A Fast Pulsed Power Supply for Pulsed Electron Beam Applications

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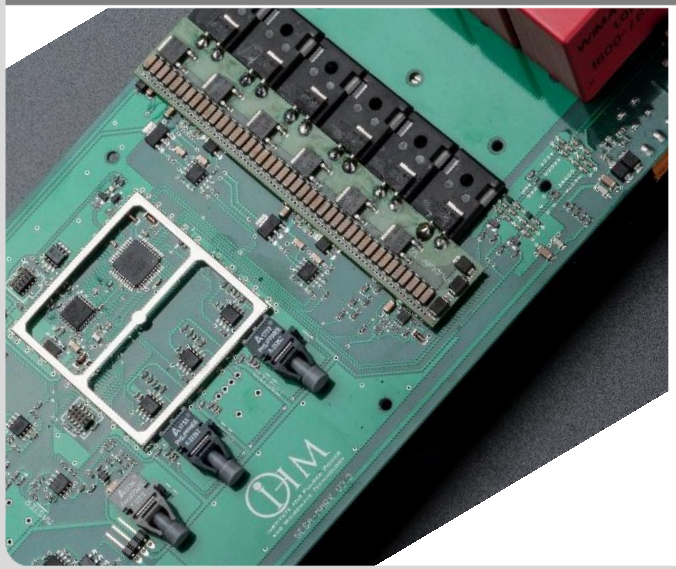
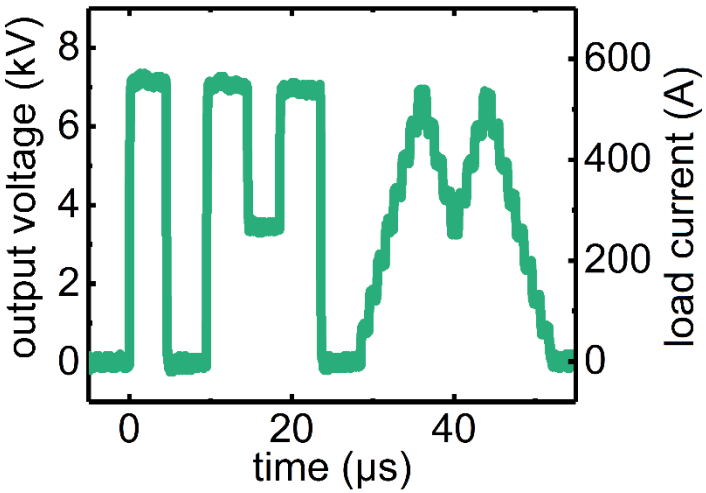
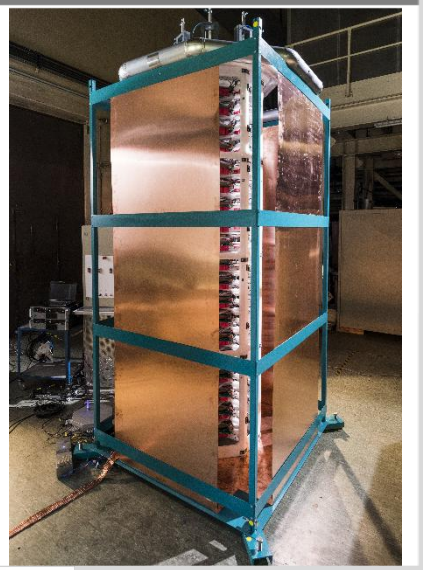
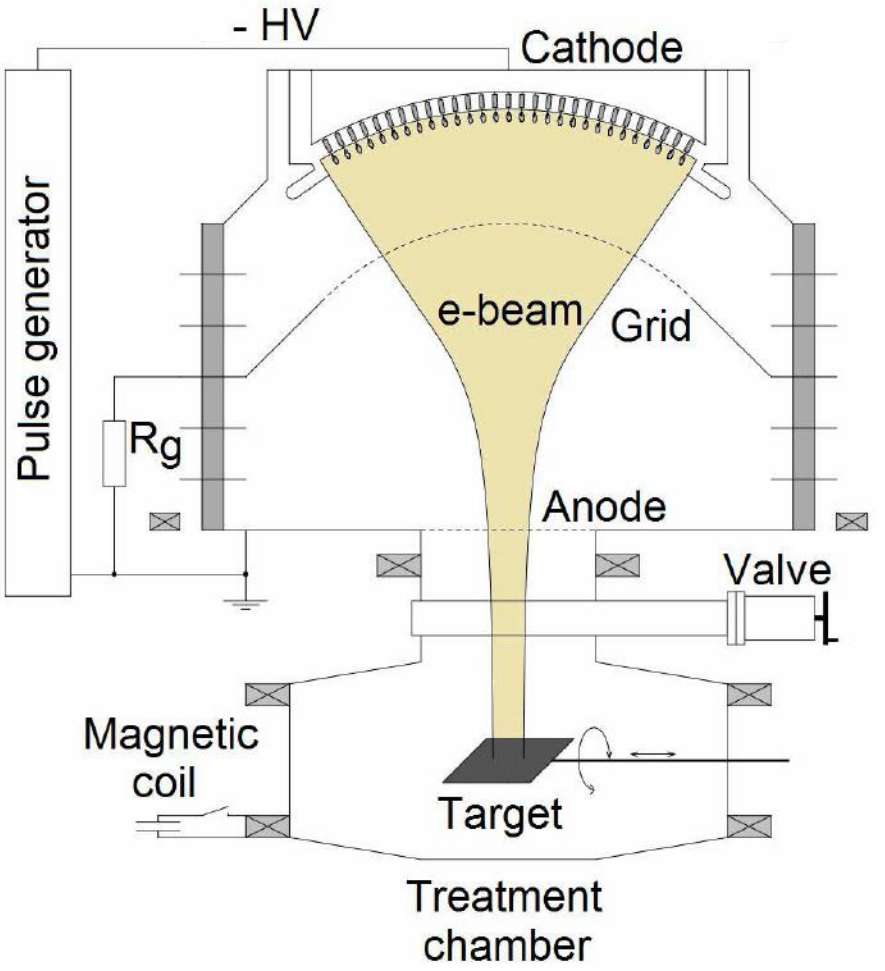




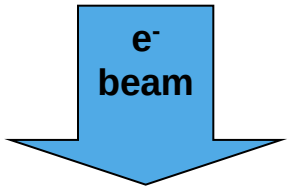


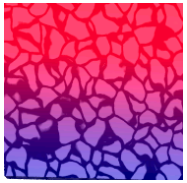
The GESA device



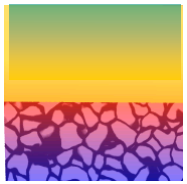
Surface modification by pulsed electron beams

- Fast heating/cooling of the surface
- Changes in surface structure
  - Hardness
  - Wear resistance
  - Corrosion resistance
- Changes in surface stoichiometry
  - Surface alloying by melting a coated surface

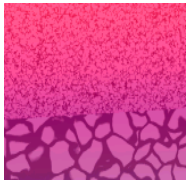




Volumetric Heating:
rate: $< 10^9$ K/s
time: < 40 µs

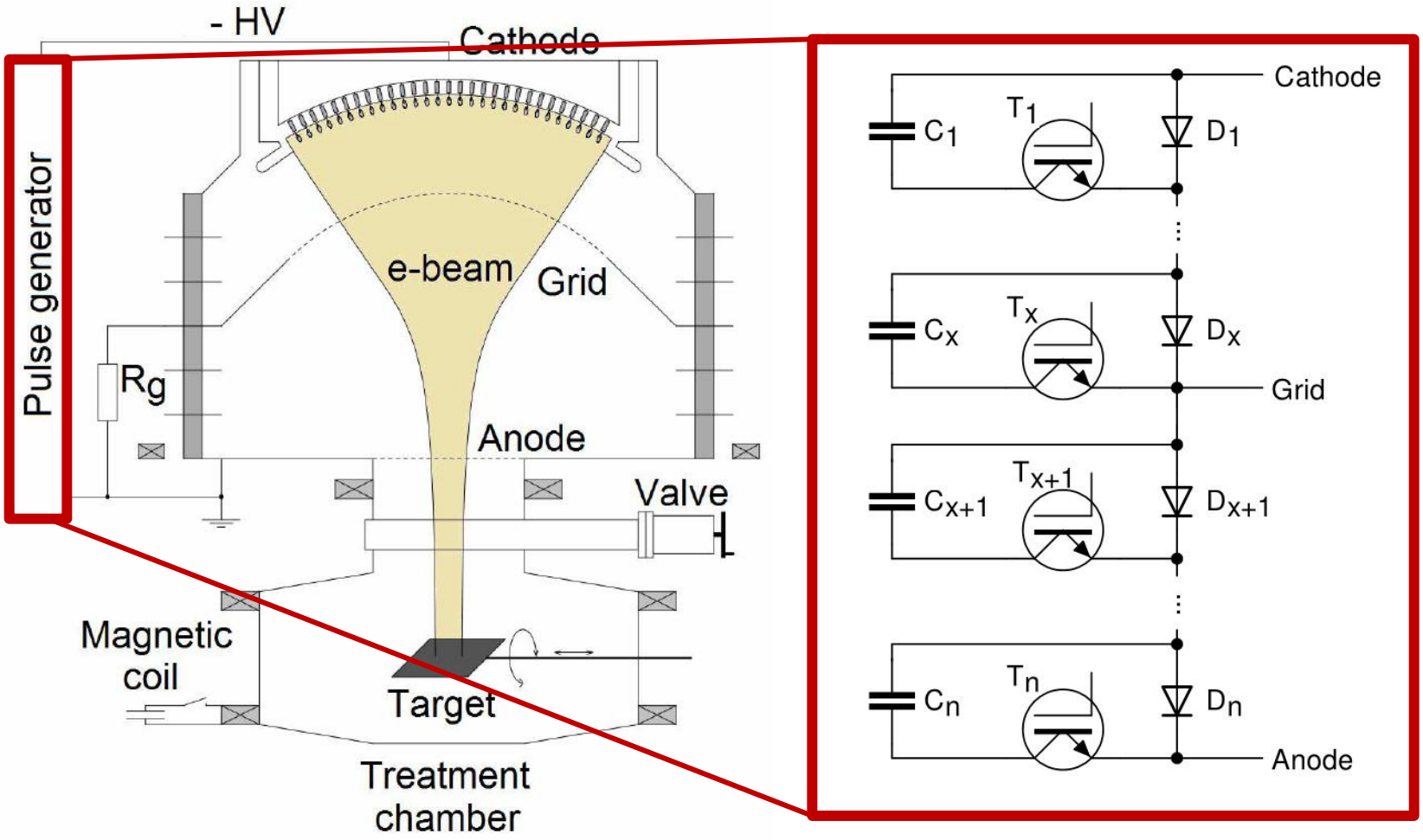


Molten surface layer:
depth: < 100 µm
Cooling rate: $< 10^7$ K/s (heat)



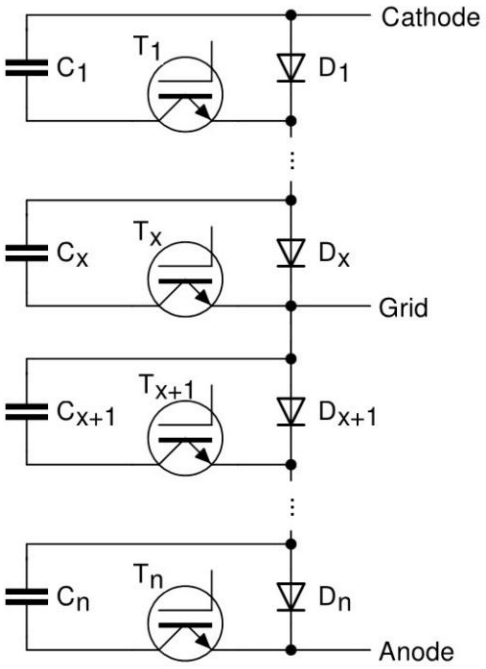
restructured surface layer

Connection of the new Marx generator

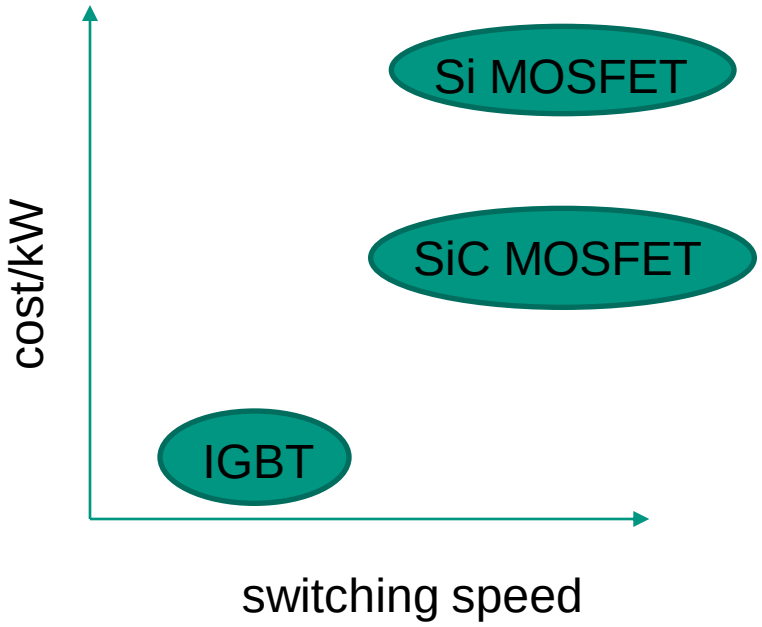


Requirements

- Pulse parameters
  - 120 kV @ 600 A for up to 100 µs
- Fast rise time (100 kV/100 ns)
  - ➡ proper selection of semiconductors
  - ➡ low inductance arrangement
- Arbitrary output voltage generation
  - ➡ Switching signal generation
  - ➡ EMI robustness
- Dynamic load
  - ➡ Fast over-current protection



Selection of Switching Elements



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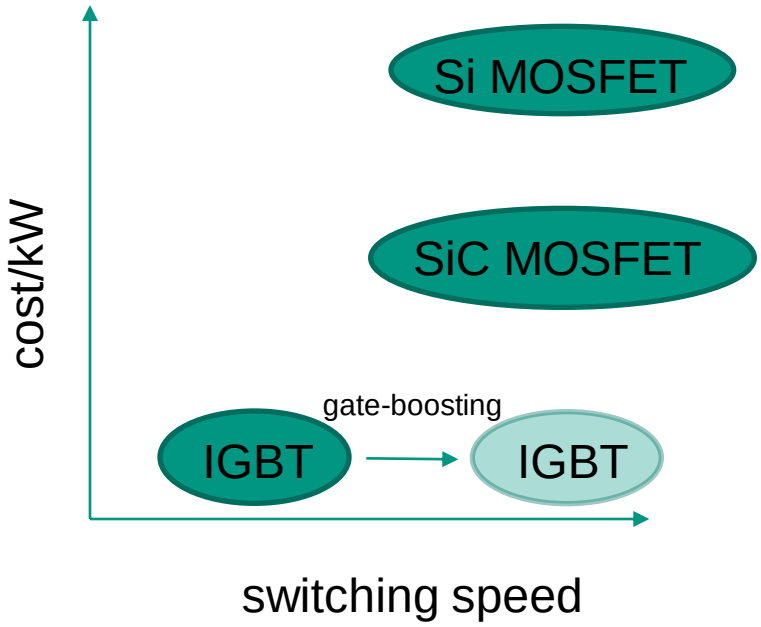
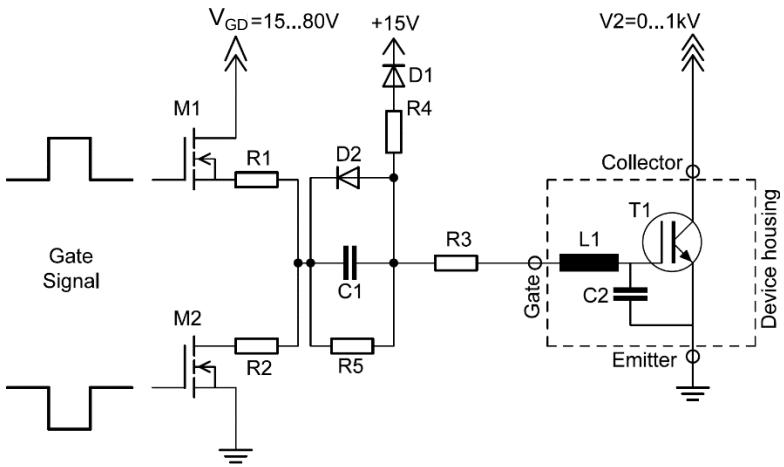
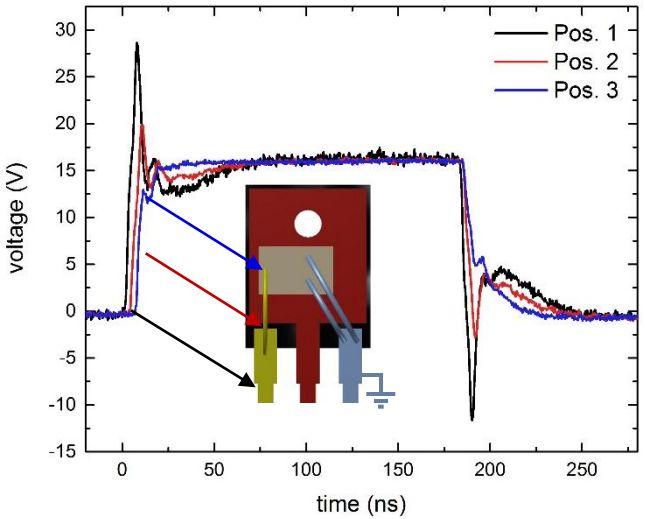


Fast switching by gate boosting

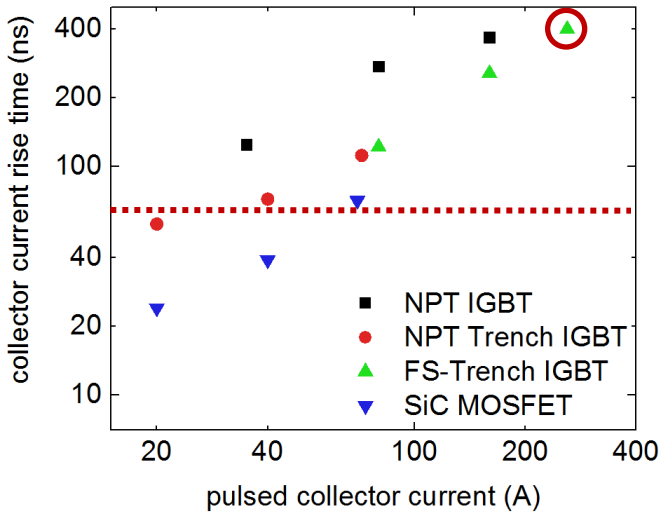




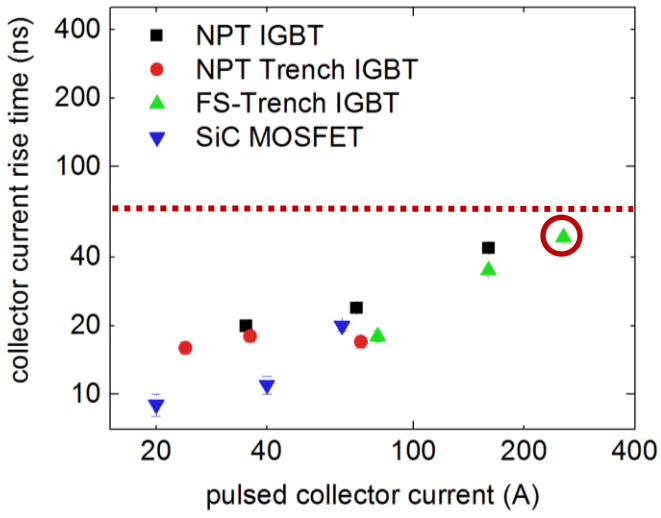
- Damped capacitive divider
- 0 V and 15 V ensured in steady-state
- Benefits:
  - Simple, exact determination of switching moment
  - Use of high gate drive voltages while staying within the datasheet limits

Fast switching by gate-boosting

Standard gate drive



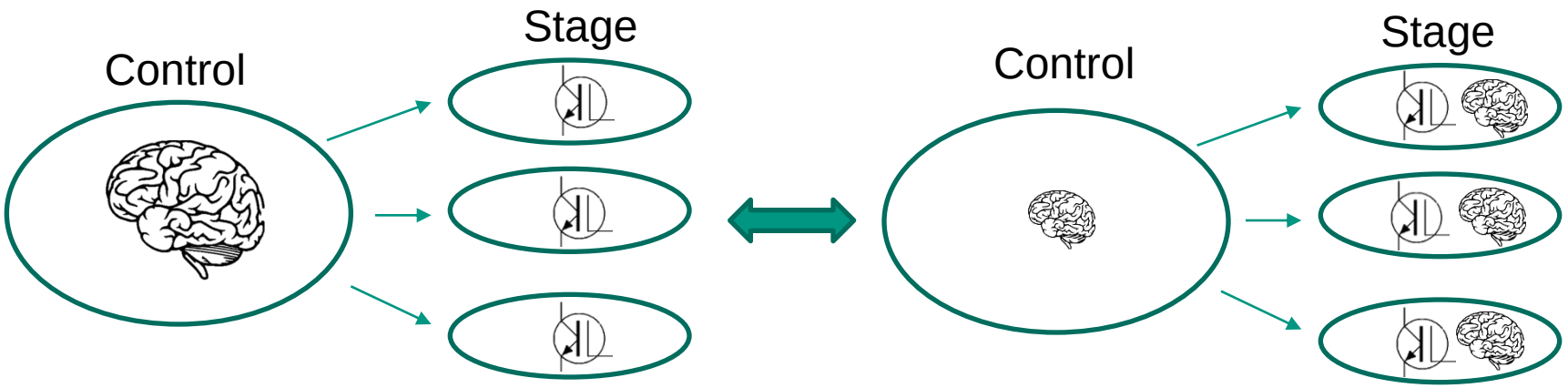
Gate-boosting



- Screening of different commercially available devices

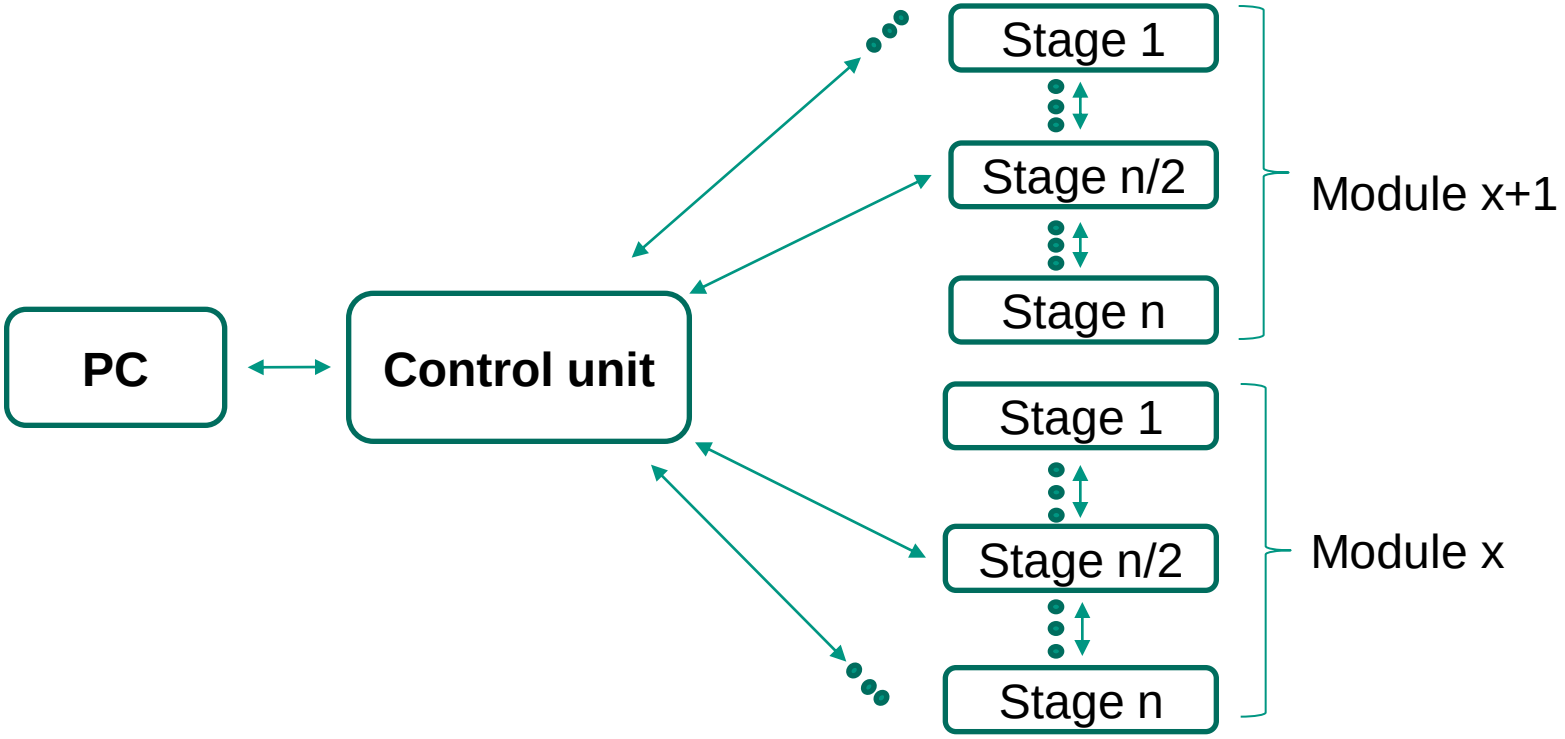
➡ Considerable increase in switching speed allows the use of cheap IGBTs

Switching signal generation



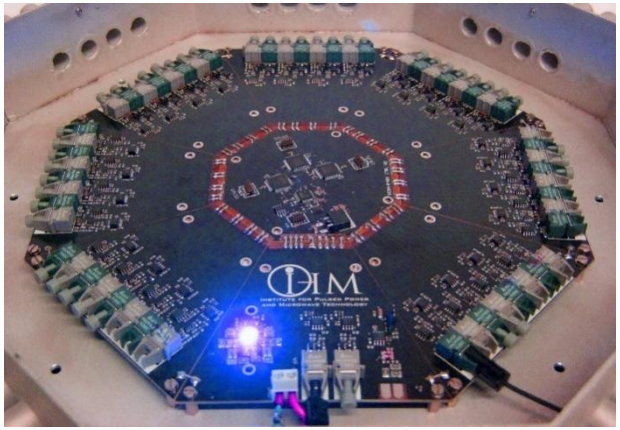
- Each stage generates its own switching signal
- Simplified control circuitry
- Increased safety against malfunctioning

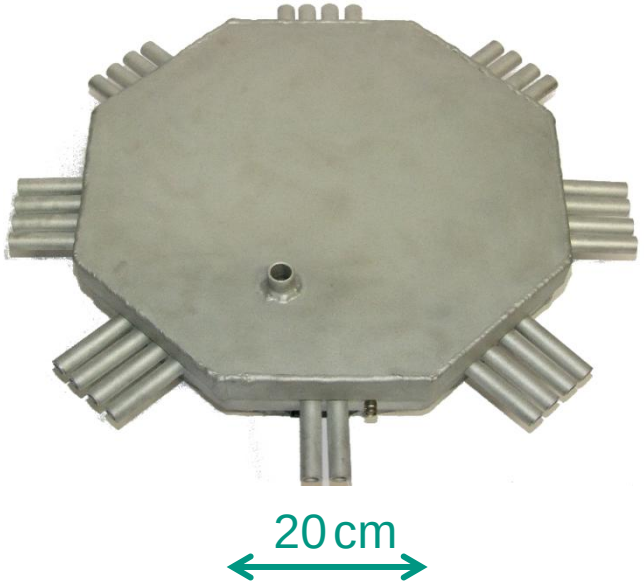
Fast optical bus



- Simplification of electrical and mechanical constraints on control unit
- Pulse generation
  - Pulse preparation: Transmission of switching commands
  - Trigger signal: Synchronized pulse start
  - Self-timed execution of switching commands

Simplified control circuitry

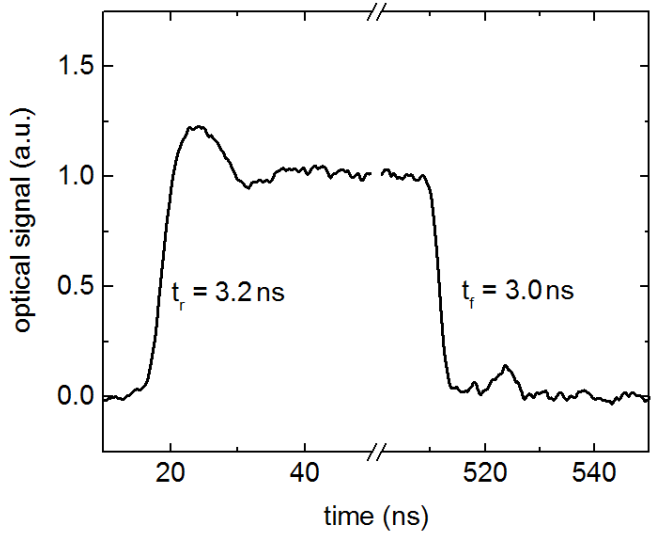


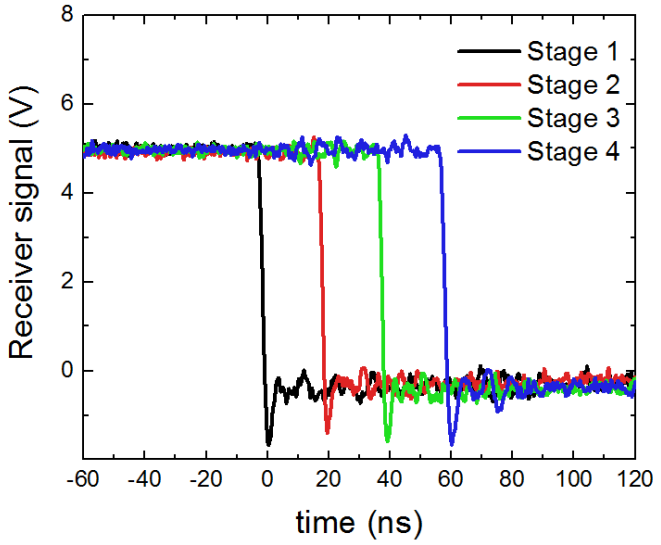


- For communicating with 150 stages:
  - 17 fiber-optic connections
- Over-current detection
- Interface with experiment's control unit
- Small footprint → simple EMI shielding

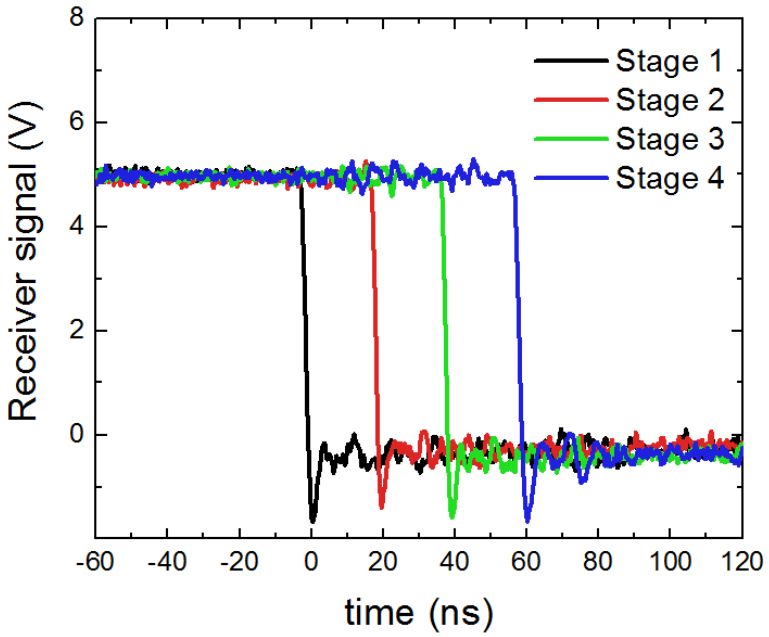
Distribution of control signal

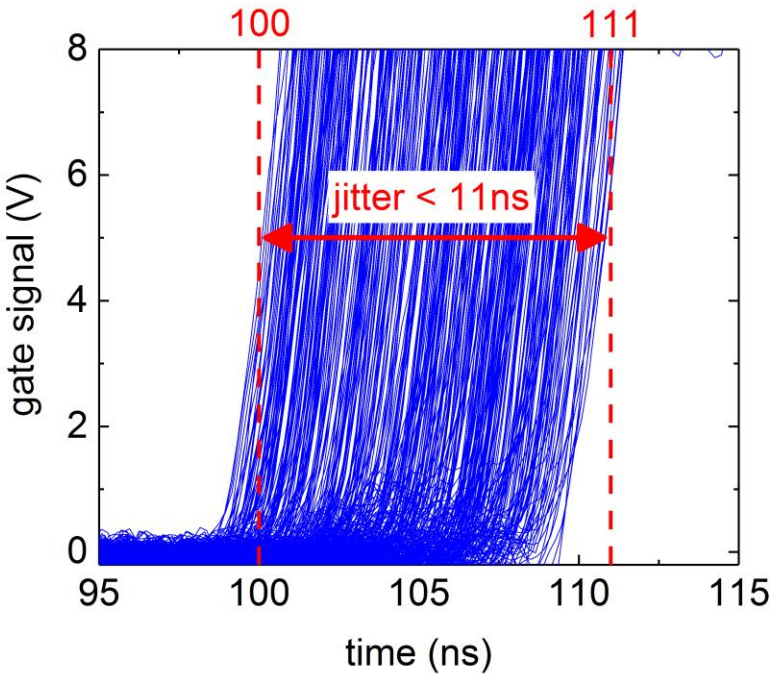
- Commercial LED housing for easy assembly
- Fast current feedback amplifier:
  - DC transmission possible
  - Cost-efficient
- Delay compensation





Fast signal transmission



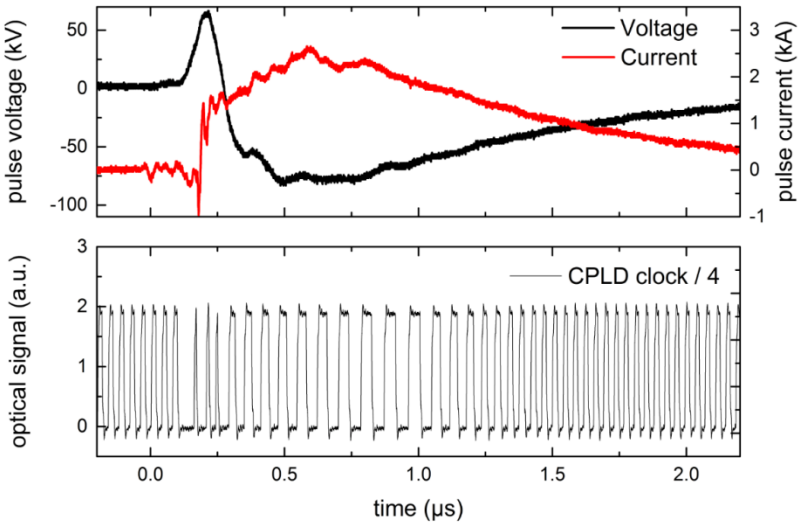


- Optical signal is transmitted from stage to stage
  - 20 ns time delay is compensated
- Gate signals of 4 stages in a bus (100 pulses overlapped)
  - Residual jitter < 11 ns due to limited clock speed (100 MHz)

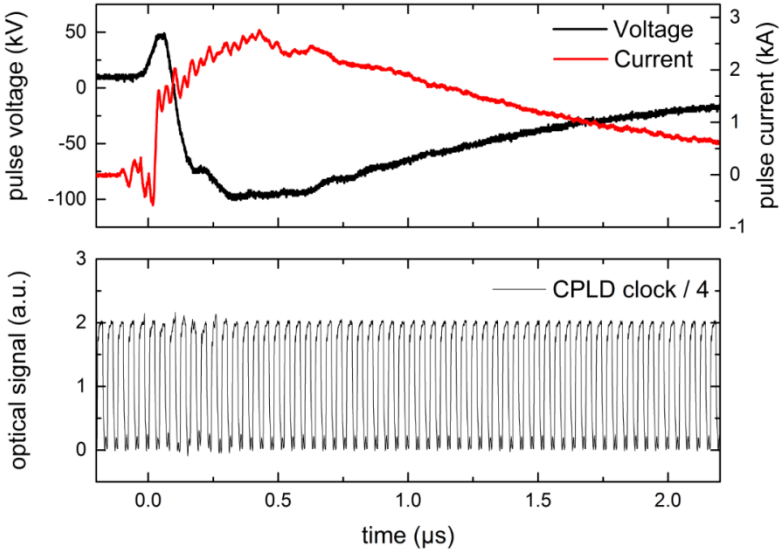
EMI challenges at high voltages

- Tests of one stage at -100 kV (external Marx generator)
- Unshielded: Microprocessor clock generator is vulnerable

Unshielded



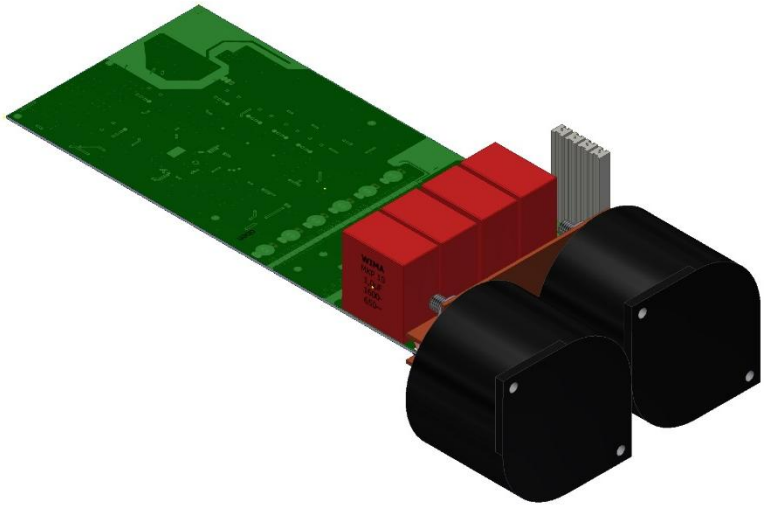
Shielded



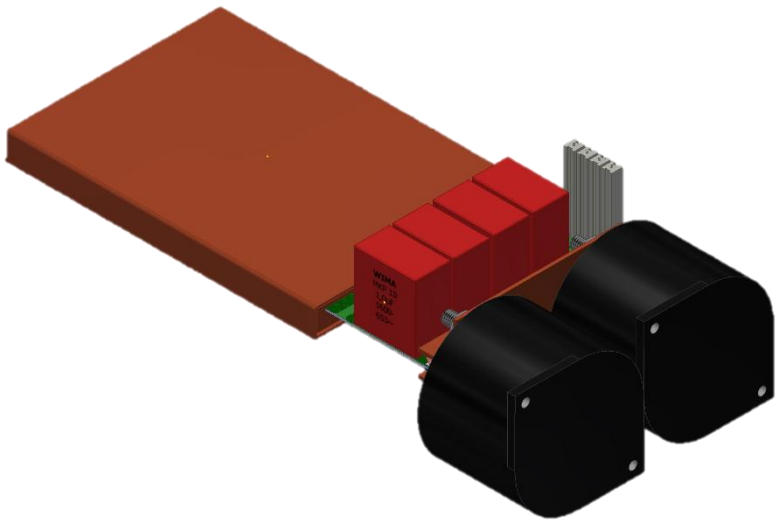
EMI challenges at high voltages

- Tests of one stage at -100 kV (external Marx generator)
- Unshielded: Microprocessor clock generator is vulnerable
- Closed copper housing enhances EMI robustness

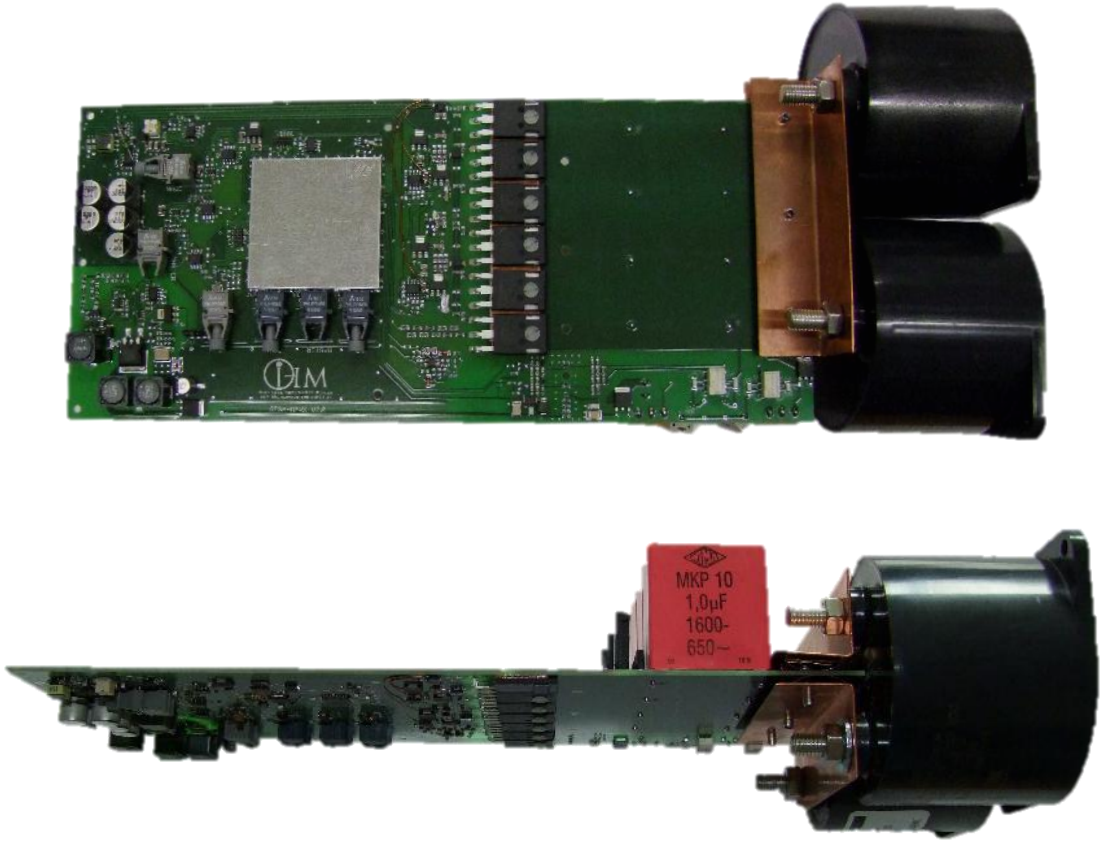
Unshielded



Shielded

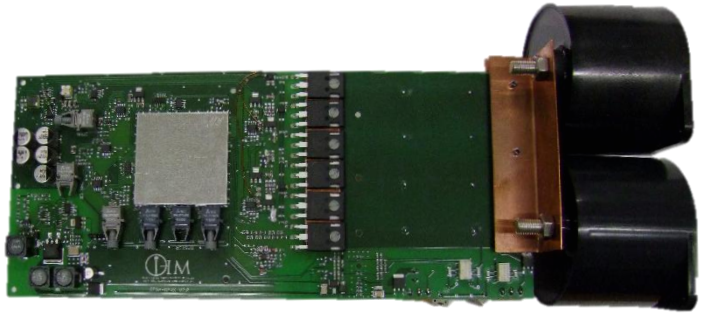


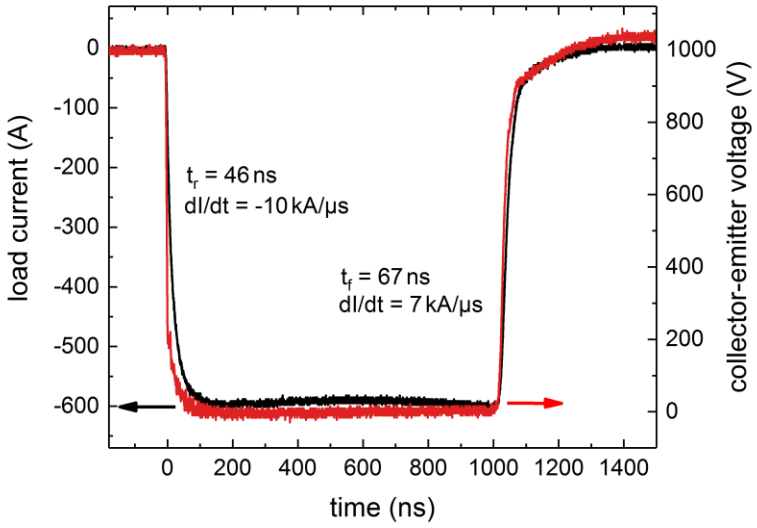
Stage arrangement

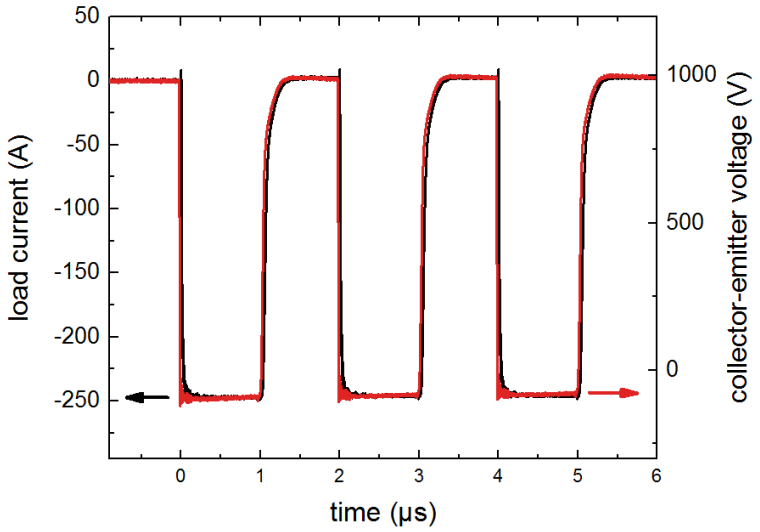


Pulse tests of one stage

- Operation of complete control chain
- Tests in low-inductive test circuit





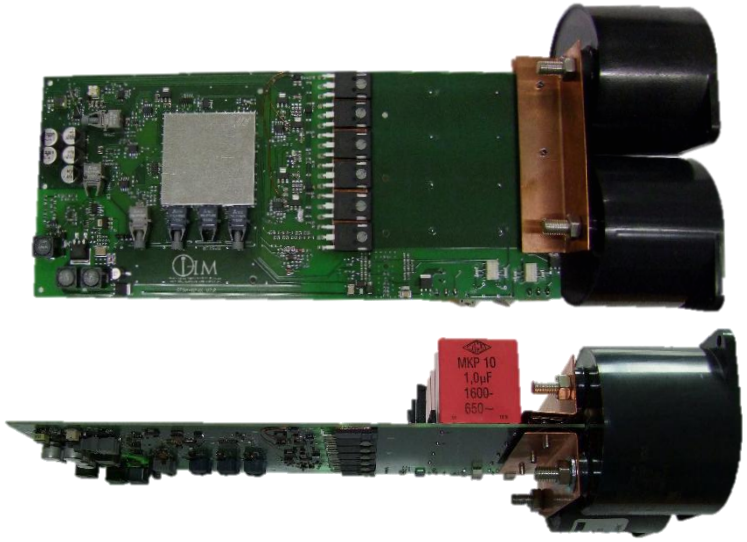


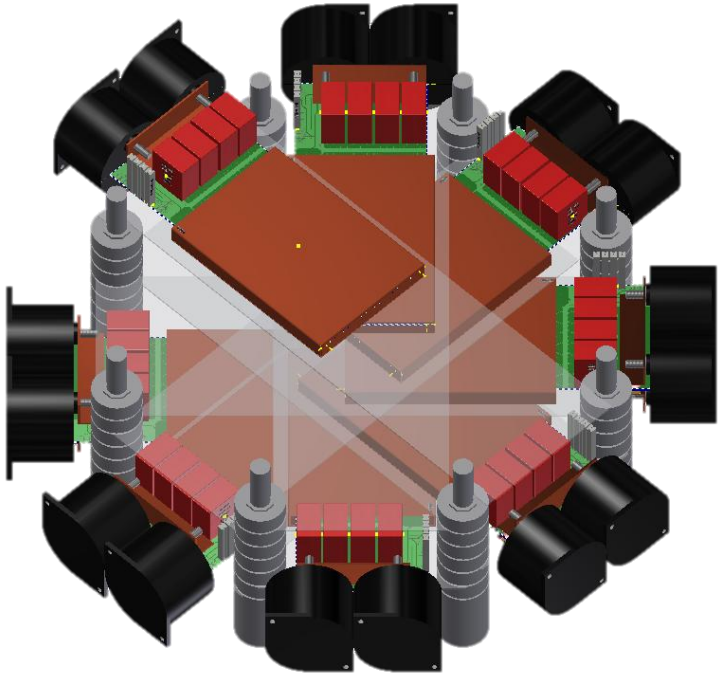
➡ 46 ns rise time for 600 A load current
10 kA/µs current rise rate

➡ Arbitrary waveform generation
(500 kHz toggle)

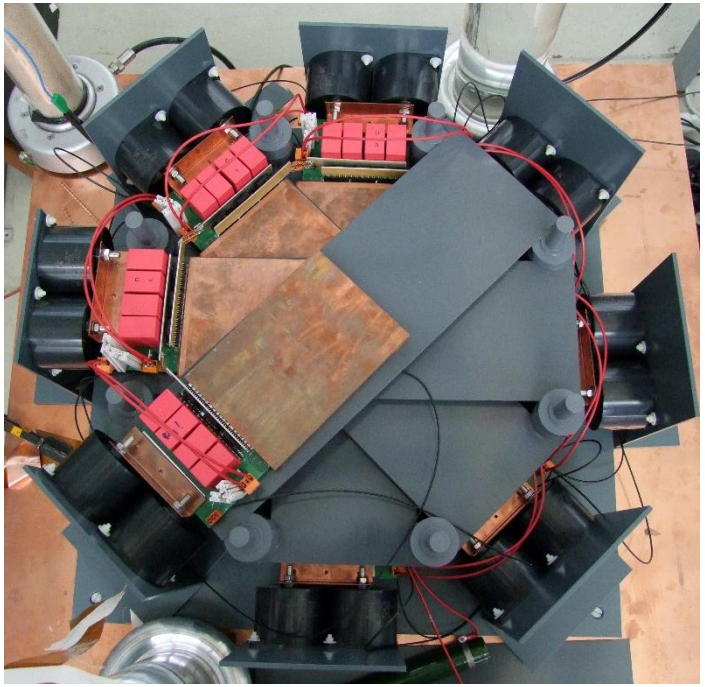
Stage arrangement constraints

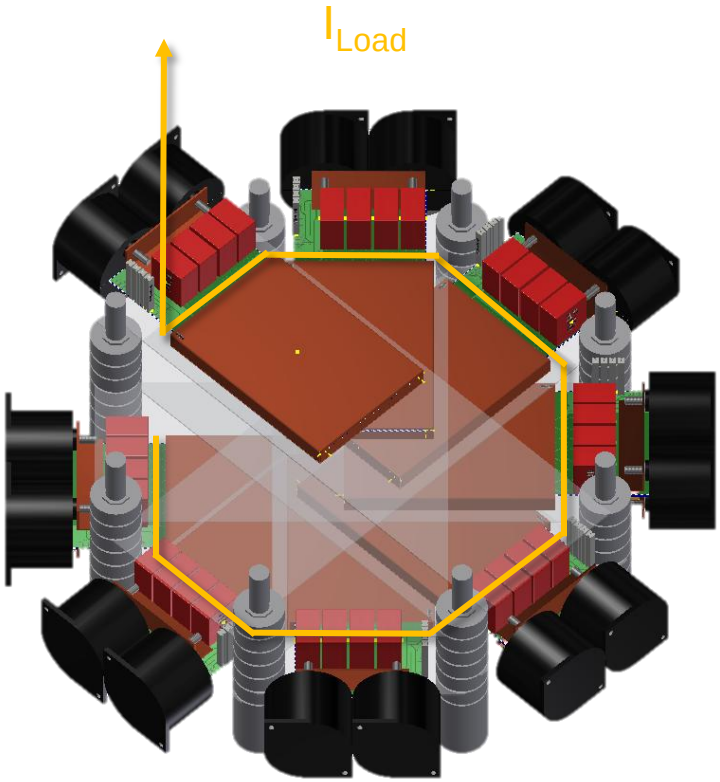
- Minimize connection length between stages
- Minimize area enclosed by load current
- Keep height as low as possible (~150 stages!)
- Minimize construction costs





8-stage Generator setup

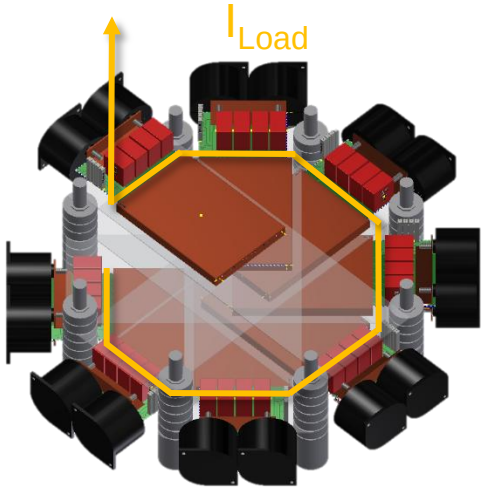


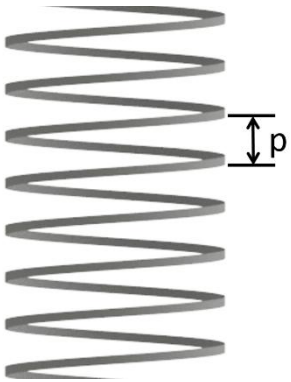


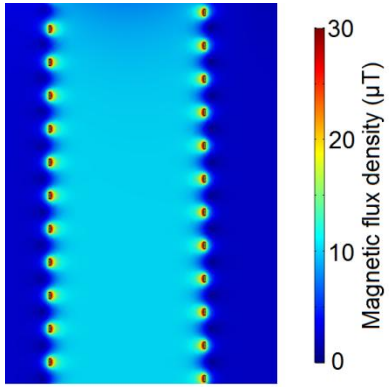
Generator inductance

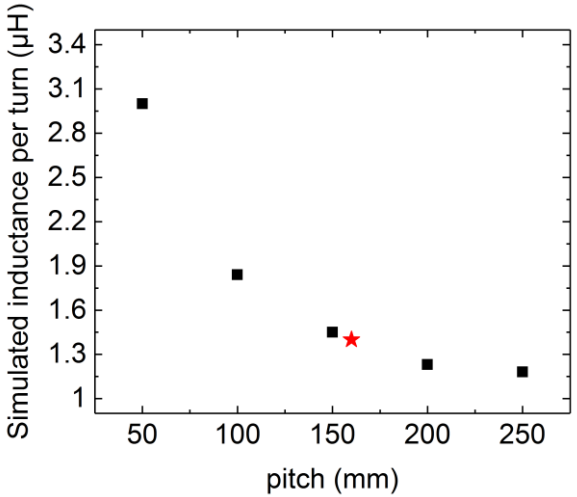
- Coil-like current path may increase inductance
- Pitch determines coupling
- For high pitch:
  Conductor length determines inductance

➡ Due to spacial constraints: p ≈ 160 mm



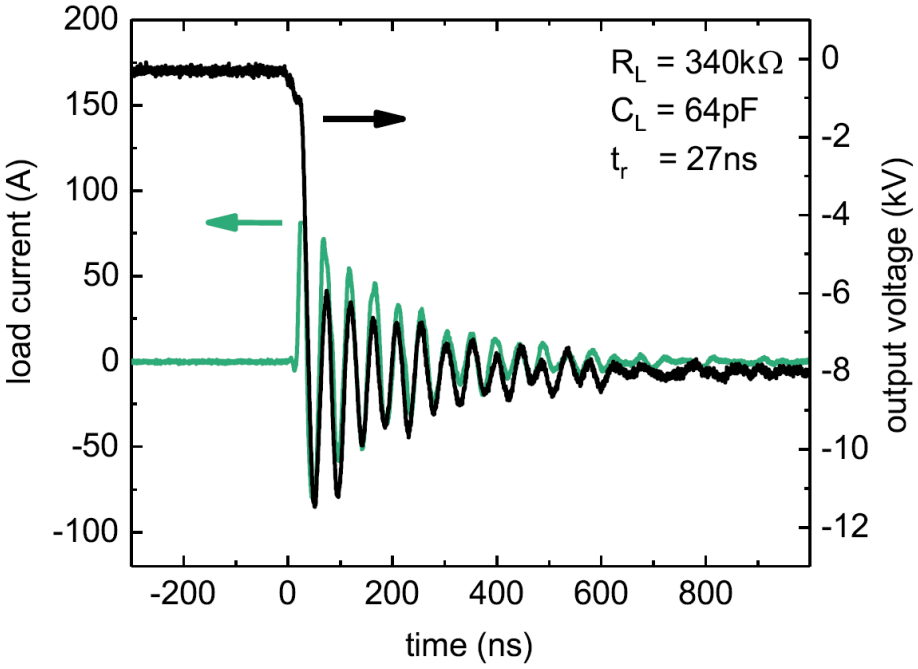


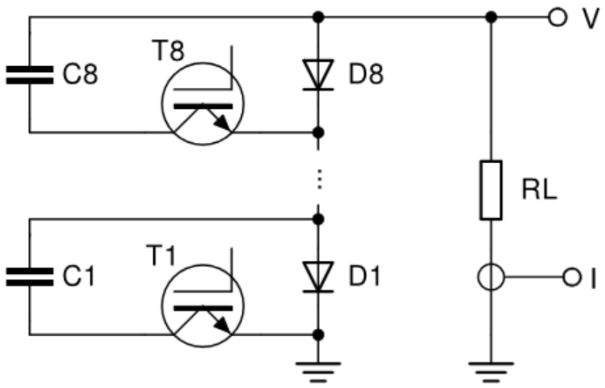




Results on a 8-stage generator

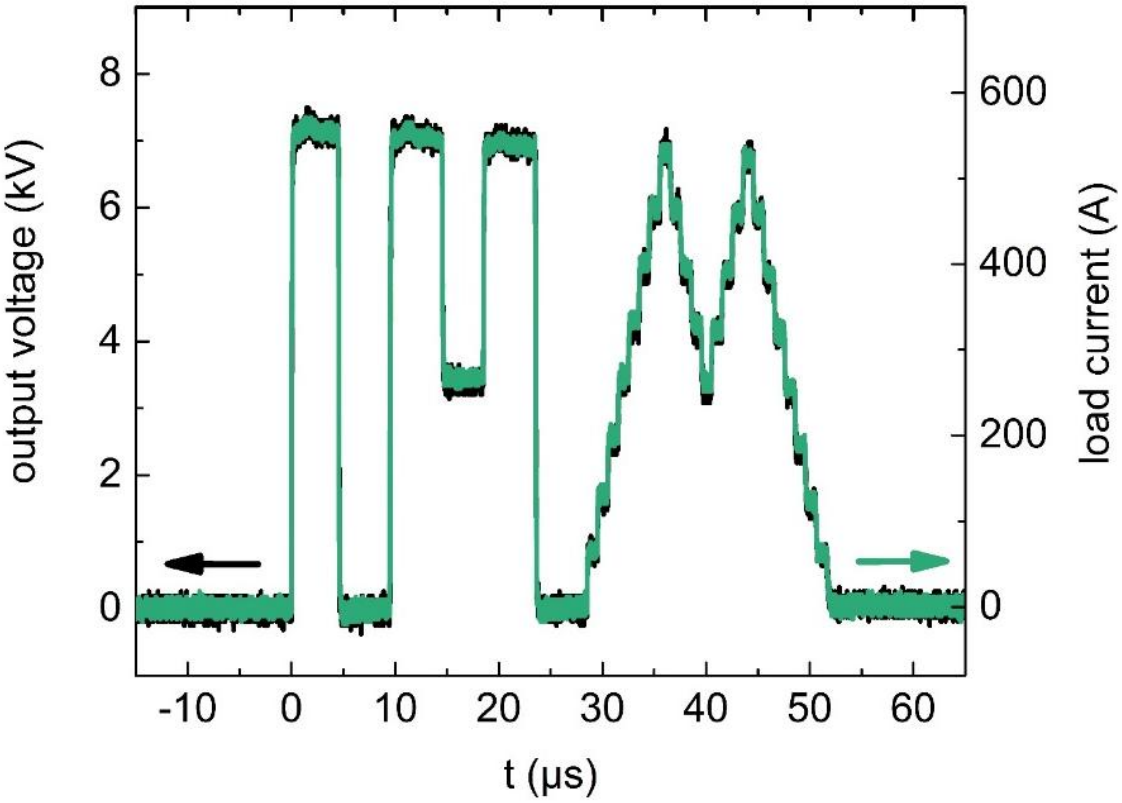
- Operated in complete control chain
- 27 ns voltage rise time verified in open circuit conditions

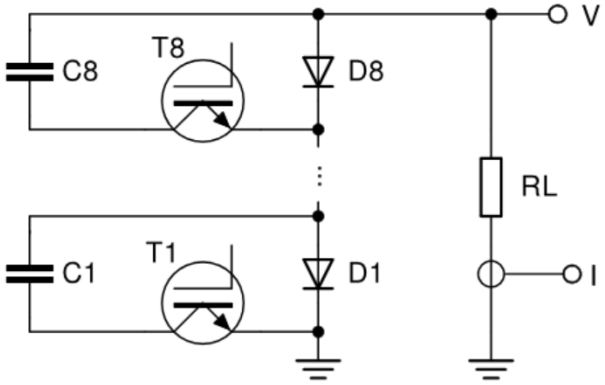




Results on a 8-stage generator

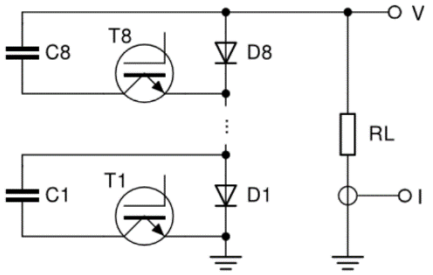
- Operated in complete control chain
- Arbitrary output waveform generation verified

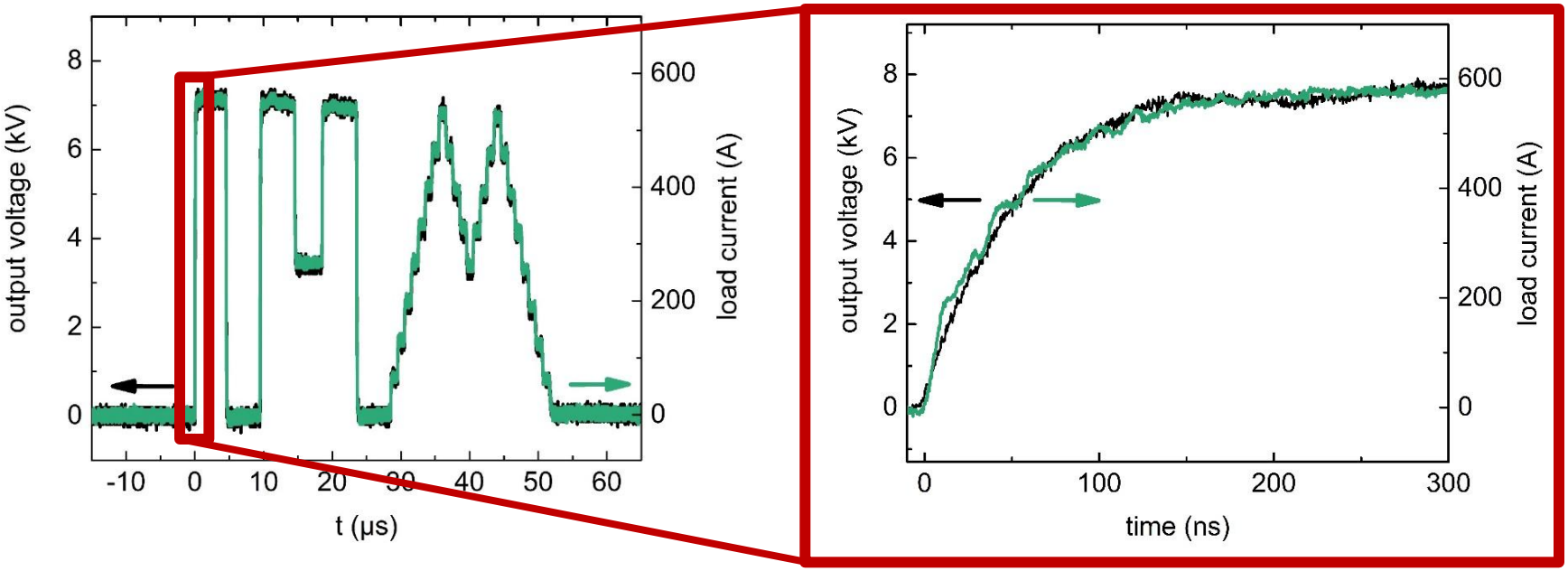




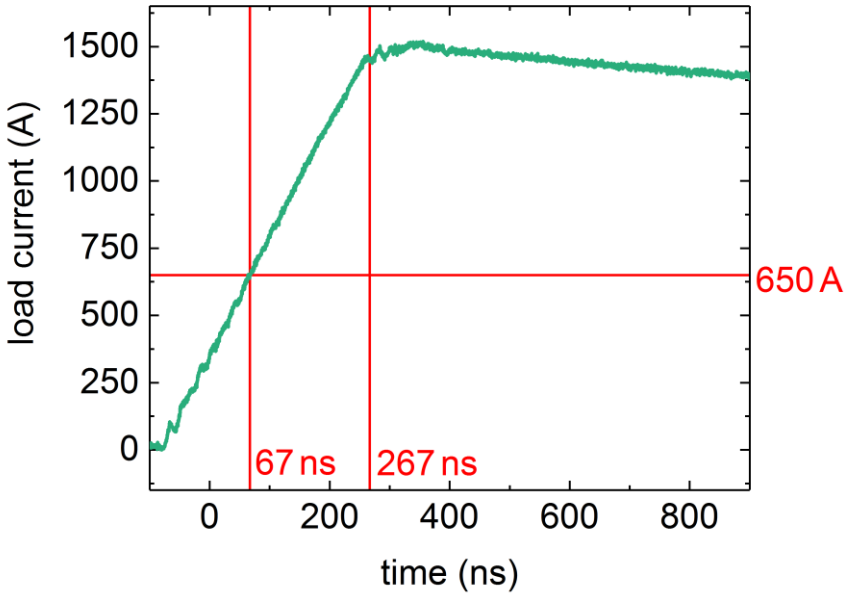
Results on a 8-stage generator

- Operated in complete control chain
- Arbitrary output waveform generation verified
- Total inductance < 1.4 µH
- Current rise time: 106 ns @ 600 A

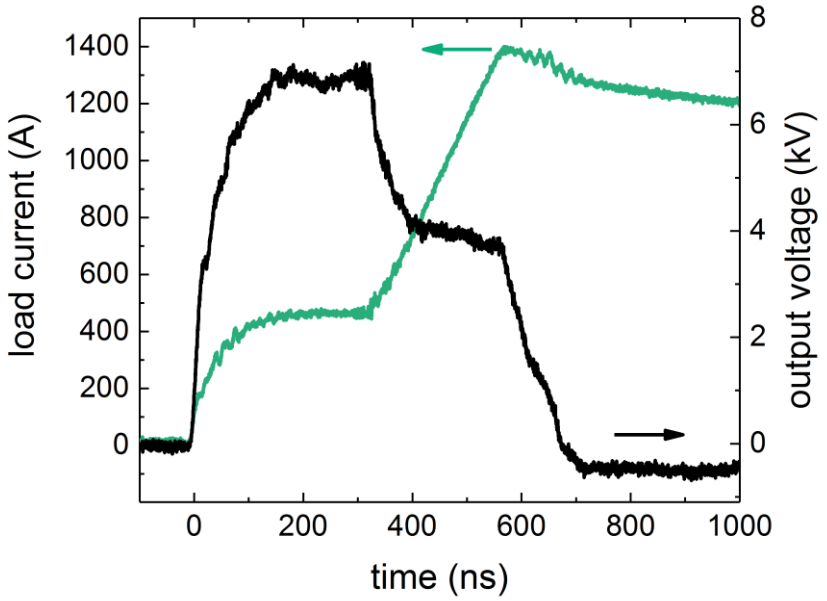




Fast over-current protection



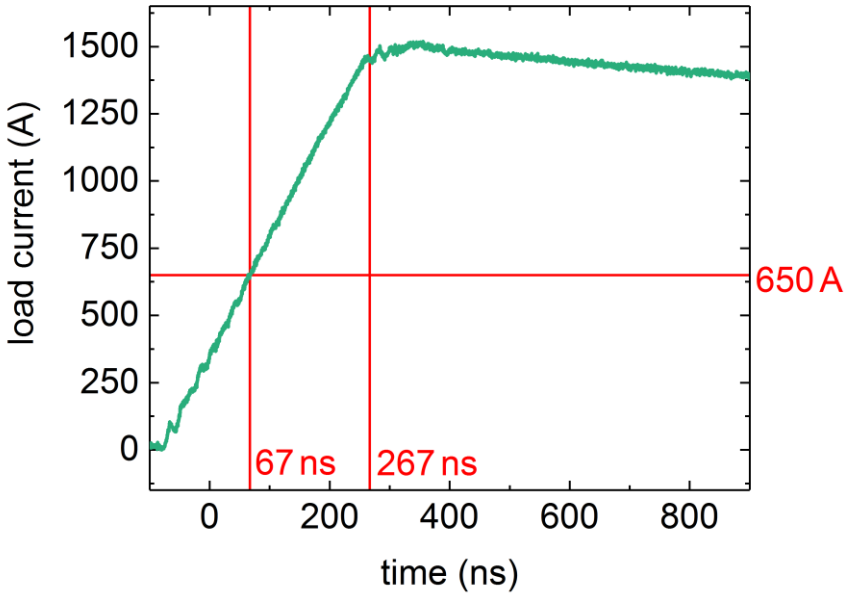
Hard-Switched Fault



Fault Under Load

- Operation on highly dynamic load -> Overcurrent protection crucial
- Maximum current rise rate: 4 kA/µs
- 200 ns time delay between over-current detection and turn-off

Fast over-current protection



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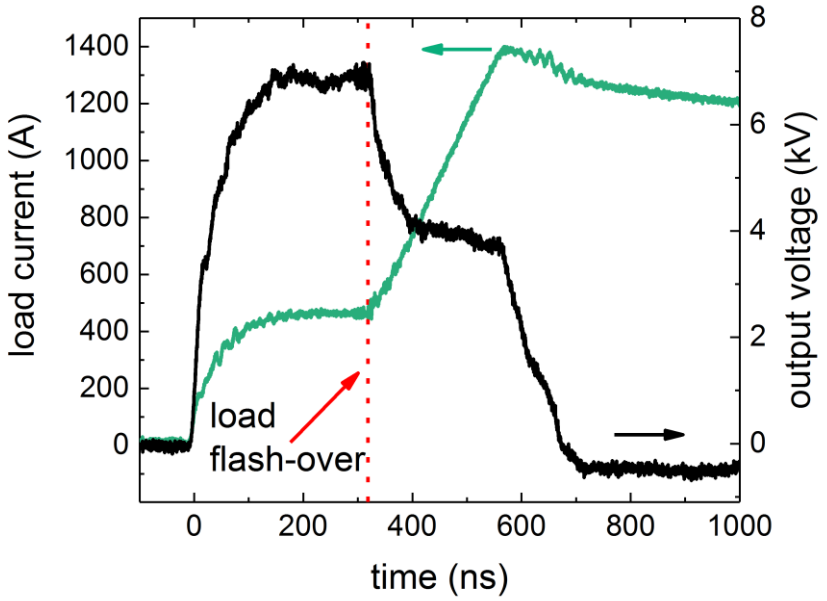

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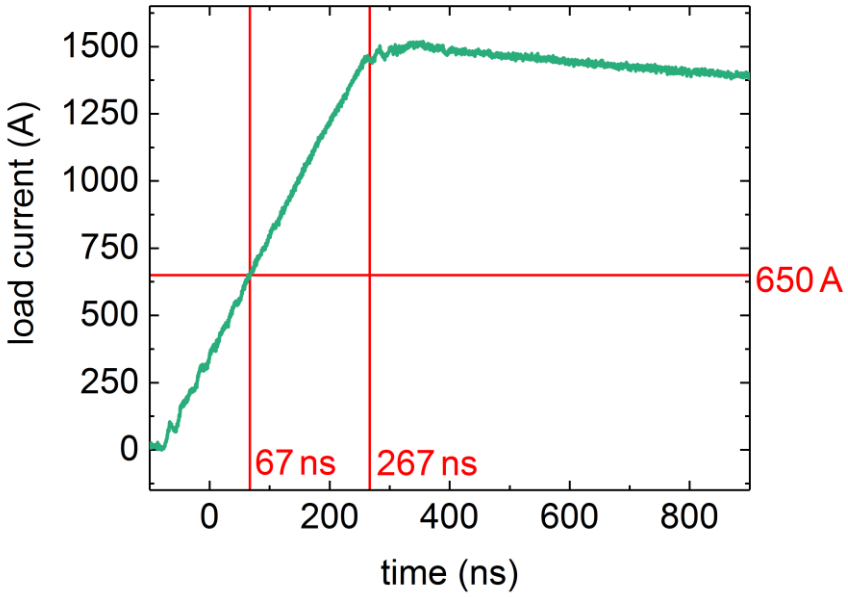

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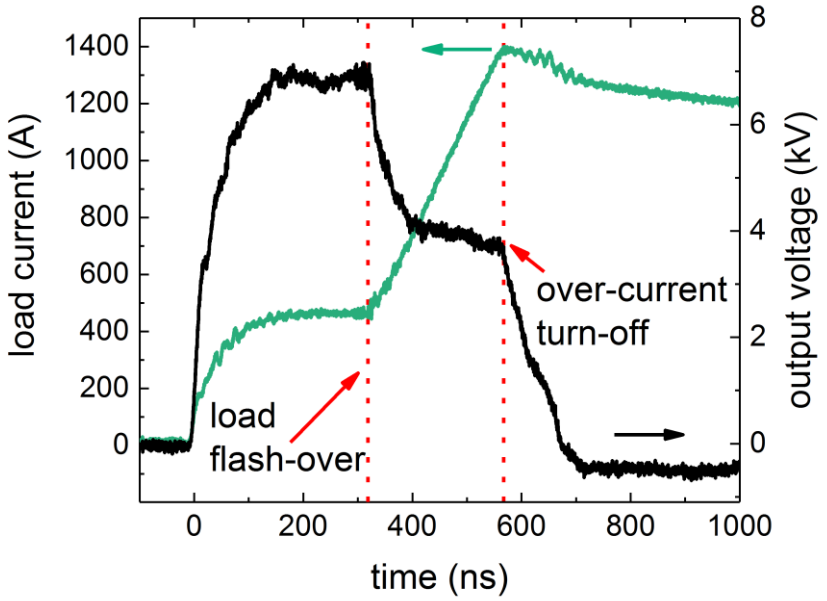

Fault Under Load

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- Maximum current rise rate: 4 kA/µs
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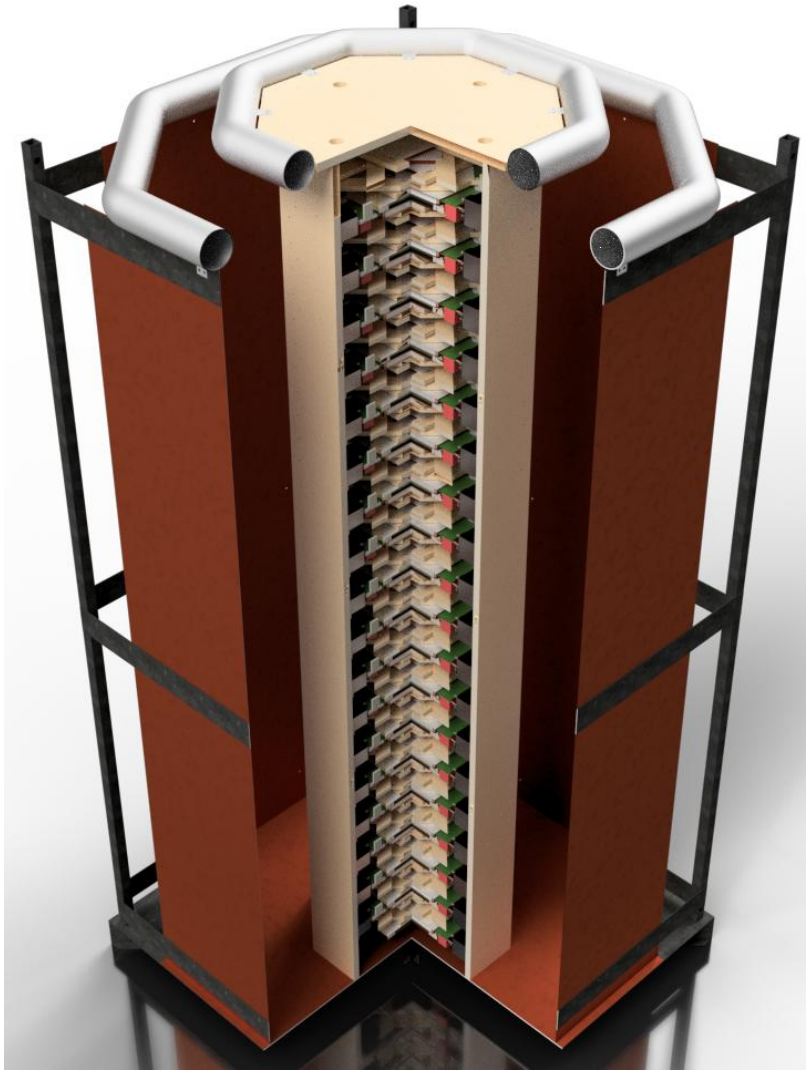
Project status

- Design of generator verified in a small-scale setup
  - Pulse components
  - Control scheme
  - Over-current protection



Special thanks to the IHM workshops

Project status

- Design of generator verified in a small-scale setup
  - Pulse components
  - Control scheme
  - Over-current protection
- Manufacturing of mechanical and electrical components completed
- Final assembly in progress

Next steps:

- Full-scale testing