

NEW BESSY BOOSTER SOLID STATE KICKER PULSE POWER SUPPLIES

Olaf Dressler - PULPOKS 2023 Workshop,
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Traveling Wave Kicker Pulser Systems of BESSY Booster

Control electronics



Pulse forming lines

Booster injection:

- 1 Kicker system
(16kV, 16A, 350ns, rectangular)

Booster extraction:

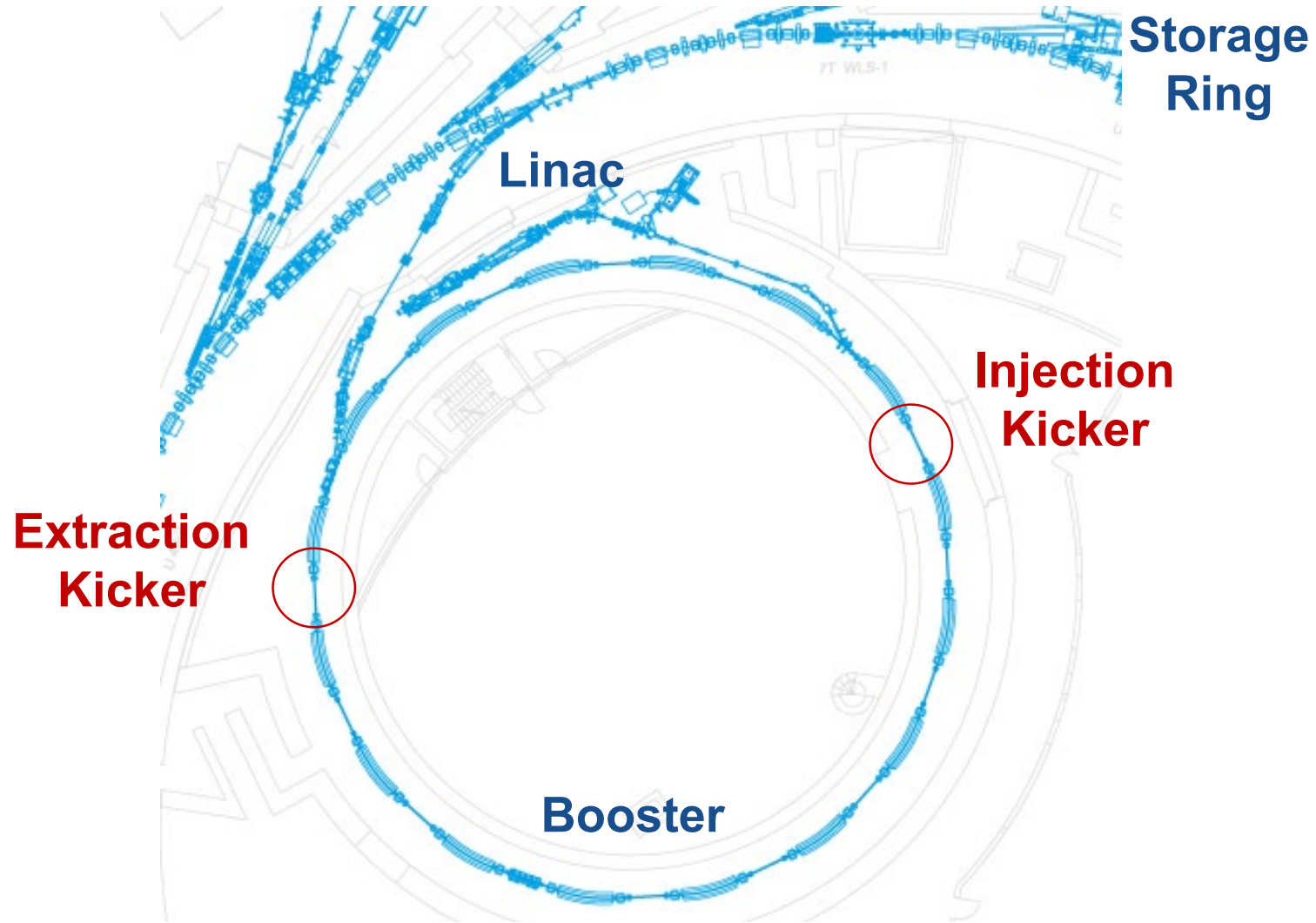
- 2 Kicker systems
(30kV, 600A, 350ns, rectangular)

HV power supplies



Traveling wave kicker pulsers

The BESSY Injector System with the Booster Kicker Magnets

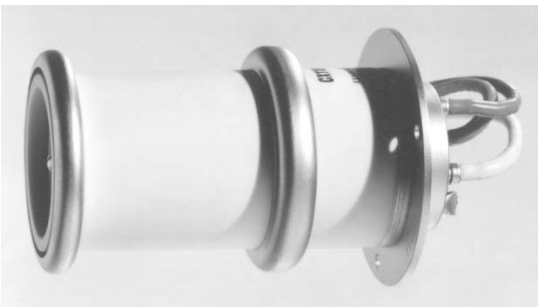


The Booster Kicker Pulsers

Traveling wave kicker pulser
designed at DESY



Thyratron e2v CX 1154 used
in kicker pulser unit



For the operation of BESSY II booster is required:

- High availability and reliability of kicker systems during operations,
- High average lifetime of the switches used and the entire pulser systems,
- The best possible stability for suppressing timing jitter and drift.

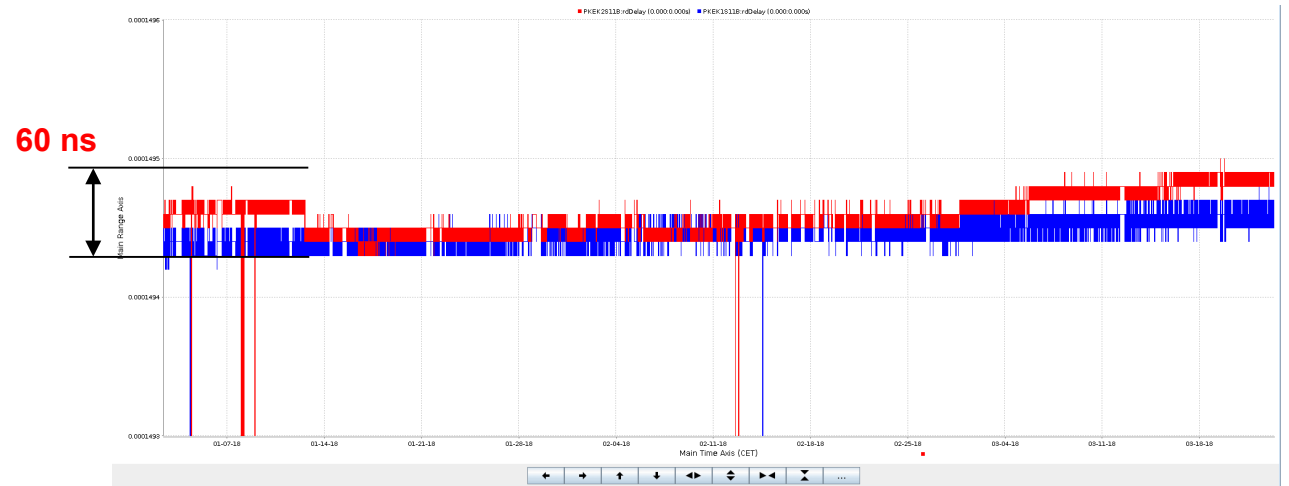
Challenges with the pulser systems currently used:

1. First, damage of the insulation in the kicker pulser boxes by heating of the thyratrons,
2. Short life time of the thyratrons in the traveling wave circuit topology,
3. Ageing of the thyratron causes strong timing drifts.

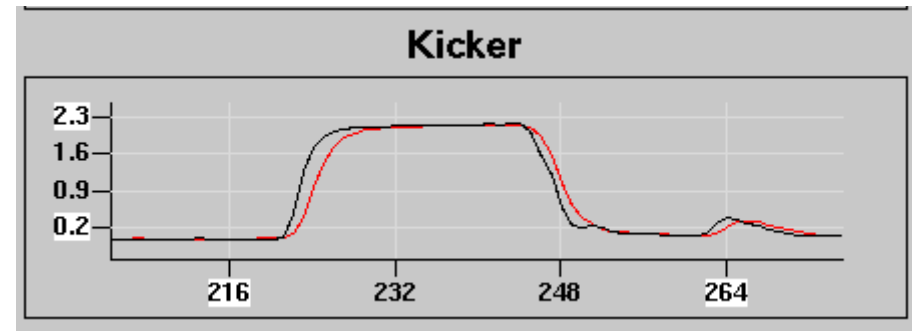
Booster Kicker Magnet – Pulse Current Drift



Two booster extraction kicker magnets



Drift of measured kicker pulser output currents of booster extraction kicker 1 and 2 over 80 days



Incomplete overlap of the two booster extraction kicker 1 and 2 currents.

Challenge and Mitigation

- Traveling wave kicker pulser units currently in operation 24/7 at BESSY II were designed and manufactured at DESY for the HERA accelerator.
- The thyatron switches inside the boxes age within the kicker pulsers during operations and require replacement in injection kicker pulser after 11 month, in the extraction kicker pulsers after approx. 2 years.
- The cost of a new e2v CX 1154 thrytron is at the moment at 8 k€, tendency increasing. It used to be half that sum when the technology was commissioned.
- The kicker pulser boxes show wear and tear because of the permanent heating of the thyatrons.
- Companies try to make thyatrons obsolete, it may well be that some of the thyatron types will be discontinued.

Mitigation → Kicker pulser renewal project!

Solid State Prototype Kicker Pulsar Unit for BESSY II Injection

Specifications for Prototype Bipolar Pulse Generator

Parameter	Value
Voltage	± 8 kV
Peak current	160 A
System load impedance	50 Ω
Pulse repetition rate	≤ 10 Hz
Operation	24h/7d
Pulse length	350 ns
Rise time	80 ns
Flat top deviation	$\leq \pm 1\%$
Timing jitter	≤ 10 ns

High voltage power pulser with local PLC control and BESSY control system interface by serial RS 485 connection located in 19" cabinet.

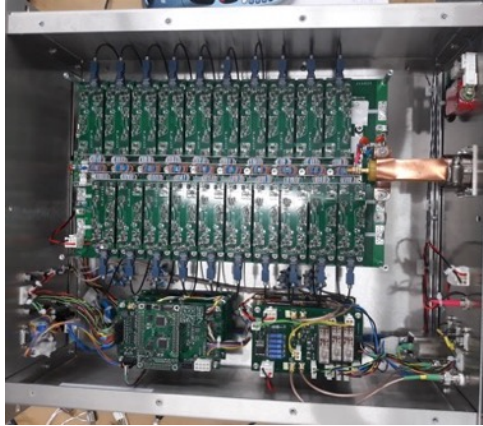
Project Partner:

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¹Instituto Superior de Engenharia de Lisboa, GIAAPP/ISEL, Portugal

²EnergyPulse Systems, Lisbon, Portugal

Tests with Prototype Kicker Pulsar Unit at HZB



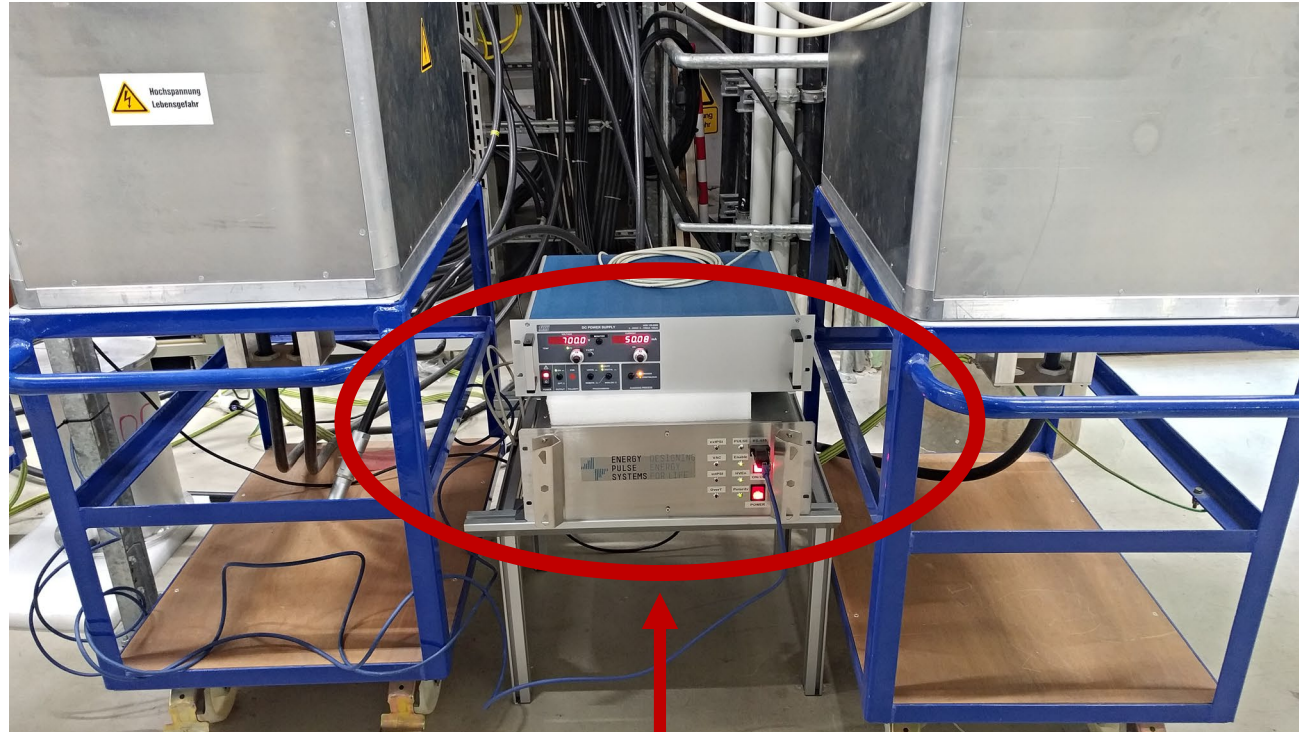
With testing of prototype Marx kicker pulser unit we achieved in September 2019:

- Having a working prototype kicker pulser unit from the company Energy Pulse Systems (EPS) from Lisbon / Portugal,
 - Confirmation of specified design parameters,
 - Developing further the system integration,
 - Testing of RS 485 serial interface, etc.
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- Finding out the validity of the Marx Type Kicker Pulsar System since it is not the same as the originally used Traveling Wave Kicker Pulsar System.



L. M. Redondo, A. Kandratsyev, T. Atkinson and O. Dressler, "Testing of a Bipolar Solid-State Marx Generator for Berlin BESSY II Injection Kicker System," in IEEE Transactions on Plasma Science, vol. 49, no. 6, pp. 1936-1940, June 2021, doi: 10.1109/TPS.2021.3075026.

Testing the Kicker Pulser Prototype for Booster Operations

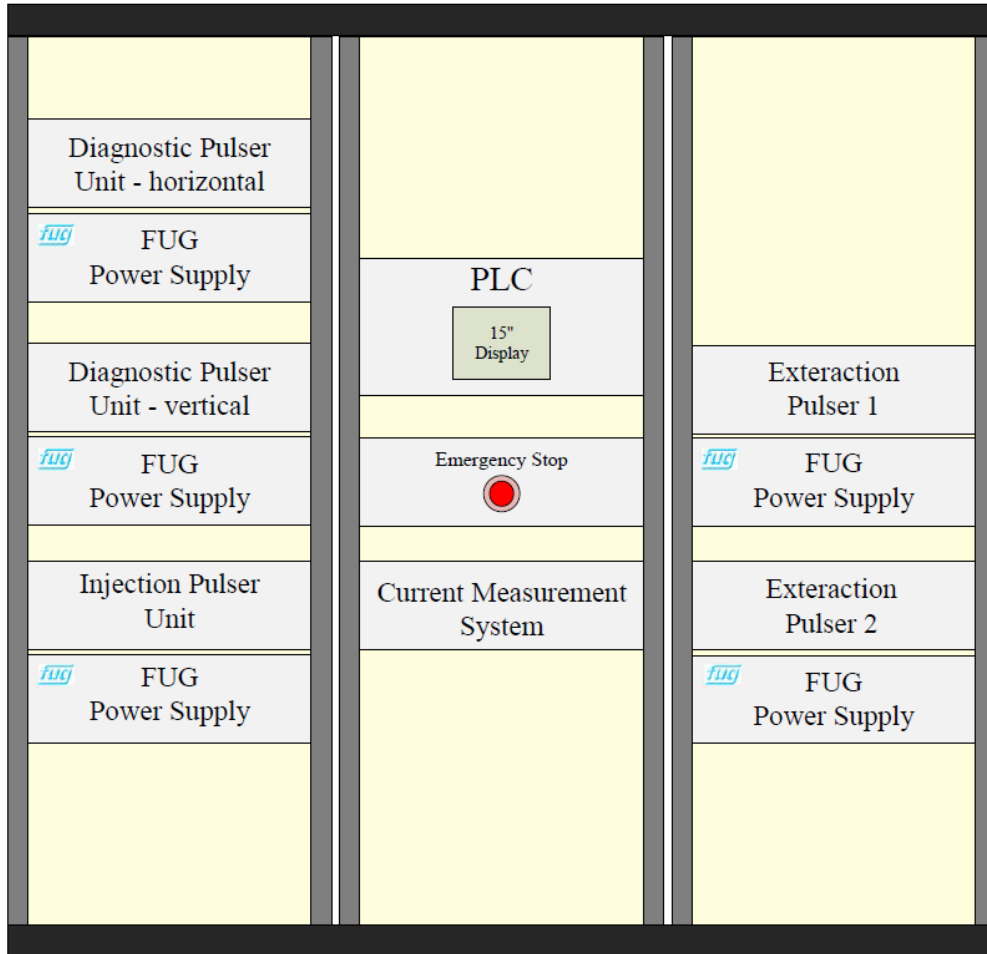


Marx Type Kicker Pulser and FuG HV PS

Procedure for the development and purchasing process of the kicker pulser replacement systems:

1. Commissioning and life testing of the already made prototype bipolar diagnostic kicker pulser unit as booster injection kicker,
2. Development of a booster diagnostic kicker systems with a new kicker stripline,
3. Stepwise acquisition of the booster injection and extraction kicker pulser units with all required spare parts and successive commissioning to maintain BESSY II booster operations and provide improved parameters for injection.

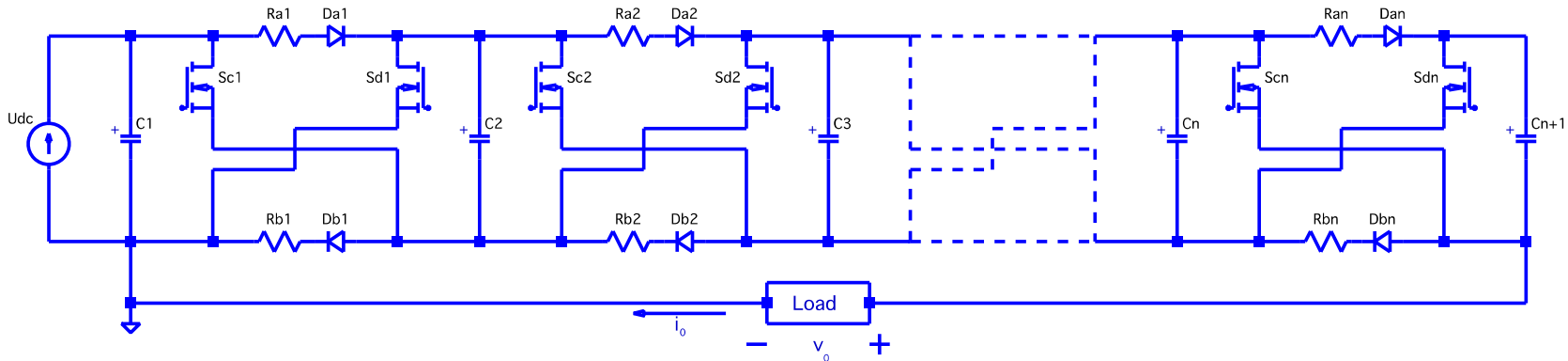
Installation of Solid-State Kicker Pulsers



Mechanical set-up in 19 inch cabinets outside the accelerator:

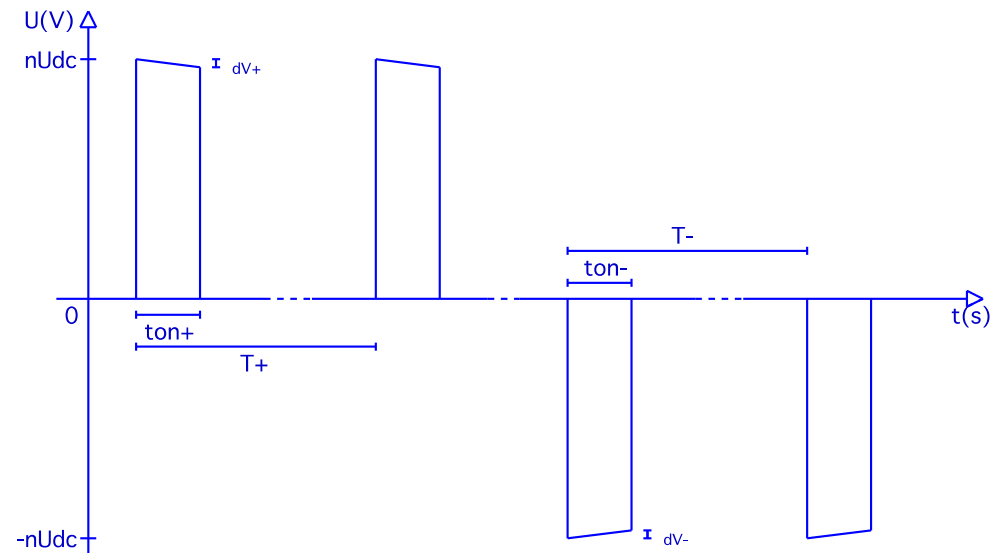
1. Marx type solid state pulse generators,
2. High voltage charging power supplies,
3. One PLC for local controls and interconnection to BESSY control system.

Bipolar Marx Generator Topology



Bipolar Marx Generator:

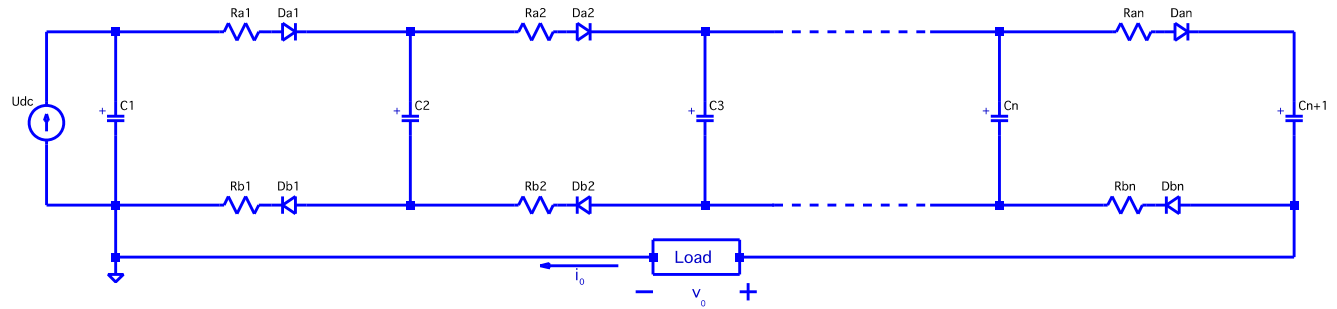
- Rai/Dai & Rbi/Dbi for charging
- Sci for positive pulse
- Sdi for negative pulse
- n switching stages
- n+1 capacitors
- Each switch hold $2U_{dc}$
- Possible multilevel operation
- C1 for positive pulse only
- Cn+1 for negative pulse only



Bipolar Marx Generator Operating Modes

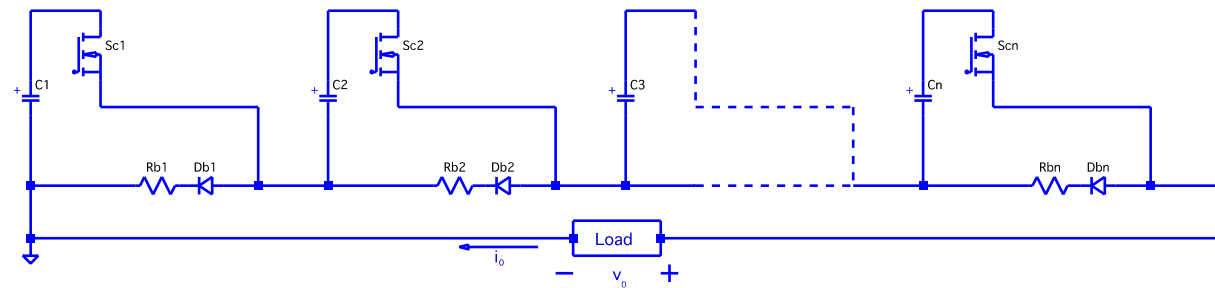
Charging mode:

- R_{ai}/D_{ai} & R_{bi}/D_{bi}



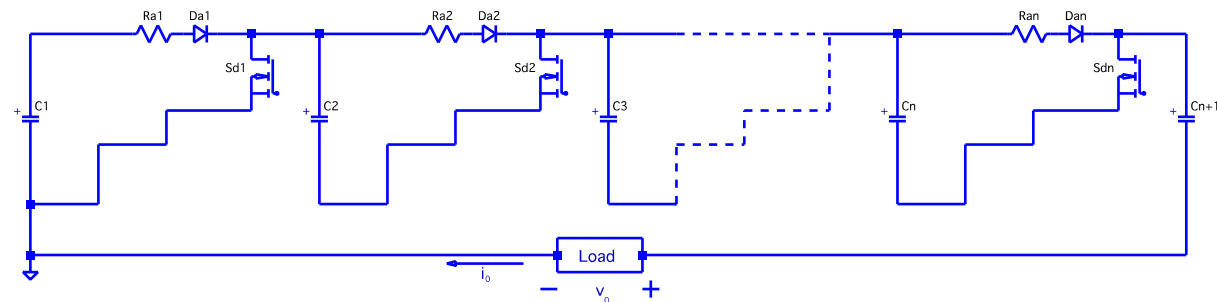
Positive pulse mode:

- S_{ci} on & R_{bi}/D_{bi} self discharge
- C_1 for positive pulse only



Negative pulse mode:

- S_{di} on & R_{ai}/D_{ai} self discharge
- C_{n+1} for negative pulse only

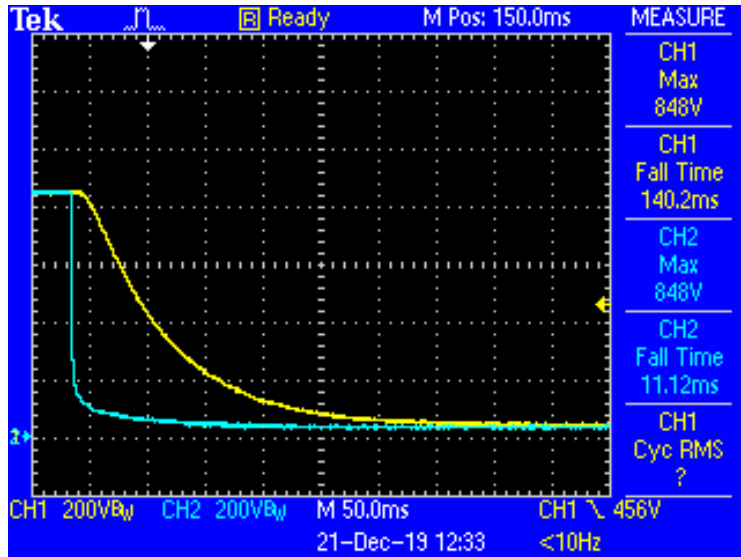


Bipolar Marx Generator Design Issues

Marx generator

- 11 capacitors
 - 10 switching stages
 - $U_{dc}=800V$
 - Sci & Sdi 1600V hold-off and 160A
 - $8\mu F$ capacitors, $dV < 70V$
 - Rai & Rbi 50Ω
-
- Marx Generators work like switched mode power supplies, with a big charging capacitor.
 - This causes a personnel safety problem, since a fault condition detected by the personnel safety interlock cannot easily suppress succeeding kicker pulses. It is challenging to de-energize the system quickly.
 - The originally intended bipolar operations is limited by the speed of the interface to change from one polarity output pulse current to the other.
 - Arbitrary pulse patterns are compromising on the pulser output current stability, because of the exponential recharging curve of the HV PS.

Personnel and Safety Interlocks, Machine Protection and General Integration Issues



Mitigation of described technical limitations

Quick discharge or grounding of generator capacitance is limited to the exponential decay of the internal capacitor voltage.

Personnel and Safety Interlocks:

- In case of a tripping interlock, the Marx generator must be de-energized faster. A fast discharge option is integrated now.
- The re-triggering is suppressed.

Machine Protection:

- Vacuum interlock on pulser interface,
- Other interlock channels are feasible.

General Integration Issues:

- Interlock switches on the pulser box that cause system turn off when box is opened,
- Emergency stop on the pulser cabinet, to turn power off with mushroom button in case of emergency.

Summary

1. The kicker pulser renewal project is ongoing,
2. Several delays where caused by 'Corona times',
3. The already delivered bipolar diagnostic kicker pulser unit is running as the BESSY booster injection kicker pulser in a long term test.
4. The decision was made to repeat the first stage with the building of diagnostic kicker pulser unit but now with local PLC as control unit and sufficient interconnection to BESSY control system for appropriate remote control.
5. Then we will proceed with the injection and extraction kicker pulser units.
6. Delivery is expected to be now (4.) and 2024 (5.)
7. The solid state pulser unit proved to be extremely reliable in accelerator operations.