Karlsruhe Institute of Technology

Experiments with a superconducting full-bridge inverter

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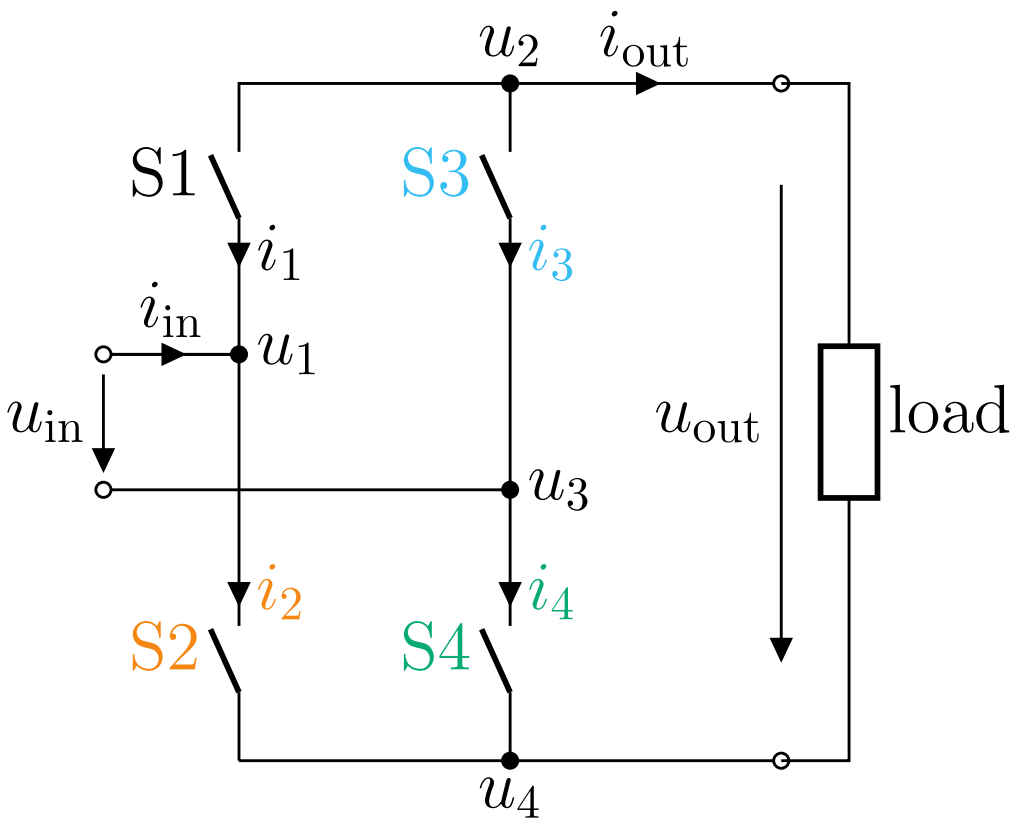
Gawith et al, 2019, „An HTS power switch using YBCO thin film controlled by AC magnetic field“, Supercond. Science and Technology 32, 095007,
„...when the switch is used in a real power converter“

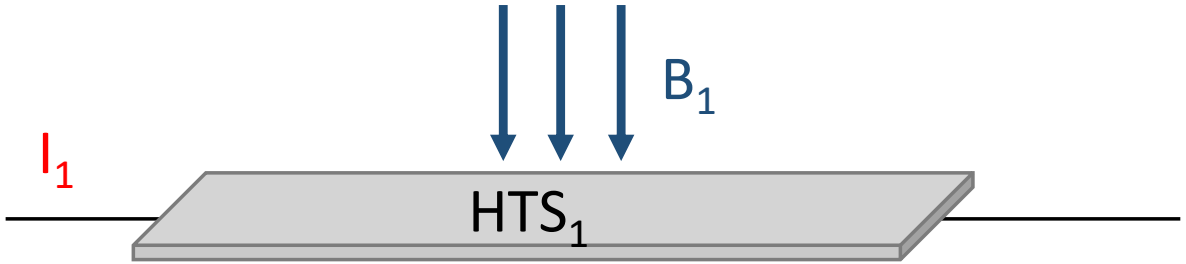
Bykowskiy et al, 2019, „Thermally activated ReBCO switches for charging high current magnets“, IEEE Transactions on Applied Superconductivity, Vol. 29, No. 5, August 2019.
„**Manufacturing and test of an all ReBCO-rectifier demonstrator is planned is planned as a mid-term goal“**

Working principle

H-bridge circuit

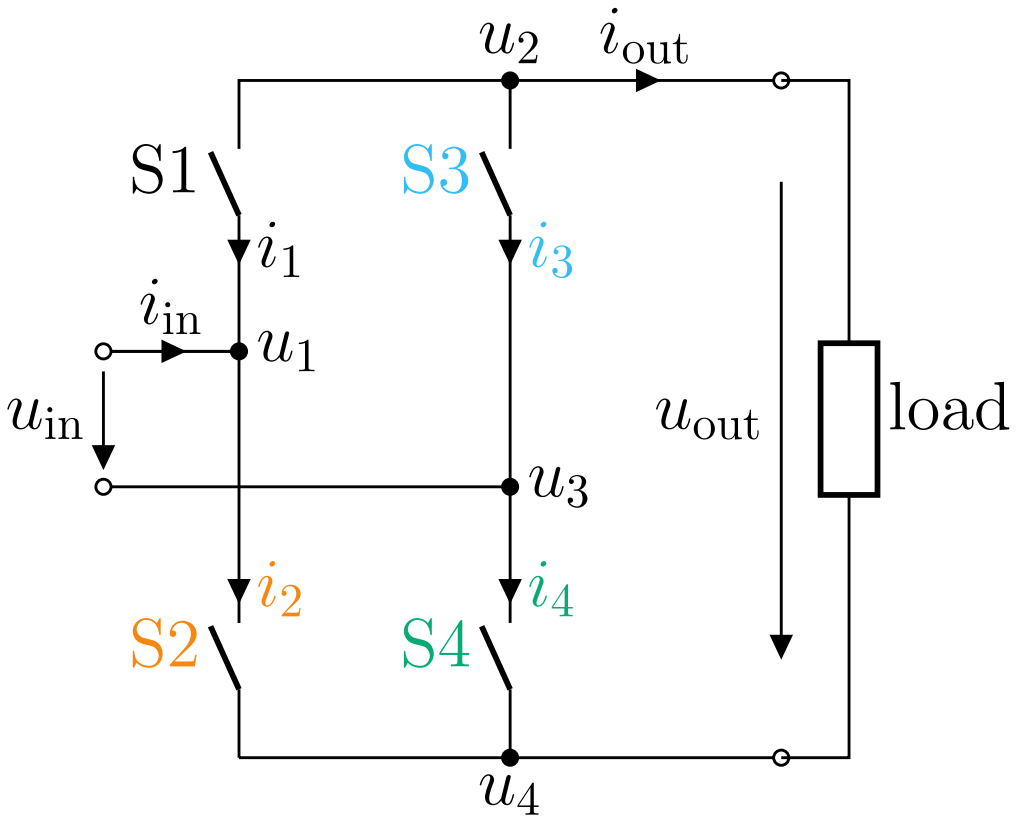


To realize a switch we use the dynamic resistance of ReBCO tapes controlled by AC magnetic field

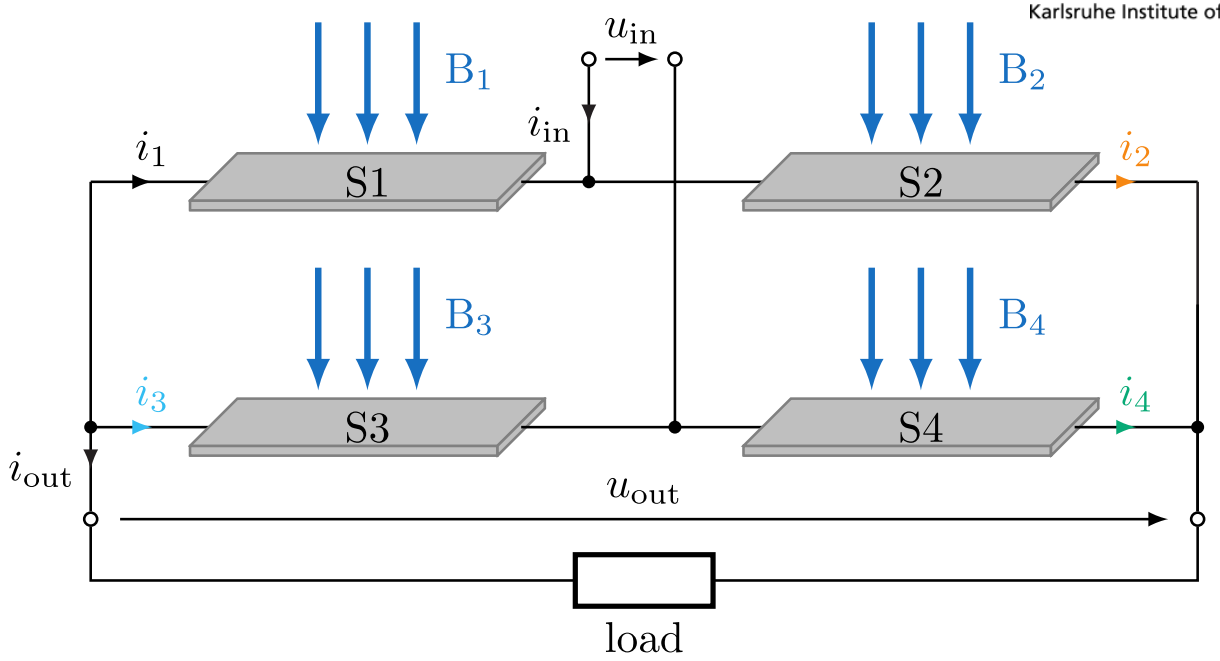


Working principle

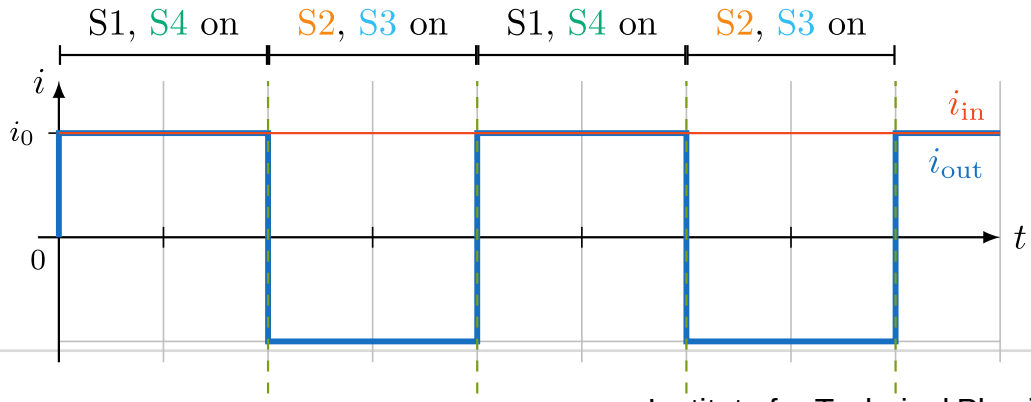
H-bridge circuit



Schematic with SC

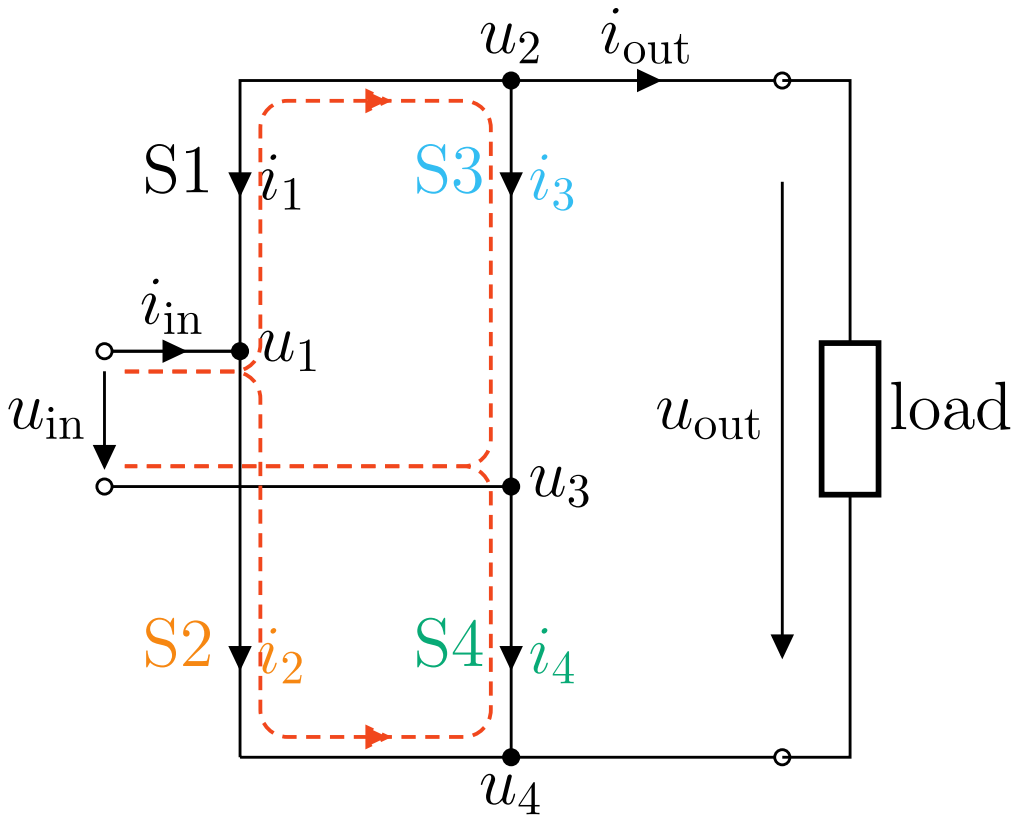


Current

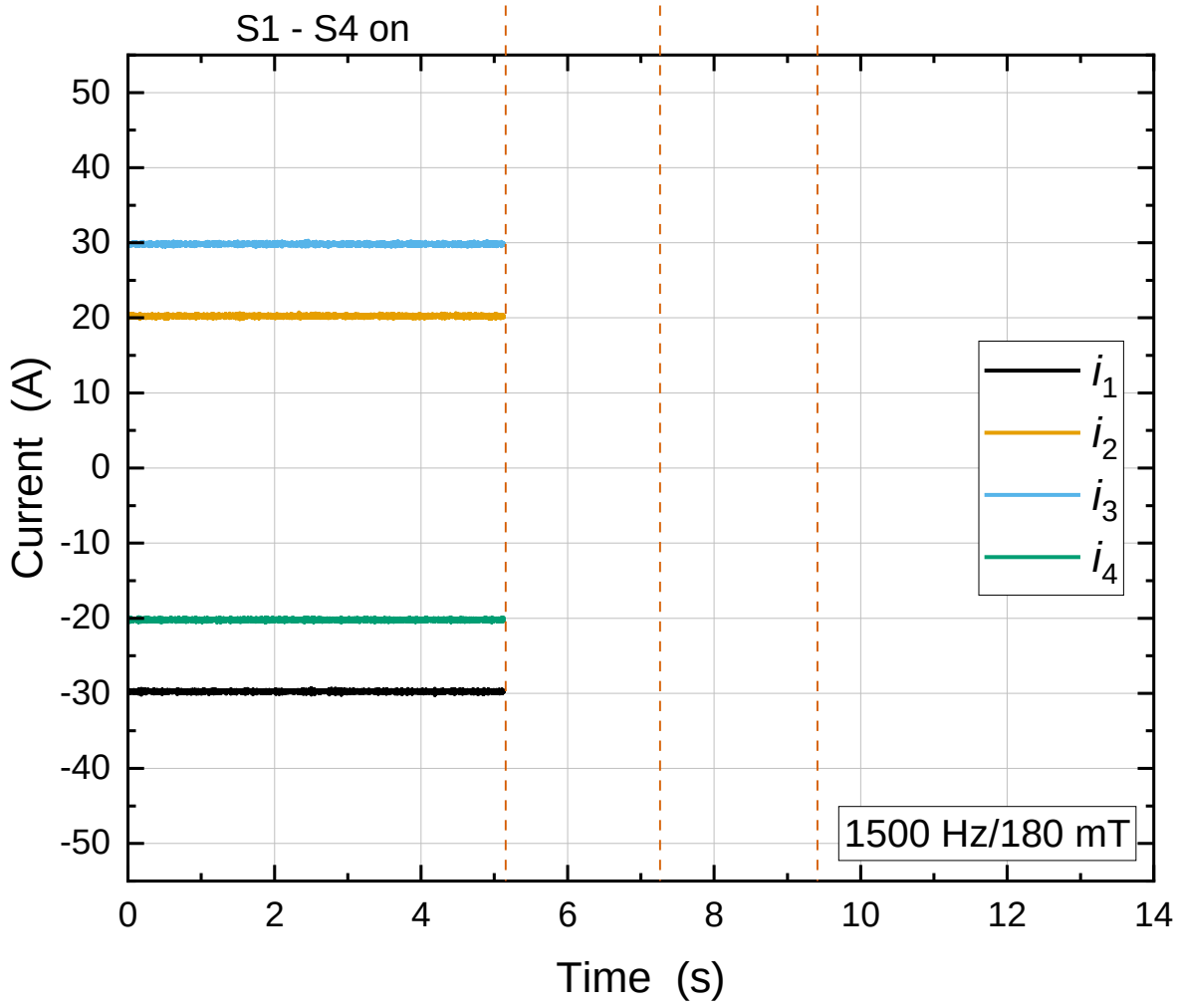


Working principle

H-bridge circuit

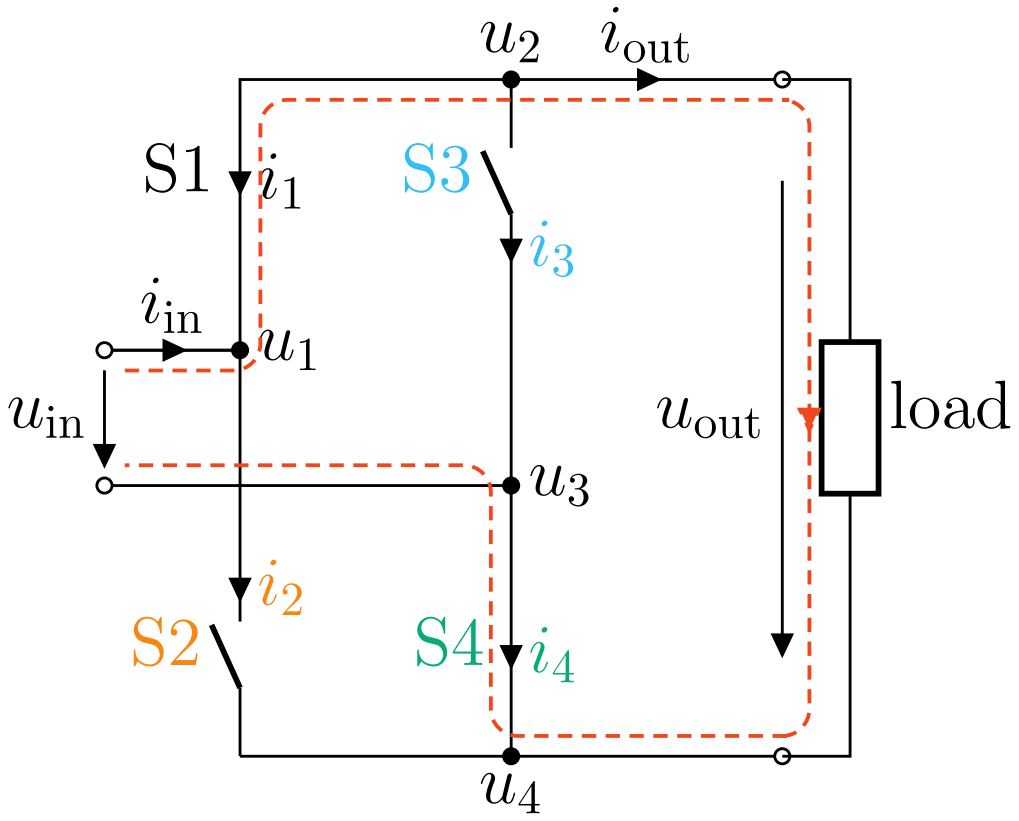


Current distribution

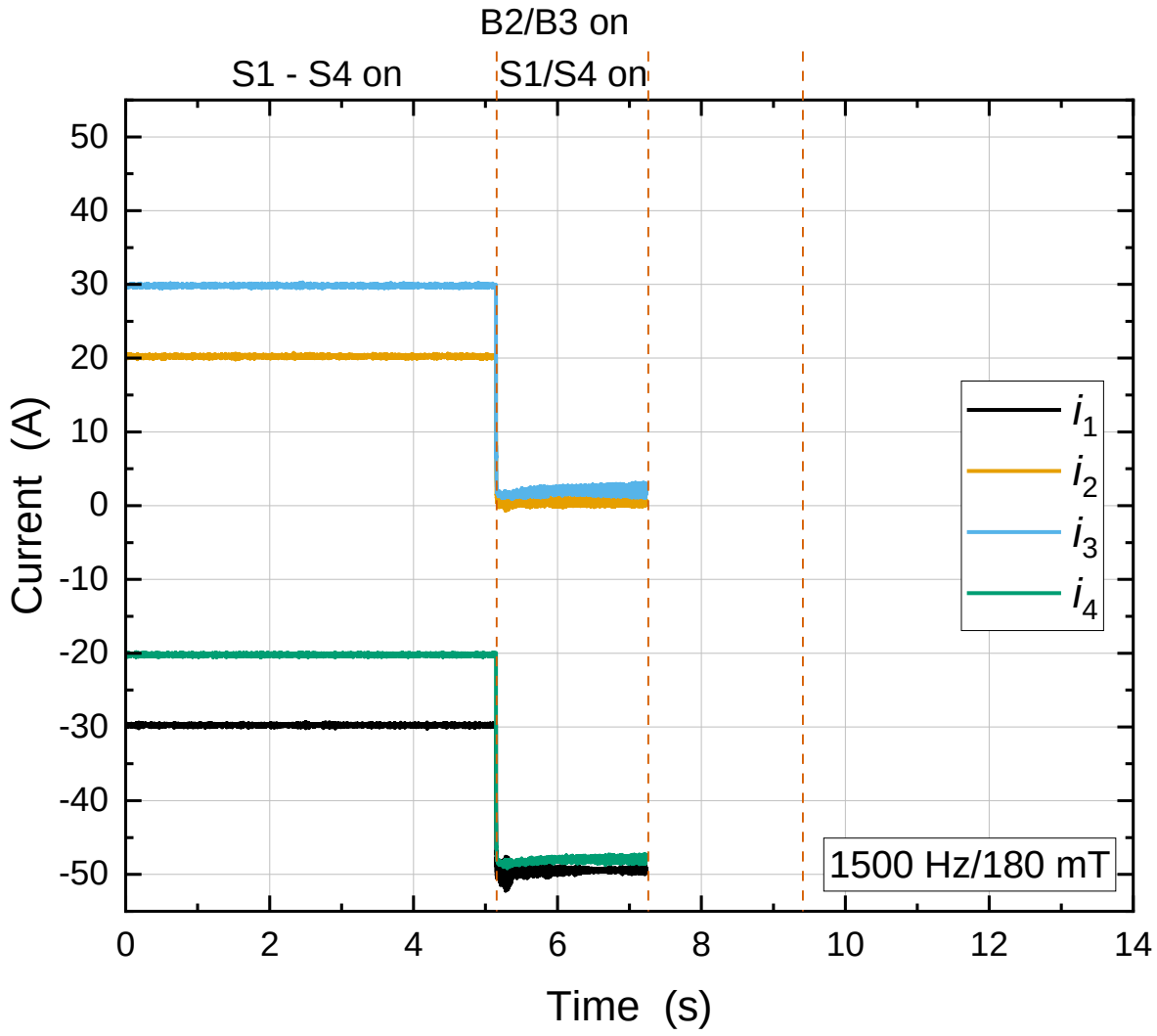


Working principle

H-bridge circuit

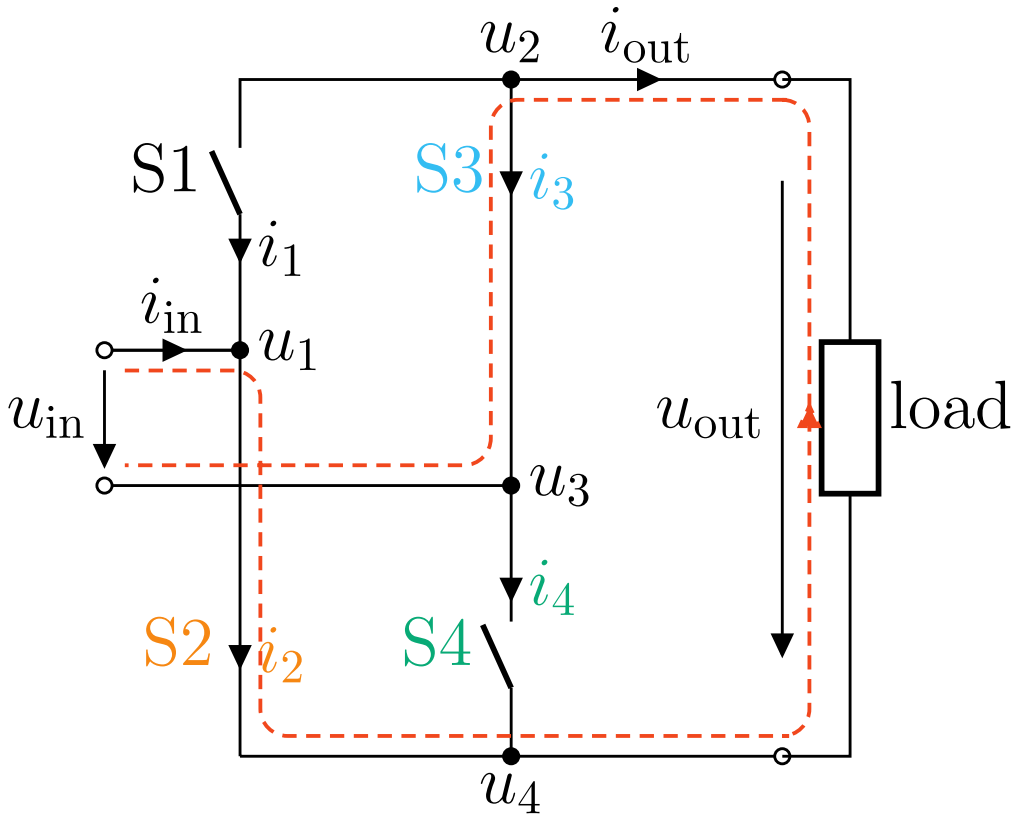


Current distribution

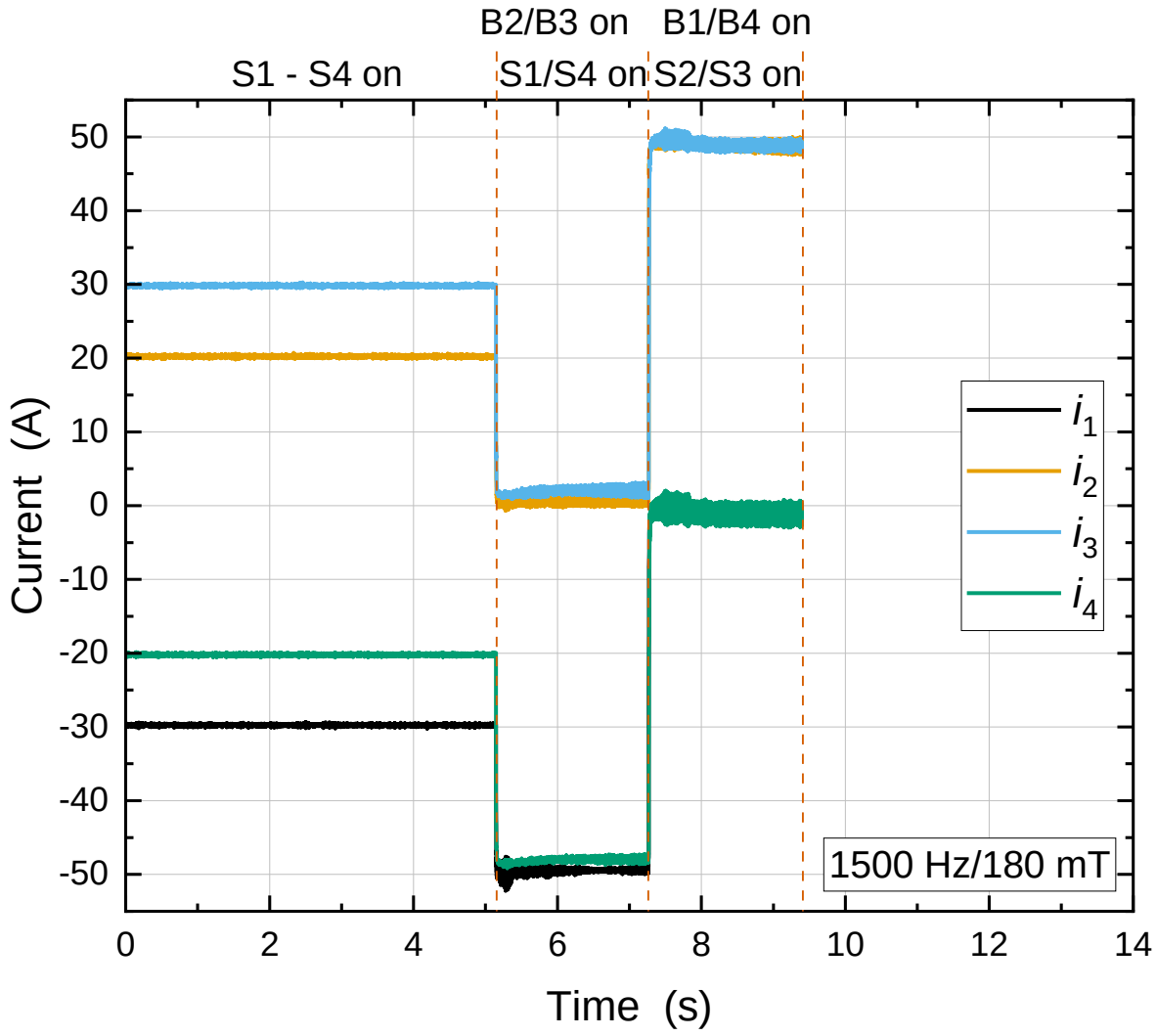


Working principle

H-bridge circuit

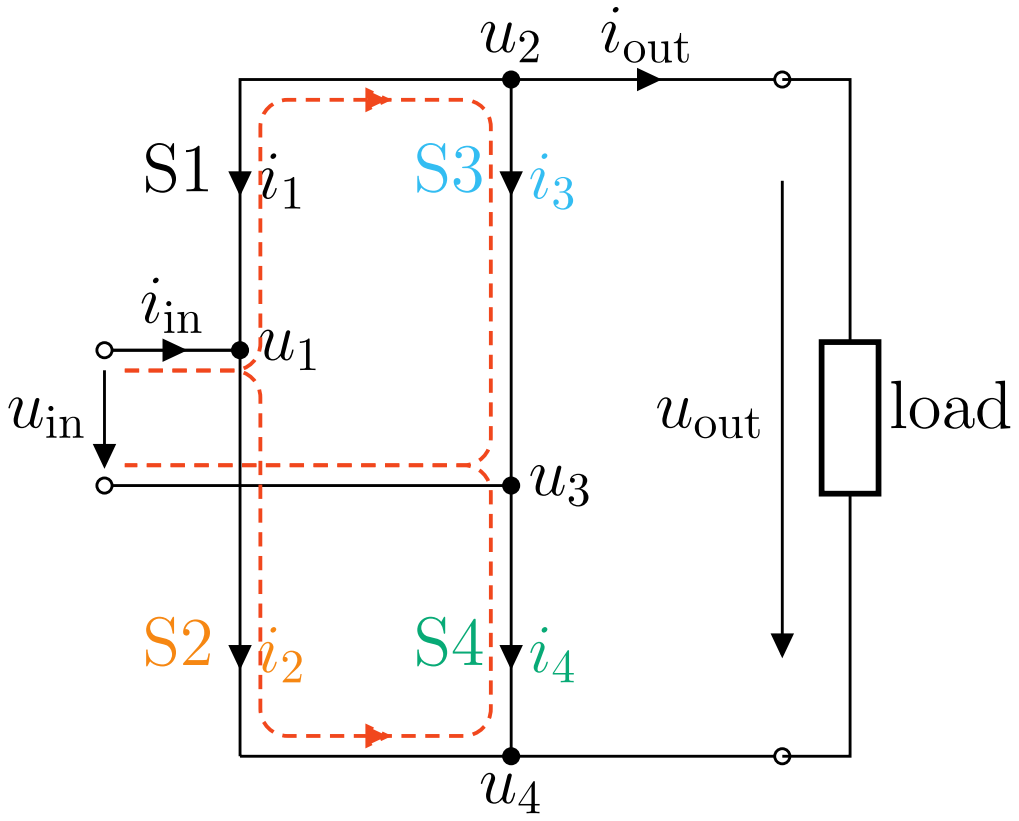


Current distribution

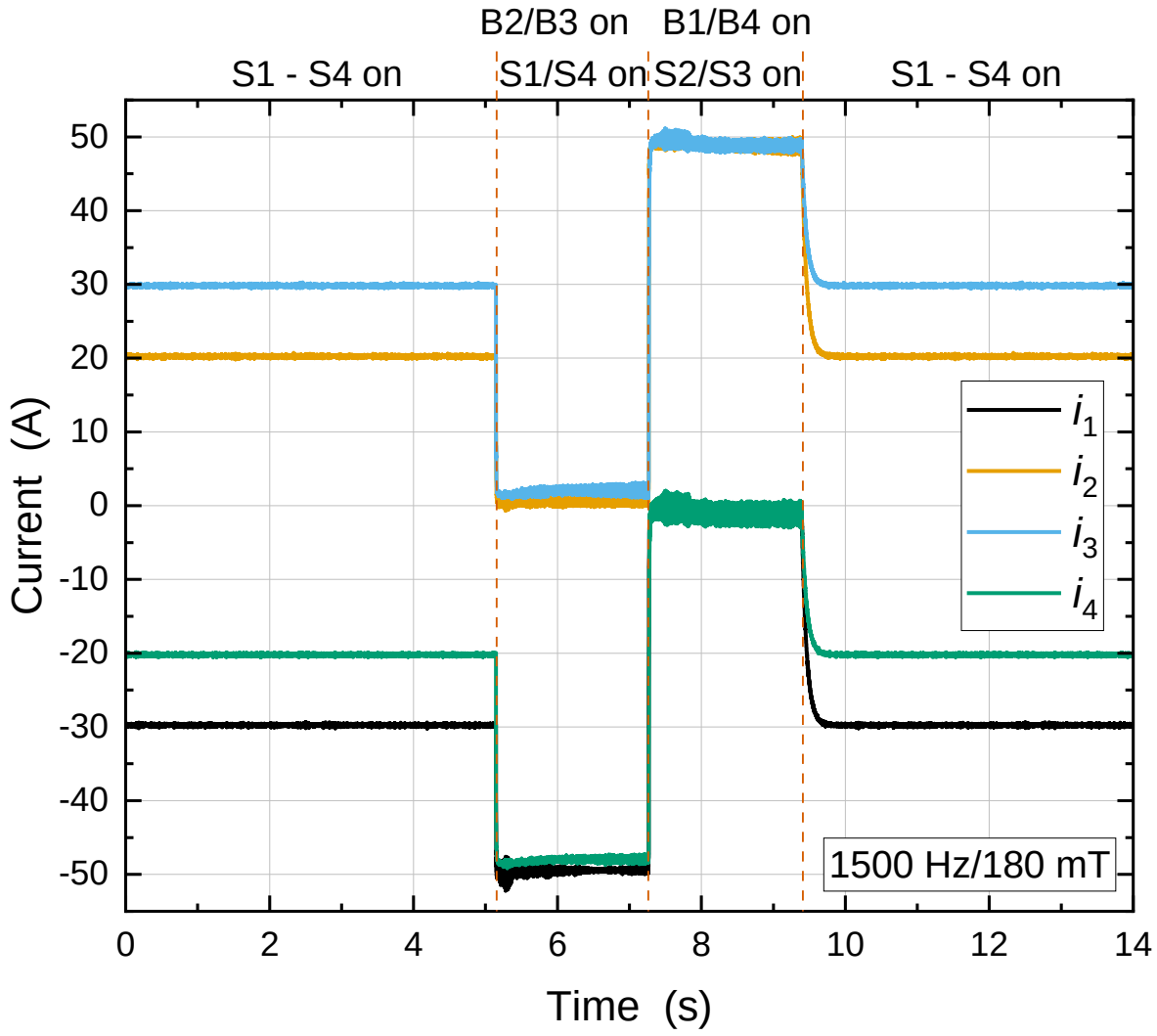


Working principle

H-bridge circuit

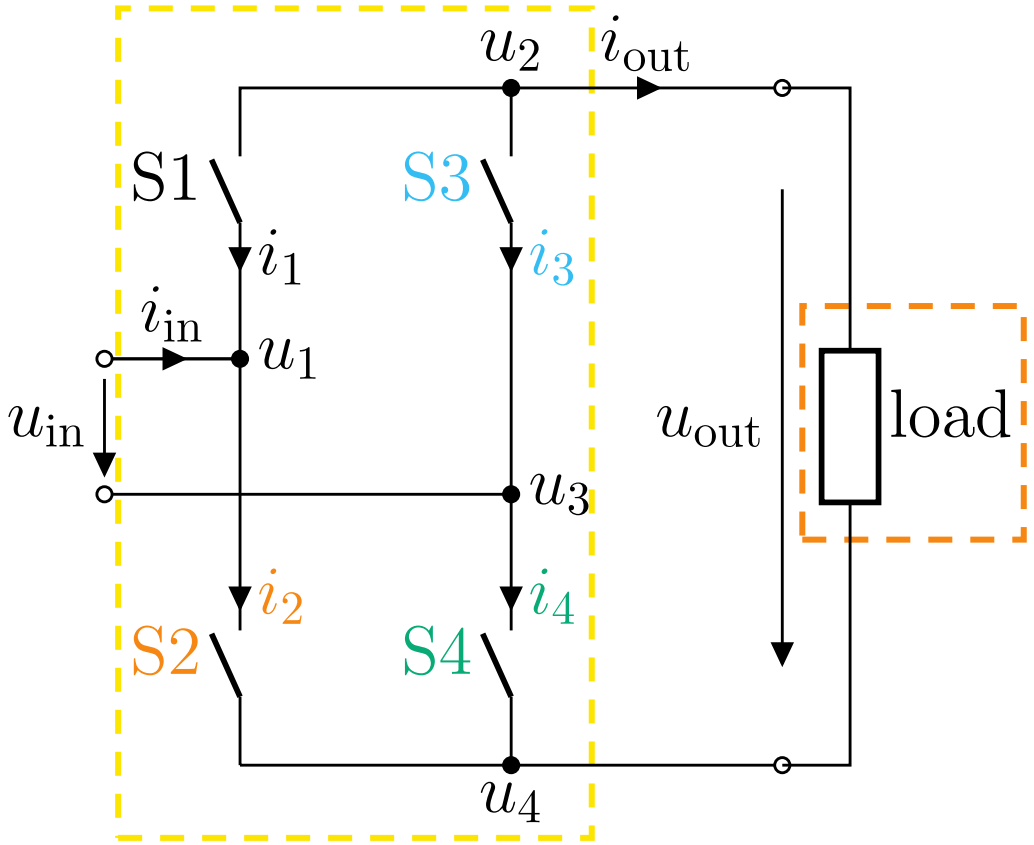


Current distribution

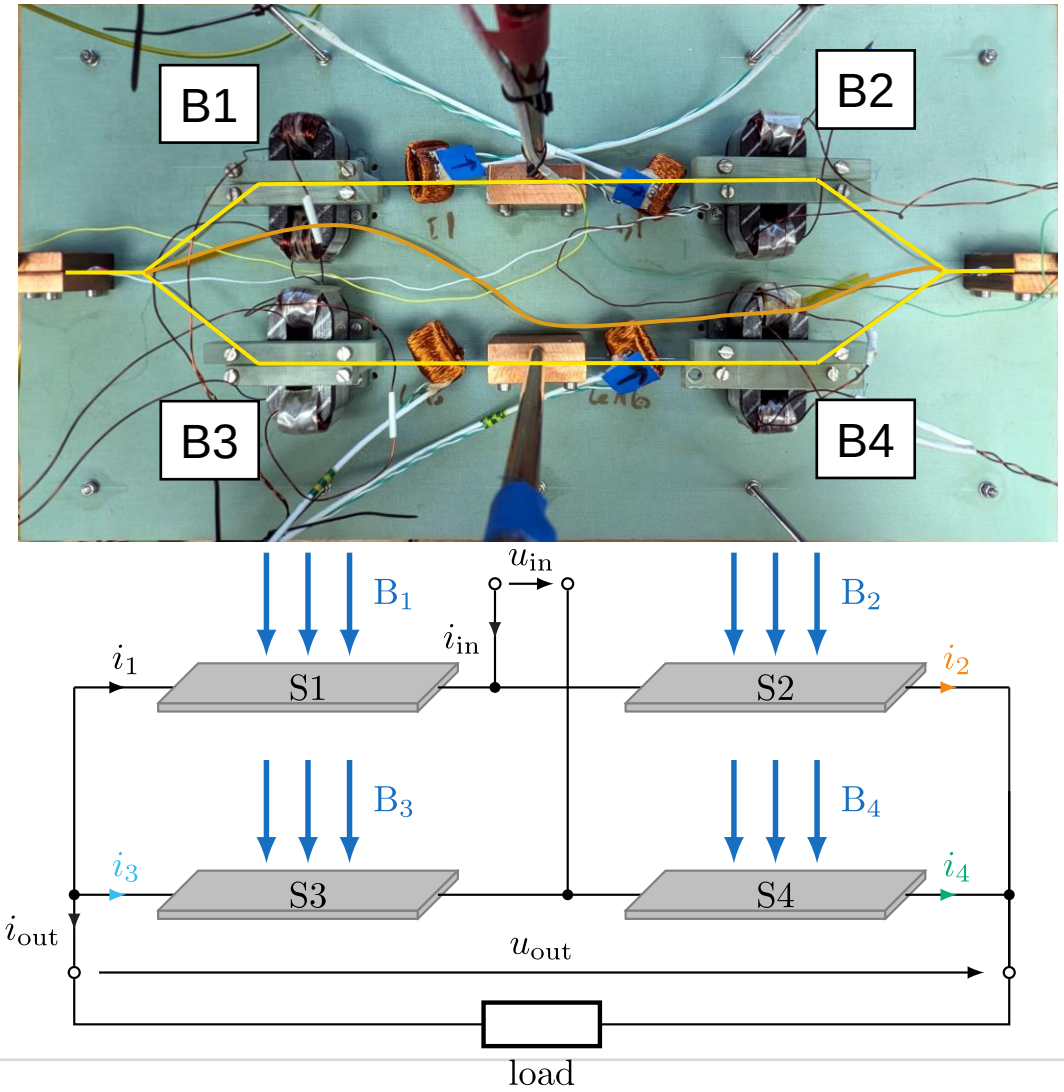


Superconducting inverter

H-bridge circuit

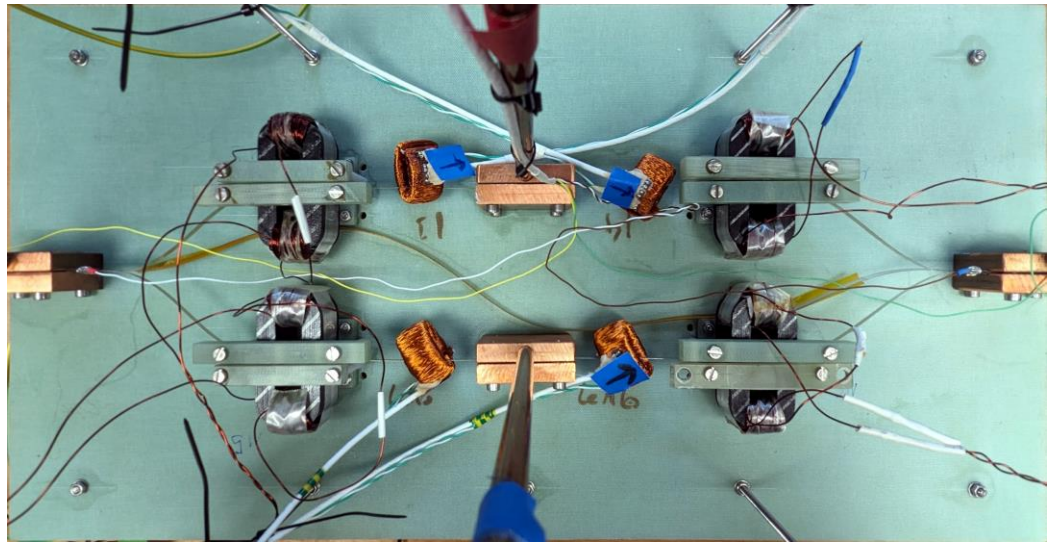


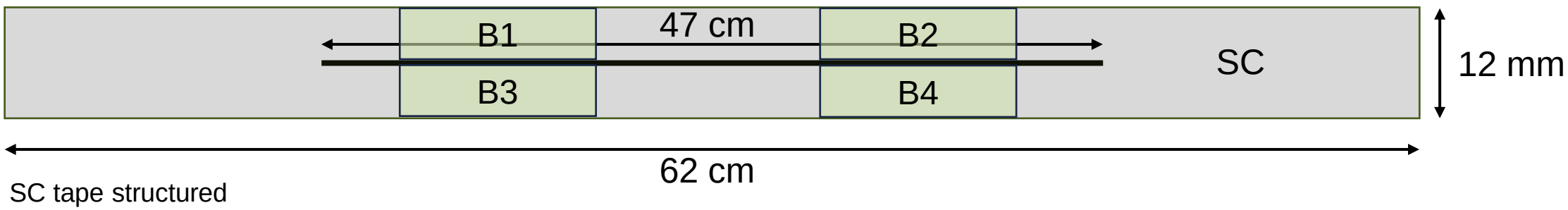
Experimental setup



Superconductor properties

Parameters SP SF12100			
B_{ext}	0…400 mT	t_{sc}	1.5 µm
f	500 Hz, 1000 Hz	t_{Ag}	2 x 1.4 µm
I_{c0}	380 A	t_{subs}	100 µm
I_t	50 A	ρ_{Ag}	2.7 nΩm @ 77 K
w	12 mm	ρ_{subs}	1.23 µΩm @ 77 K

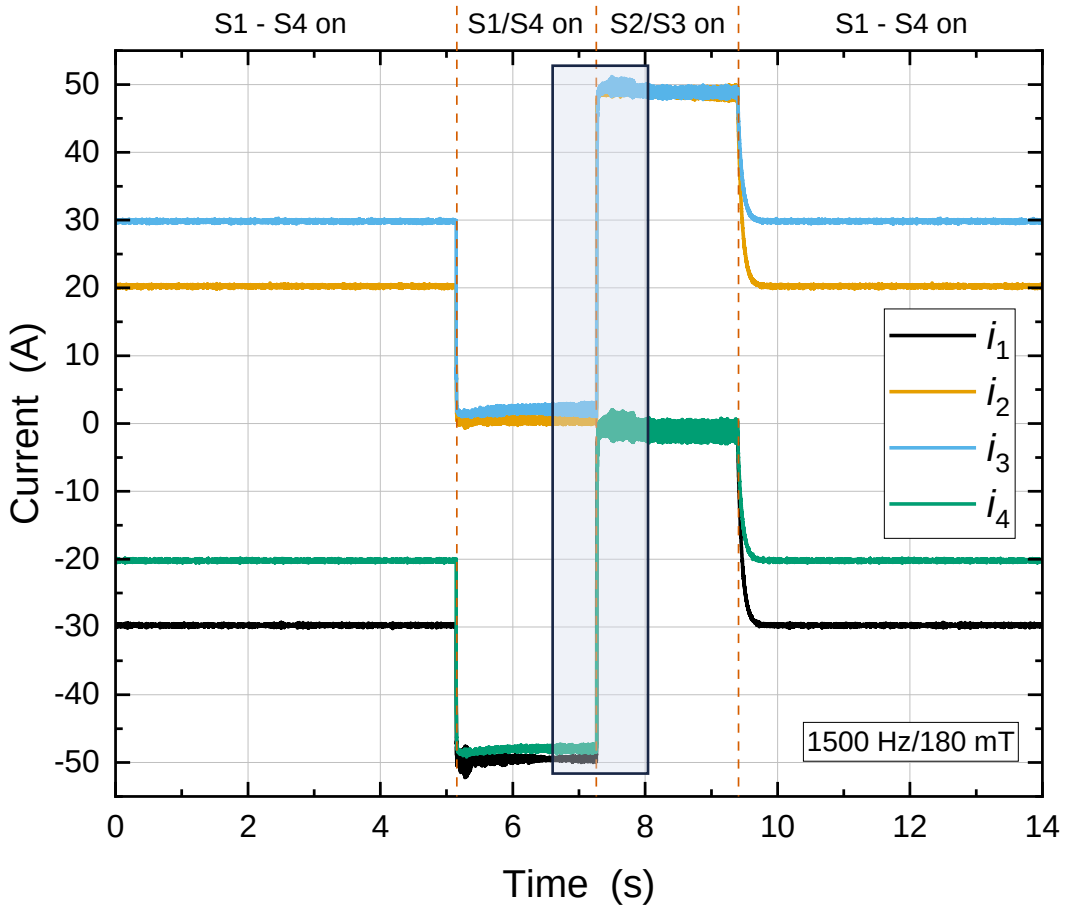




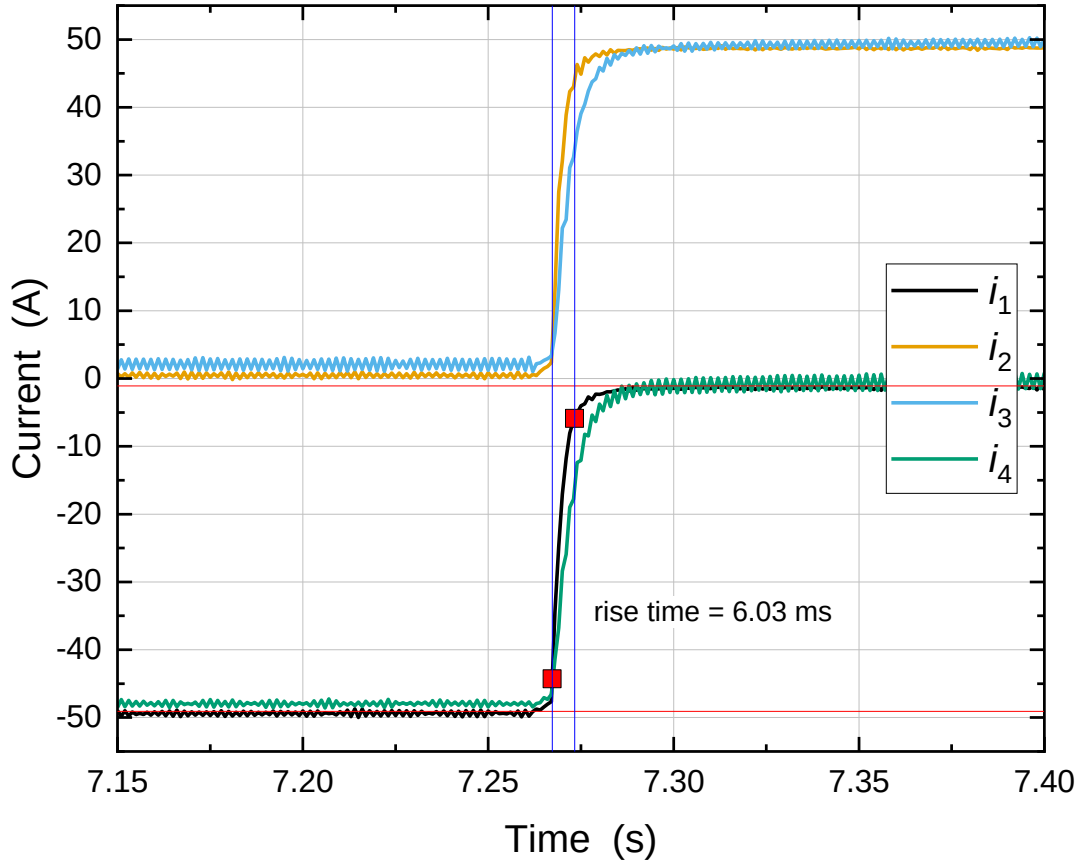
SC tape structured

Minimizing commutation times

Current distribution



Evaluation of rise time



Minimizing commutation time

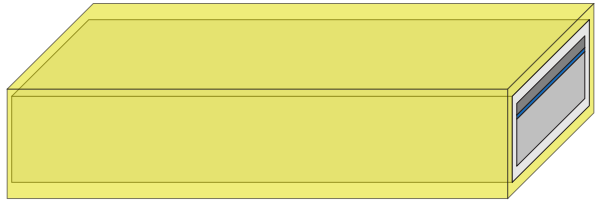
- Depends on
  - Dynamic resistance
    - frequency
    - magnetic field
    - current
    - length
    - critical current
    - width of tape

$$\frac{R_{sc,dyn}}{L} = \frac{4\,w}{I_{c0}} f\,(B_{ext} - B_{th})$$

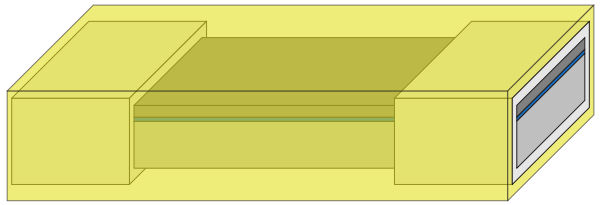
Minimizing commutation time

- Depends on
  - Dynamic resistance
    - frequency
    - magnetic field
    - current
    - length
    - critical current
    - width of tape
  - Inductance of circuit
  - Resistance between H-bridge legs
  - Normal conducting resistance

Config. A



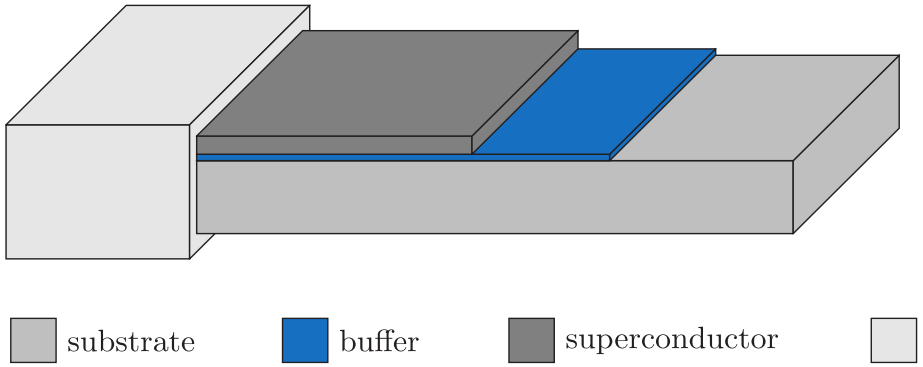
Config. A
Kapton



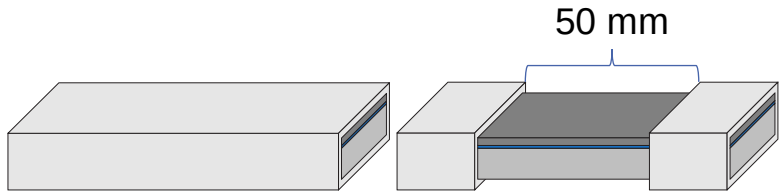
Config. B
Kapton

Theoretical DC resistance per length

Resistances at 77 K

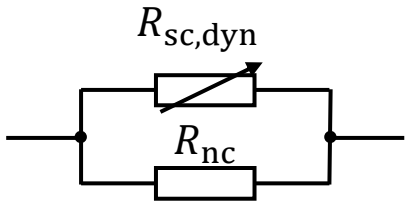


SC probes

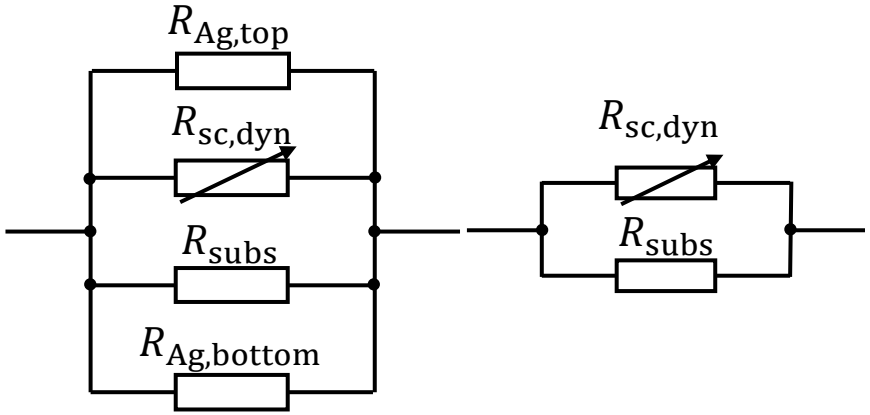


Configuration	A	B
Resistance per length (mΩ m^{-1})	72.9 || $R_{sc,dyn}$	1025 || $R_{sc,dyn}$

R_{ag} = 78.5 mΩ m^{-1}
R_{subs} = 1025 mΩ m^{-1}

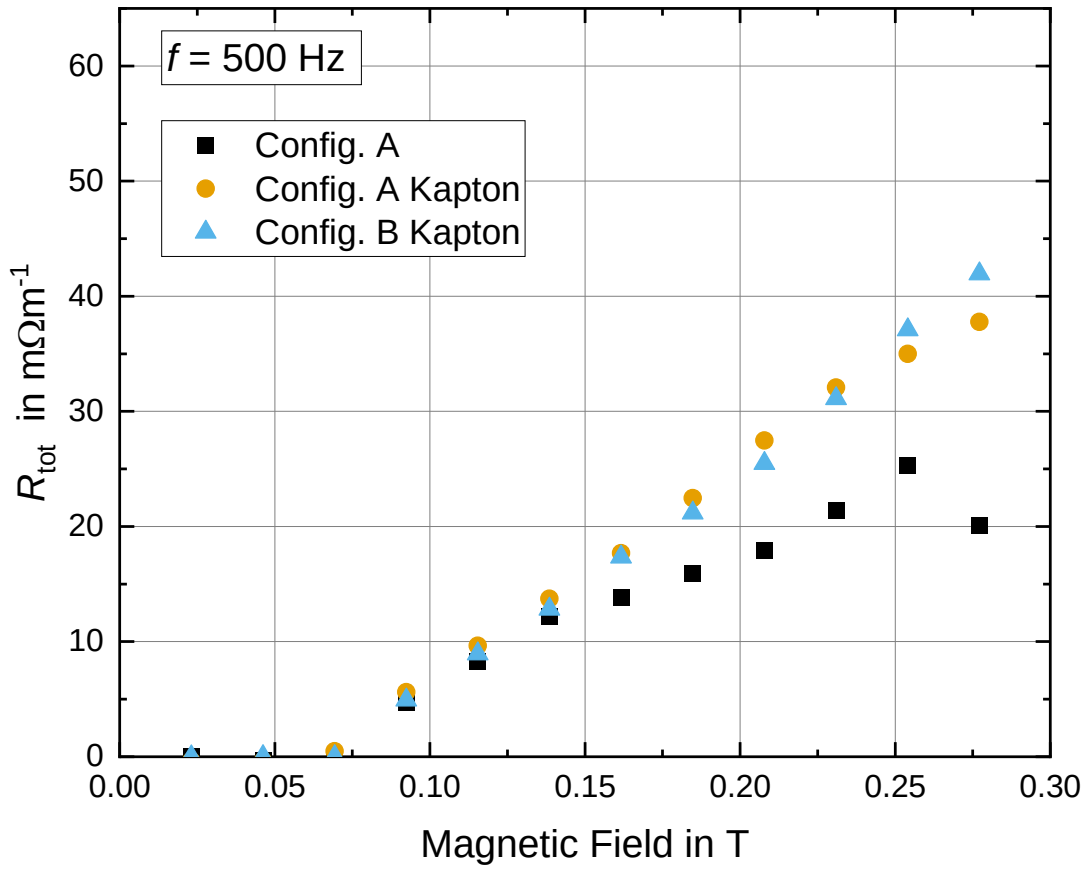


$$R_{tot} = R_{nc} || R_{sc,dyn}$$

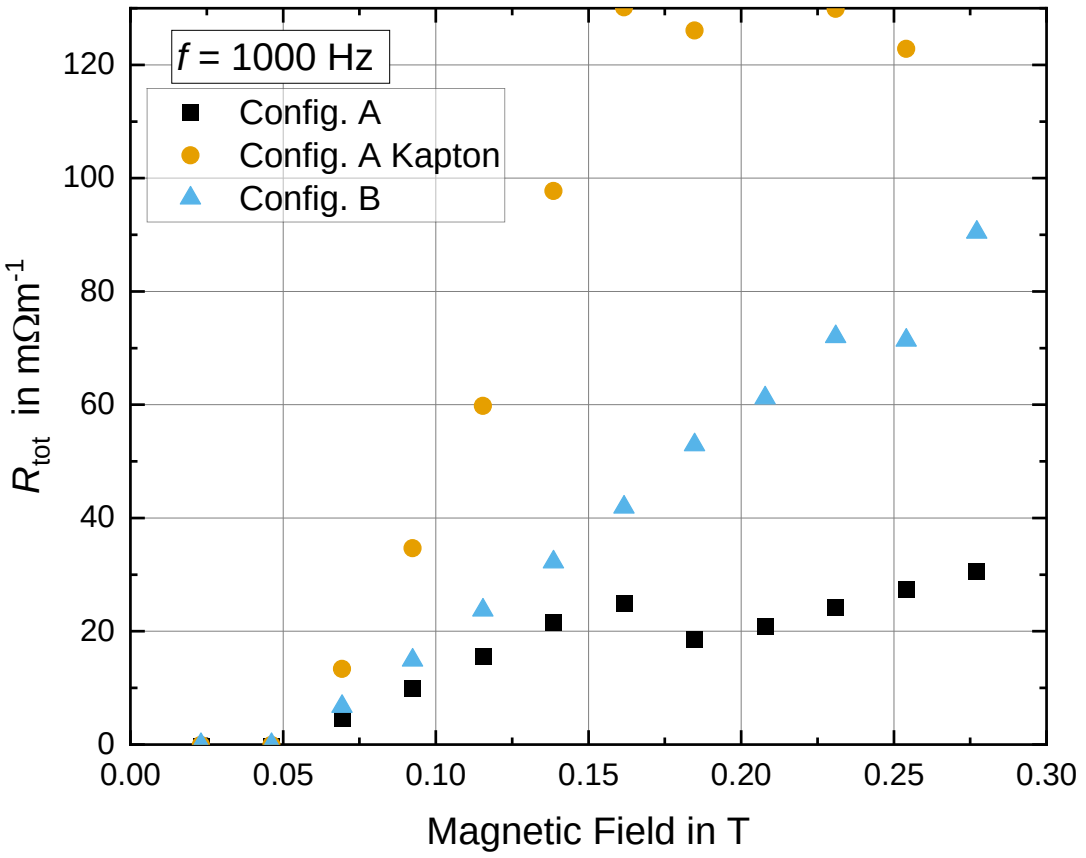


Total Resistance - Comparison

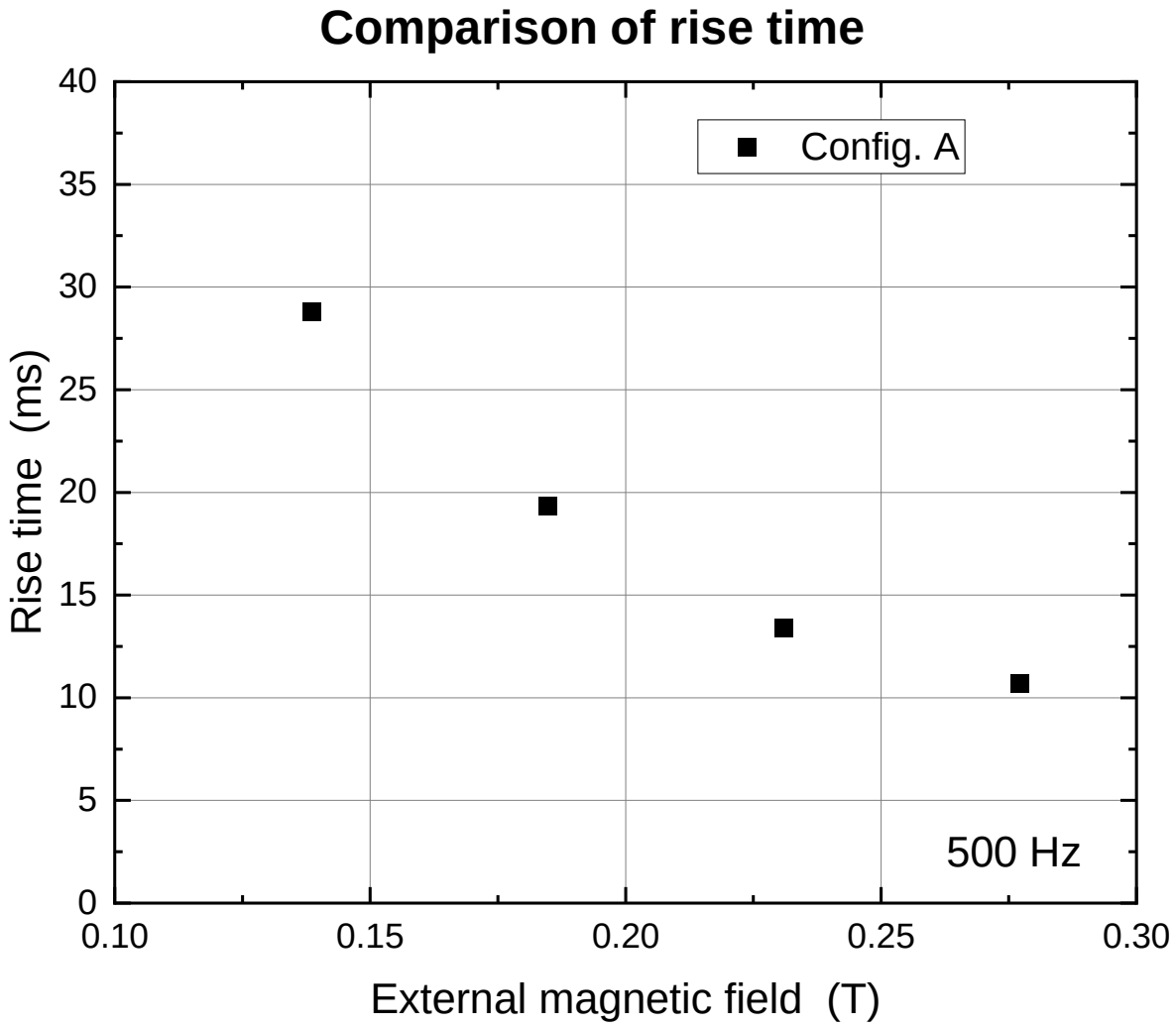
Total Resistance at 500 Hz

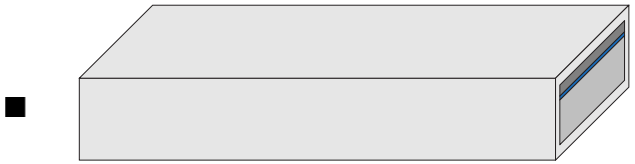


Total Resistance at 1000 Hz



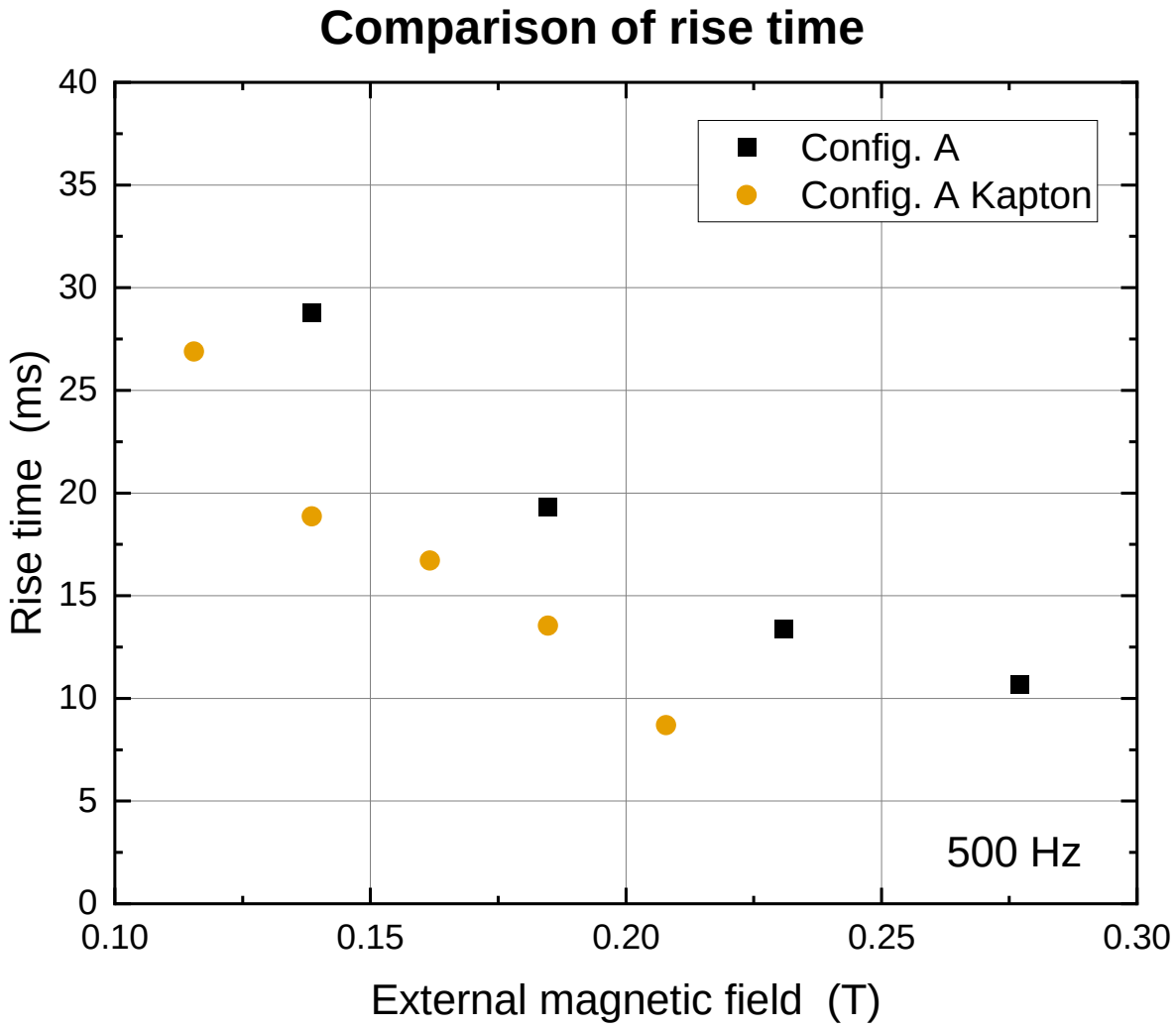
Minimizing commutation time

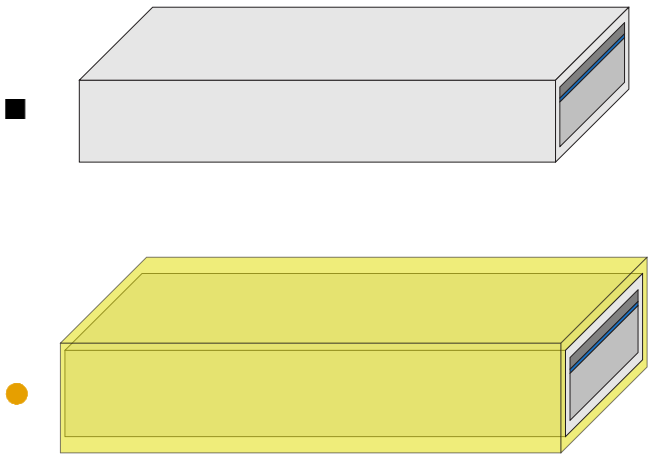




Config. A

Minimizing commutation time

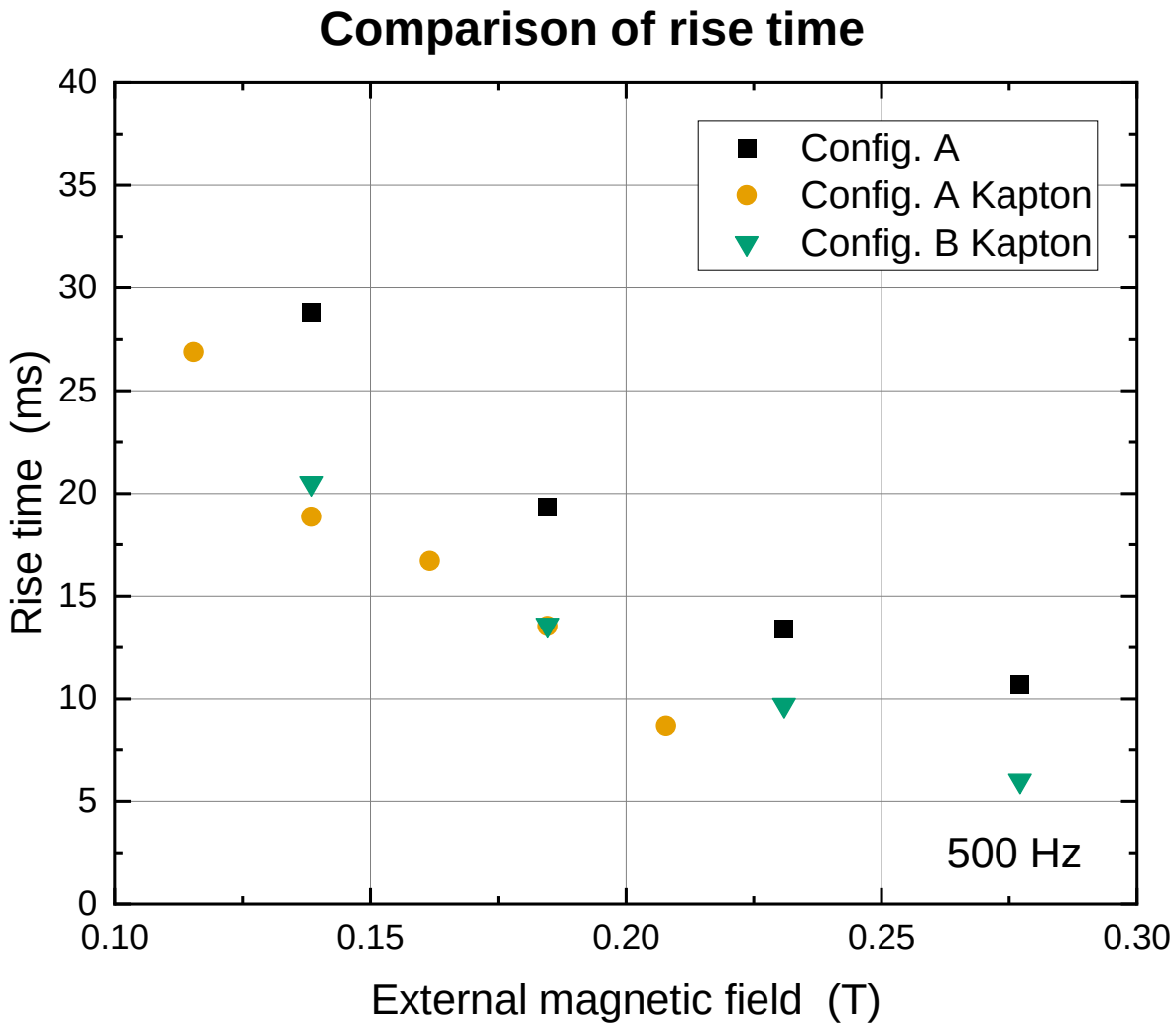


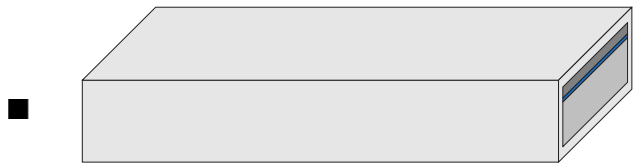


Config. A

Config. A Kapton

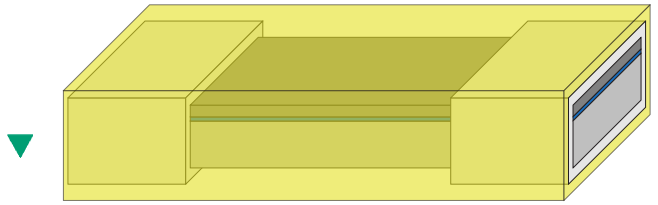
Minimizing commutation time





Config. A

Config. A Kapton



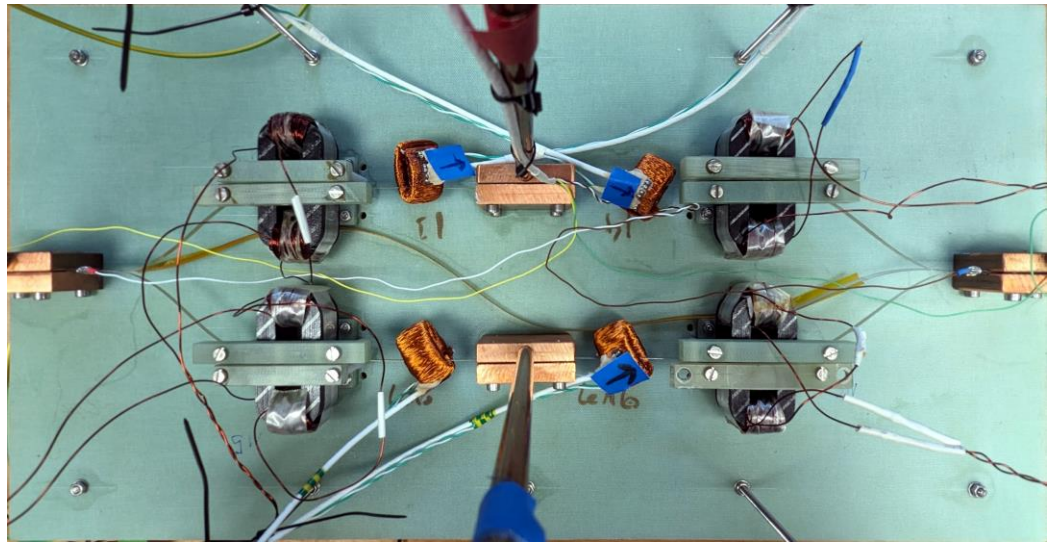
Config. B Kapton

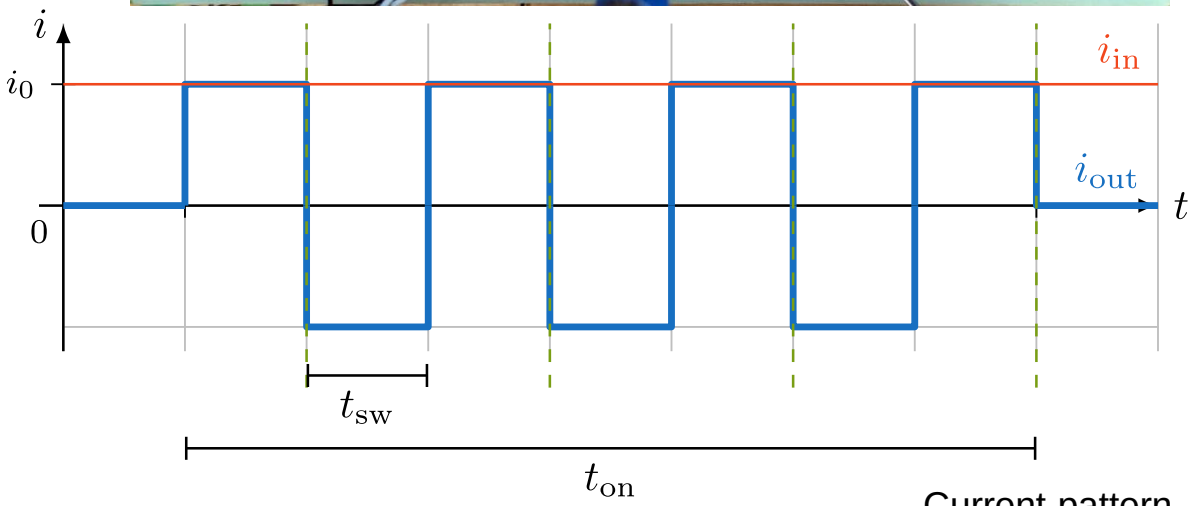
Losses and heat dissipation of the tape are the determining factors.

Continuous stress

- Variation of
  - switching time t_{sw}
  - on time t_{on}
  - magnitude and frequency of magnets

Variable	Range
b	50 … 230 mT
f	500, 1000, 1500 Hz
t_{sw}	25 ms … 1 s
t_{on}	20 … 120 s

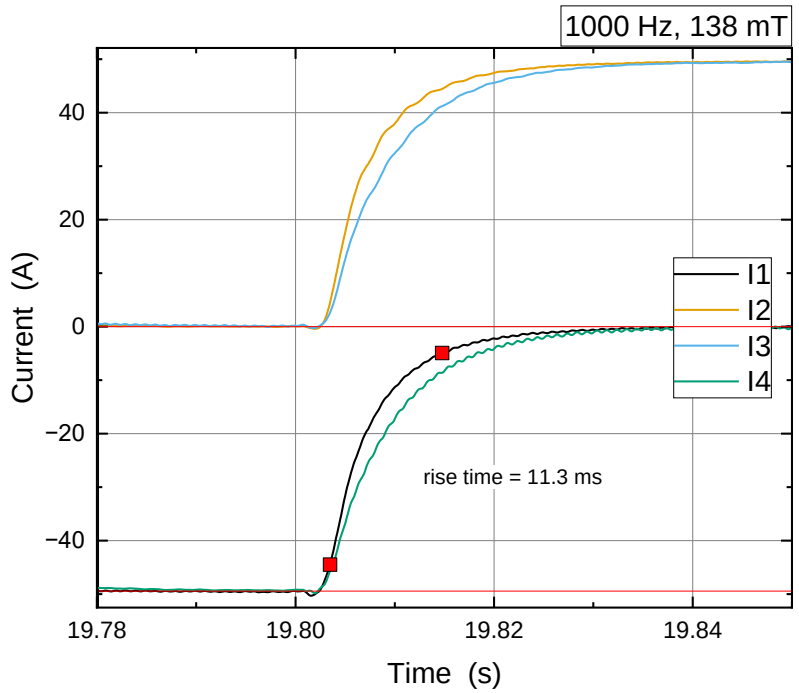




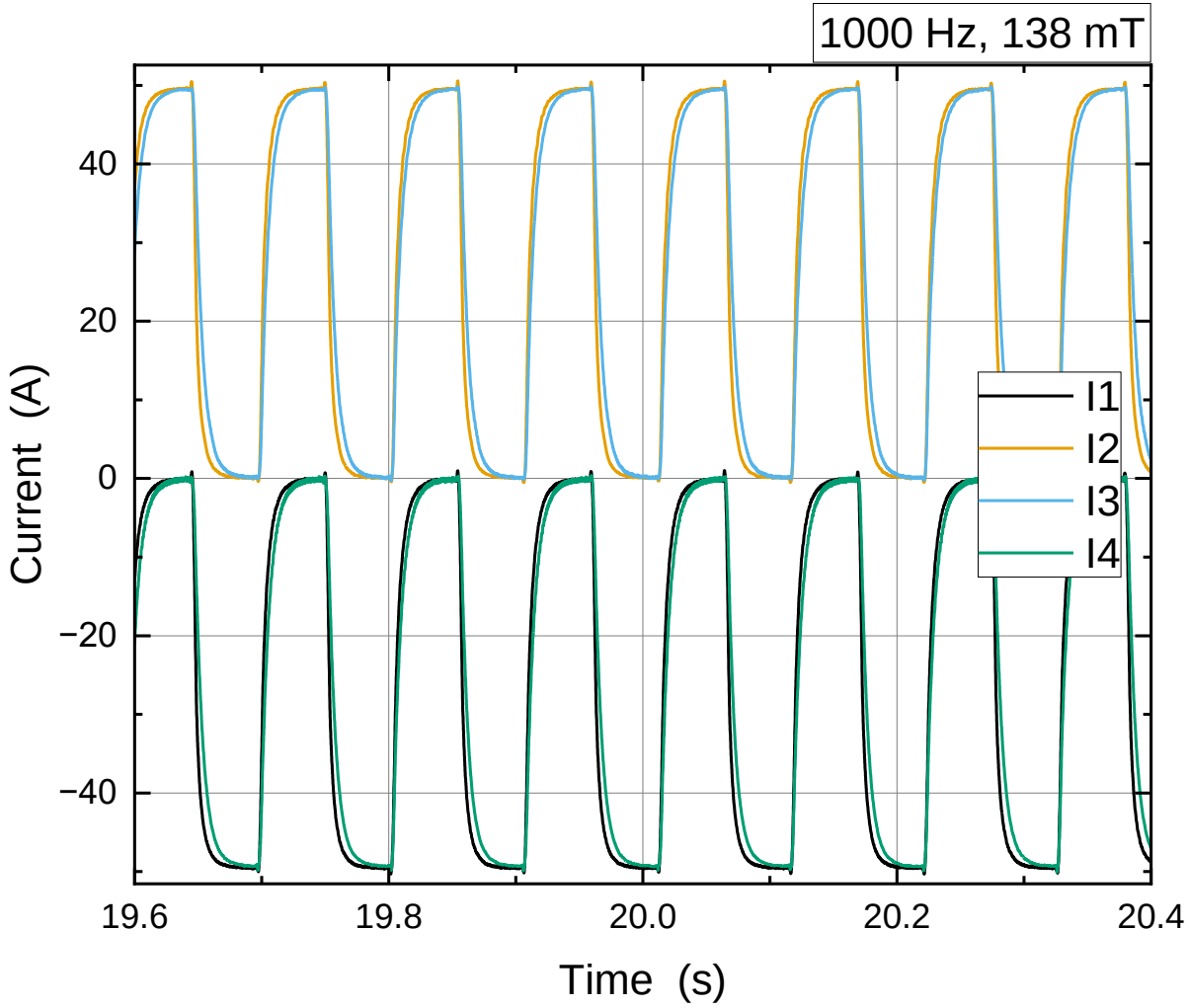
Current pattern

Continuous stress – Results

- t_{sw} = **50 ms**
- t_{on} = 20 s
- t_{rise} = 11.3 ms



Current pattern



Summary and Conclusion

- For the first time, the principle of a full bridge converter using the dynamic resistance of superconductors is experimentally demonstrated.
- Commutation times of down to 5 ms were achieved. Further reduction by increasing superconductor length is possible.
- Influence of magnetic field, frequency and superconductor properties were investigated.
- Long operation times have been achieved.

- Upscaling towards faster switching times and higher voltages by further increasing superconductor length.