Investigation of a fast high-repetitive 10-kV SiC-MOSFET switching module

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A joint initiative of

DGA

Ministère des Armées

Bundesministerium der Verteidigung

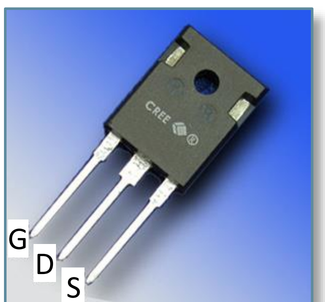
Outline

- Background/Motivation
- Switching module design
- Experimental setup
- Experimental results
- Summary & Outlook

Introduction – Semiconductor (SC) based pulsed power systems (1)

- Progressive transition from classical gas/(liquid) discharge based towards **semiconductor based pulsed power systems (switches & generators)**

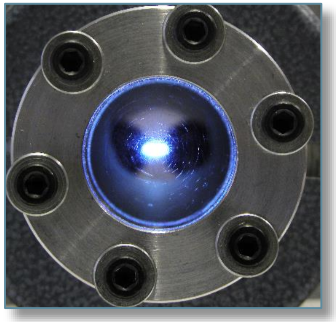
- Switching technology comparison:



SiC power MOSFET

SiC power MOSFET		Spark gap
Very good	Reproducibility and controllability	Electrode burn-up
t_{on} = 20 ns	Turn on time	t_r = 7 ns
f up some MHz	Pulse repetition frequency	$f \leq$ 200 Hz
(almost) infinite	Lifetime (normal operation)	$<10^7$
Worst case → 1	Lifetime (excess voltage/current)	($<10^4$)
$V_{DS} \leq$ 1200 V	Switching voltage (Series arrangement)	$V \geq$ 50000 V
$I_{D(pulse)} \leq$ 80 A	Switching current (Parallel arrangement)	$I_D \geq$ 10000 A

→ Complexity (Synchronous triggering) & Costs

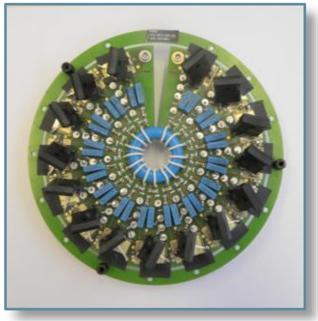


Spark gap

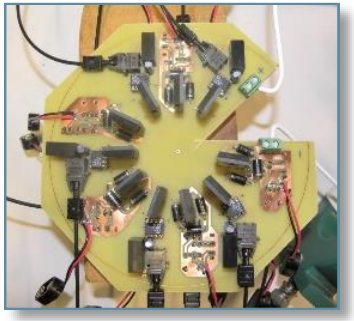
Introduction – Semiconductor (SC) based pulsed power systems (2)

- ⇒ Our objective:
  Development of SC based fast high voltage (and high current) switching modules & generators for short pulse applications in the defense sector (**Electromagnetic emitter**, electric armor, rail gun, detonators, …)

- Questions:
  - Operational behavior of SC HV switches & generators on non-resistive/transient loads?
  - SC switch / HV pp system protection?

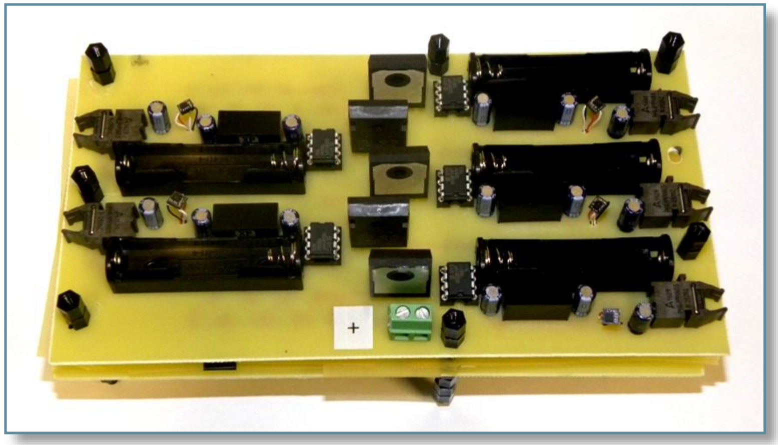


20-kV module with 1700-V SiC MOSFETs (ABB-ISL circular design)

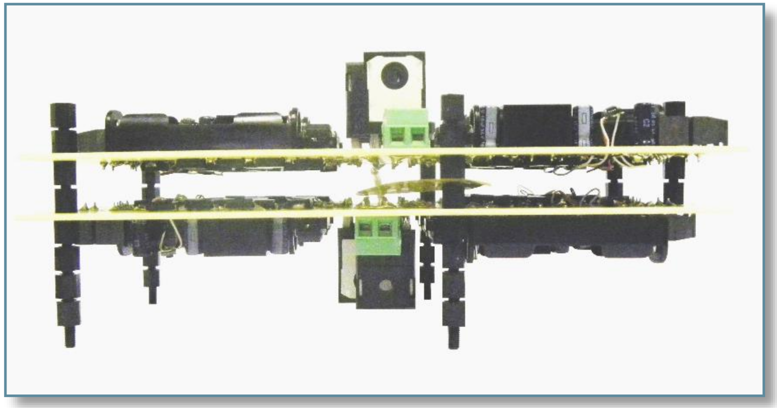


1st-generation 10-kV module with 1200-V SiC MOSFETs (ISL circular design)

2nd generation 10-kV SiC MOSFET switching module – General design



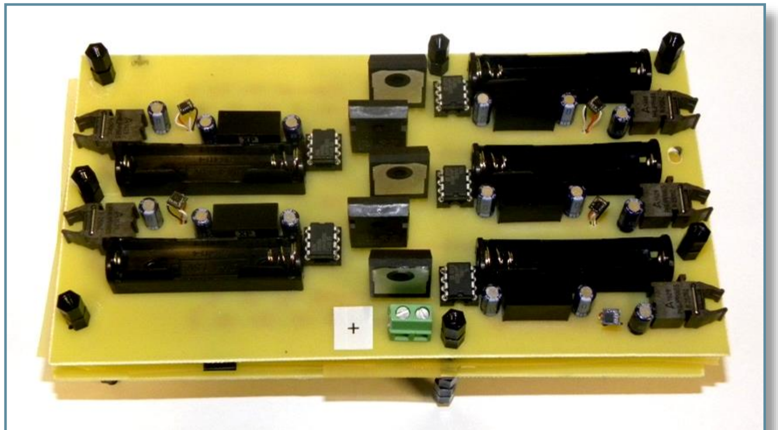
Top view



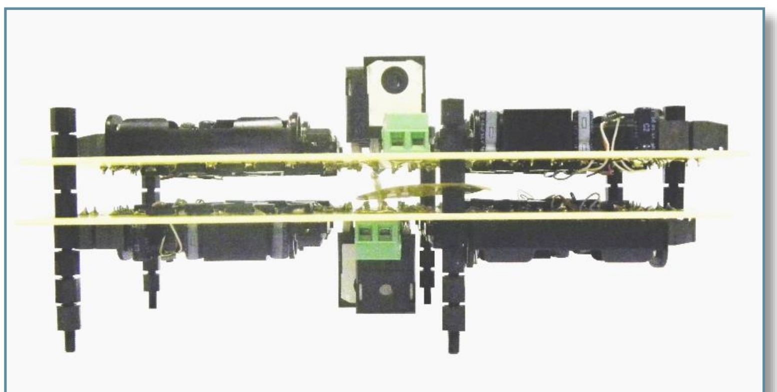
Side view

- General Design:
  - COTS
  - 1200-V SiC MOSFETs: Wolfspeed/CREE C2M0080120D
  - 2-layers with each 5 switches
  - Size: (177 x 95) mm^2, Layer distance: 13 mm
  - → Low-inductive
  - Battery powered
  - Optical galvanic insulation
  - Scalable

2nd generation 10-kV SiC MOSFET switching module – System Protection



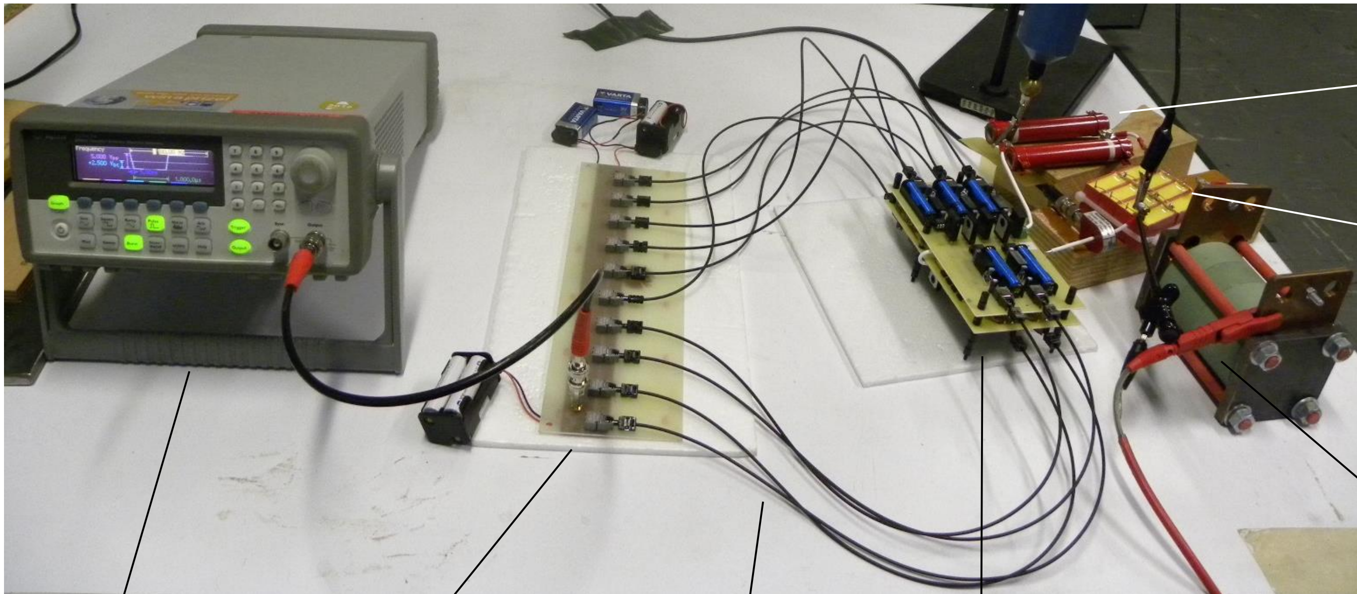
Top view



Side view

- Multiple system protection:
  - 5-MΩ resistors for voltage balancing
  - TVS diodes against transient over-voltages
    - Onset @ 1169 V ⇔ SiC MOSFETs
    - Onset @ 6.6 V ⇔ Opto-receivers
  - External FREDs against voltage reversal (optional)

Experimental setup



Load resistor
R_{load} = 250 Ω

C = 45.4 µF

Charging resistor
R_{ch} = 4 Ω

TTL generator

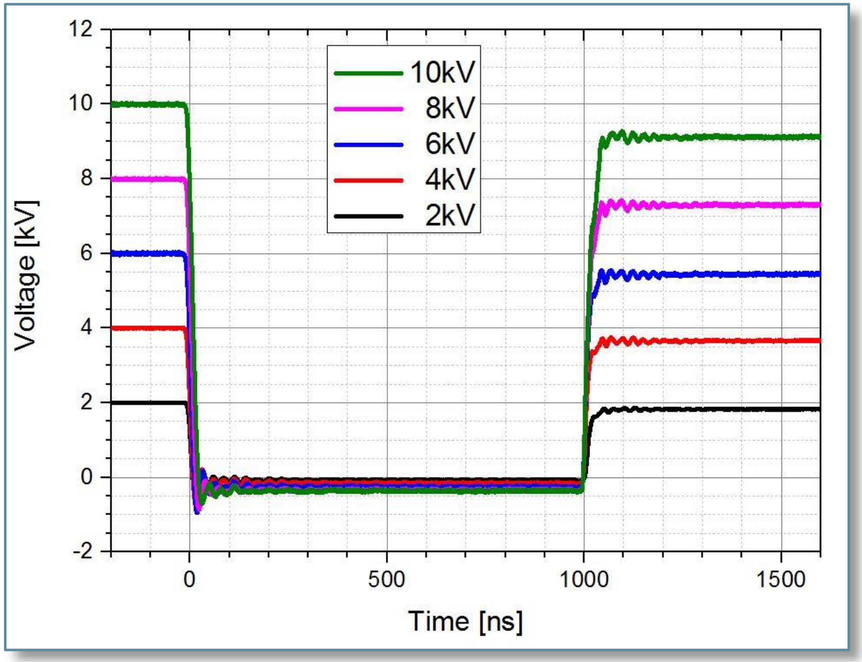
Control board with
10 opto-transmitter

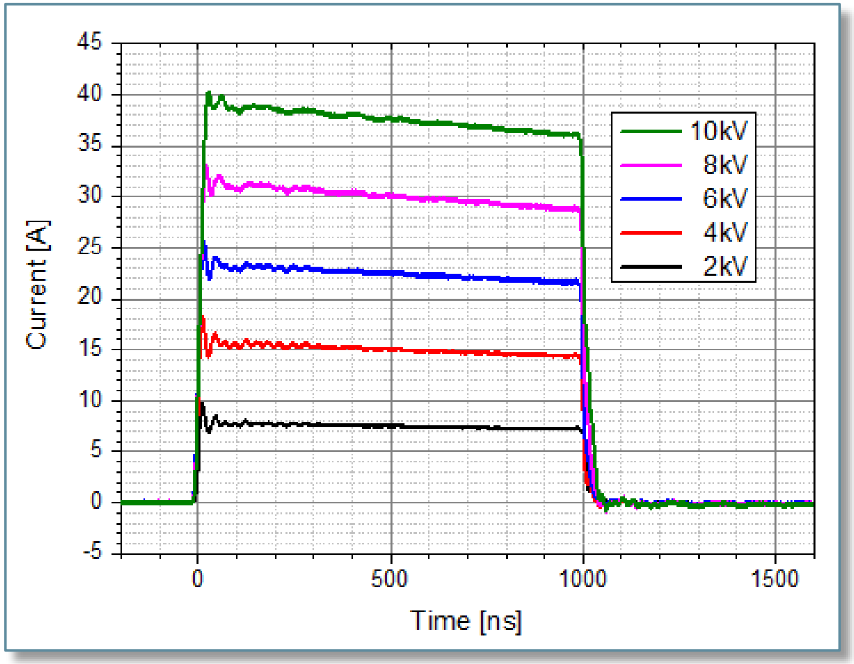
Optical cables

10-kV SiC MOSFET
switching module

HV power supply

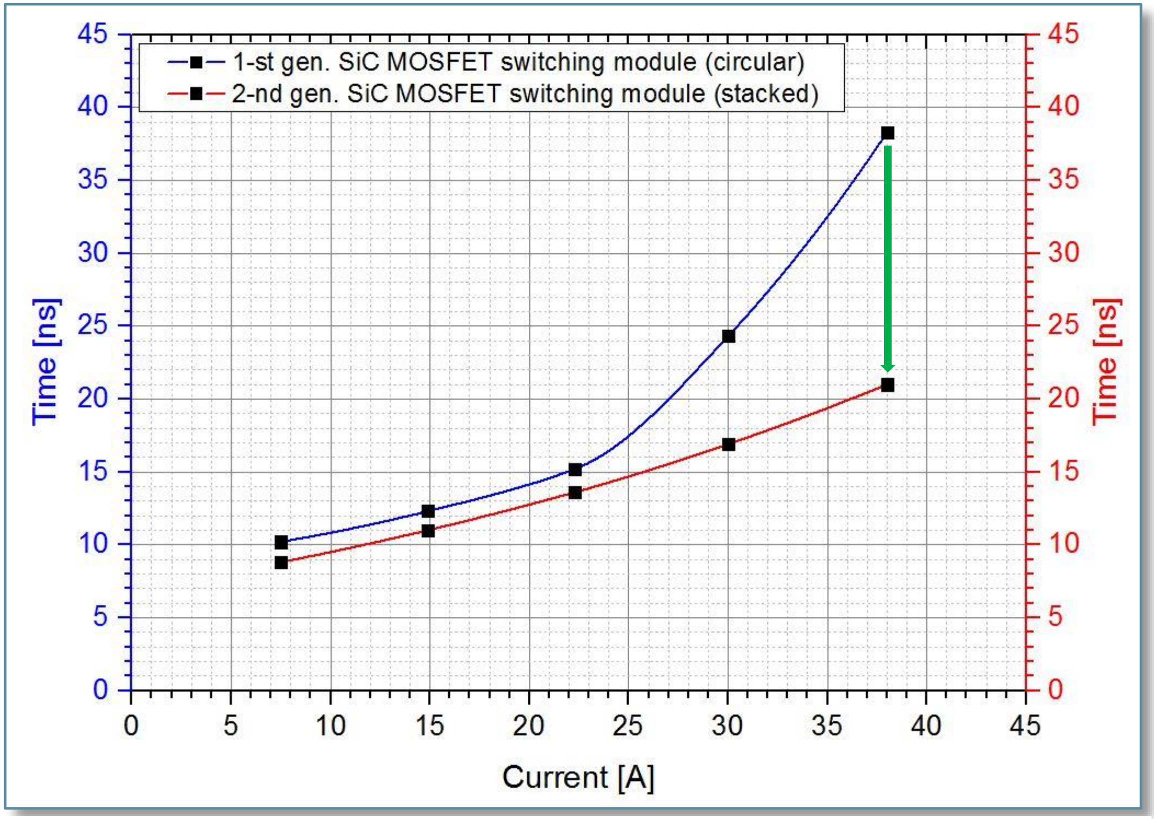
Experimental results (1) – Turn-on & turn-off behavior





Stable turn-on & turn-off behavior

Experimental results (2) – Turn-on times

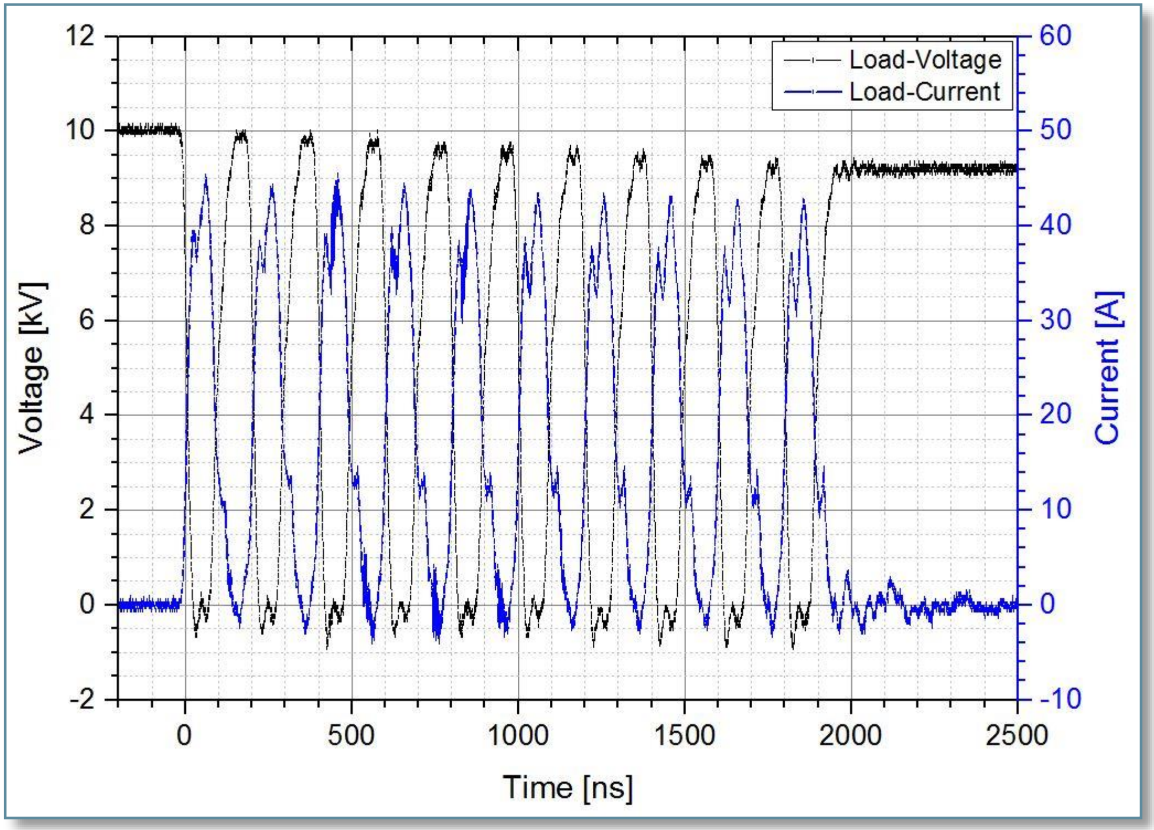


Comparison turn-on time 2nd-gen. module with 1st-gen. module

Faster current turn-on time: t_{on} = 37 ns → 21 ns @ V_{SW} = 10 kV

Increased current rise-rate: *dI/dt* = 1.0 kA/µs → 1.8 kA/µs

Experimental results (3) – Burst mode



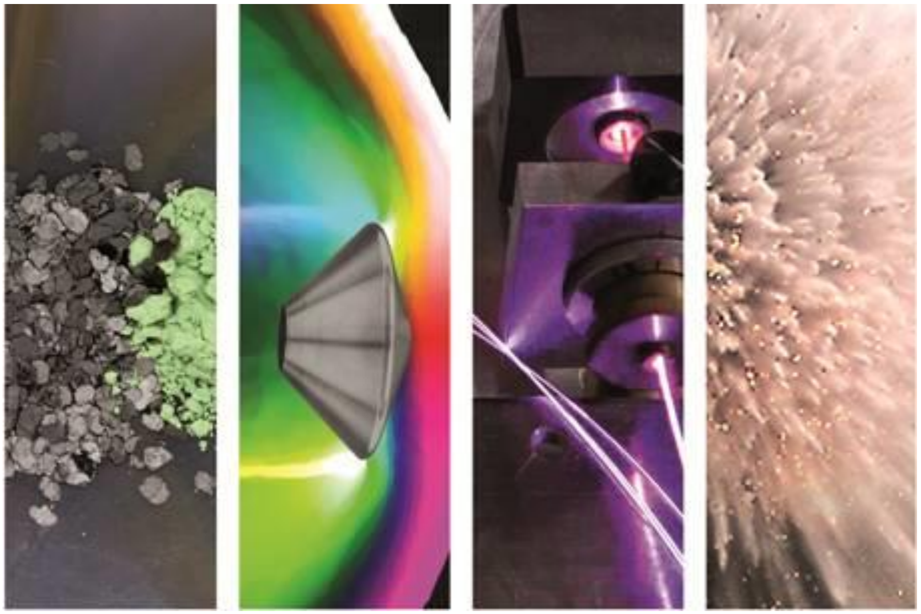
Stable 5-MHz burst mode operation (10 cycles)

Summary

- Design, development & testing of fast SiC MOSFET switching module
  - COTS parts
  - System protection
  - t_{on} = 21 ns @ V_{SW} = 10 kV & I_D = 38 A
  - Successful burst test: 5 MHz prf, 10 cycles

Outlook

- Speeding-up of turn-on time by means of gate-boosting techniques
- Upscaling to 30-kV switching module class
- Development & testing of multi-stage SC based MARX generator



Thanks for your attention

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