PULPOKS 2023

A stacked MOSFET-switch for distribution of bunch trains at 4.5 MHz

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Hamburg, 24.04.2023

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

DESY.

Overview

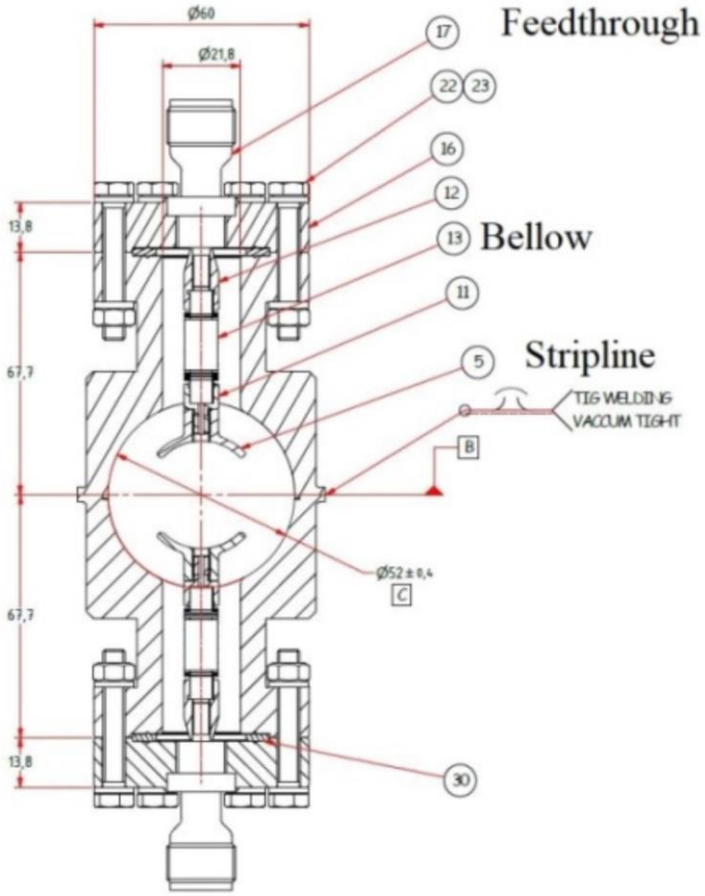
- Specifications
- Necessary Components
  - Mosfets
  - PCBs
  - Ferrite
  - MOSFET driver IXDD604
  - …
- Prototype measurements with IsoVu probes
- Outlook

XFEL dump pulser specifications

Development of a 4.5MHz, 8kV, 50Ω dump kicker

Currently we use a 5kV pulser from FID

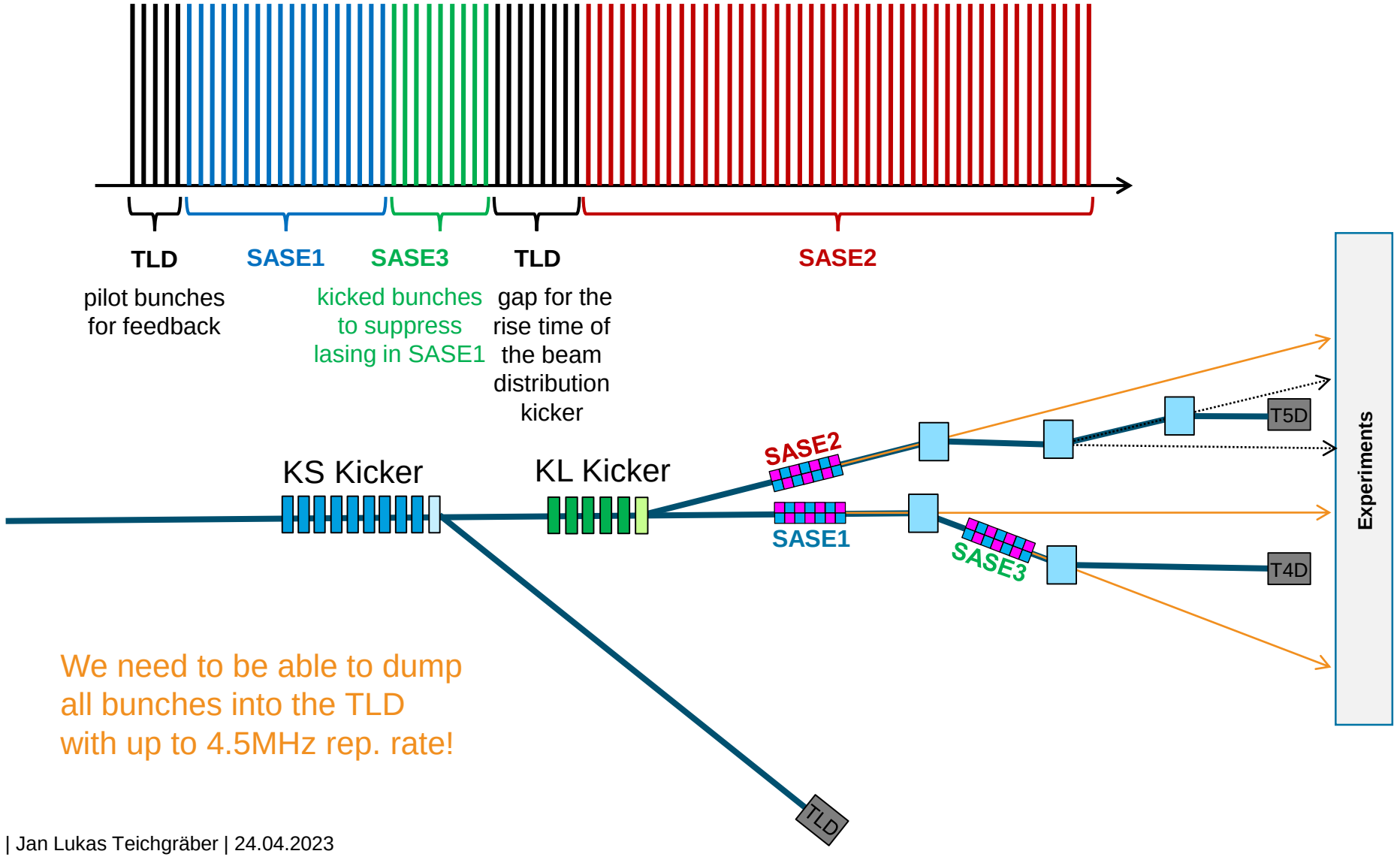
necessary kick angle	φ = 0,5mrad
beam energy max.	E = 17,5GeV
kicker length	l = 2000mm
kicker tube inner diameter	d = 52mm
kicker gap	a = 30mm
impedance	Z = 50Ω
conductor width	din = 30mm
pulse width	tp = 30 – 100ns
rise time	tr = 15ns
fall time	tf = 15ns
pulse shape	rectangle
max. current	I = 160A
max. voltage	U = 8kV
puls frequency	f = 4,5MHz
no. of pulses	2700 per train
rep. rate	10Hz



-> reduce the dependancy from single company

XFEL dump pulser

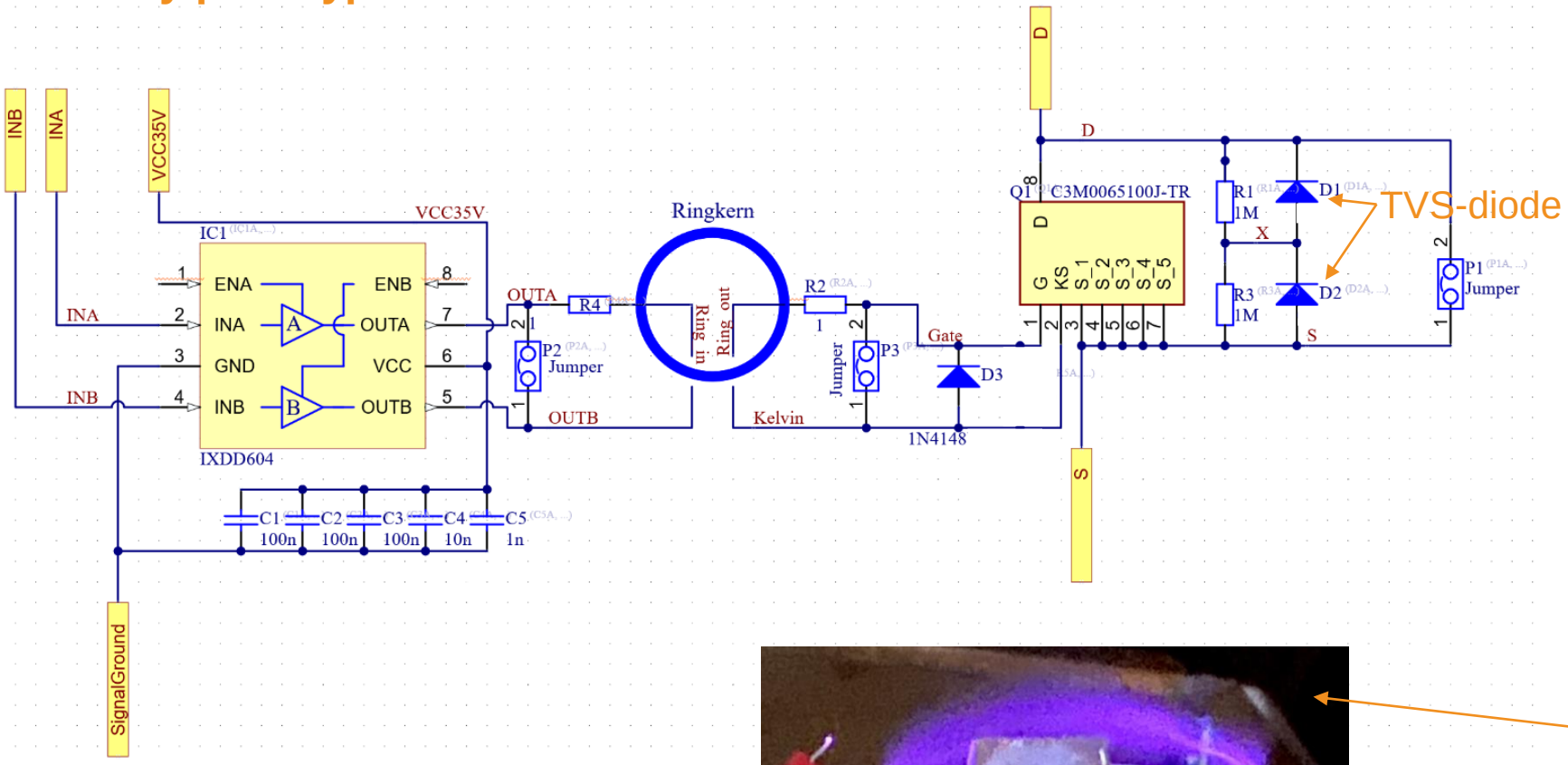
Driving SASE1, SASE2 and SASE3 simultaneously

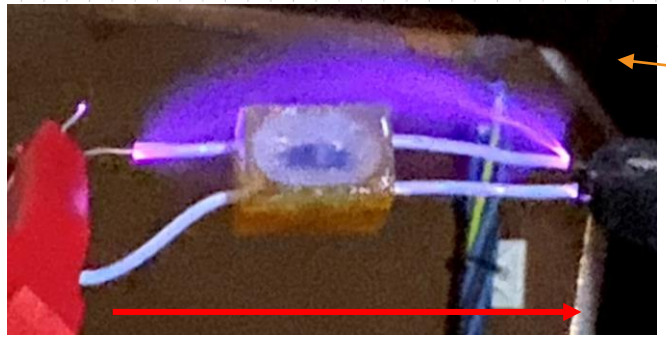


We need to be able to dump
all bunches into the TLD
with up to 4.5MHz rep. rate!

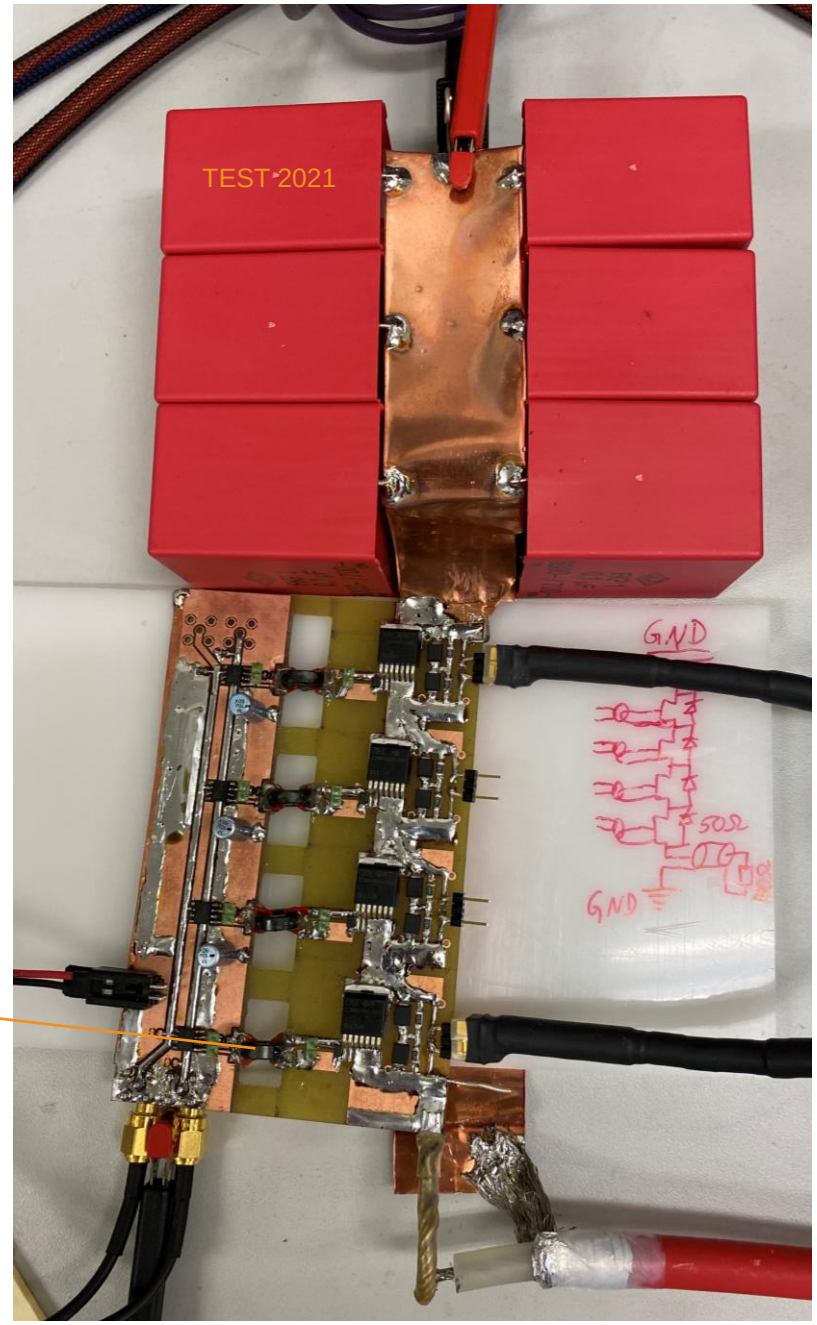
XFEL dump pulser

Early prototype with 4 MOSFETS





20kV
no problems at 10kV

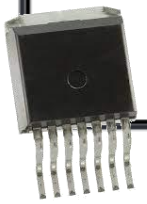


XFEL dump pulser specifications

Development of a 4.5MHz, 8kV, 50Ω dump kicker

- 16 MOSFETS in series -> **safety factor 2**
- 32 MOSFETS per pulser (2 in parallel)
  - expected losses up to 20W per MOSFET (mostly switching losses)
  - 640W have to leave the system while providing galvanic isolation
- possible solution:
  - cooling fins?
  - submerge in oil?
  - thermally conductive and isolating substrate?

Vmax = 1000V



C3M0065100J

Figure 22. Safe Operating Area

XFEL dump pulser

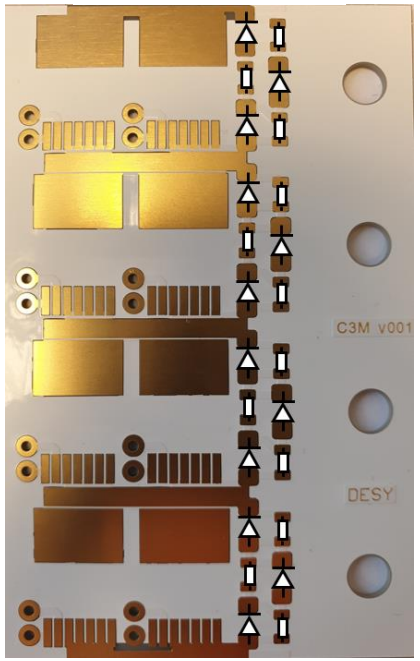
Materials - PCBs

- **PCBs made of Aluminium nitride**

- thermal conductivity ≈170W/mK (copper 400W/mK)
- dielectric strength > 17 kV/mm
  - 2mm should be sufficient for 8kV
- dielectric constant (1MHz) ≈ 8∼10

- PCBs can be bought e.g. from *ceramic-pcb.com*

≈100€ each

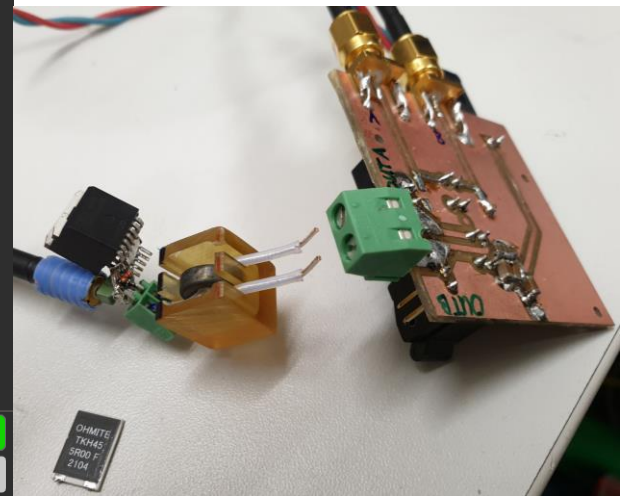


XFEL dump pulser

Materials - Ferrite

the MnZn ferrite core:
AMIDON FT37-77

there is approx. 500ps delay between the different cores.
too much to ignore



XFEL dump pulser

Ferrite test with 24V driver

Paralleling more MOSFETS requires changes in the gate driving structure.

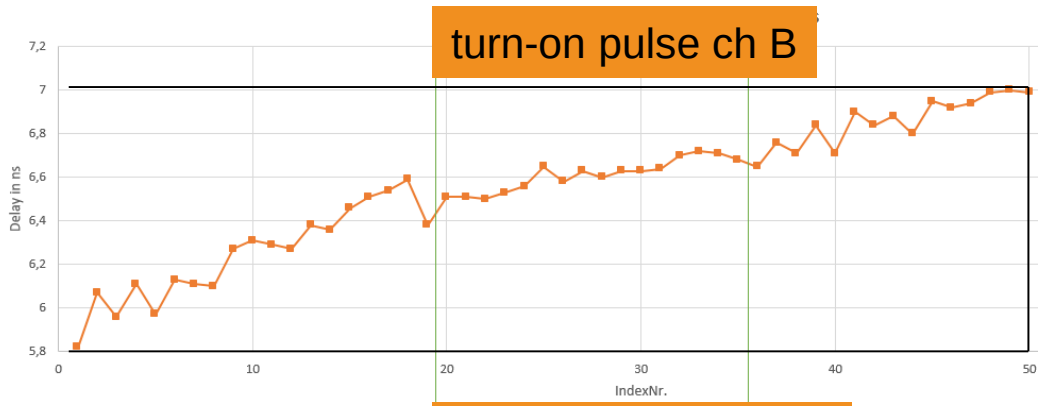
XFEL dump pulser

Materials – MOSFET driver IXDD604

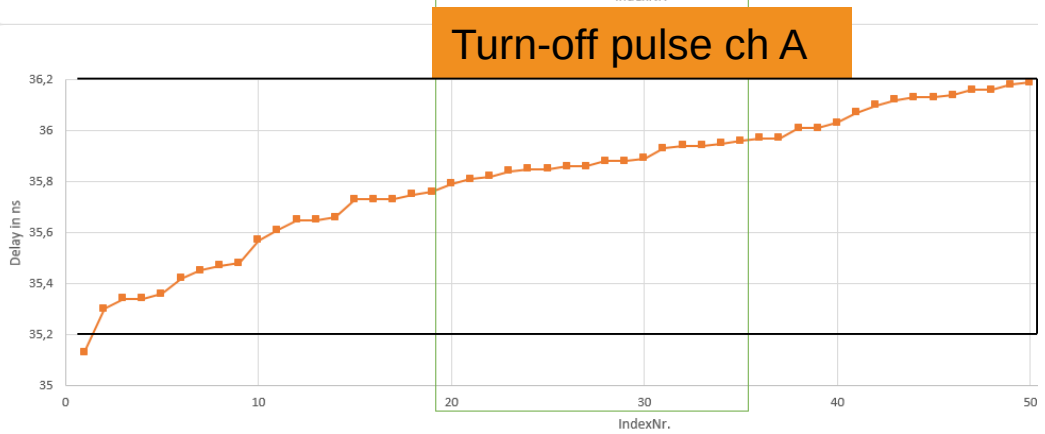
	A	B	C	D
1		Messung der IXDD604SIATR bei VCC = 24V; bei der Kreuzung mit der 12V-Linie wird der skew zu Kanal 1 gemessen		
2	IndexNr.	Treibernummer	CH B	CH A
3	01	46	5,82	35,13
4	02	44	6,07	35,3
5	03	12	5,96	35,34
6	04	21	6,11	35,34
7	05	43	5,97	35,36
8	06	48	6,13	35,42
9	07	20	6,11	35,45
10	08	15	6,1	35,47
11	09	08	6,27	35,48
12	10	50	6,31	35,57
13	11	30	6,29	35,61
14	12	18	6,27	35,65
15	13	47	6,38	35,65
16	14	22	6,36	35,66
17	15	19	6,46	35,73
18	16	24	6,51	35,73
19	17	27	6,54	35,73
20	18	02	6,59	35,75
21	19	49	6,38	35,76
22	20	28	6,51	35,79
23	21	23	6,51	35,81
24	22	25	6,5	35,82
25	23	03	6,53	35,84
26	24	29	6,56	35,85
27	25	32	6,65	35,85
28	26	16	6,58	35,86
29	27	14	6,63	35,86
30	28	06	6,6	35,88
31	29	26	6,63	35,88
32	**30**	**09**	**6,63**	**35,89**
33	31	05	6,64	35,93
34	32	17	6,7	35,94
35	33	10	6,72	35,94
36	34	04	6,71	35,95
37	35	07	6,68	35,96
38	36	01	6,65	35,97
39	37	13	6,76	35,97
40	38	11	6,71	36,01
41	39	33	6,84	36,01
42	40	38	6,71	36,03
43	**41**	**34**	**6,9**	**36,07**
44	42	31	6,84	36,1
45	43	36	6,88	36,12
46	44	37	6,8	36,13
47	45	39	6,95	36,13
48	46	41	6,92	36,14
49	47	35	6,94	36,16
50	48	45	6,99	36,16
51	49	42	7	36,18
52	50	40	6,99	36,19
53		Mittelwert:	**6,405**	**35,66**

Die Kanäle A und B innerhalb der Treiber scheinen recht gut zueinander zu passen (maximal 250ps Differenz zwischen A und B).
Die Treiber sind nach dem Delay des Abschalttriggers CH A sortiert.
Am sinnvollsten ist es wohl nach dem Ausschalttrigger zu sortieren, also Kanal A. Die Differenz ist hier aber so gering, dass es keine Rolle spi

Für die erste Platine werden die Treiber Index20 bis Index35 verwendet.
Das sind also die grün eingefärbten Treiber (28, 23, 25, 03, 29, 32, 16, 14, 06, 26, 09, 05, 17, 10, 04, 07)



ΔT = 1.2ns



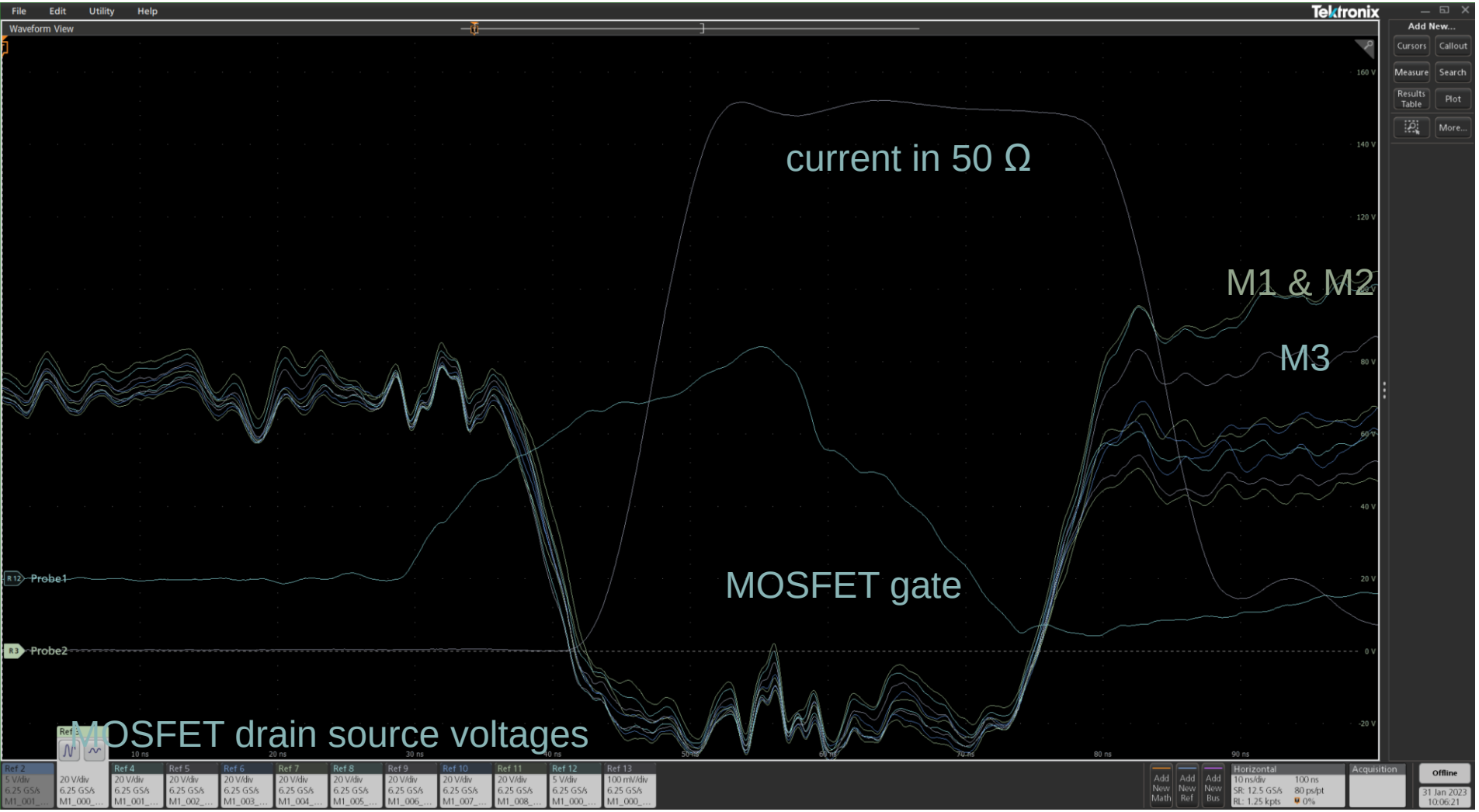
ΔT = 1ns

different turn off time
-> different turn off voltage
-> 1ns delay in gate voltage is too much
-> 500ps looks good enough

we haven´t found an easy way to reliably change the pulse length and delay for each individual channel

XFEL dump pulser

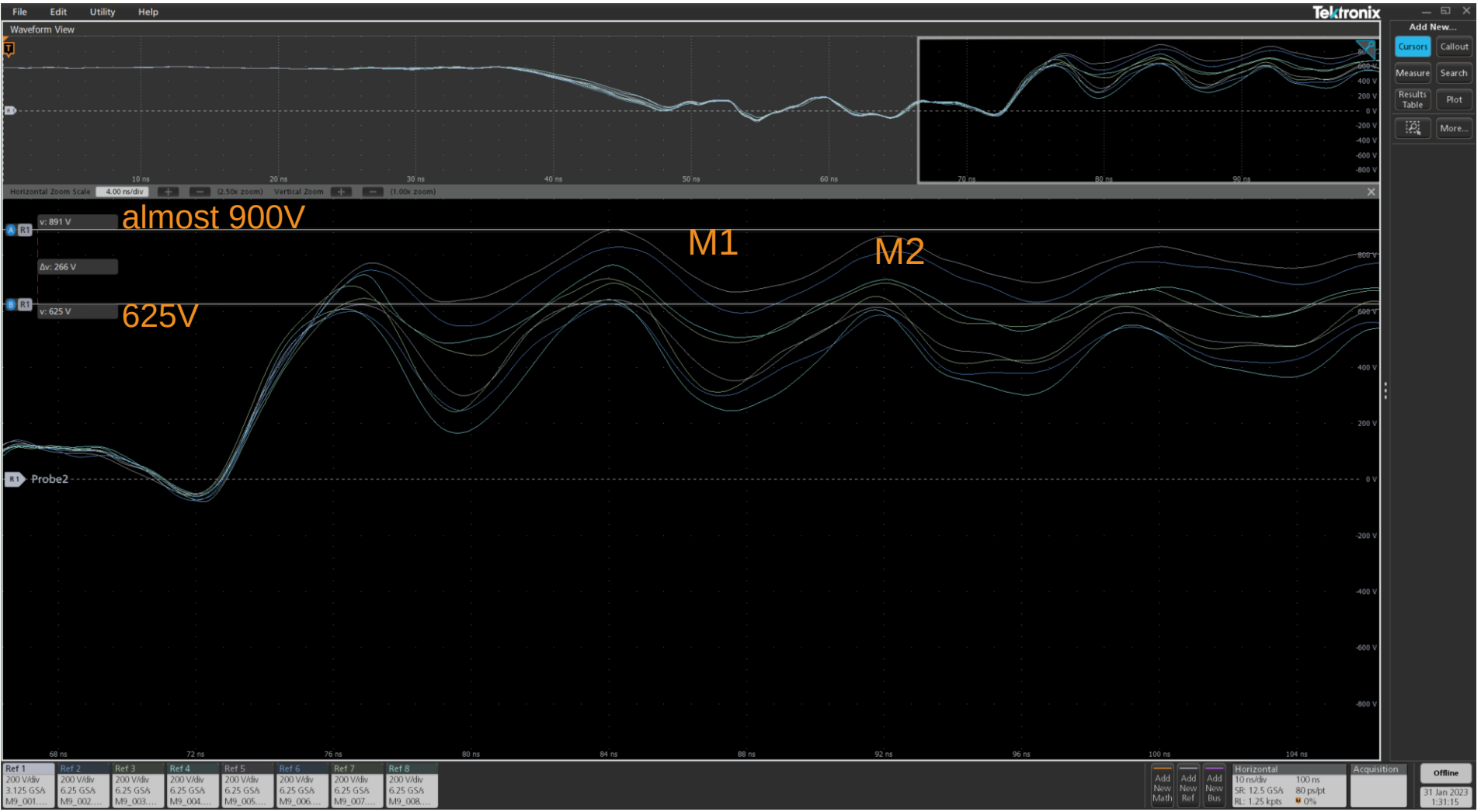
Measurements – 800V with 8 MOSFETS in series and 2 parallel



the turn off voltage over the 8 MOSFETs is not the same

XFEL dump pulser

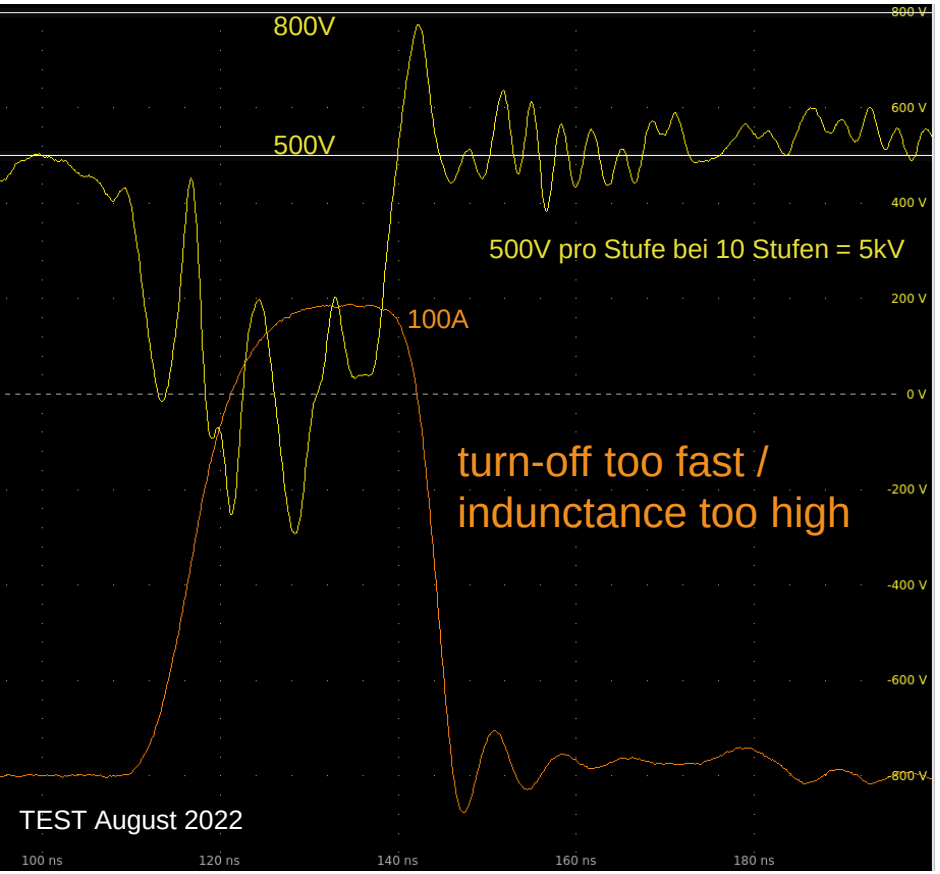
Measurements – 5000V with 8 MOSFETS in series and 2 parallel



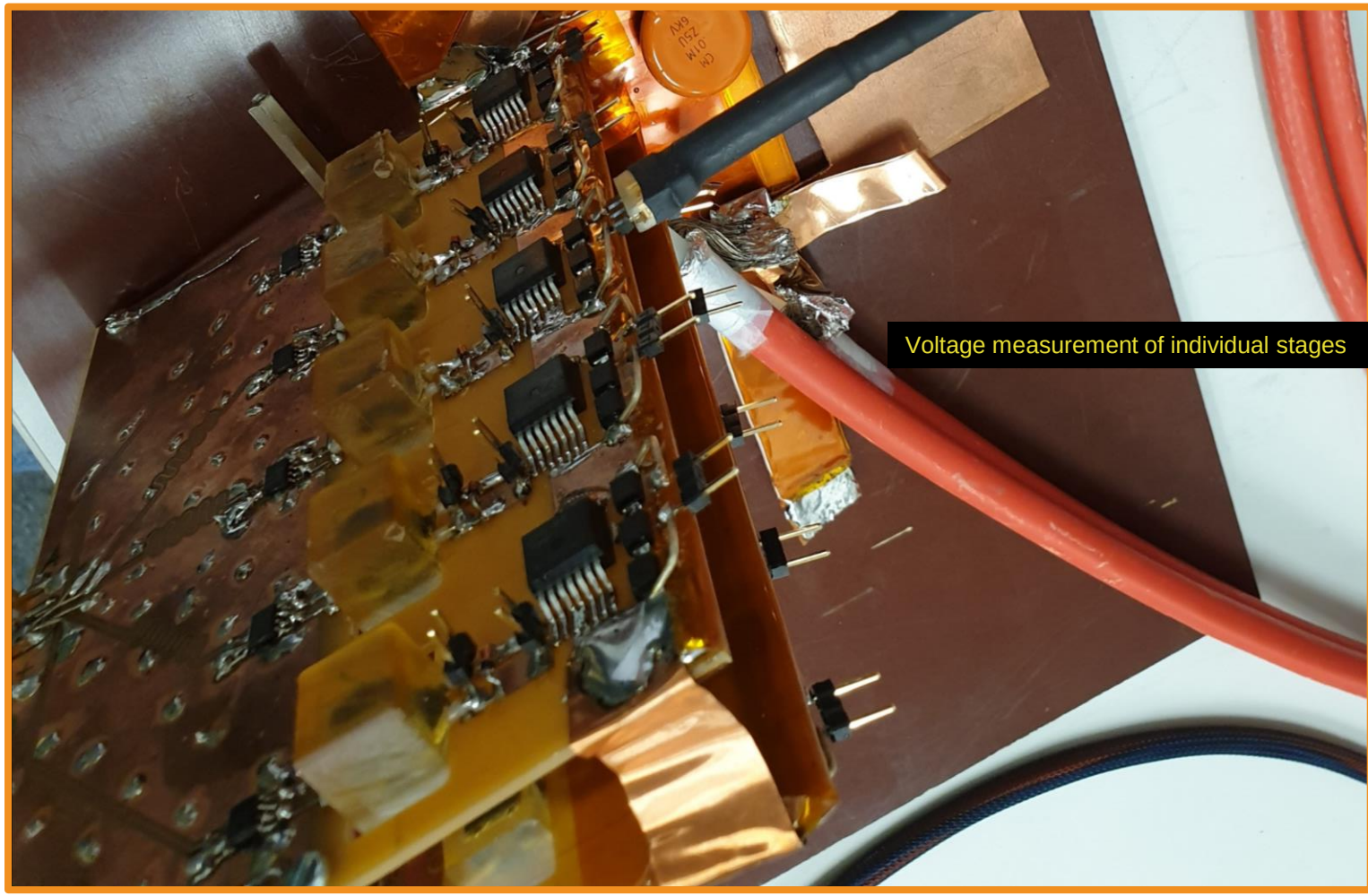
the turn off voltage over the 8 MOSFETs is not the same

XFEL dump pulser

Measurements – 5000V with 8 MOSFETS in series

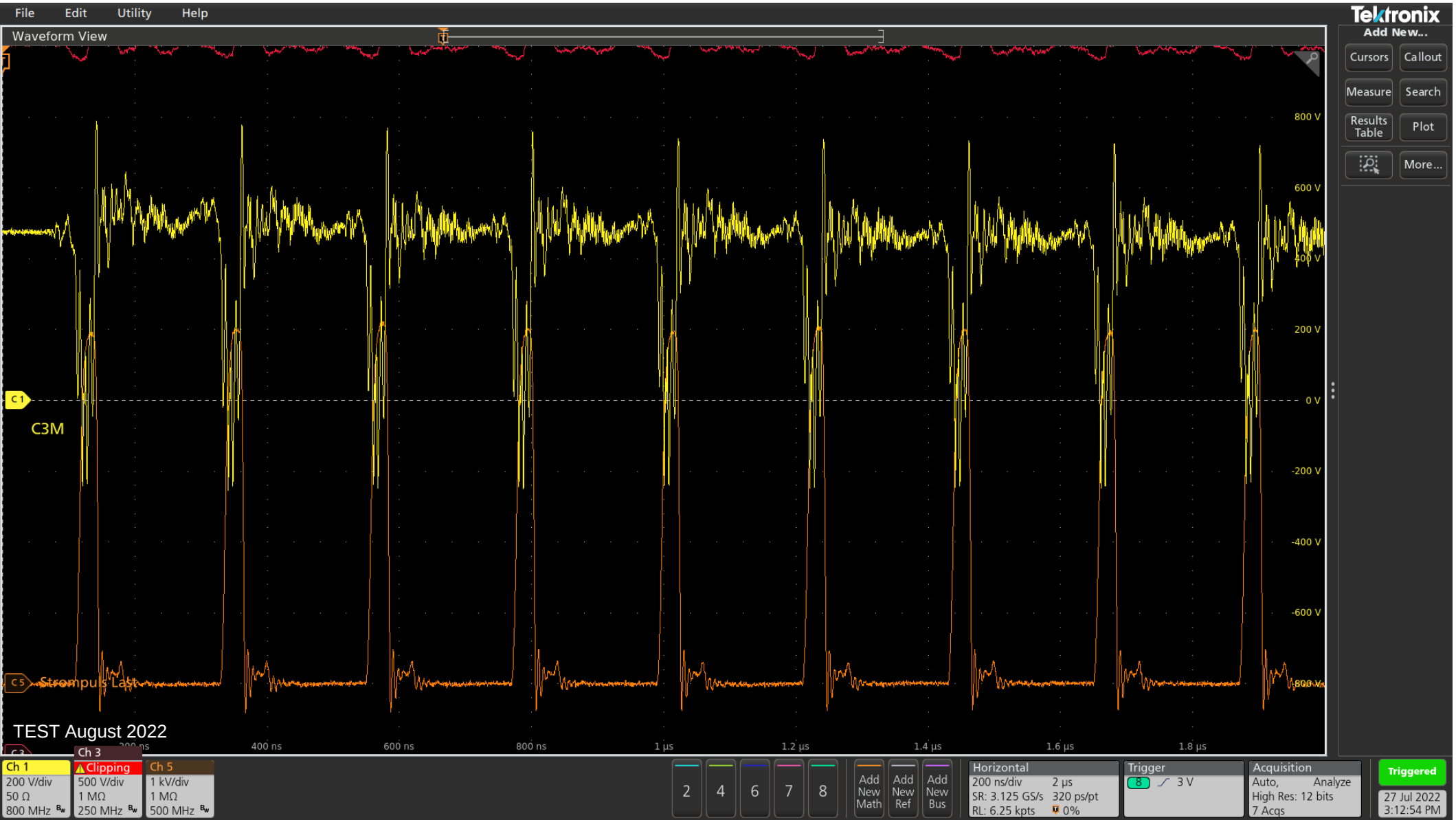


cooling is difficult without parallel MOSFETs



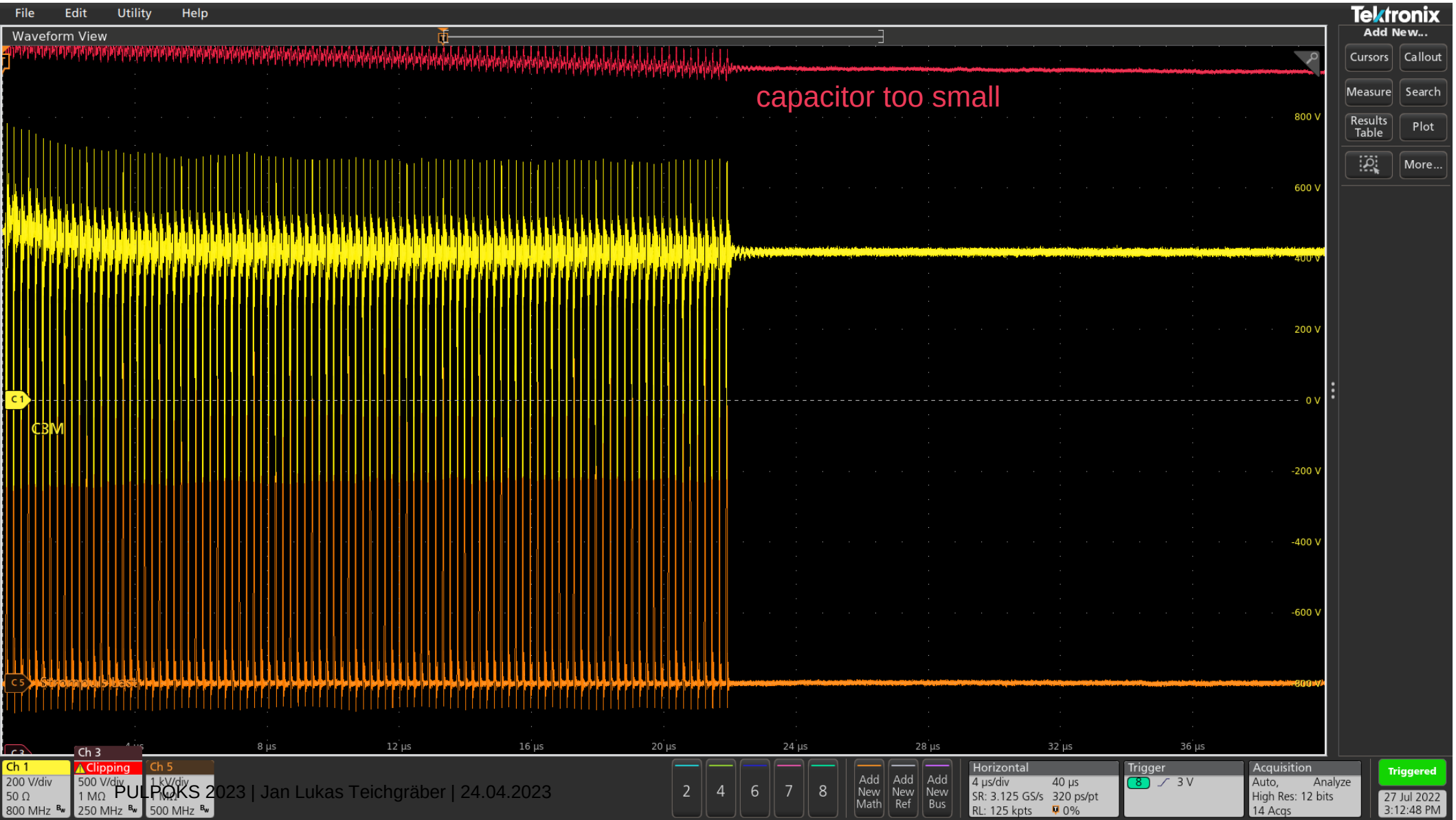
XFEL dump pulser

Measurements – 5000V with 8 MOSFETS in series

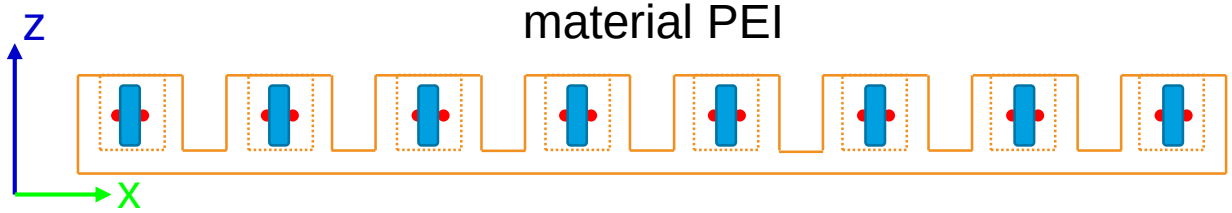


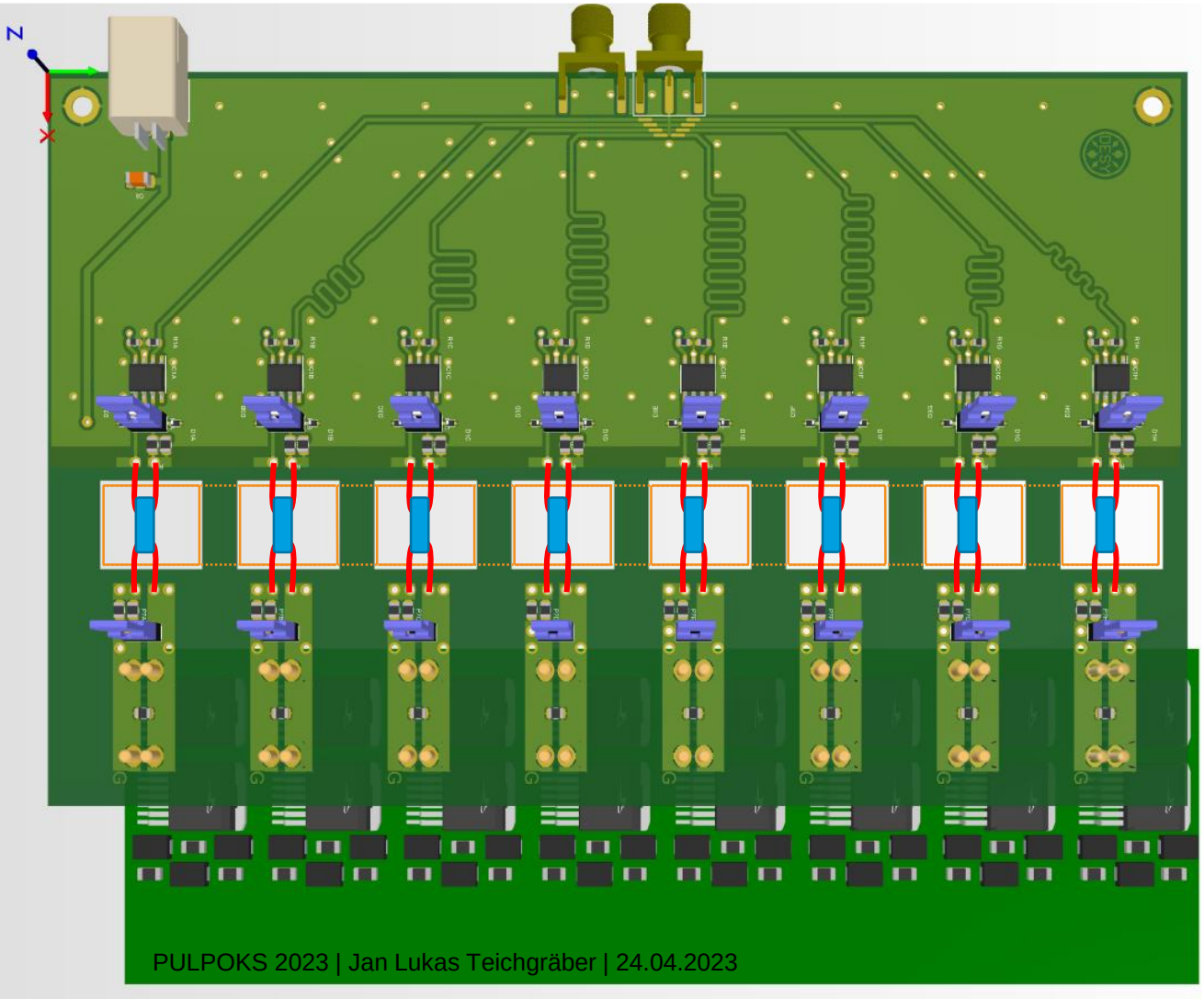
XFEL dump pulser

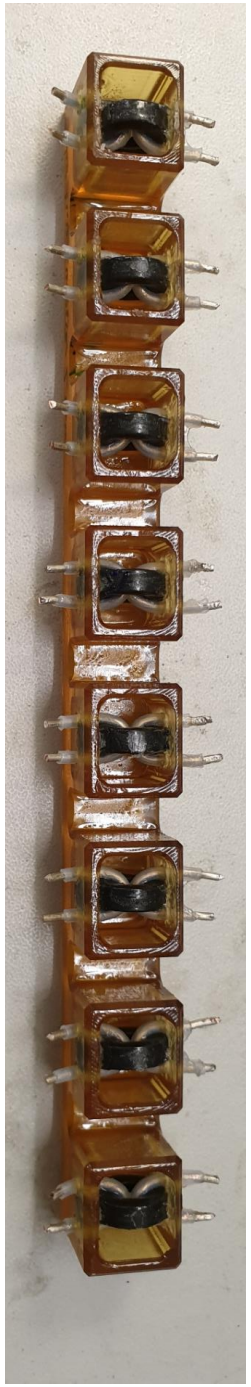
Measurements – 5000V with 8 MOSFETS in series



material PEI





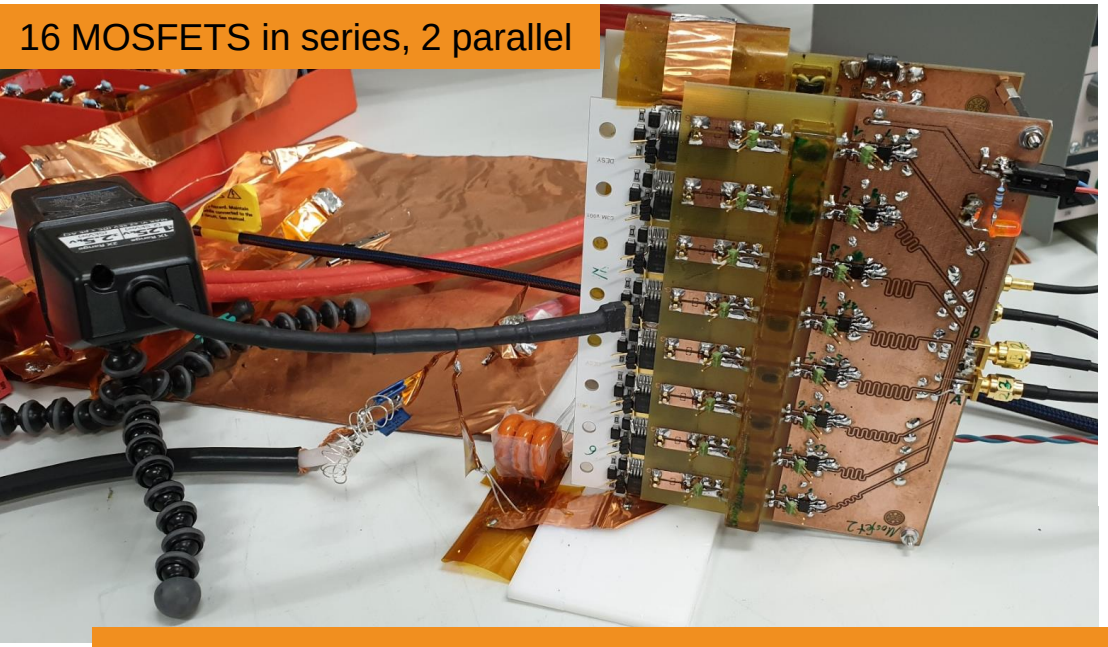


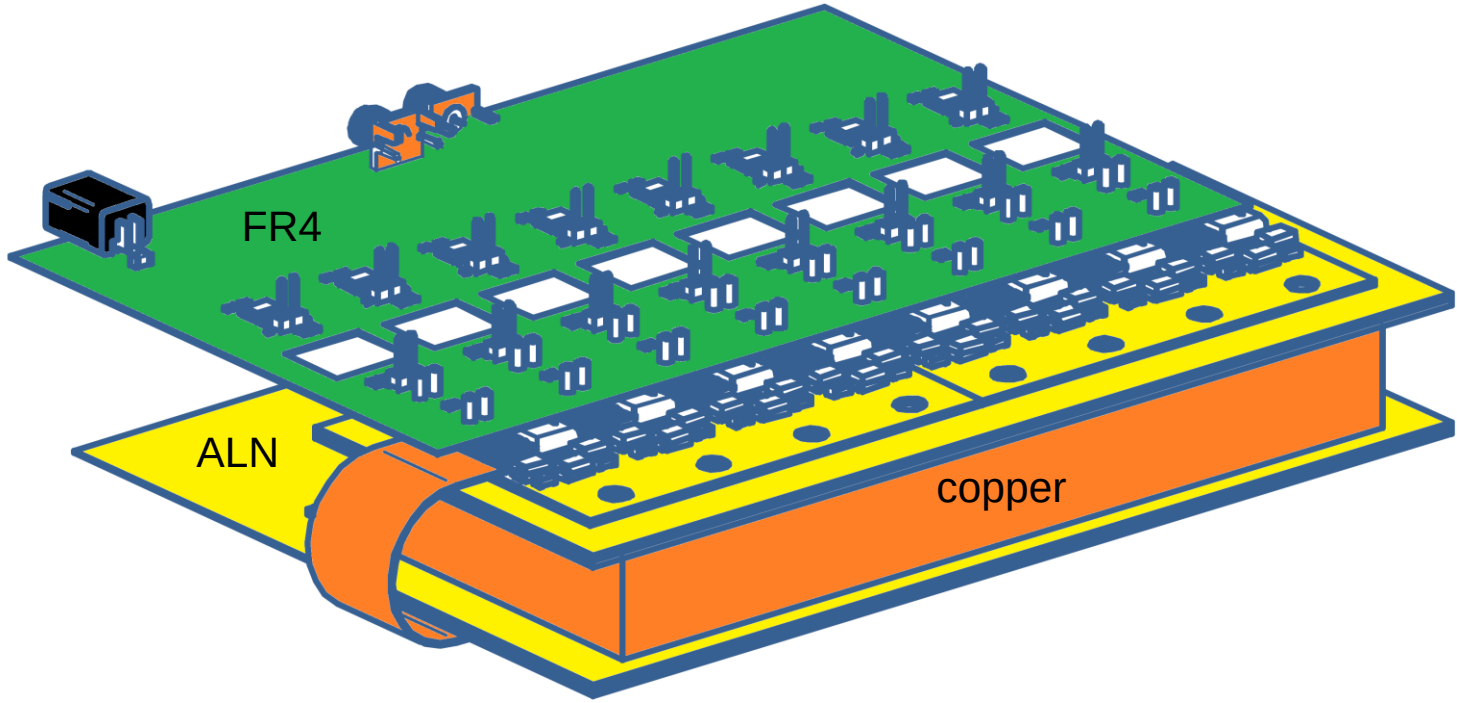
ferrites are glued in the holding device for reliable placement and high isolation

XFEL dump pulser

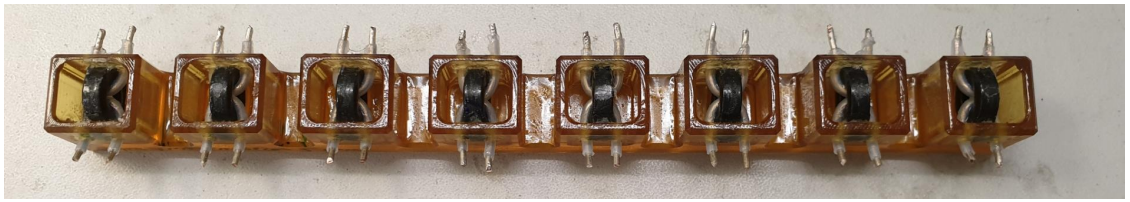
Development of a Mosfet Stack

16 MOSFETS in series, 2 parallel





Aluminium nitride PCBs mounted on a copper block for cooling



Summary

- The current design looks promissing.
  - Several days of 5kV operation have been achieved with the current prototype
  - Can the prototype handle 27000 bunches per second?
    - More capacitors and a bigger power supply necessary
    - Oil isolation is still on the table
- Higher voltages only with reduced inductance of the pulser
  - More then 10kV are probably troublesome due to the high timing requirements
  - Higher voltage MOSFETS to reduce number of stages
- Higher voltage per pulser reduces the number of pulsers and reduces redundancy

Thank you for your attention!

Contact

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