Inductive Voltage Adder for driving Kicker Magnets with a Short-circuit Termination

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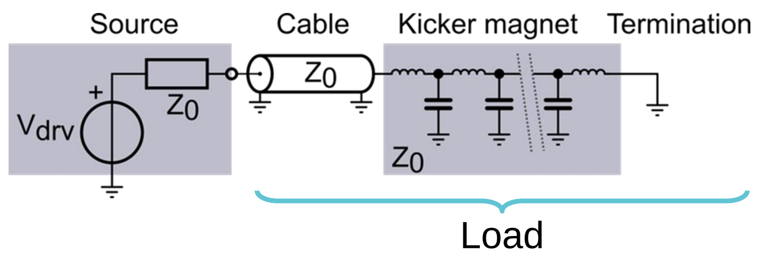
Abstract

For future upgrades of some CERN kicker systems, doubling of the driving current by replacing a matched impedance by a short circuit termination is of interest, because it allows a doubling of the kick strength, without an increase in magnet length or generator voltage. To drive these kicker magnets, featuring a short circuit termination, a novel approach for a pulse generator architecture based on an inductive voltage adder is currently under investigation. For this application, a specifically tailored branch module has been developed and tested. To account for the reflection at the short circuit, the branch module has a topology comprising two independently controlled semiconductor switches. This allows energy to first be injected into the kicker magnet, then to circulate the resulting current in a freewheeling-interval, and the energy to be reabsorbed at the end of the pulse. In this contribution, selected design details of the branch module and measurements obtained in a test setup, with a replacement load representing a short circuit terminated kicker magnet, will be presented. The results confirm the advantages of the novel design and the circuit concept of the module.

Introduction

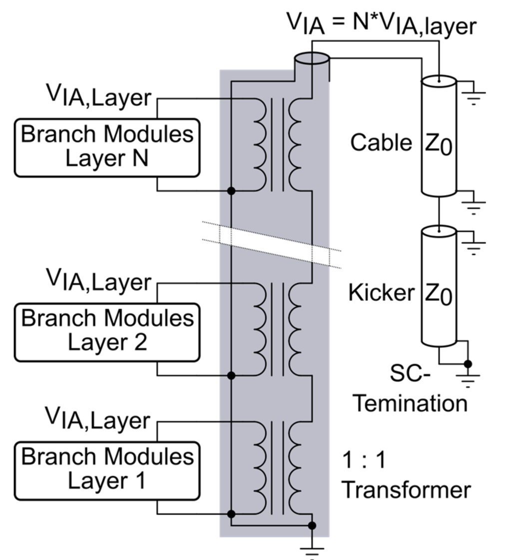
Application: Pulse generator for driving a kicker magnet terminated in a short circuit Intended as a possible replacement for pulse generators based on PFNs/PFLs

Kicker magnet: Used for dynamically deflecting particles for injecting into and extracting from circular particle accelerators



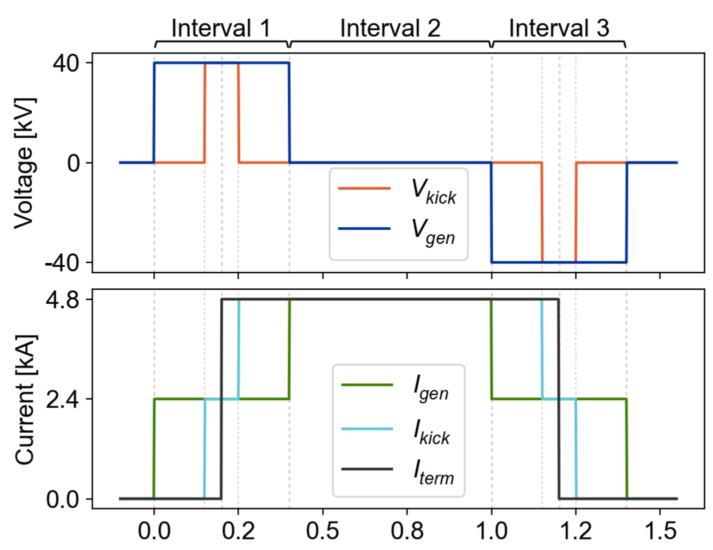
Load:
- Transmission-line type kicker magnet
- Terminated in a short circuit
  - Doubling of the current and thus the deflecting field in the magnet, in relation to the voltage seen by the magnet

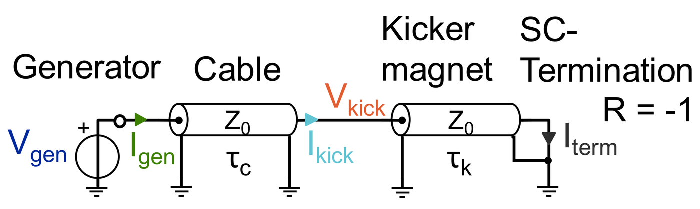
Inductive Voltage Adder



- Branch modules paralleled in layers sharing the load current
- Layers stacked for adding up the voltage
- Ground referenced layers
- Excellent scalability in both voltage and current

Mode of Operation



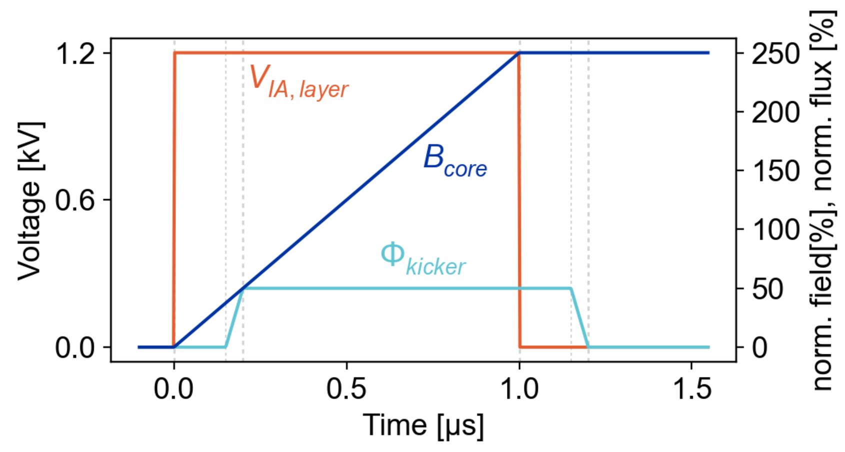


- **Interval 1:** Energy is fed into the connecting cable and the kicker magnet
- **Interval 2:** Energy is stored inductively and kept constant during the pulse flattop
- **Interval 3:** Energy is extracted by the source at the end of the pulse.

Core Size Requirements

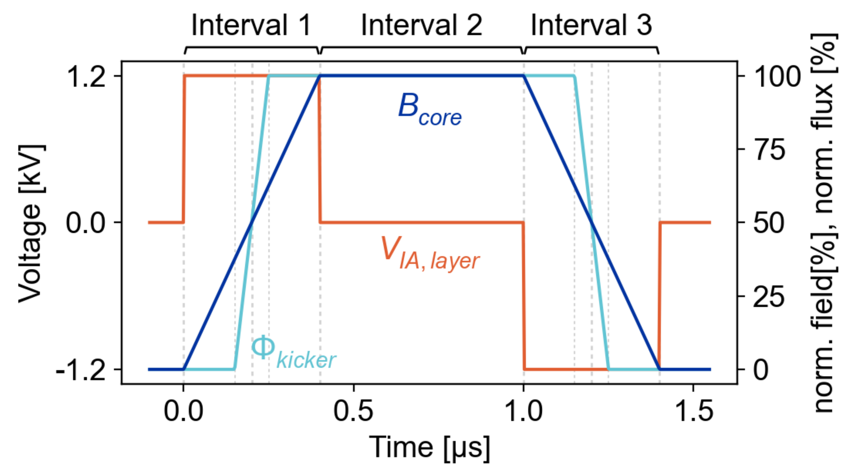
- Idealized simulations: Same parameters for the kicker magnet and the magnetic cores

With matched termination



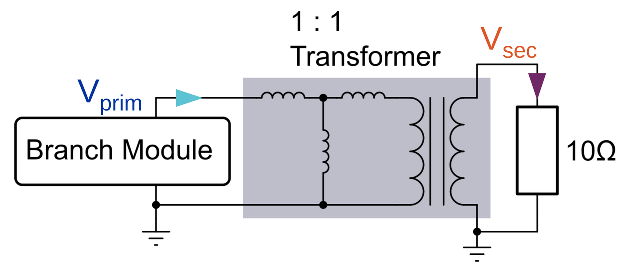
Required core size:
Determined by pulse length

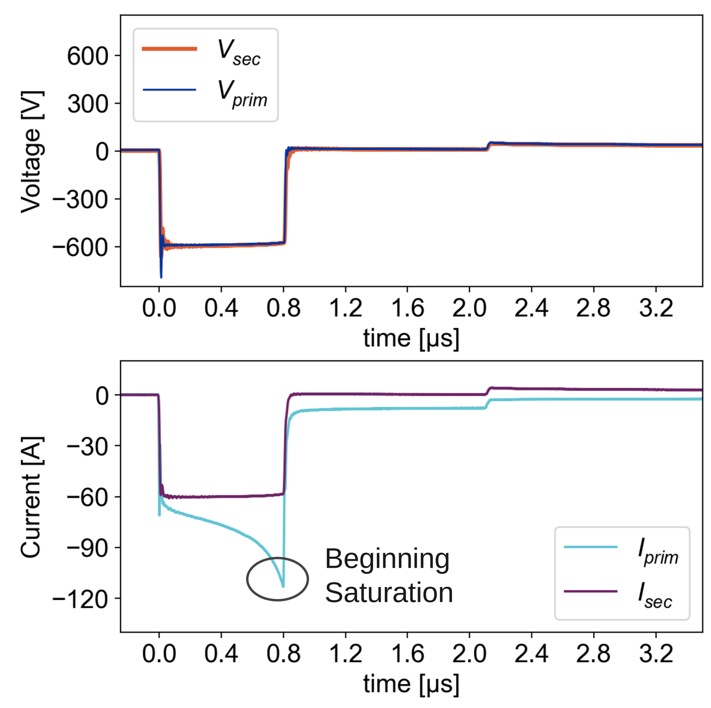
With short circuit termination



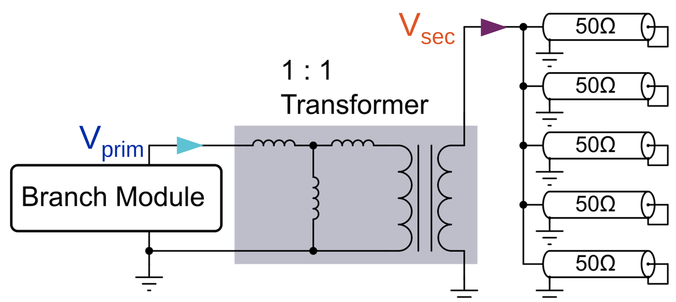
Required core size:
Determined only by sum of the transit times of kicker magnet and connecting cable

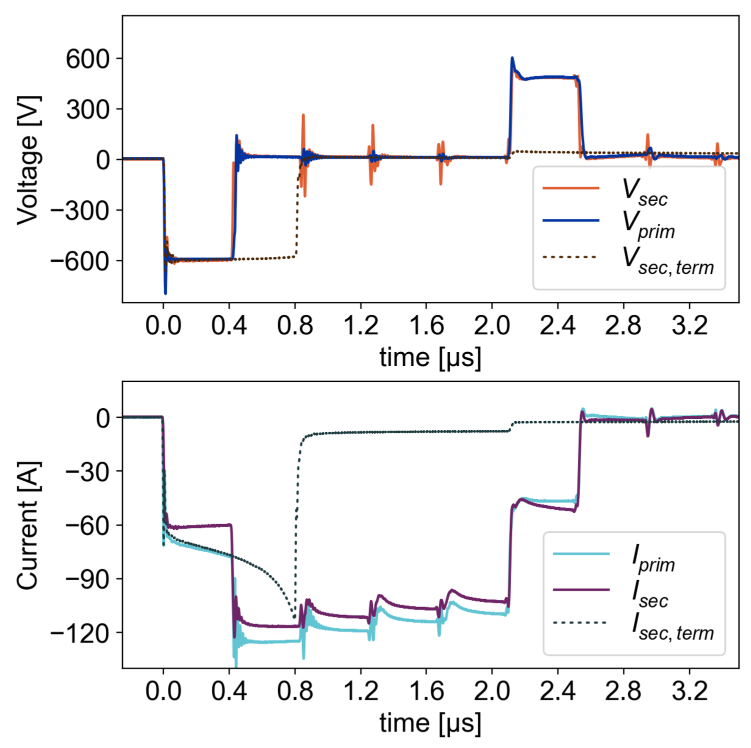
Operation with output Transformer





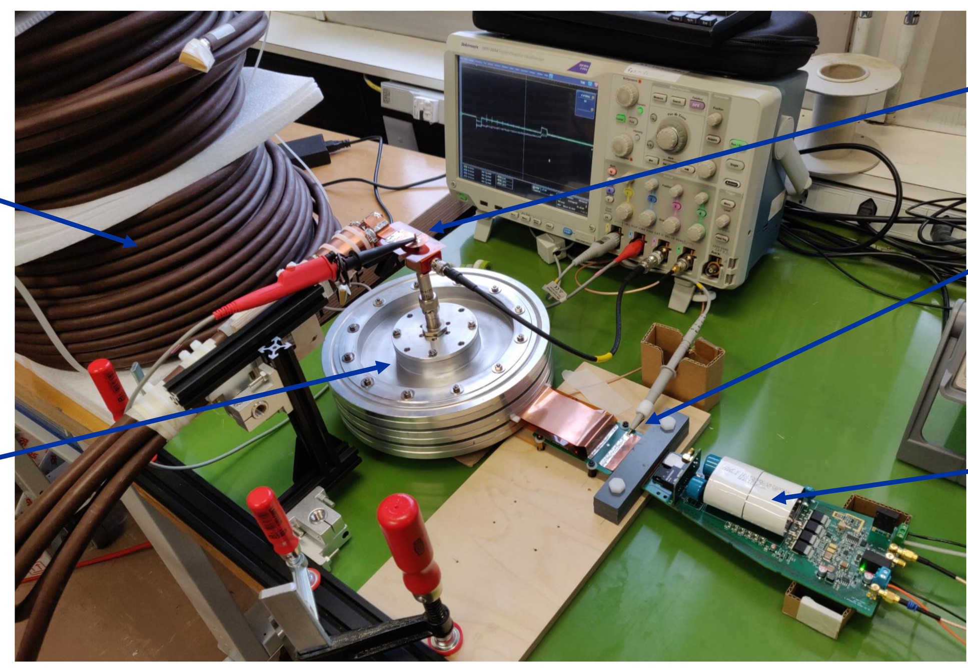
- Resistive load (R = 10 Ω) connected to branch module with one layer of an inductive adder as output transformer
- Magnetic core starts to saturate after ca. 800ns



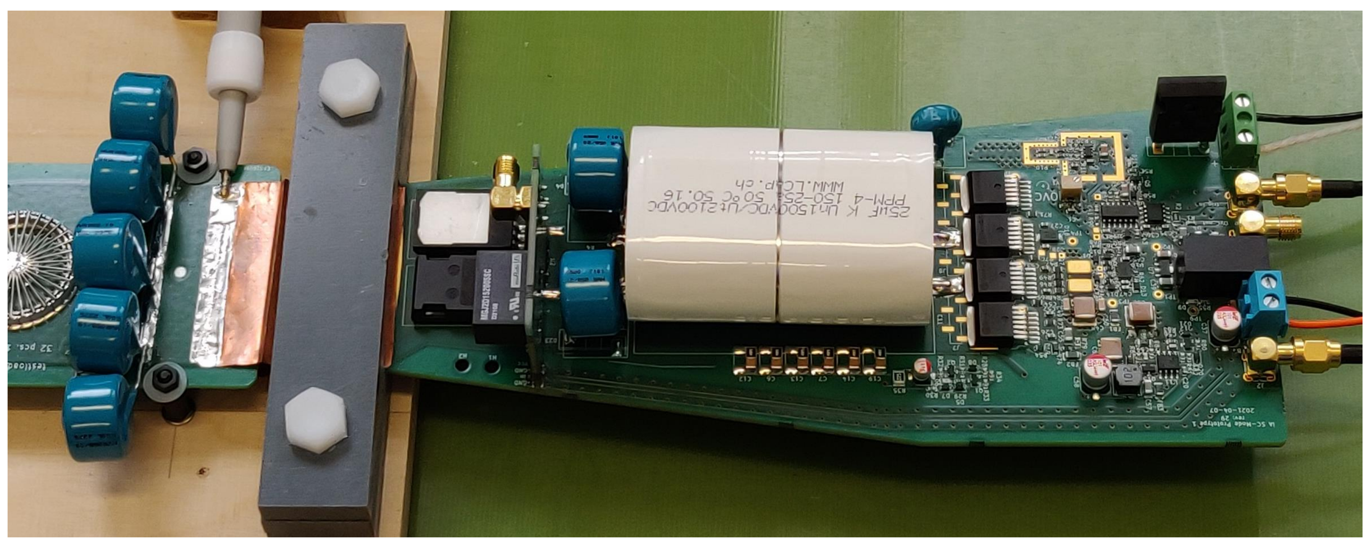


Dotted lines: Measurement with resistive load for comparison

- Replacement load: 5 parallel 50Ω coaxial cables individually terminated with a short circuit (208ns one way delay) → 10Ω load
- Pulse length shown: 2 µs



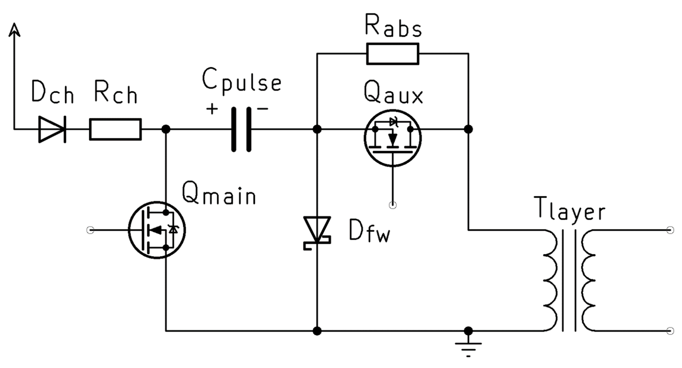
Branch Module for SC-Mode



Voltage	Peak Current	Pulse Repetition Rate
1200 V	200 A	10 Hz

Photo of the branch module connected to a resistive load of 10 Ω.

Circuit Topology of the SC-Mode Branch Module



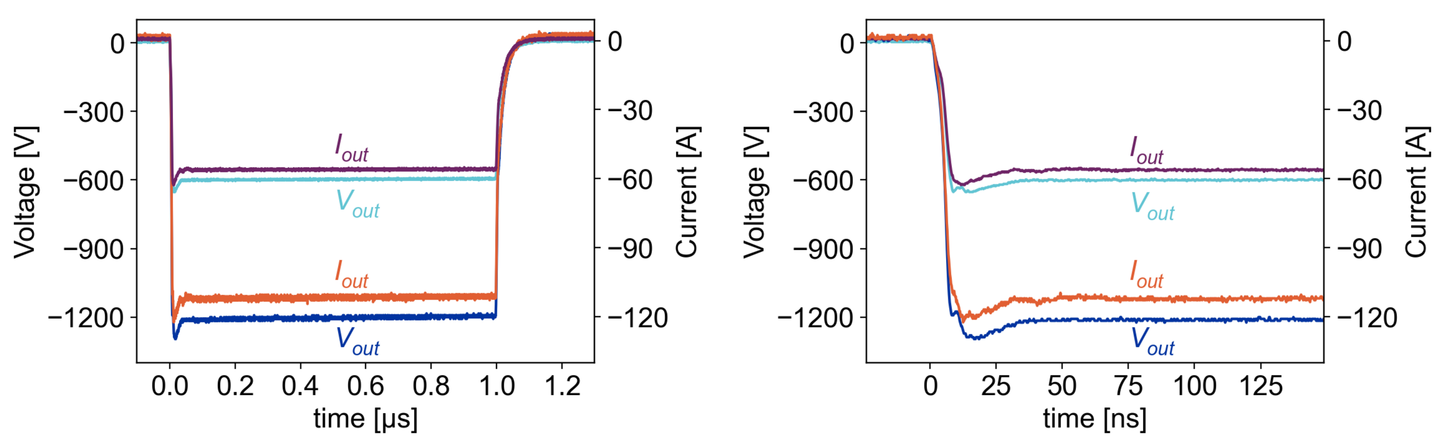
Simplified circuit diagram of one branch module.

Mode of operation: Reflections at the short circuit termination
- Energy is fed into the connecting cable and the kicker magnet
- Both MOSFET switches Q_{main} and Q_{aux} are closed
  - Wave travels through the kicker magnet to the short circuit

- Energy is stored inductively and kept constant during the pulse flattop
  - When the wave reflected from the termination reaches the branch module, switch Q_{main} opens
  - Doubled current commutates into freewheeling diode D_{fw}
- Energy is extracted at the end of the pulse.
  - Switch Q_{aux} opens
  - Energy stored in the load dissipates in the resistor R_{abs}

Module Performance with a Resistive Load

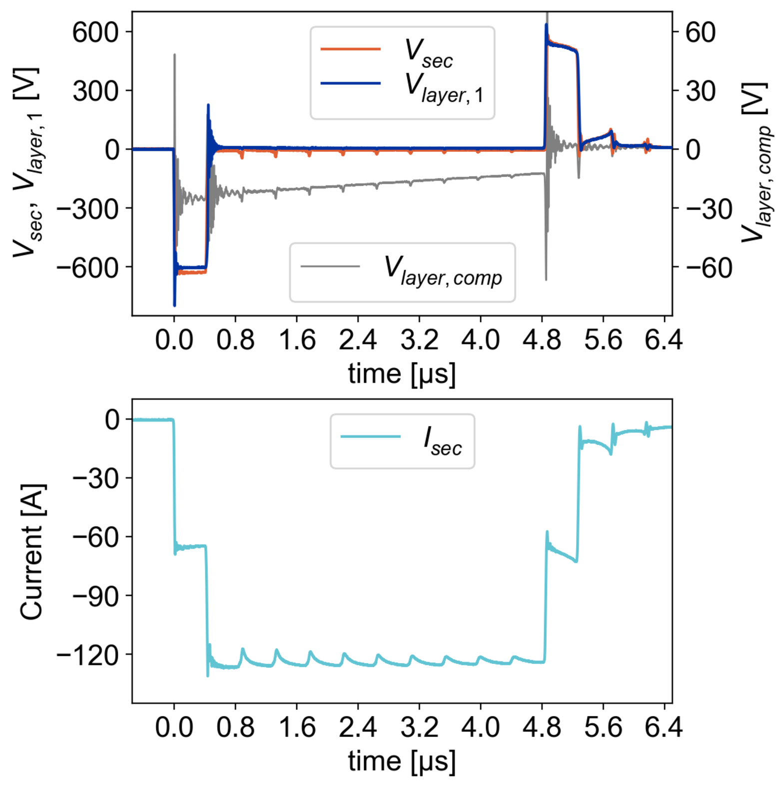
Measurements with a Resistive Load of 10.8 Ω



- Charging Voltage: 600 V
  - Current: 55 A
  - Current rise time(10% to 90%): 5.4 ns
- Charging Voltage: 1200 V
  - Current: 110 A
  - Current rise time (10% to 90%): 5.0 ns

Loss compensation

- Measurement with a compensation charging voltage of V_{comp} = 27V (determined experimentally) applied during interval 1 and 2 via a separate layer of the inductive adder



Conclusion

A branch module for an inductive voltage adder for driving a kicker magnet with a short circuit termination has been designed and built. With a resistive load, at 1200 V a rise time of the load current of 5.0 ns has been achieved. Measurements with a replacement load emulating a kicker magnet terminated in a short circuit, confirmed, that, neglecting losses, the maximum achievable pulse length is not limited by the size of the magnetic cores of the inductive adder. It was demonstrated, that the stepwise decrease of the load current flattop caused by unavoidable losses during the freewheeling interval can be counteracted by applying a compensation voltage during this interval.