

Modulators with pulse cables for XFEL

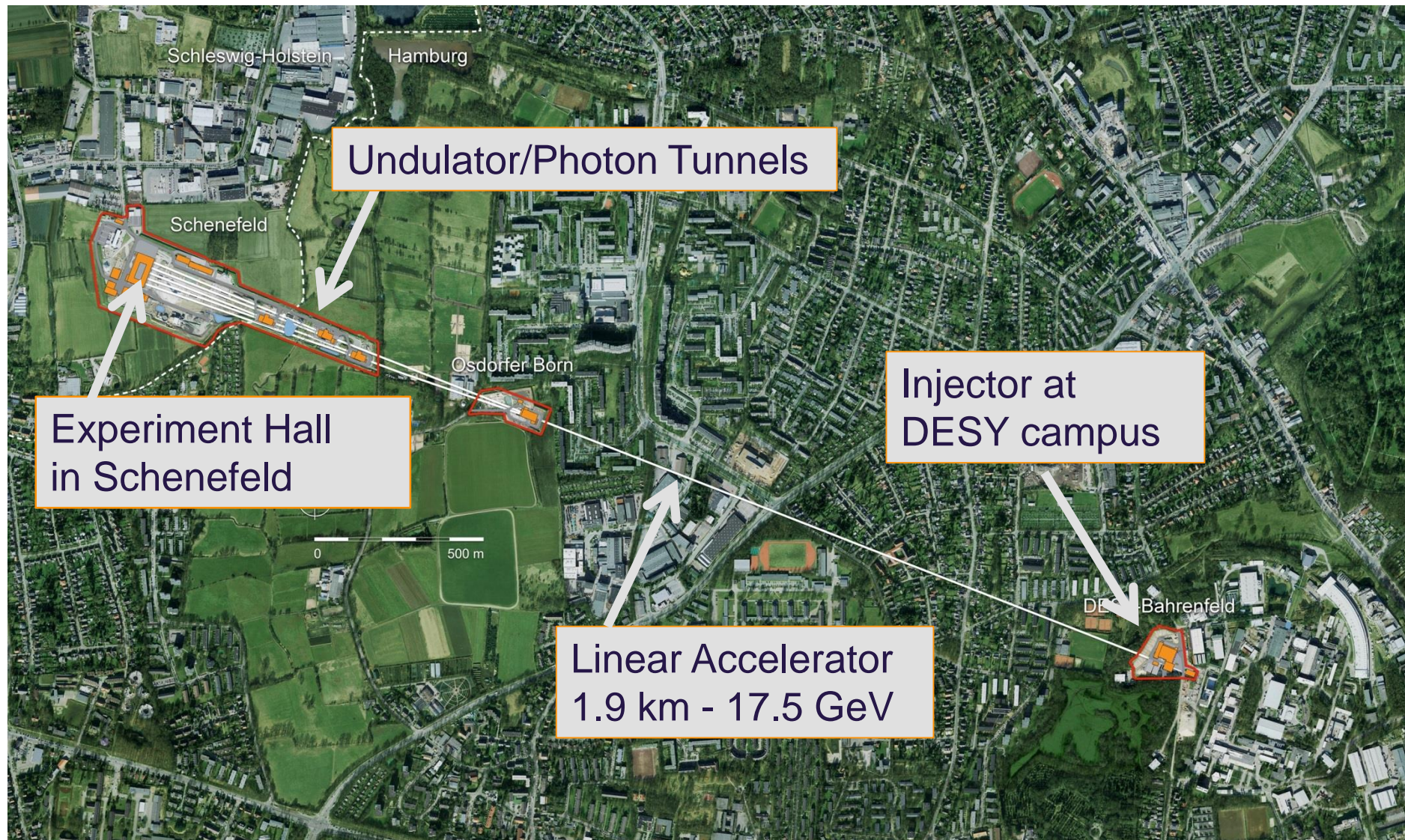
Time line

Eckoldt, Hans-Jörg
Campinas, 10.-11.09.2018

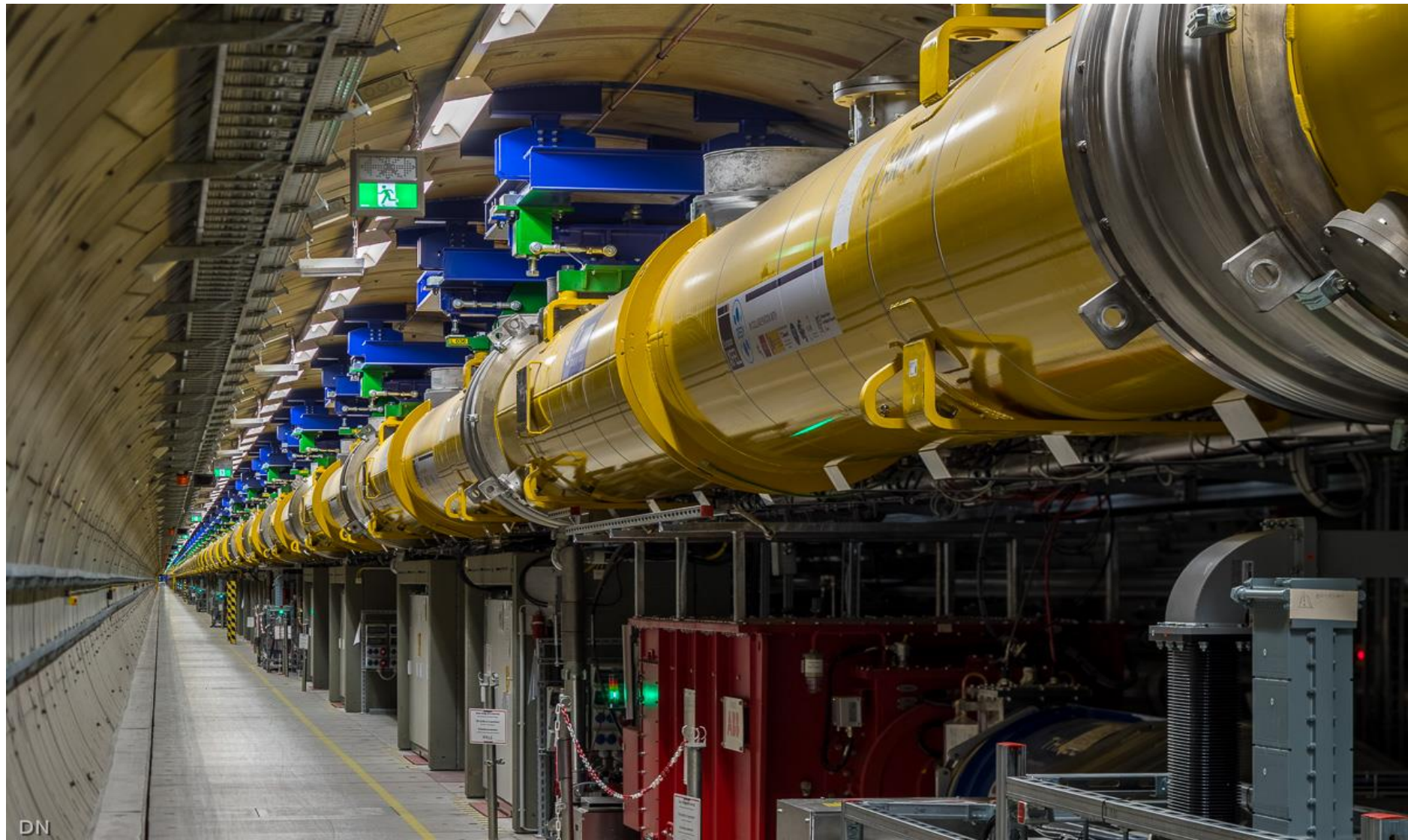
Structure

- XFEL
- What are modulators?
- Why pulse cables?
 - Specification
 - R&D on cables
- Installation, commissioning

European XFEL Layout



View along accelerator section



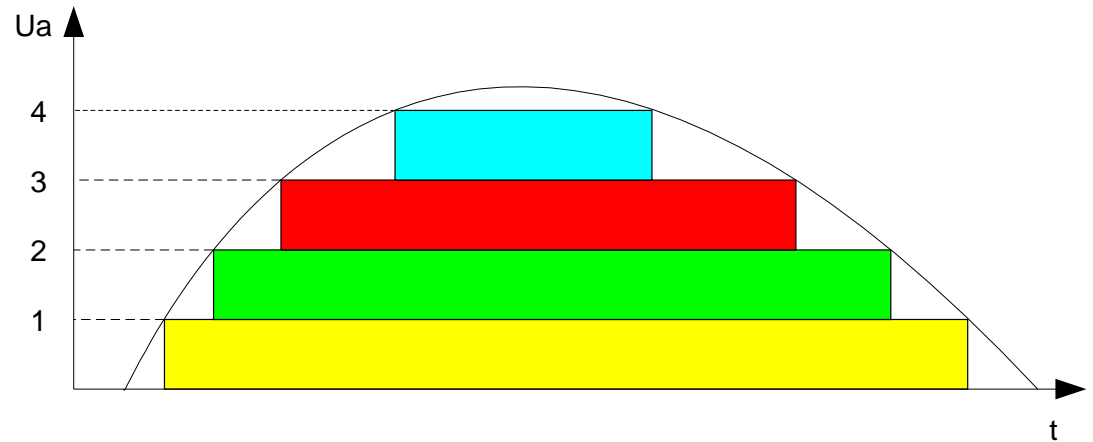
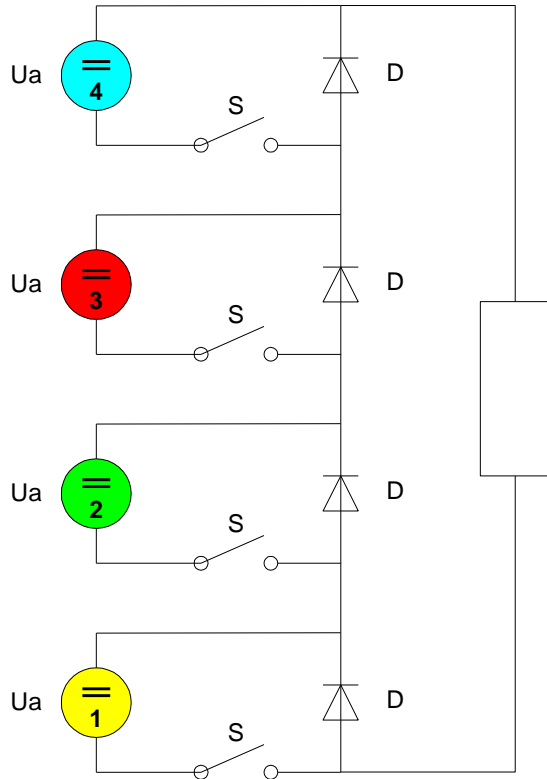
DN

Modulator Specification

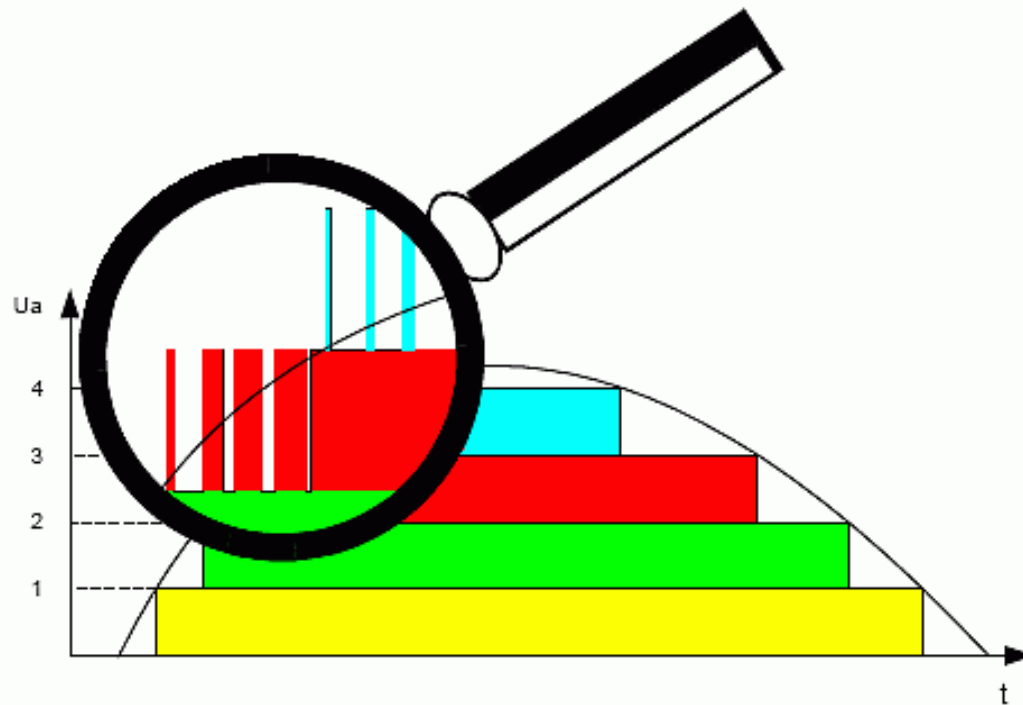
- - > Max. klystron gun voltage: 120 kV
- - > Max. klystron gun current: 140 A
- - > Primary Voltage: 10 kV
- - > Primary Current: 1680 A
- - > High voltage pulse length: 1.54 ms (design 1.7 ms)
- - > Pulse repetition frequency: 10 Hz
- - > Max. ripple on flat top +/- 0.3 %
- - > Max. pulse power: 16,8 MW
- - > Average power: 300 kW
- - > Number of modulators: 27

Pulse Step Modulator (PSM)

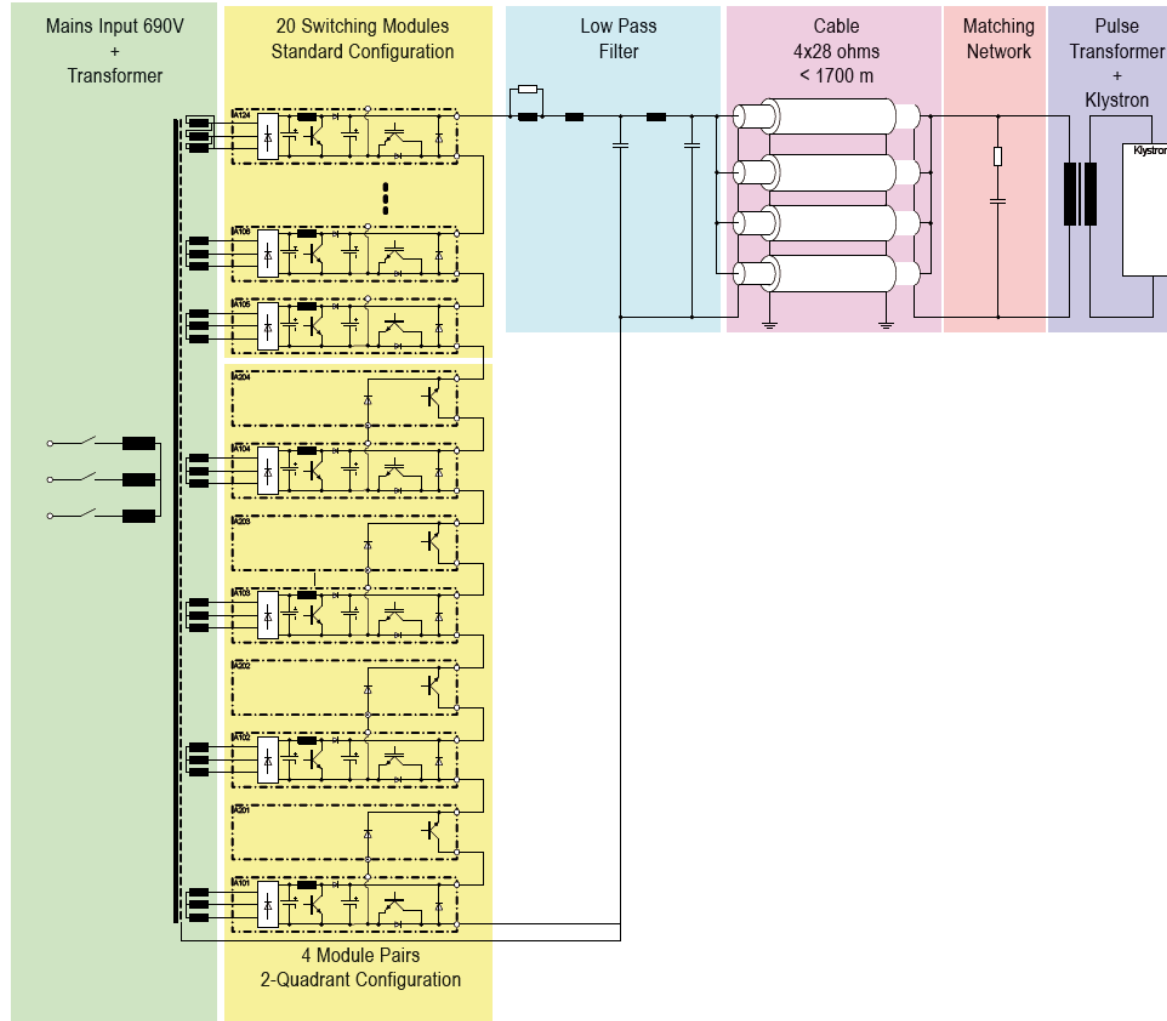
design by Ampegon



PWM in PSM



Ampegon modulator for XFEL





People in Red Ampegon Blue DESY

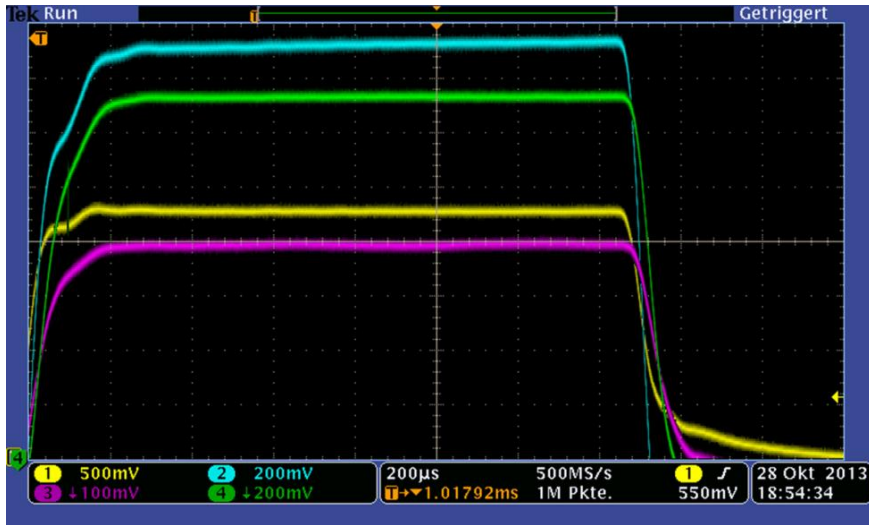


Modulator hall with 29 modulators



Ampegon modulator for XFEL

- Waveforms of modulator
- Flat top 30 Vpp

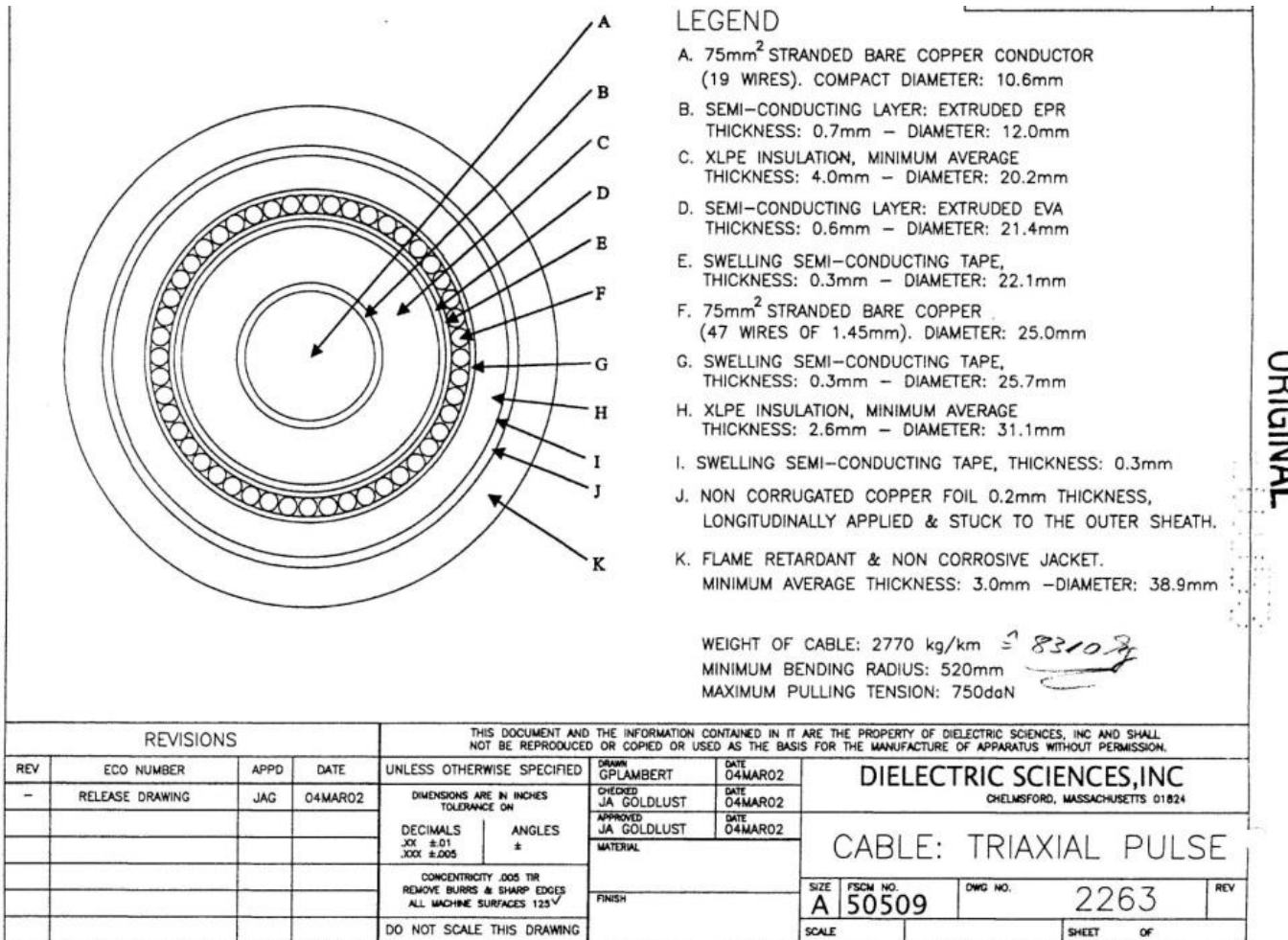


Pulse Cable Requirements

- At the start of the project, the requirements were not defined, but an optimum had to be found. These demands were:
 - > No significant delay of the pulse
 - > Low distortion of the voltage wave form
 - > Low electromagnetic noise
 - > Losses <2%
 - > Good fire resistance due to tunnel installation
 - > Radiation hardness
 - > High reliability <1 failure in 15 years
 - > Use of industry standards for production

Pulse cable

Tri-axial design



ORIGINAL

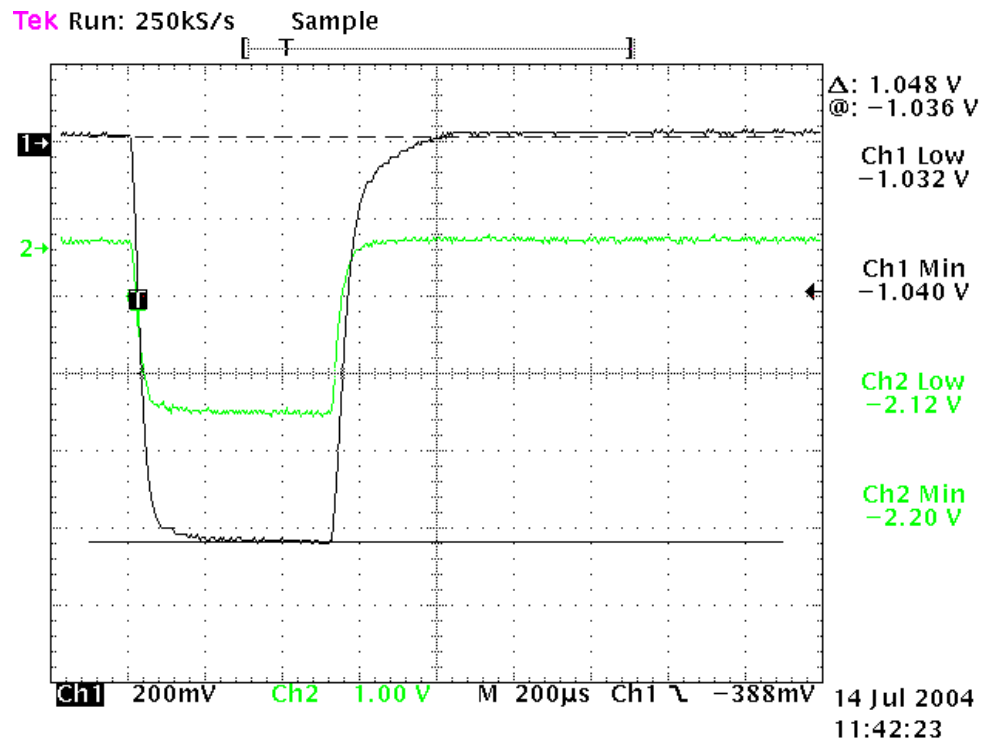
Pulse cable

Tri-axial design



Goal reached 128 kV

14.07.04 11.45



Conclusion in the year 2004:

The pulse cables behave in the way it is foreseen.

The functionality is now proven for XFEL

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A lot of problems occurred with EMI

2007

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Shortly afterwards: ????

Installation of cable in 2012-2013

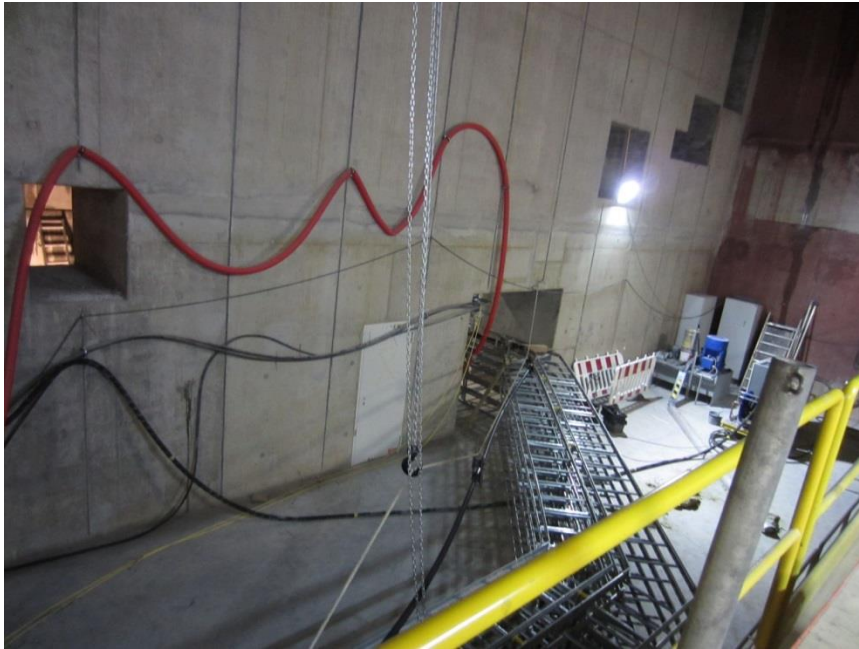
Data of installed cable

- Produced by General Cable near Paris (Fountainbleu)
- Length of 106 km
- Precut for installation
 - Four cable on lengths
 - During installation 15 - 20 m waist per length
- Time of installation 6 months 2012-2013
- Cost of cable app. 3 Mio €

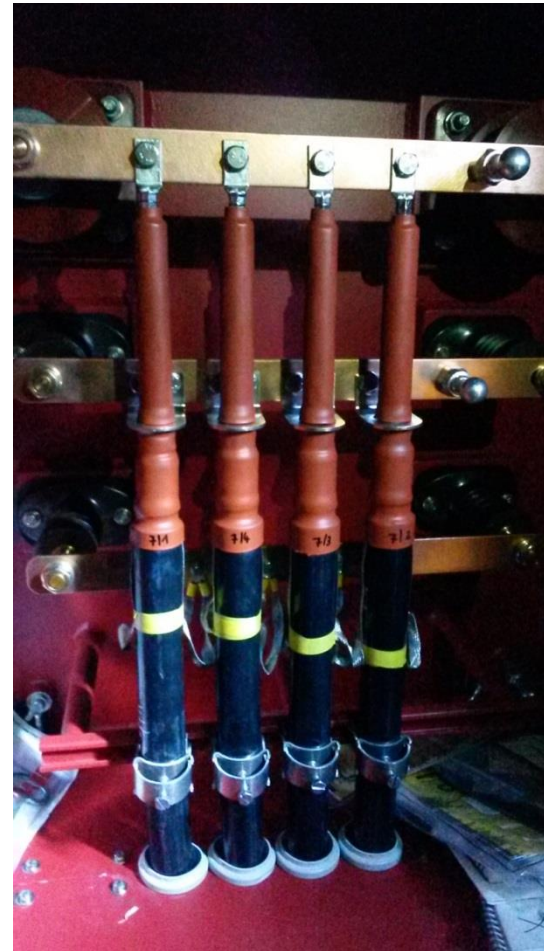
Pulse cable installation



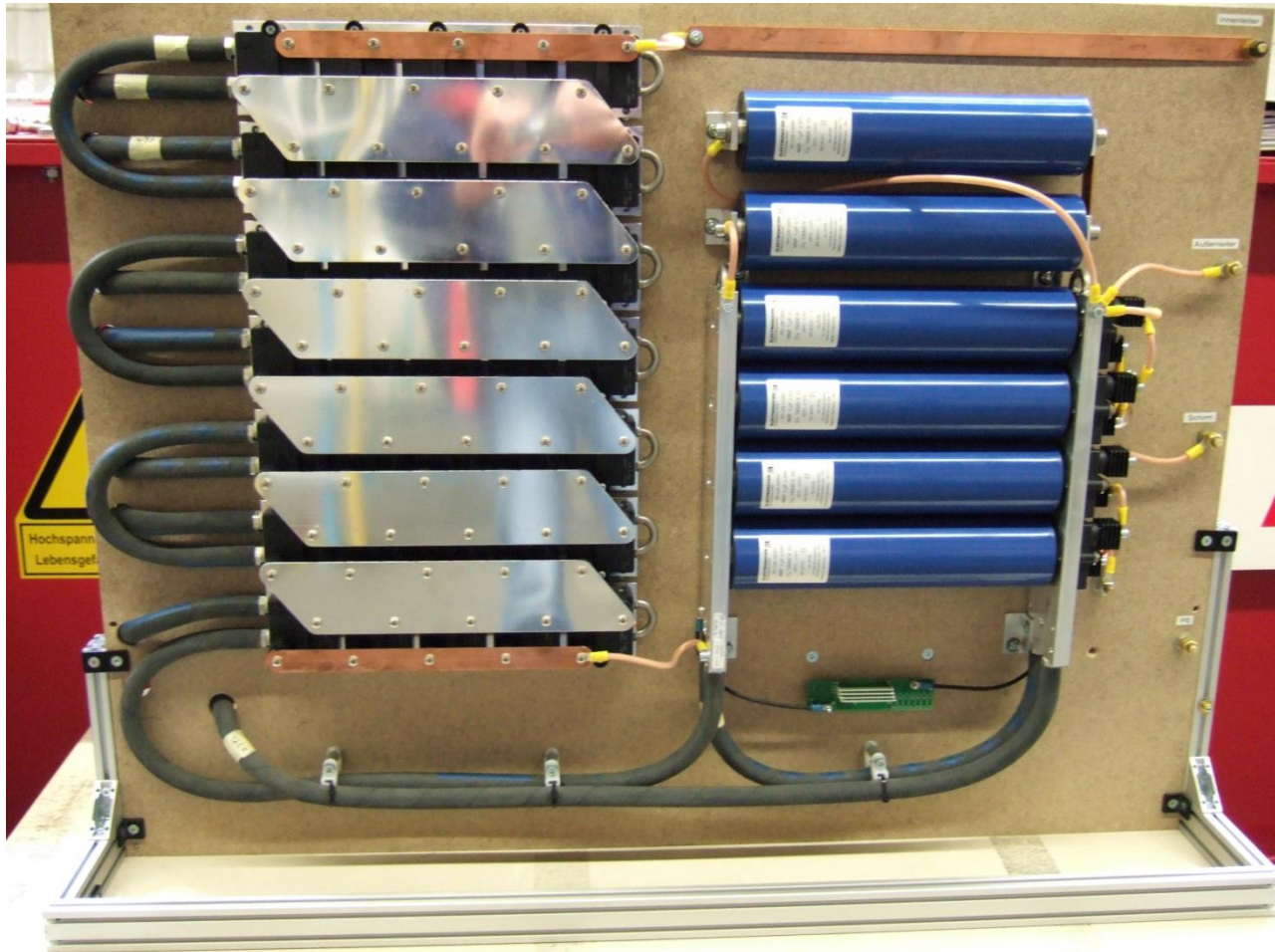
Pulse cable installation



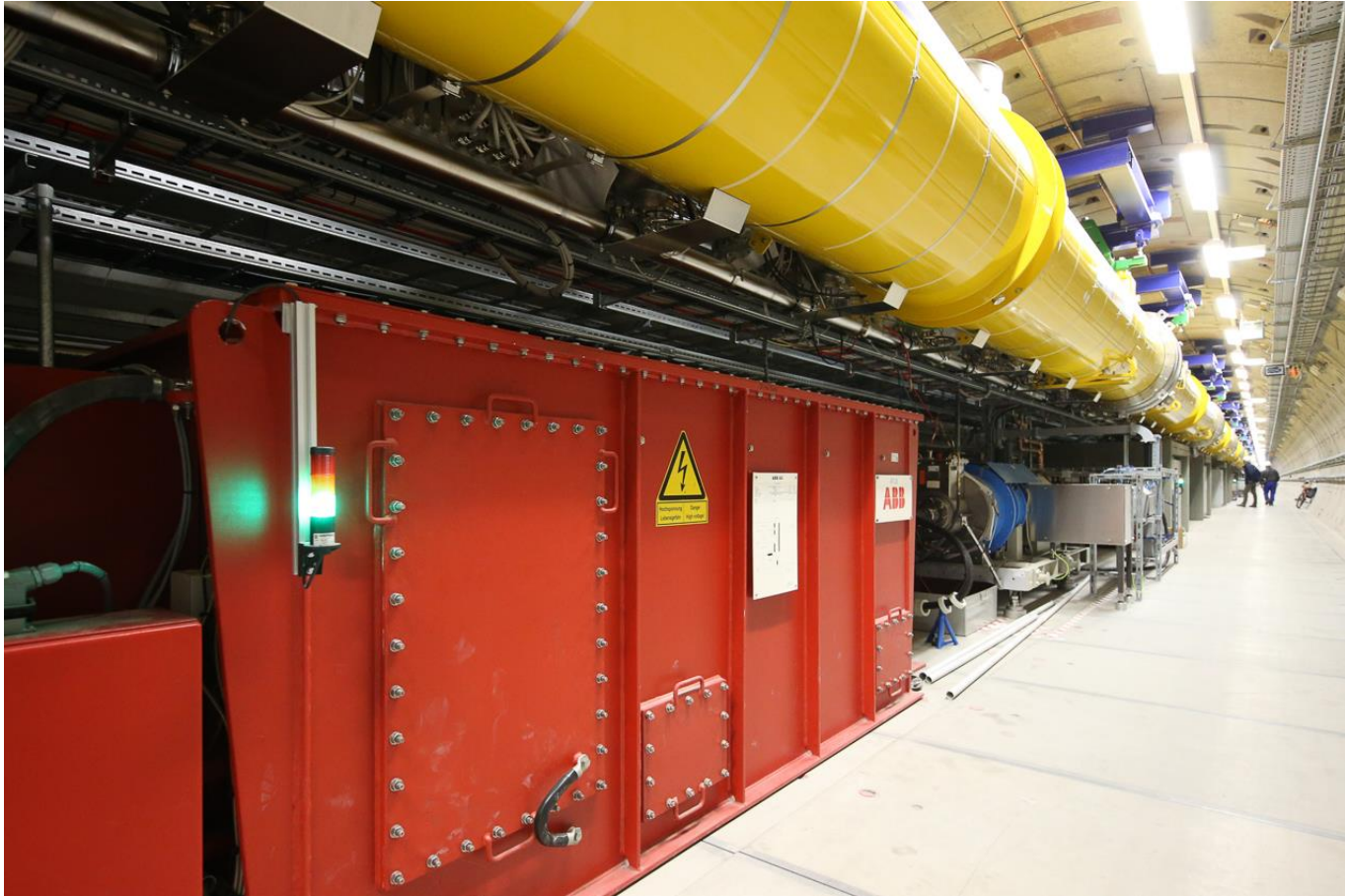
Pulse cable installation



Adaptation Network



Transformer - Klystron

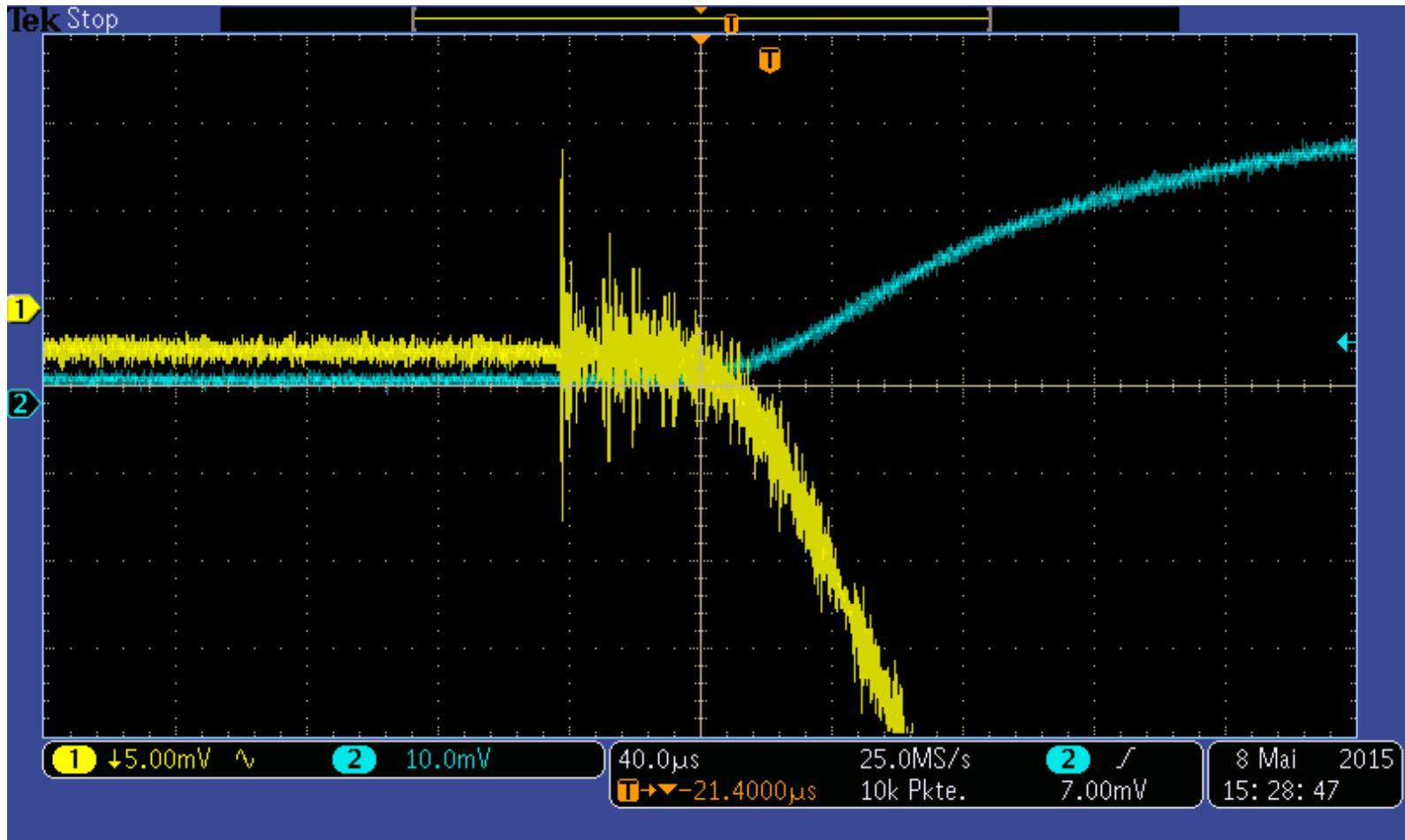


First measurements in reality 2015

Pulstransformer



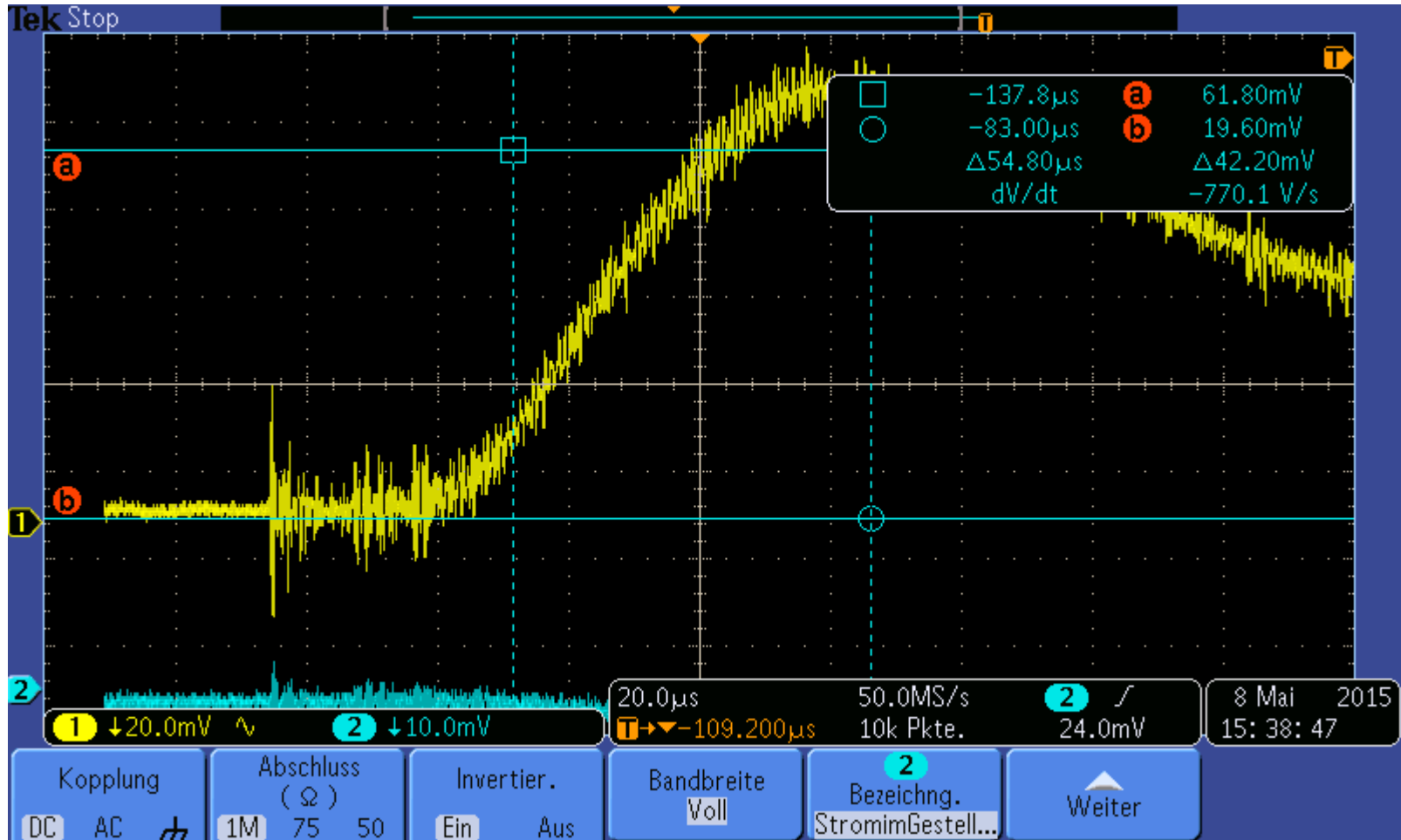
Strom über Feuerlöschgestell



Die Hochfrequenz wird vom Modulator erzeugt

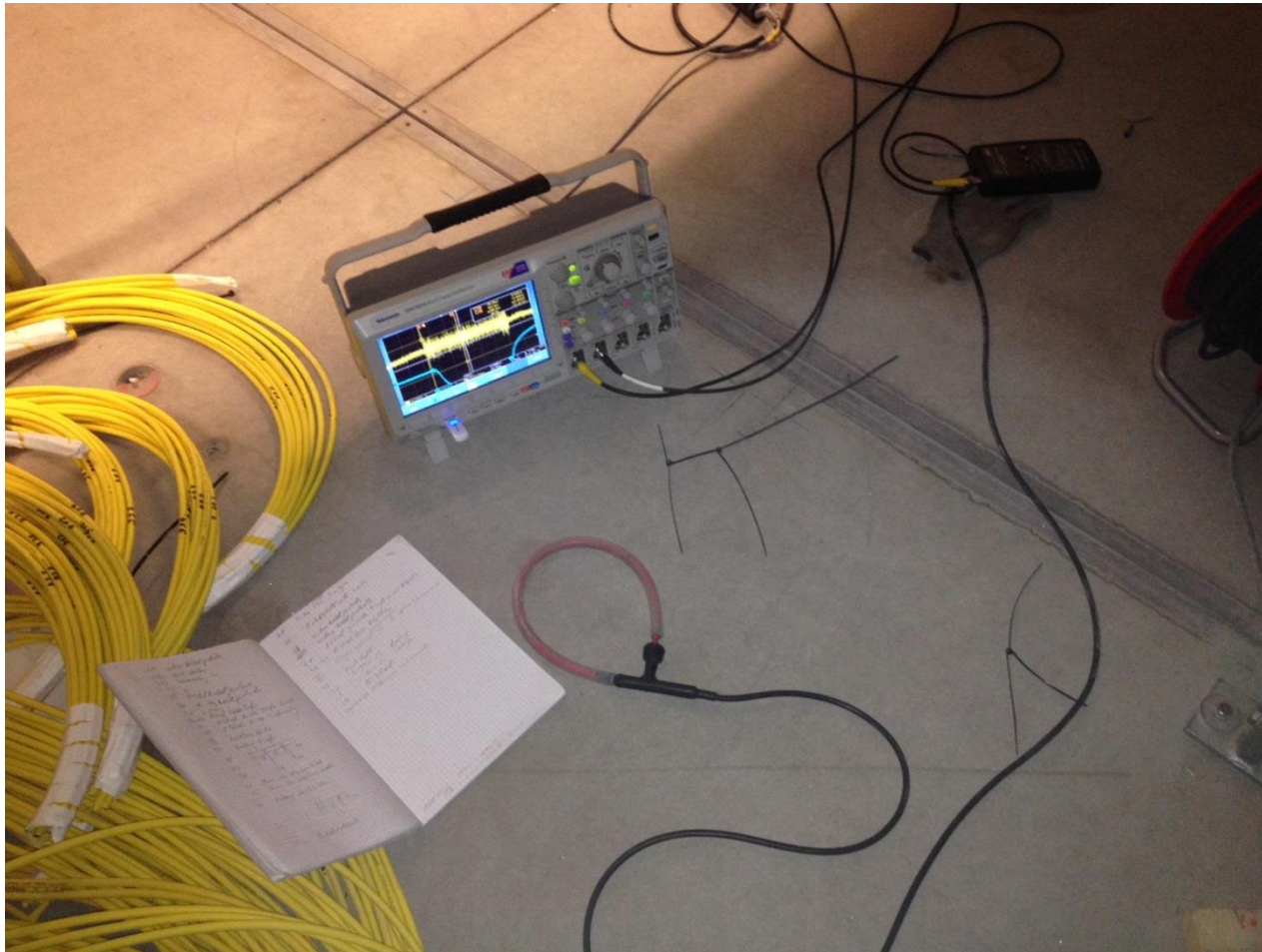
Common mode noise on the pulse cable

When starting commissioning at XFEL



Yellow: 20mV=200mA app. 500 mA_{pp}

Measurement of EMI noise



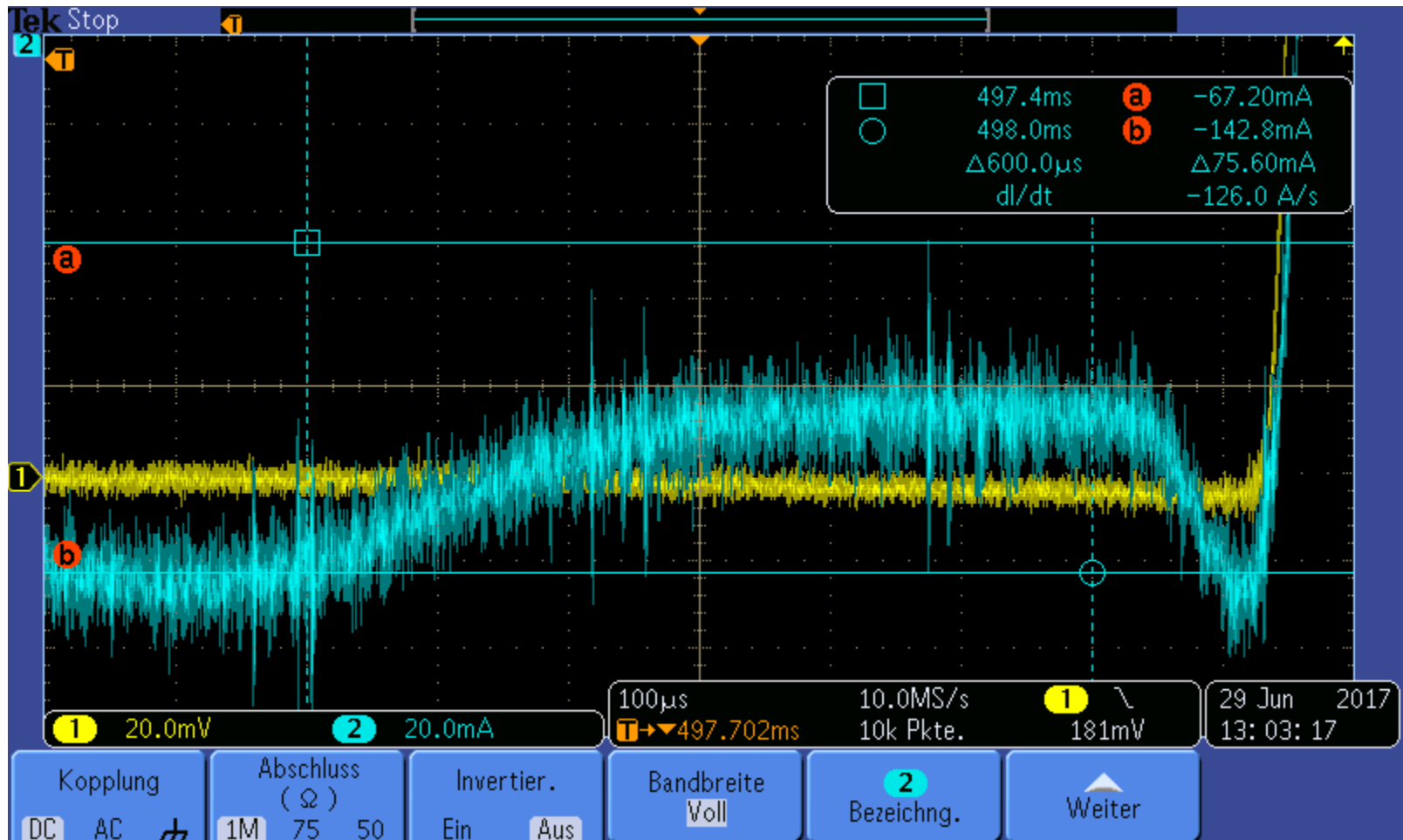
Changes in Modulator to improve EMI behavior



- New routing of cabling
- Exchange the support of the chokes to non-conducting material
- Additional EMI filter in the filter compartment

Common mode noise on the pulse cable

Final solution



Blue: 20mA app. 40 mA_{pp}

2017 It works!!!
~~2007~~

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~~Shortly after this conclusion:~~

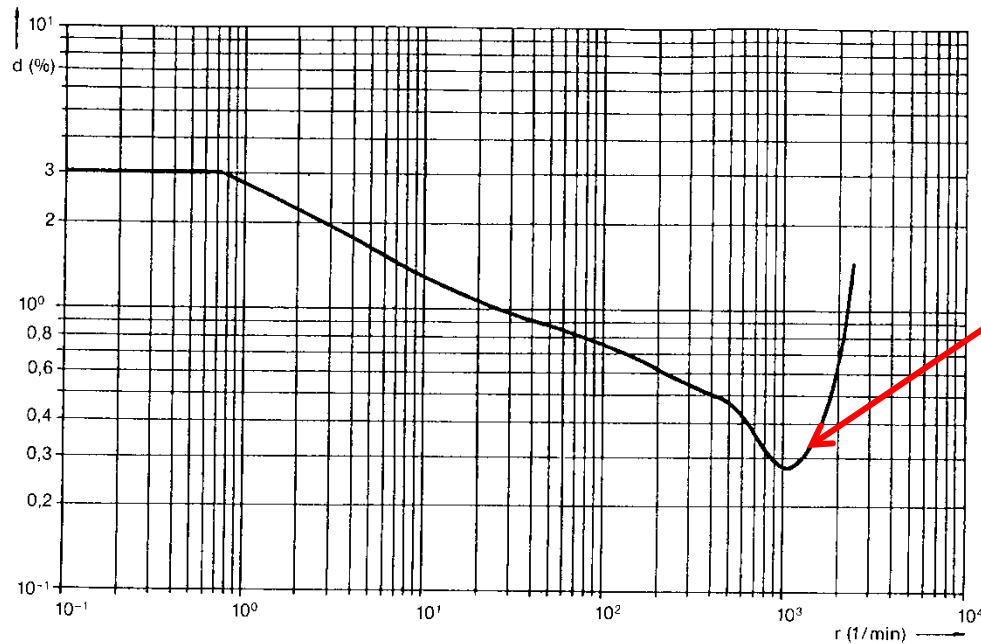
~~A lot of problems occurred with EMI~~

~~Shortly afterwards: ?????~~

**Thank you for your
attention**

Questions?

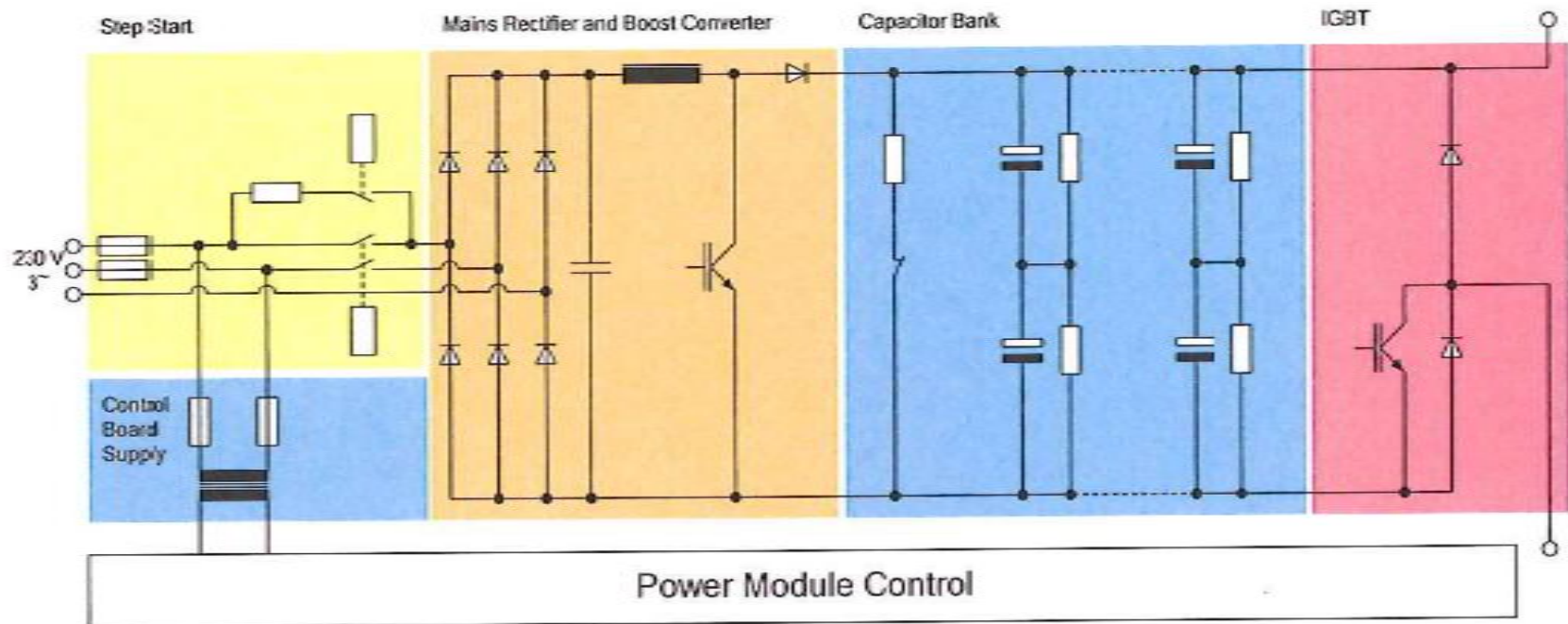
Allowed disturbances to the grid according to IEC 38/VDE 0838



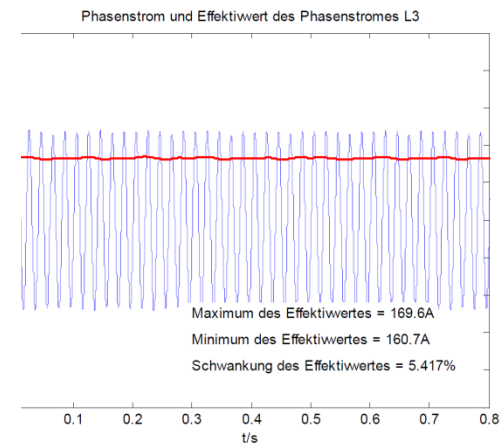
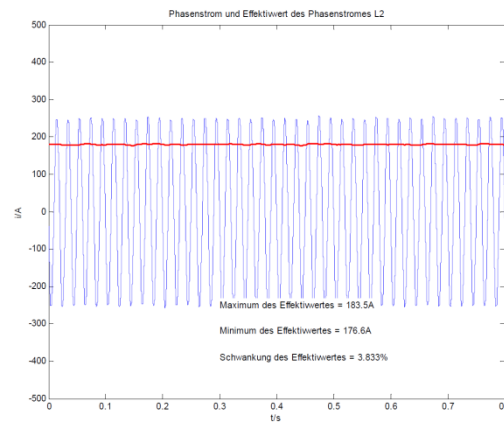
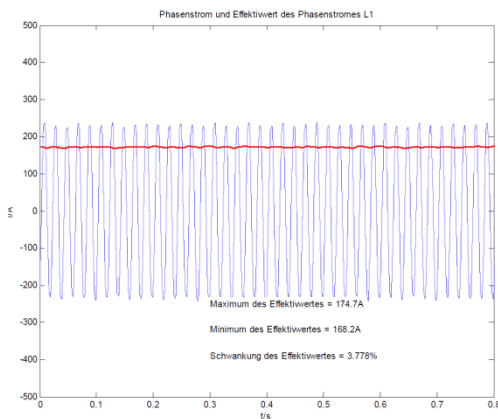
Operation point of
XFEL 10 Hz
 $d \approx 0.28 \%$

Bild 5-2: Verträglichkeitspegel für regelmäßige rechteckförmige Spannungsänderungen

Thomson Power Module

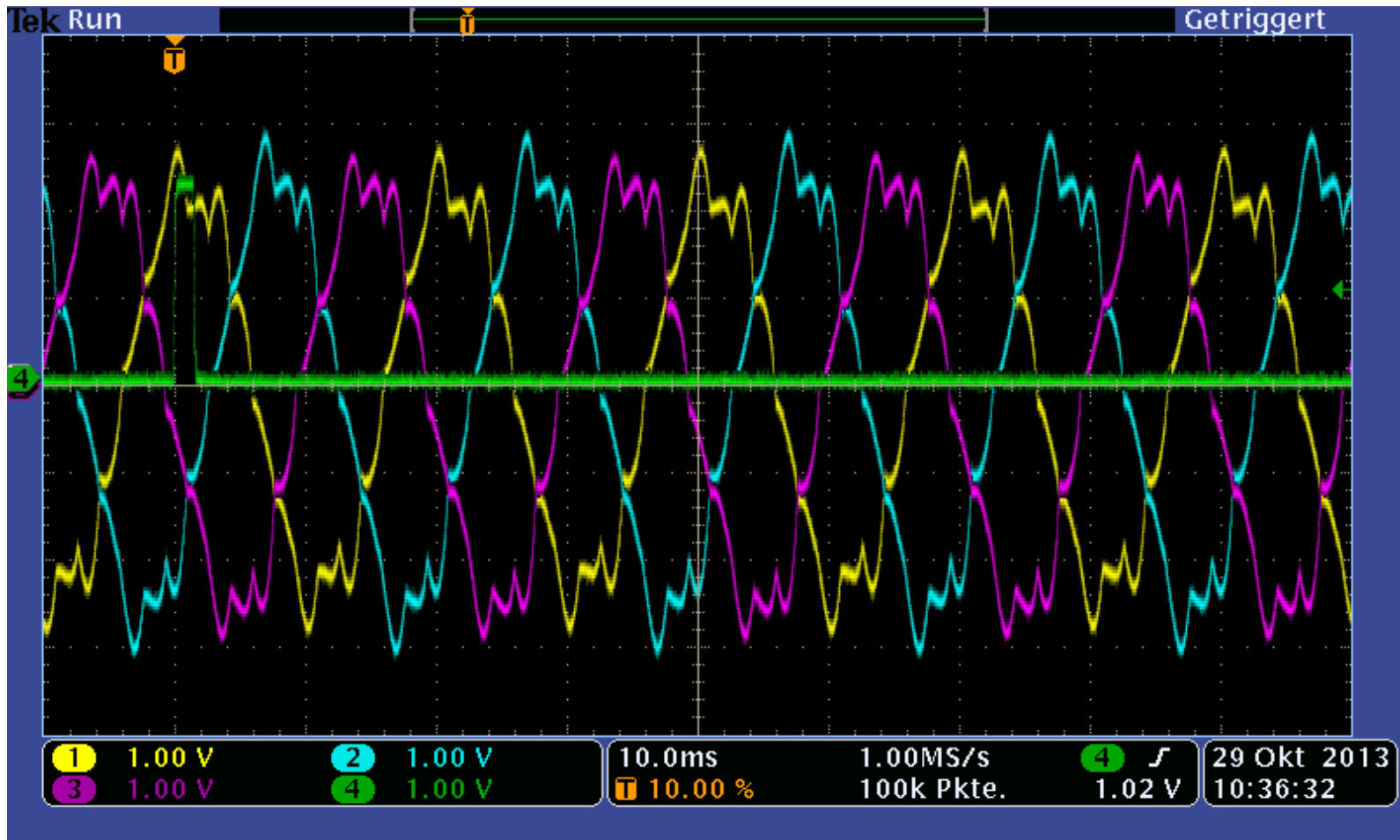


Variation of the mains current Thomson modulator

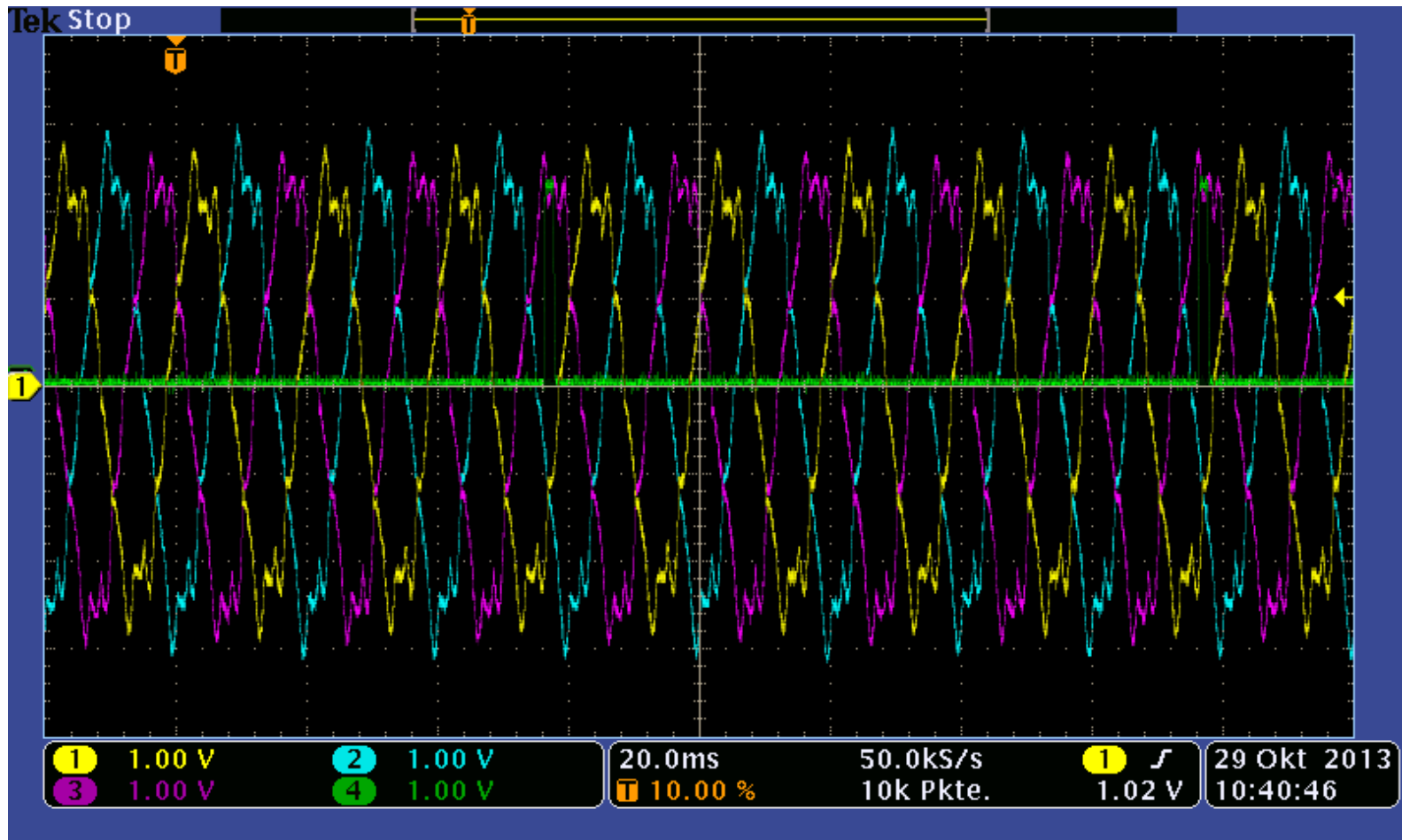


The 10 Hz is suppressed. Assuming the max deviation in L3 as symmetric
This leads to $S = \sqrt{3} * 690 V * 9A = 10.7 \text{ kVA}$ (worst case)

No distortions to the grid



No distortions to the grid



Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

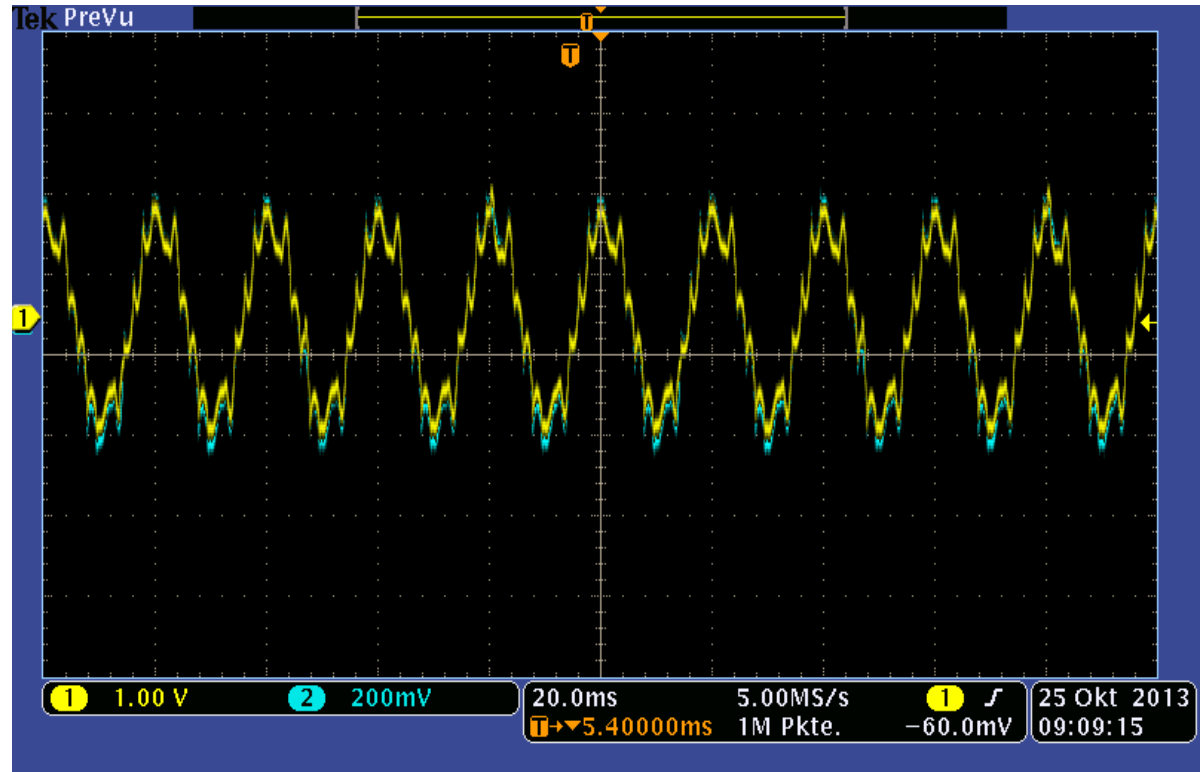
Hans-Jörg Eckoldt

MKK6

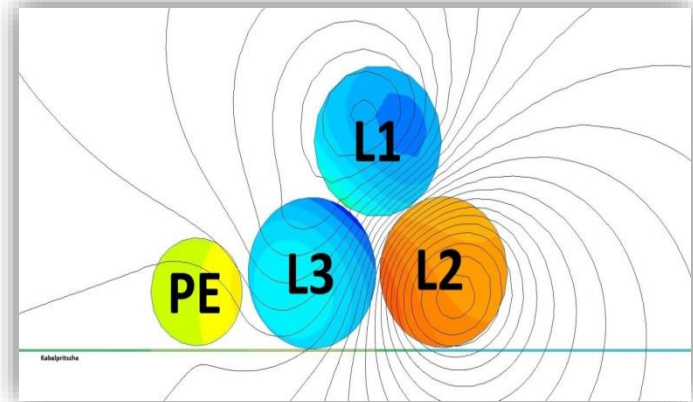
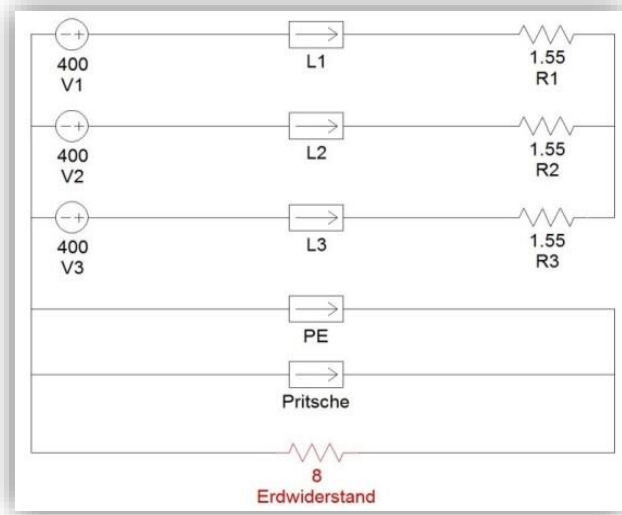
[hans-joerg.eckoldt@](mailto:hans-joerg.eckoldt@desy.de)

Phone: +49 (0)170 634 2366

AC cabling with 3 * 185 mm² cables plus PE

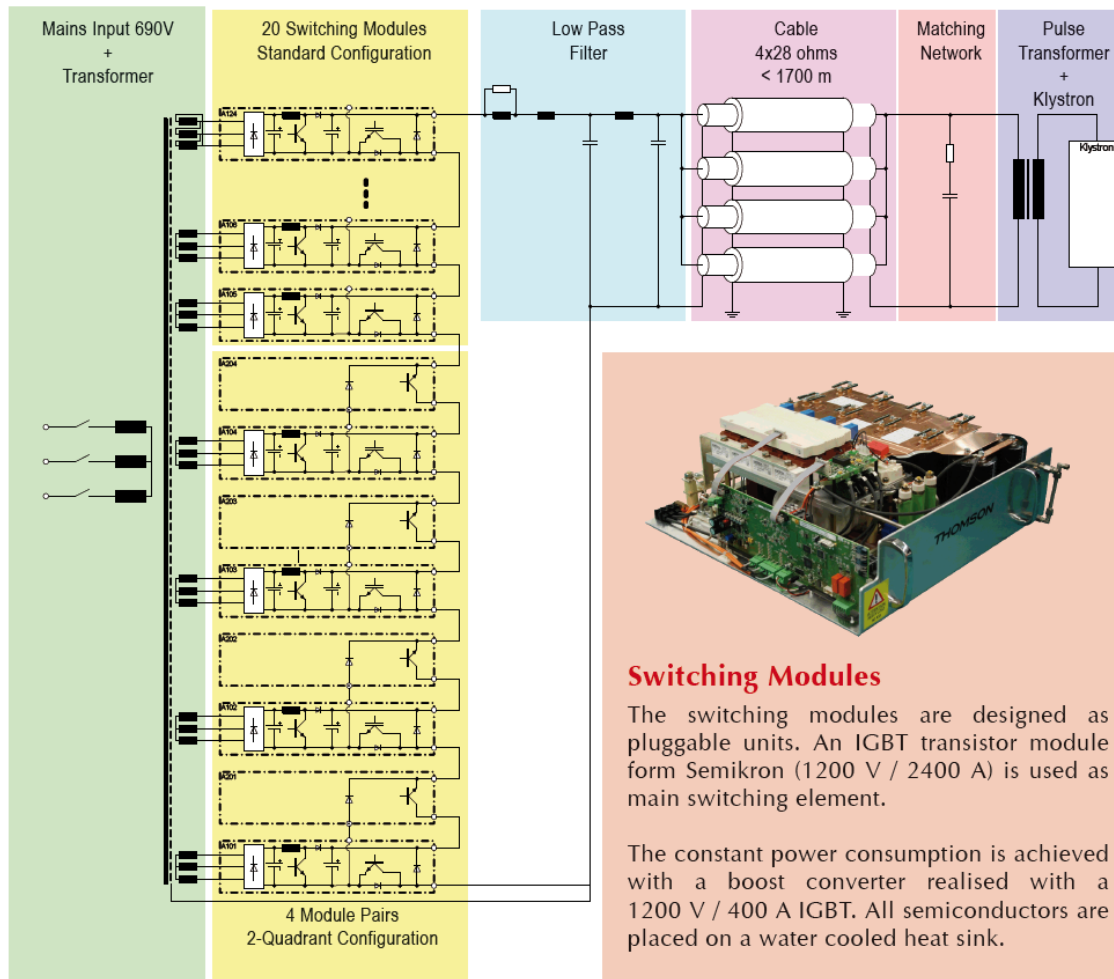


App. 50App/50Hz in PE-conductor



- App. cond





Switching Modules

The switching modules are designed as pluggable units. An IGBT transistor module from Semikron (1200 V / 2400 A) is used as main switching element.

The constant power consumption is achieved with a boost converter realised with a 1200 V / 400 A IGBT. All semiconductors are placed on a water cooled heat sink.