A Marx for a Kicker Magnet Pulse Generator based on SiC MOSFETs

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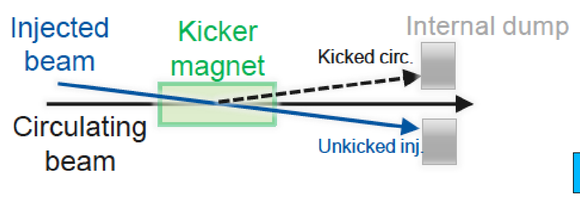
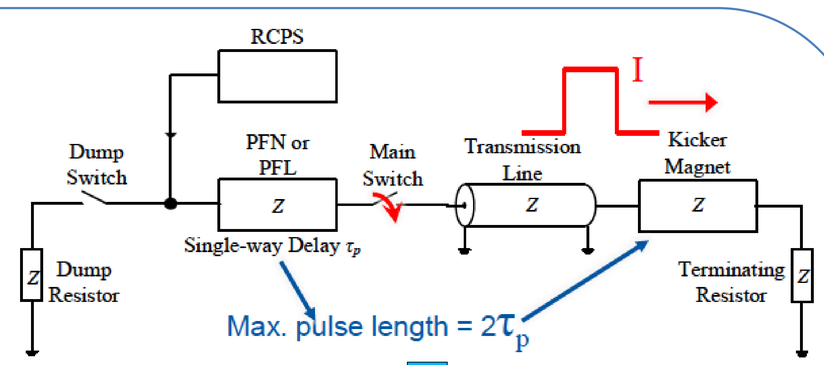
Summary

The design of a solid-state Marx Generator prototype, based on SiC MOSFETs, for replacing existing Thyratron modulator technology, in particle accelerators, is described. The aim of the work is to develop a generator for output pulse specifications: 16 kV, 2.56 kA, 2 µs voltage flat top, 75 ns rise and fall-times, 1 Hz repetition rate and 10 Hz burst mode (based on the requirements of the injection system for a proposed Future Circular Collider (FCC)). This Marx prototype is also considered a "proof of principle" demonstrator for possible replacement of a Thyratron and PFL in an existing CERN kicker system. The design, assembly, constraints and initial results are discussed.

Introduction

Kicker magnets are specialised elements of particle accelerator beam transfer systems, 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.



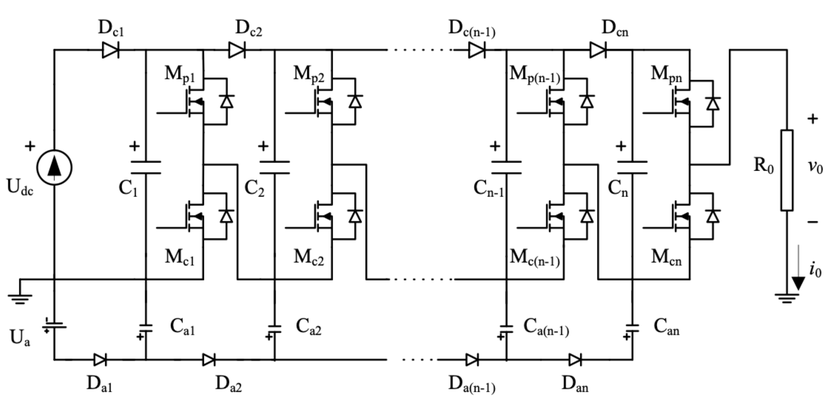


Most existing kicker systems at CERN rely on established technologies, which include thyratron switches and pulse-forming networks/lines (PFN/PFL). The long-term availability of thyratron and high-voltage PFL technology is a concern. A semiconductor switch capable of both closing and opening allows replacement of the PFN/PFL by a capacitor bank.

Goal: reliable, fast-switch technologies based on semiconductor devices. Inductive adder (<3us pulse width for a terminated load) and Marx generator technologies are being actively pursued.

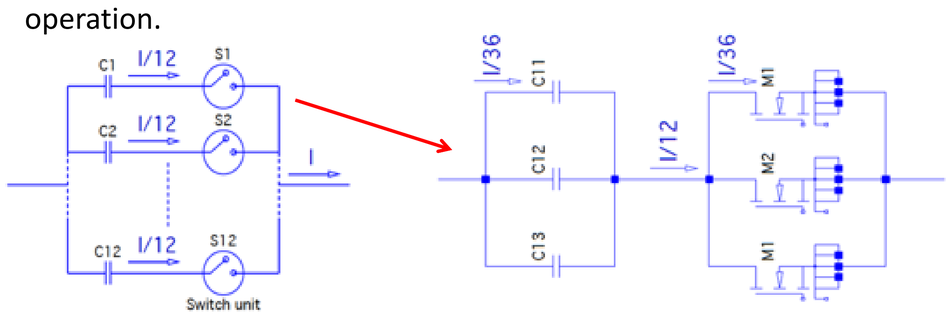
Marx generator concept: *n* capacitors charged in parallel by a relatively low voltage power supply U_{dc}, through M_{ci} switches and diodes D_{ci}. Subsequently M_{pi} switches connect all Ci capacitors in series with the load, applying approximately nU_{dc}. For fast rectangular pulses MOSFET technology is required.

- CREE SiC MOSFET C3M0065100J
- EPCOS Capacitor B32776G8306K



Design

- *20* stages, 800 V per stage
- 1080 µF/stage (36x30 µF)
- Each M_{pi} comprises 36 parallel MOSFETs (≈70 A/MOSFET c.f. 90A pulse rating) , and M_{ci} 4 parallel MOSFETs.
- Trigger signal transmitted by opto-coupler, power supplied by bootstrap operation.



Pulse switch S_{pi} for each Marx stage, each stage comprising 12 switch units

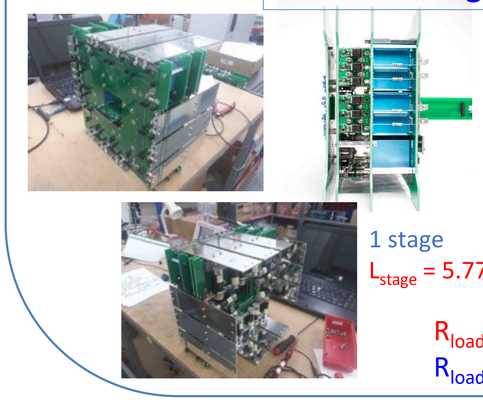
Each switch unit has 3 parallel capacitors, and 3 parallel MOSFETs

Considering the pulse energy of:
$E_p=U_p.I_p.t_{on}=16000x2560x2.35x10^{-6} \approx 96$ J

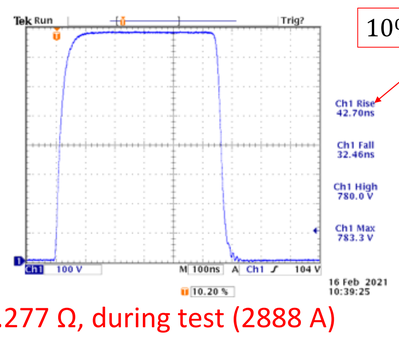
Energy stored in the Marx, for 20 stages:
$E_M=20.(0.5).C.U_{dc}^2=20x0.5x1080x10^{-6}x800^2= 6912$ J

This gives a pulse voltage droop of about 112 V, which is within the specified ±0.5 % (±80 V).

Coaxial Marx generator, 1 stage, 800 V



1 stage
L_{stage} = 5.77 nH

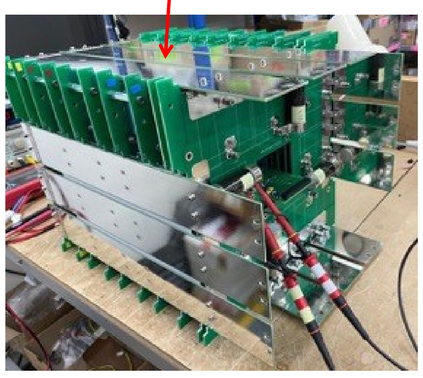


R_{load}= 0.277 Ω, during test (2888 A)
R_{load}= 0.3125 Ω, for nominal current

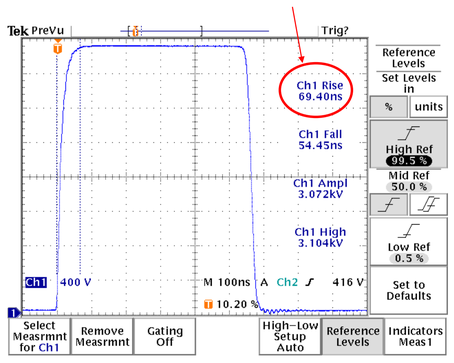
Results & assembly

Coaxial Marx generator 4 stages (1 module), 3200 V

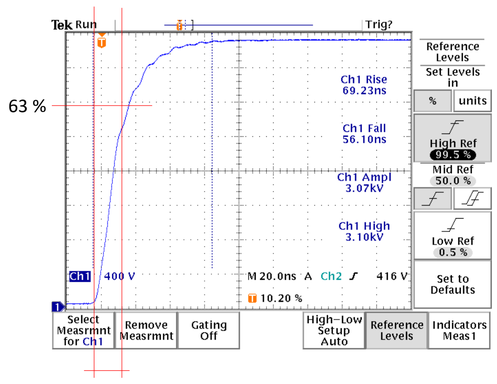
Return path to lower the inductance



4 stages



R_{load}= 1.131 Ω, during test (2820 A)
R_{load}= 1,25 Ω, for nominal current



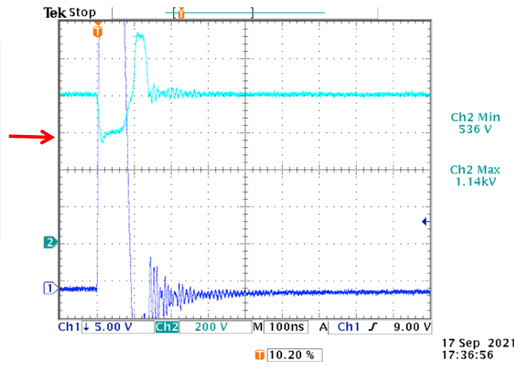
τ≈ 16 ns (~4.5nH/stage)

Overcurrent protection

Marx generator has two SC redundant protections:
- *Classic de-saturation protection that measures the V_{ds} at each MOSFET*
- di/dt protection that measures the current rate-of-change in the MOSFET emitter pin

Conditions: Load SC
Udc=800V
Vds: 200V/div (Cyan), clamps at 1140V
Trigger signal (blue) 5V/div for syncronization
The 500ns pulse turns-off at 80ns

Results for one Marx stage SC operation



Full device assembly

20 stage Marx is being assembled:
1st tests: each individual stage (x20)
2nd test: each module, with 4 stages (x5)
3rd test: the full, 20 stage Marx.

Finally, test at CERN

Conclusions

The preliminary measurements presented, with 1 stage and 4 stages, are promising. However, there are still the 20 stages (full Marx) tests to perform, which will indicate if this technique can be considered a candidate for high current pulsed power generators for accelerator applications, including long term reliability and operation with a kicker magnet terminated in a short-circuit. In addition, possible issues include: i) increased distance to the current return plates/wires, which would result in higher inductance, as the number of stages increases; ii) the length of the structure, which will be in the 1.8 m range if the structure is stacked the same way.