Semiconductor based Marx technology for Kicker Magnets

*L.M. Redondo (ISEL)
A. Kandratsyeu (EPS)
M. J. Barnes, T. Fowler (CERN)

L. M. Redondo, A. Kandratsyeu and M. J. Barnes, "Marx Generator Prototype for Kicker Magnets Based on SiC MOSFETs," in IEEE Transactions on Plasma Science, vol. PP, no. 99, pp. 1-6, 2018.

Outline

- Motivation & Challenge
- Problem? (Power supplies for kicker magnets)
- Marx generator concept & specs
- Marx stage switch unit results
- One & four Marx stage results
- Conclusions

Motivation & challenges

SiC MOSFET technology can be used in fast high current pulsed power accelerator applications

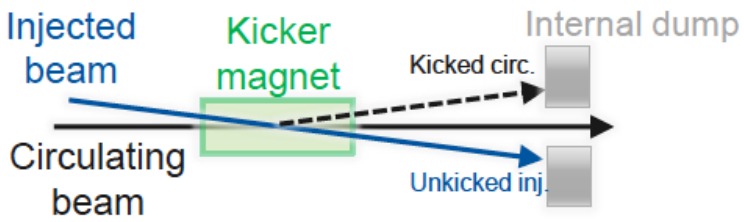
- Cost-effective
- Easy to use
- Off-the-shelf
- Flexible
- Portable
- Modular
- Electrical efficient

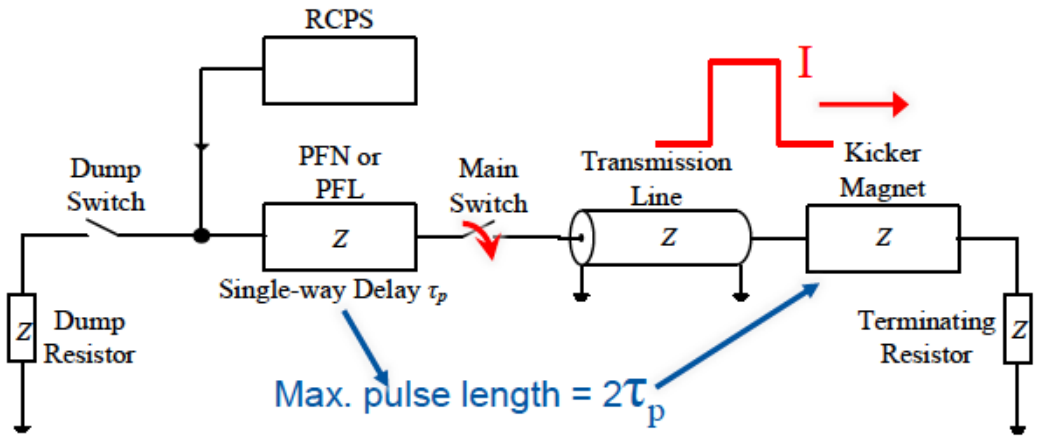
versus

- Reliability
- Continuity of work
- Robust
- Performance

Power supplies for kicker magnets

Kicker magnets are specialised elements of particle accelerators beam transfer system, used to inject and extract beam from an accelerator.
Typical field rise/fall-times from 10s to 100s of ns and pulse widths range from 10s of ns to 10s of µs.



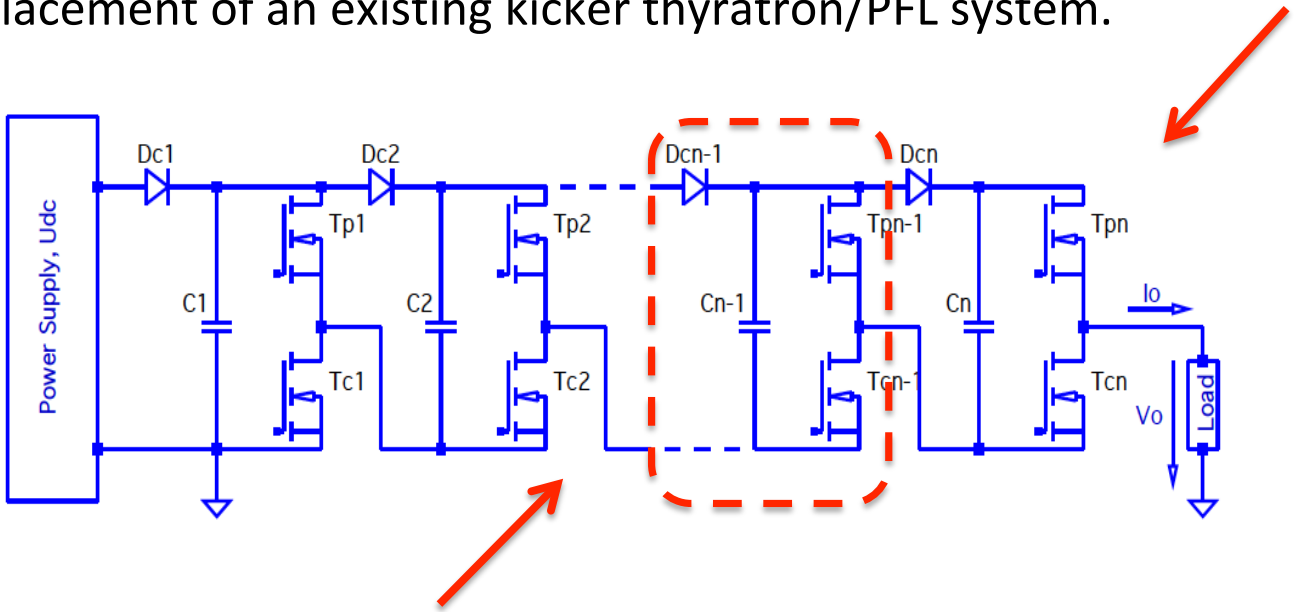


Most existing kicker systems at CERN rely on established technologies, which include thyratron switches and pulse-forming networks/lines (PFN/PFL). The long-term availability of thyratron and high-voltage PFL technology is a concern.

Goal: reliable, fast-switch technologies based on semiconductor devices: such as inductive adder (<3us pulse width) and Marx generator are being actively pursued.

Marx generator concept & specs

Design strategies & preliminary results for a Marx generator with specifications: 40kV, 3.2kA, 3µs pulse width, 30ns rise and fall-times, and 1Hz repetition rate, for possible replacement of an existing kicker thyratron/PFL system.



Marx generator concept: *n* capacitors charged in parallel by relatively low voltage power supply Udc, through Tc switches and diodes Dc, subsequently Tp switches connect all C capacitors in series with the load, applying approximately *n*Udc. Where for fast rectangular pulses MOSFET technology is required.

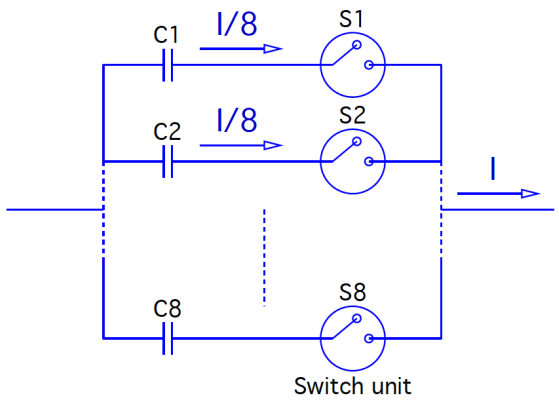
Marx generator concept

The proposed switch topology:

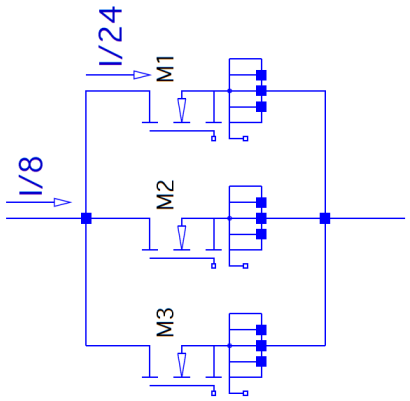
- CREE SiC MOSFET C3M0065090J, 900V, 65mΩ and 90A pulse SiC MOSFET, in D2PAK-7L package, with separate emitter for gate voltage. (Now C3M0065100J, 1000V, same specs)

- n staked stages, each stage comprising 24 SiC MOSFETs in parallel (8 capacitors, each with its own switch unit), each MOSFET conducting about 34A.

Pulse switch for Marx stage

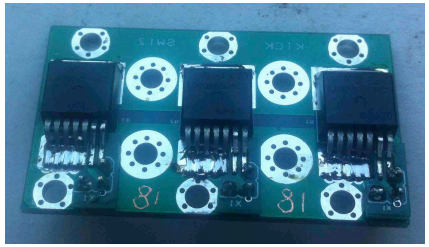


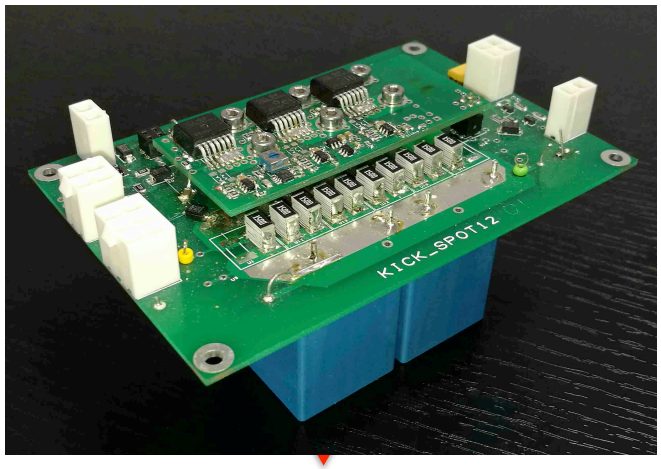
Switch unit ➔ 3 MOSFETs



Marx stage switch unit results

Switch unit: 3 parallel MOSFETs with 60µF capacitance

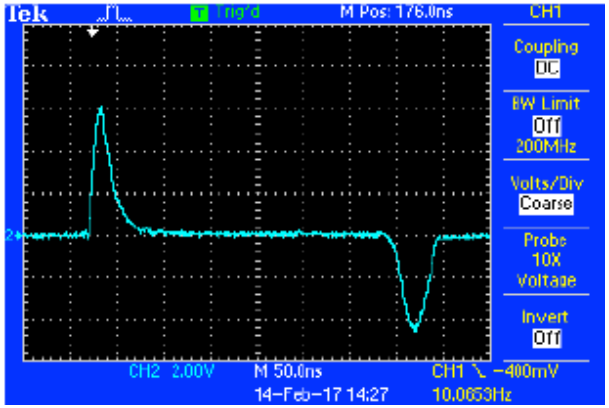




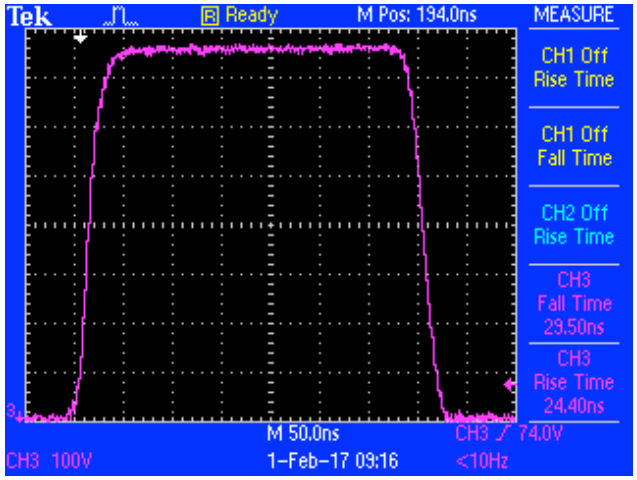
750 V pulse on 1.5Ω, 500 A

Switch unit: 3 parallel MOSFETs current sharing

M1	166 A (33.1%)
M2	152 A (30.5%)
M3	182 A (36.4%)

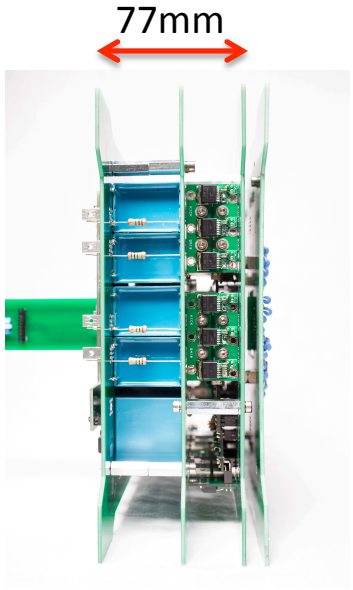


Ldi/dt on Drain pin

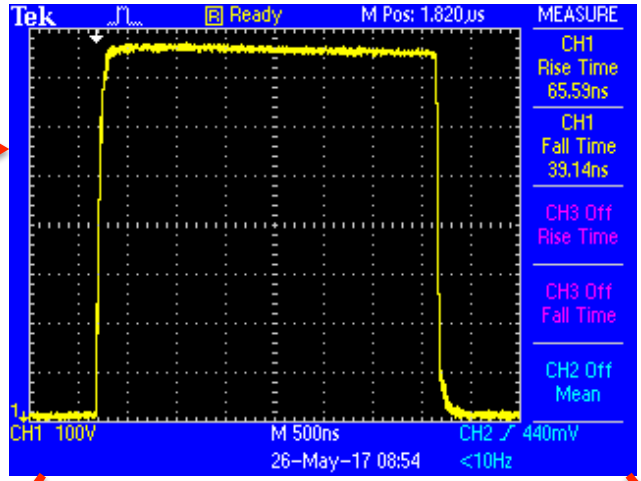


One Marx stage results

Operating conditions:
Udc=800V
R=0.25Ω

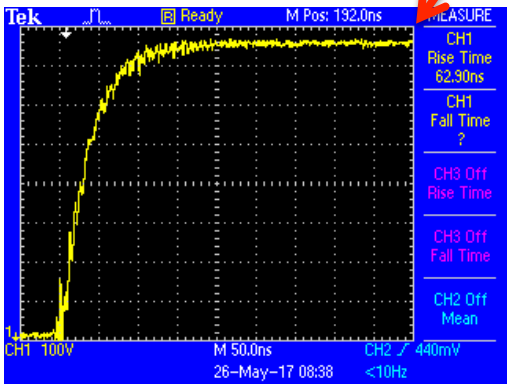


≈3200A

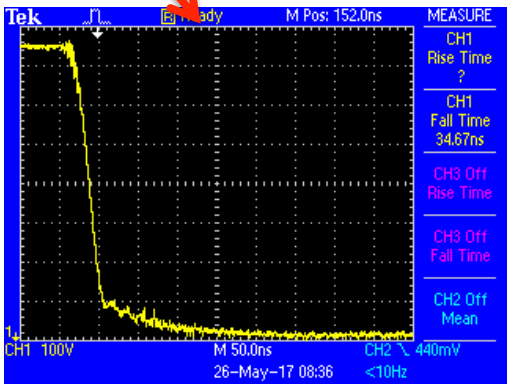


500ns/div

Voltage drop, 40V
Voltage droop, <1.5% (10V)

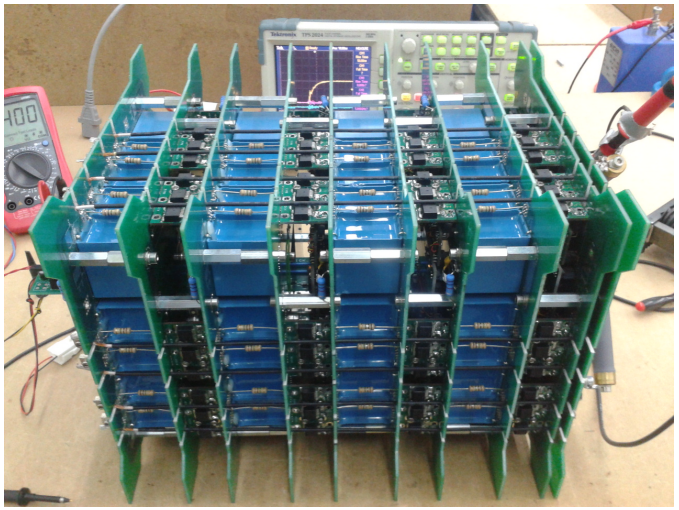


50ns/div

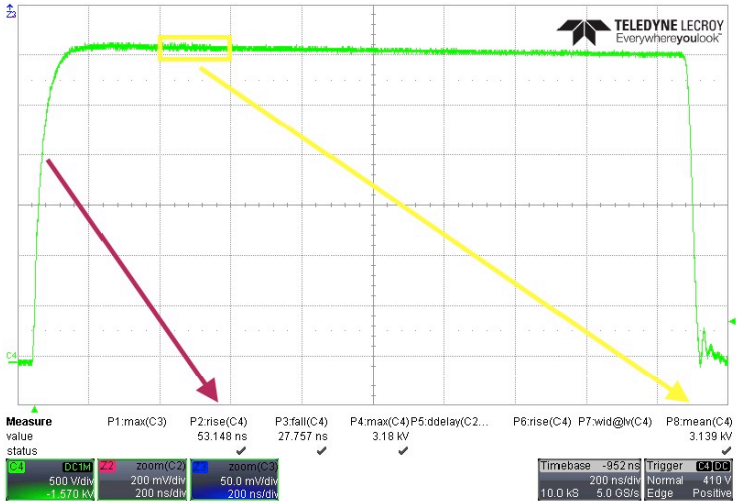


Four Marx stage results

Operating conditions:
Udc=800V, R=4Ω7//4



2.7 kA for a 3.2 kV pulse



500 V/div, 200 ns/div

Rise and fall times are, respectively, 53ns and 28ns (10%-90%).
Circuit time constant of 24 ns, and a load of 1.175 Ω, results in a calculated four stages Marx circuit inductance of about 28 nH.

Conclusions

- SiC parallel MOSFET technology can be used in fast high current pulsed power applications.
- Marx generator with SiC technology preliminary results show that it can be considered as fast-switch technology for replacing thyratrons and PFLs in kicker applications.
- One stage 3200A/800V and four stages 2700A/3200V results shown good performance.
- The Marx generator topology is a promising candidate for the high current pulsed power generators for accelerator applications.

- Future: assemble and test more stages to investigate the overall performance and reliability. Operation with frequency and short circuit behaviour
- (Voltage ≈15kV, tr≈75ns, 100Hz, few µs, short-circuit response <500ns)