
hyb-REF: t_{off}=125ns | hyb-LP7.65: t_{off}=100ns | hyb-LP1.6: t_{off}=100ns

low side		high side	
LP 7.65nH		LP 7.65nH	
LP 1.6nH		LP 1.6nH	
reference		reference	

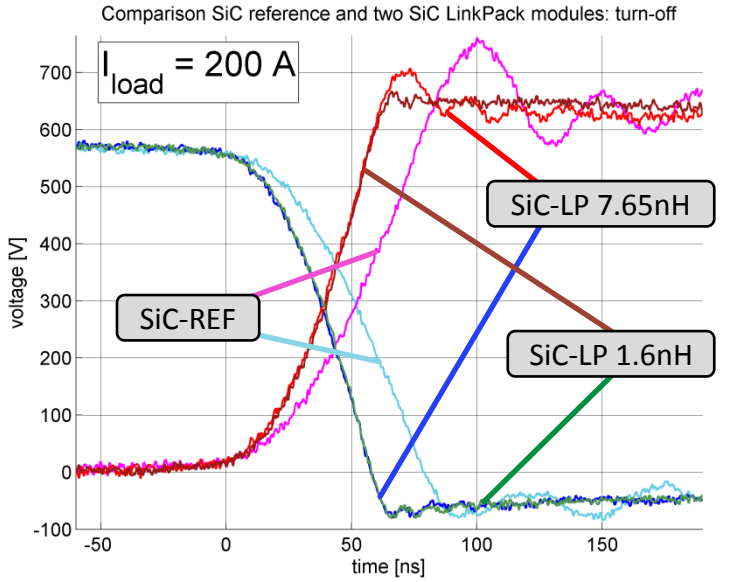
U_{OV}	
LP 7.65nH	95 V
LP 1.6nH	65 V
reference	110 V

Switching behavior – full SiC modules

600V / 200A / R_G 5.5Ω: high & low side voltages



SiC-REF: t_{on}=150ns | SiC-LP7.65: t_{on}=110ns | SiC-LP1.6: t_{on}=90ns



SiC-REF: t_{off}=85ns | SiC-LP7.65: t_{off}=60ns | SiC-LP1.6: t_{off}=60ns

low side		high side	
LP 7.65nH		LP 7.65nH	
LP 1.6nH		LP 1.6nH	
reference		reference	

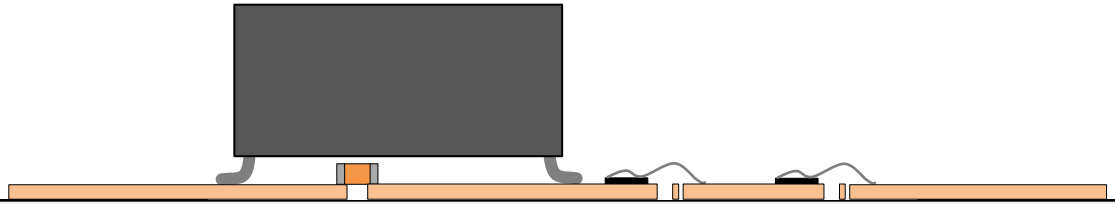
U_{OV}	
LP 7.65nH	115 V
LP 1.6nH	75 V
reference	170 V

Conclusion

- A coplanar power module design with integrated DC-link was presented.
- The module stray inductance values were determined.
- The switching behavior of the novel modules were compared to conventional modules.

Advantages	Disadvantages
✓ Only 7.65nH/1.6nH total module stray inductance	– Thermal drawbacks (additional insulation layer)
✓ Based on established packaging technologies	– Large DCB area required
✓ Faster switching speed	
✓ Less oscillation during switching transitions	
✓ Reduction of switching over-voltage	

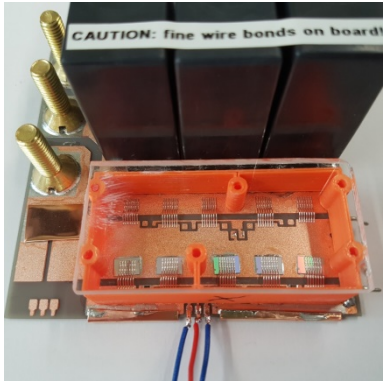
Outlook: Due to improved switching behavior and reduced switching over-voltage, even faster switching is possible by reducing R_G of novel modules.



Thank you for your attention!

Additional values

- Determined DC-link values:
  - ESL ceramic capacitors: 0.25nH
  - ESL film capacitors: 6.3nH
  - ESR film capacitors: 7.3mΩ



- Calculation values module stray inductance:
  - DCB: 0.9nH
  - Bond wires: 0.45nH