DESY Experiences
Pulse cable, EMI, grounding
constant power

ESS Klystron modulator Workshop Lund
24.04.12

Hans-Jörg Eckoldt

Hans-Jörg Eckoldt

Structure

- General information about the pulse cable
- EMI problems and solutions
- Test with new bouncer modulator
- More EMI problems and solutions
- Thomson modulator
- Constant power power supplies
- Grounding in civil construction

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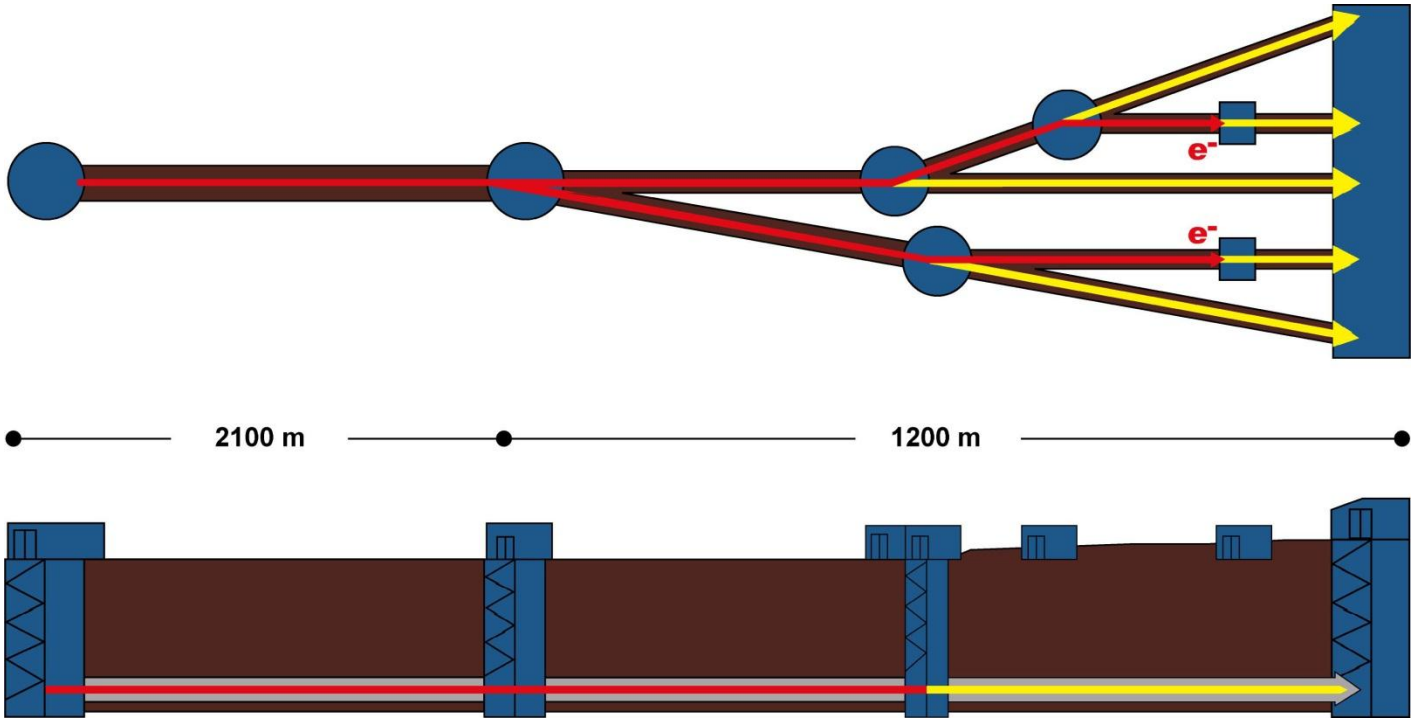
View of the XFEL Tunnel



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Technical data of modulator with MBK

- Technical data of the modulator for TESLA
- max. klystron gun voltage: 120 kV
- max. klystron gun current: 140 A
- Primary Voltage 10 kV
- Primary Current 1680 A
- high voltage pulse length: 1.7 ms for test,
  1,57 ms XFEL operation
- pulse repetition frequency: 10 Hz
- max. pulse power: 16,8 MW
- average power: app. 300 kW
- Number of Modulators in XFEL: 27

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Requirements

- No significant delay for the pulses
- No distortion of the waveform
- No “electro smog” ejected into the tunnel
- Low losses
- Radiation hardness
- Good fire resistance due to the large amount of burning material
- Very high reliability
- Good price

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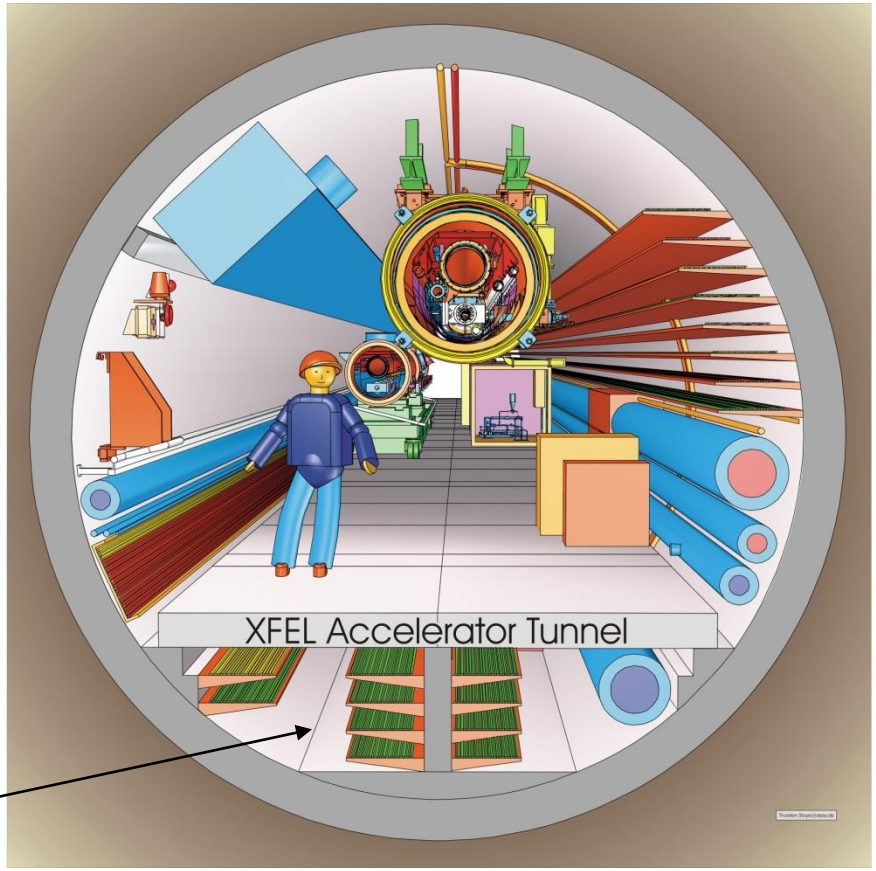
Tunnel Design



Pulse cables

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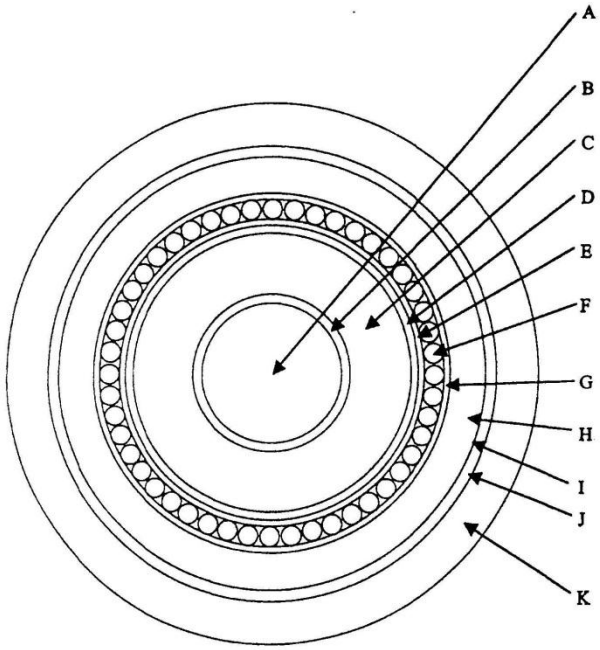
Construction drawing



LEGEND

A. 75mm^2 STRANDED BARE COPPER CONDUCTOR (19 WIRES). COMPACT DIAMETER: 10.6mm

B. SEMI–CONDUCTING LAYER: EXTRUDED EPR THICKNESS: 0.7mm – DIAMETER: 12.0mm

C. XLPE INSULATION, MINIMUM AVERAGE THICKNESS: 4.0mm – DIAMETER: 20.2mm

D. SEMI–CONDUCTING LAYER: EXTRUDED EVA THICKNESS: 0.6mm – DIAMETER: 21.4mm

E. SWELLING SEMI–CONDUCTING TAPE, THICKNESS: 0.3mm – DIAMETER: 22.1mm

F. 75mm^2 STRANDED BARE COPPER (47 WIRES OF 1.45mm). DIAMETER: 25.0mm

G. SWELLING SEMI–CONDUCTING TAPE, THICKNESS: 0.3mm – DIAMETER: 25.7mm

H. XLPE INSULATION, MINIMUM AVERAGE THICKNESS: 2.6mm – DIAMETER: 31.1mm

I. SWELLING SEMI–CONDUCTING TAPE, THICKNESS: 0.3mm

J. NON CORRUGATED COPPER FOIL 0.2mm THICKNESS, LONGITUDINALLY APPLIED & STUCK TO THE OUTER SHEATH.

K. FLAME RETARDANT & NON CORROSIVE JACKET. MINIMUM AVERAGE THICKNESS: 3.0mm –DIAMETER: 38.9mm

WEIGHT OF CABLE: 2770 kg/km ≈ 8310 lb

MINIMUM BENDING RADIUS: 520mm

MAXIMUM PULLING TENSION: 750daN

ORIGINAL

REVISIONS			
REV	ECO NUMBER	APPD	DATE
–	RELEASE DRAWING	JAG	04MAR02

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES
TOLERANCE ON
DECIMALS .XX ±.01 .XXX ±.005
ANGLES ±

CONCENTRICITY .005 TIR
REMOVE BURRS & SHARP EDGES
ALL MACHINE SURFACES 125√

DO NOT SCALE THIS DRAWING

DRAWN	GPLAMBERT	DATE 04MAR02
CHECKED	JA GOLDLUST	DATE 04MAR02
APPROVED	JA GOLDLUST	DATE 04MAR02
MATERIAL		
FINISH		

DIELECTRIC SCIENCES,INC
CHELMSFORD, MASSACHUSETTS 01824

CABLE: TRIAXIAL PULSE

SIZE	FSCM NO.	DWG NO.	REV
A	50509	2263	

SCALE | SHEET OF

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The existing cable

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Transport of the cable drum with 3000 m

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Installed pulse cable

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“tricky” installation

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First tests have been done in 2004

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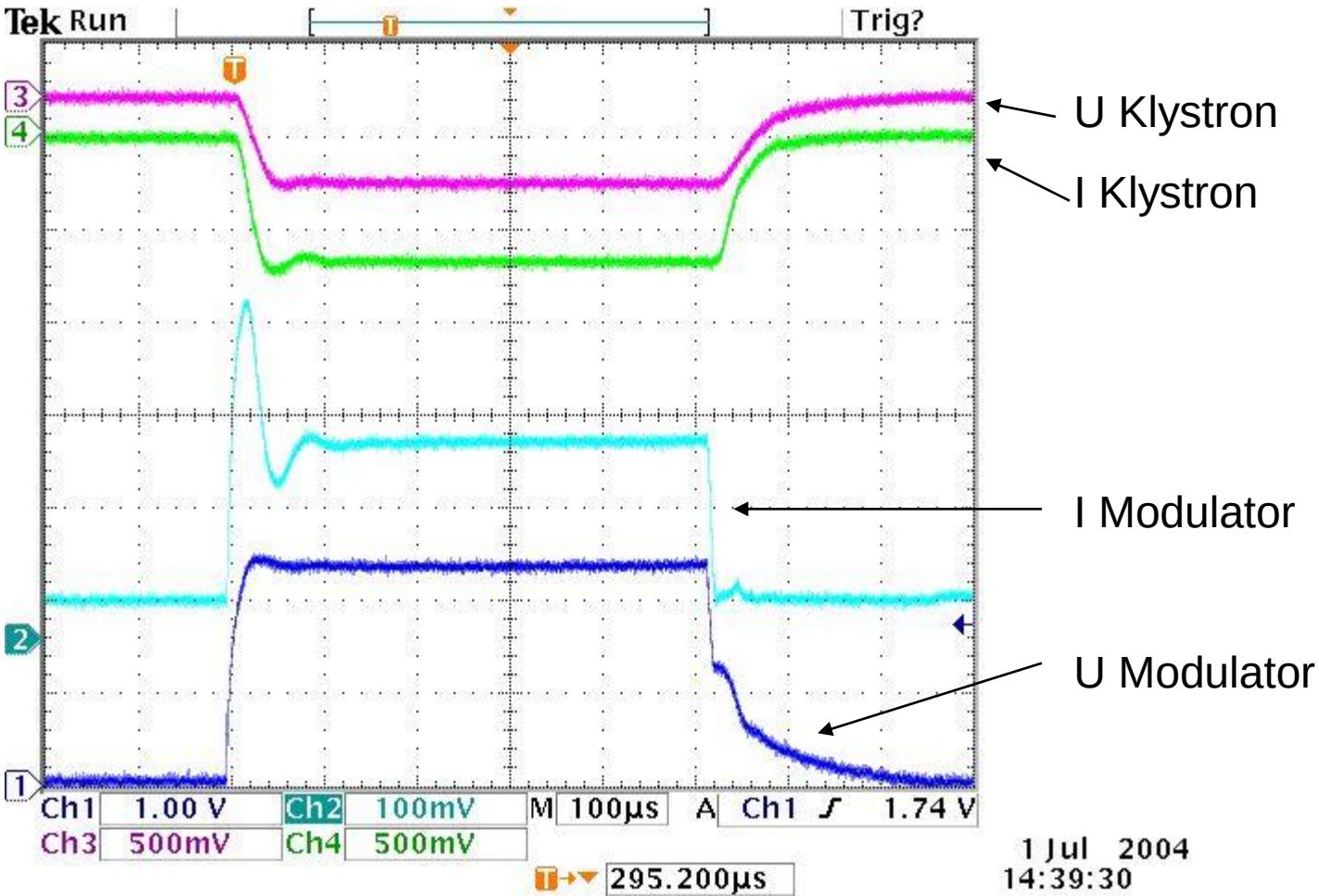
Measurement of voltages/ currents



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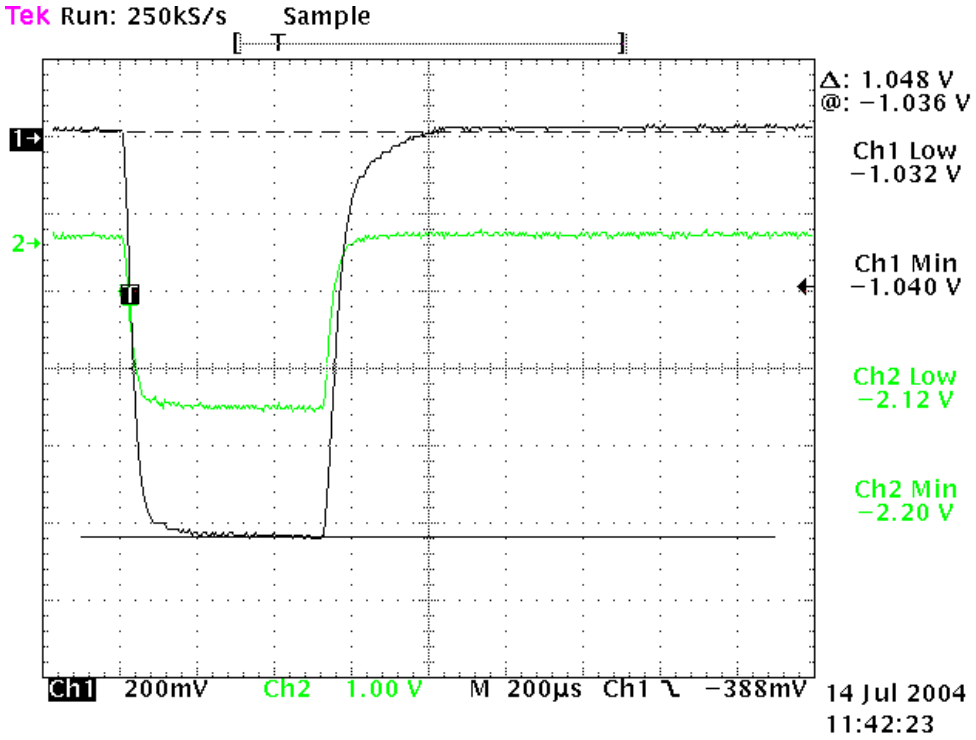
DESY MKK

Goal reached 128 kV
14.07.04 11.45



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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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Conclusion in the year 2004:

The pulse cables behave in the way it is foreseen.
The functionality is now **proven** for XFEL

Shortly after this conclusion:
A lot of problems occurred with EMI

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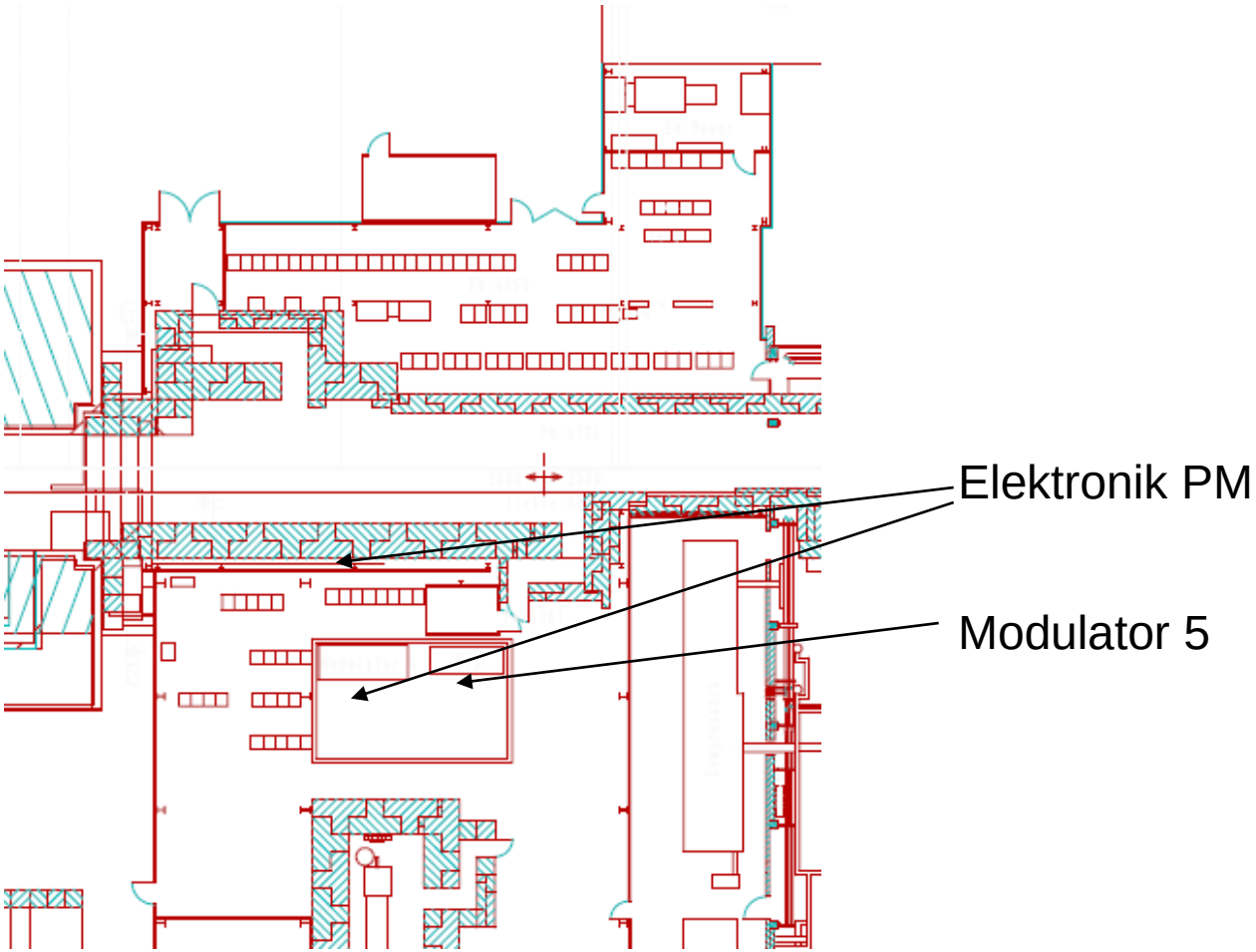
Disturbances due to the cable location of components



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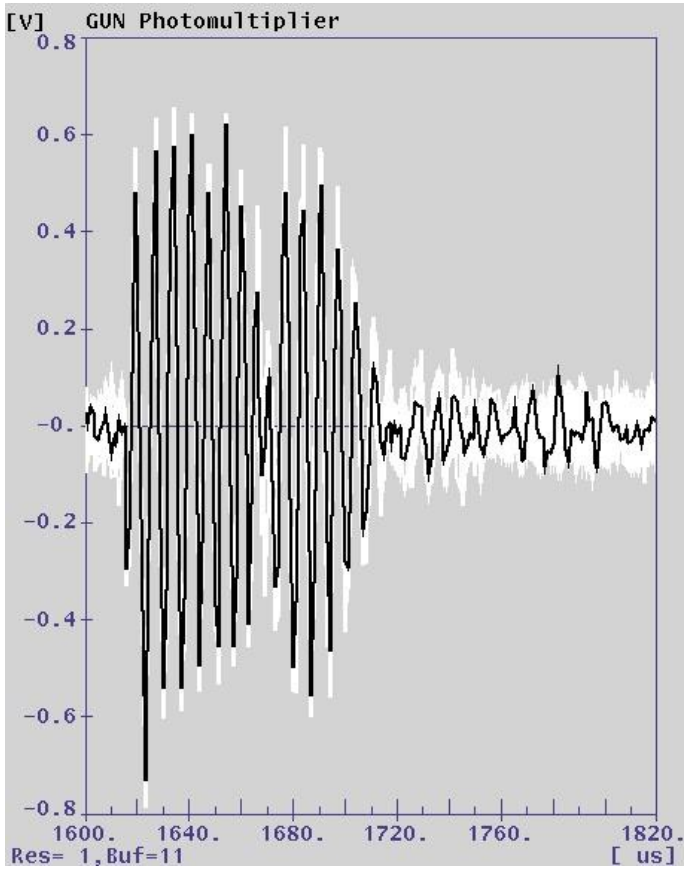
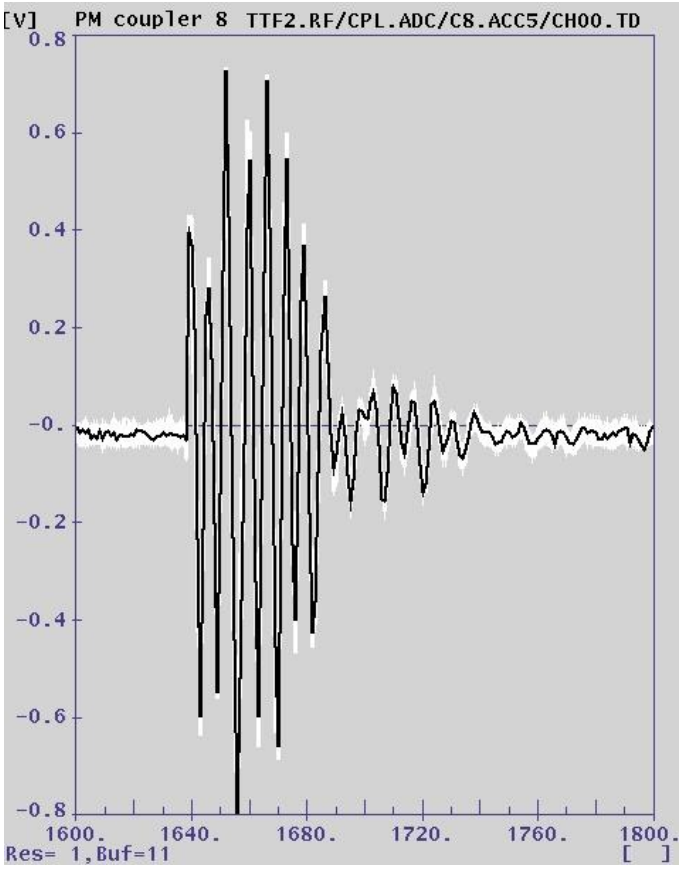
Disturbances due to the cable in the signals of the photomultiplier

(assumingly common mode problems)





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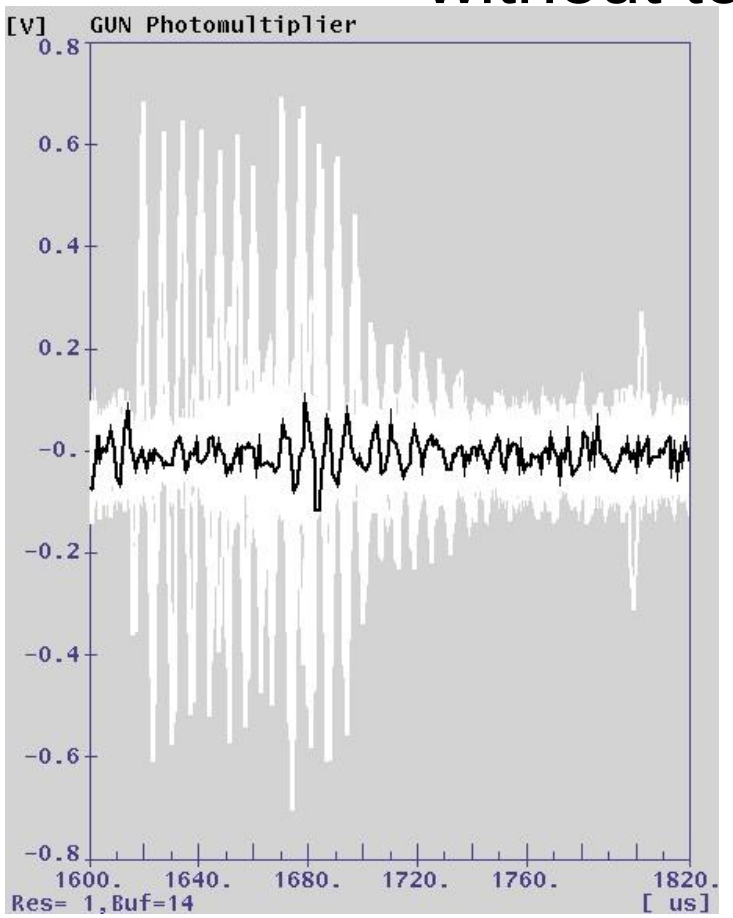
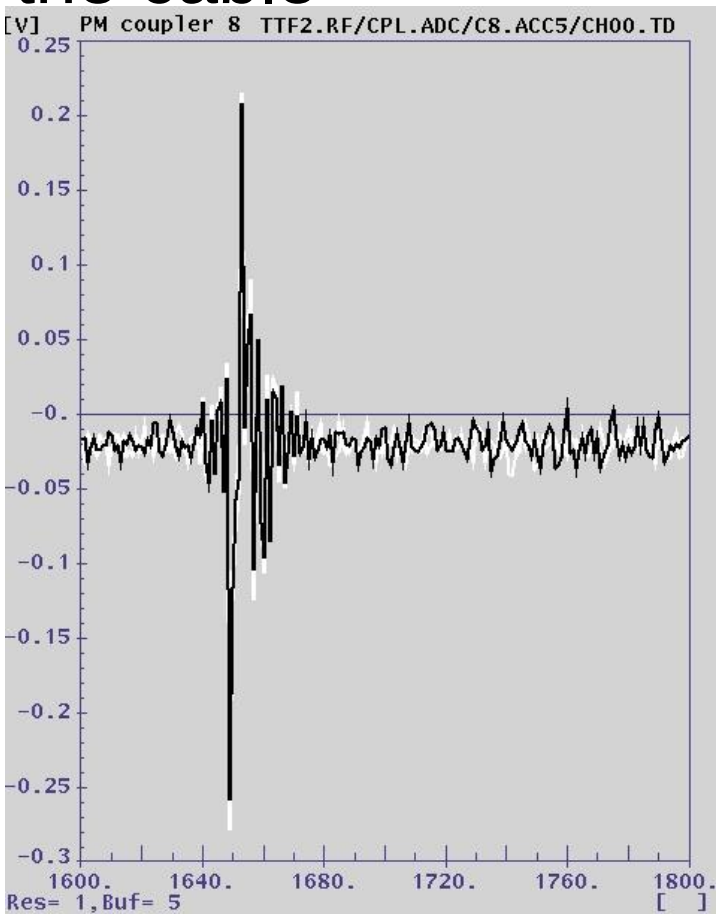
Disturbances in the signals of the photomultiplier without to the cable





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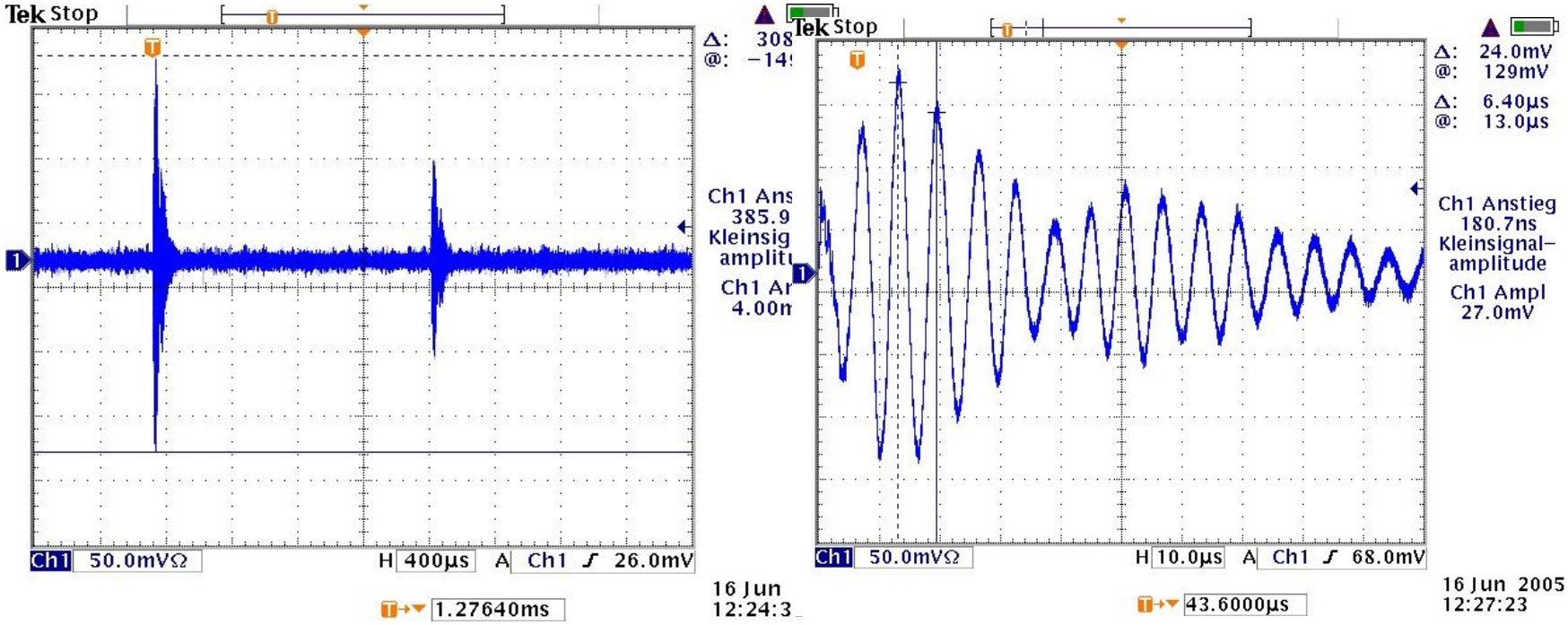
166 kHz-current in the vacuum chamber

(Measurement by L.Schreiter)



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New current probe

- Rogowski-probes have been bought
- Potential free measurement
- Large measuring head that can be opened in order to be connected to larger objects
- Frequency from 0.1 to 20 Mhz
- Current 120 A, 60A

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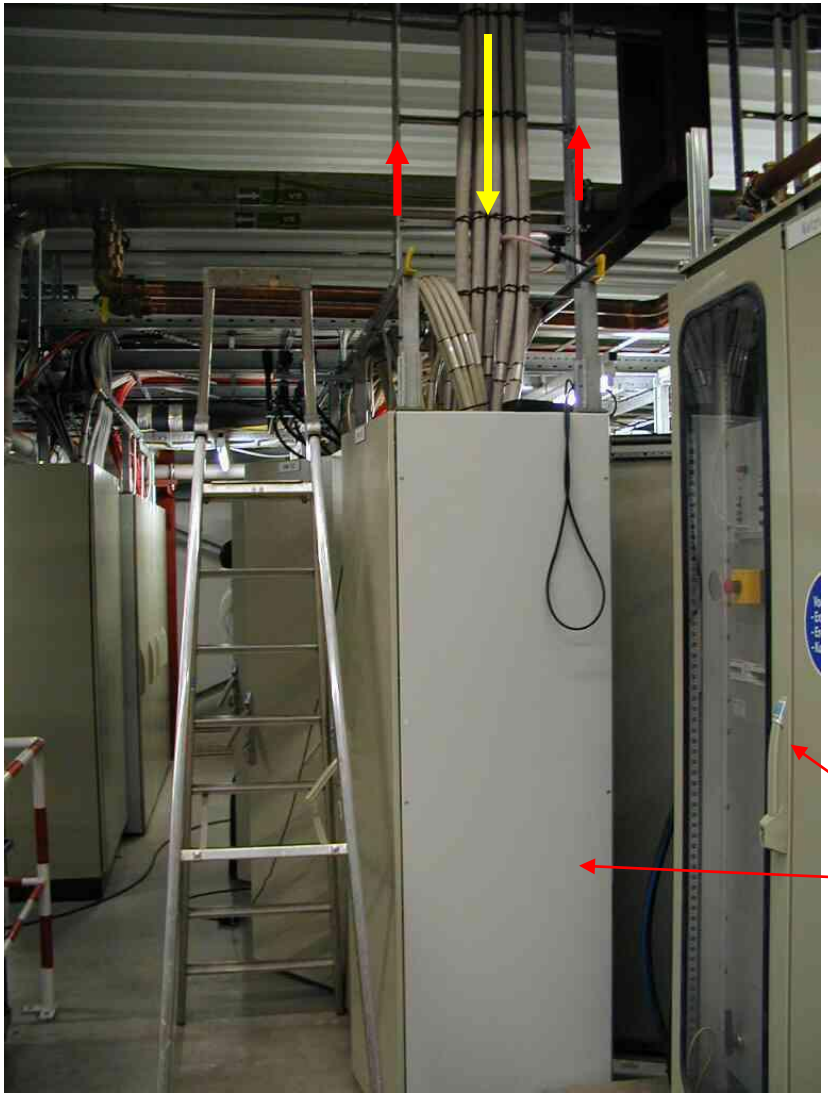

- The 166kHz current flows as indicated.
- Yellow one direction, red return
- There is no current on the grounding of the racks just on the cable trays

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- Current in the racks of the photomultiplier
- Yellow one direction, red return

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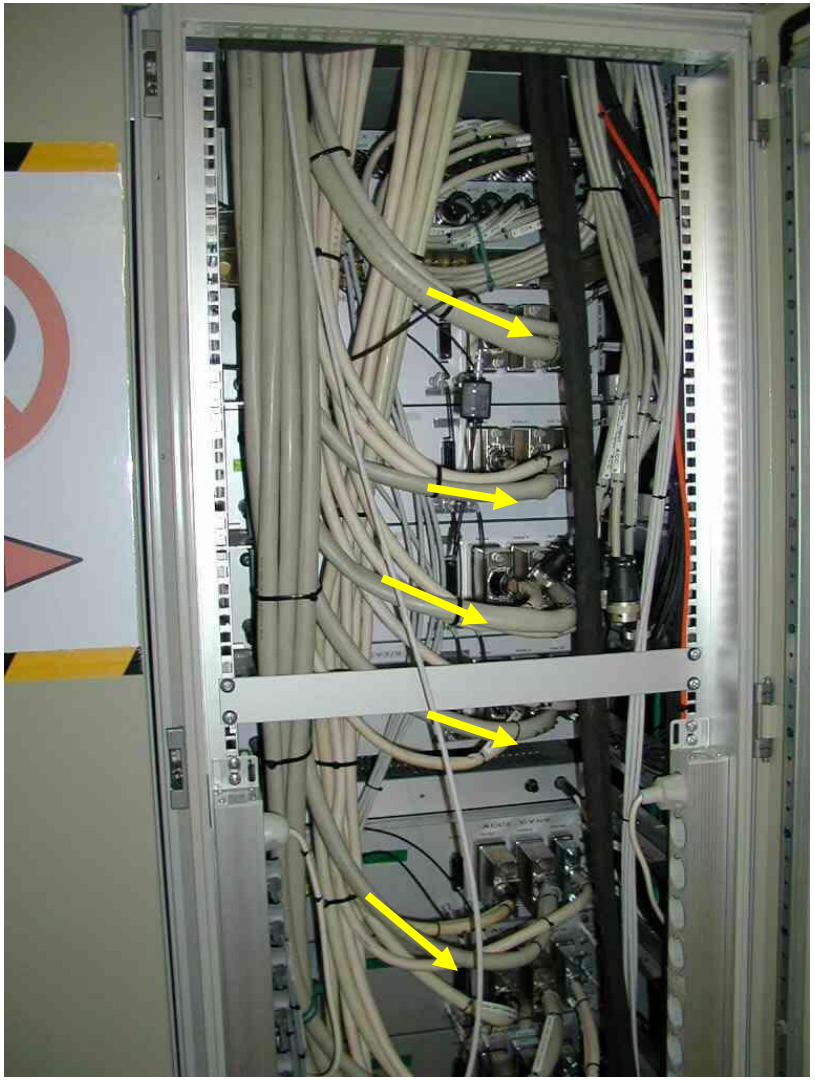

The current can be traced down into the electronics

The return current is carried via the racks and the cable trays

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New test with modulator separated from the transformer

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What has been done and why? First test installation

- In the first test installation the pulse cable was installed between an existing combination of a modulator and a transformer due to the lack of a test modulator.
- This had a few draw backs:
  - The cable was introduced as a 1.5 km long loop between modulator and transformer
  - Due to the short distances between start and end EMI currents could bypass the cable easily

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New construction of the modulator

- The concept of the bouncer was changed
  - The bouncer was put into the HV side
  - The connections of the current leads have been constructed with a sandwich construction of the bus bars. This decreases the stray impedances within the modulator and improves the EMI behaviour
  - The grounding point was put directly at the output of the modulator.
  - The series inductance was put at the output of the modulator. This additionally dumps higher frequencies. It is no longer an air coil but is an iron powder core.

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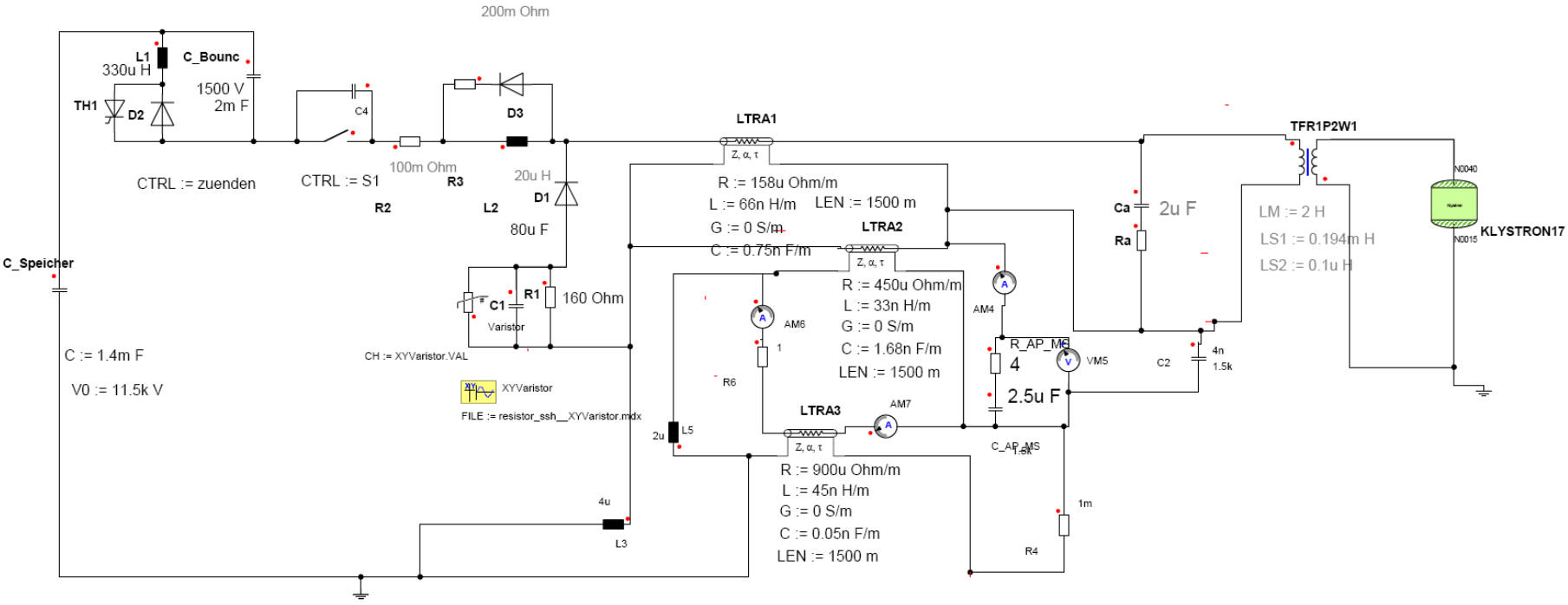
New Modulator



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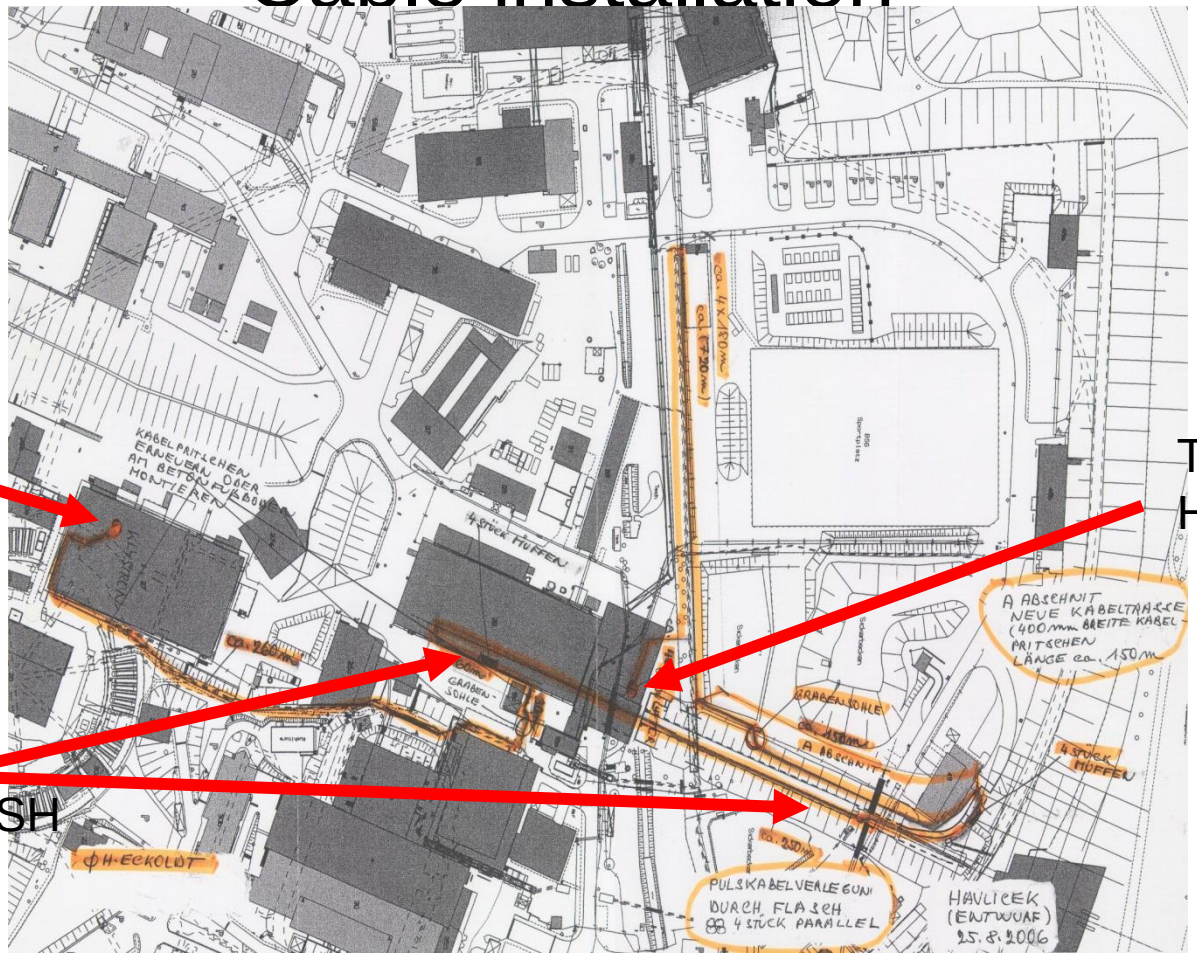
Cable installation



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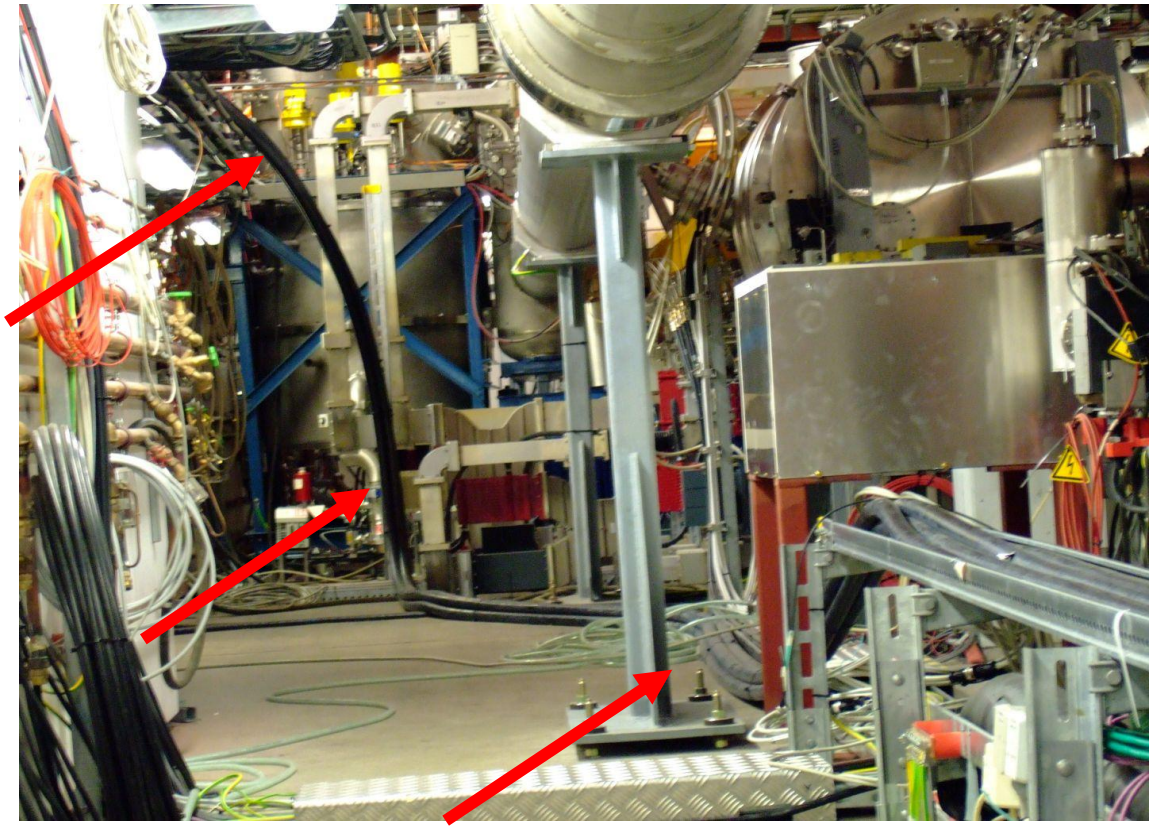
Cable in the Gun-Area



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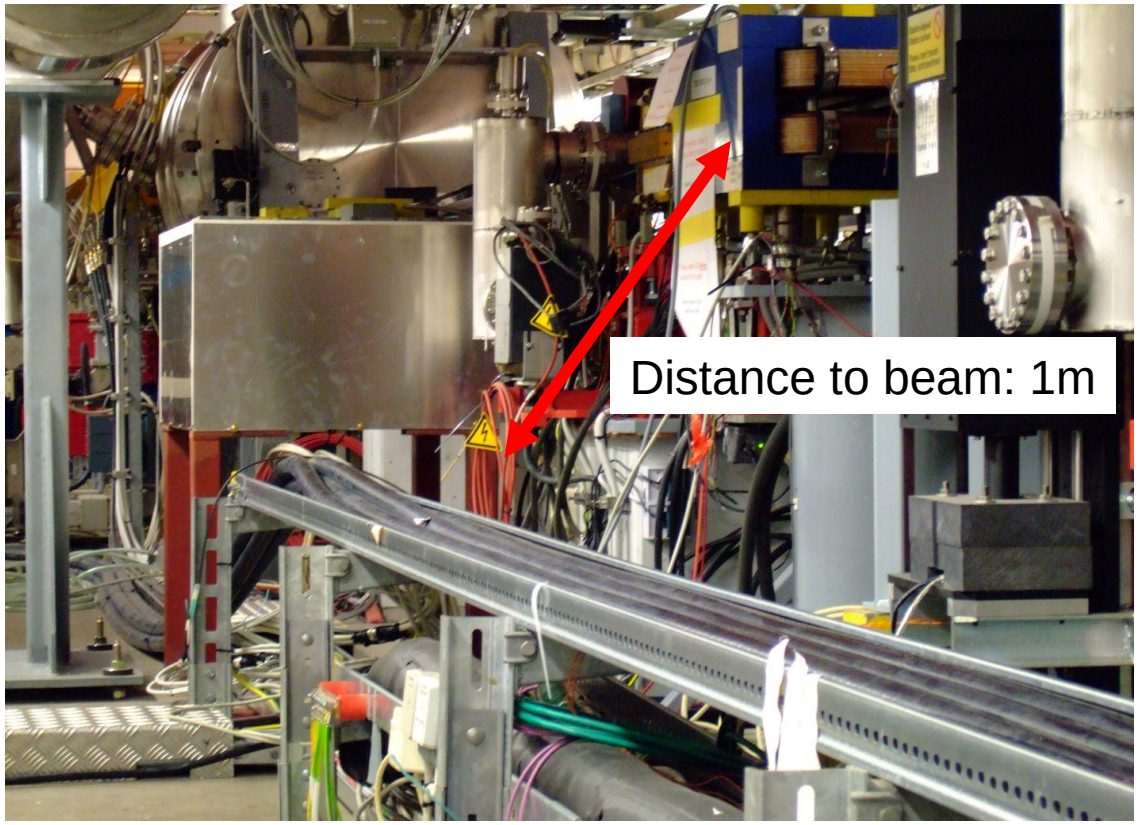
Cable in the Bunch Compressor-Area



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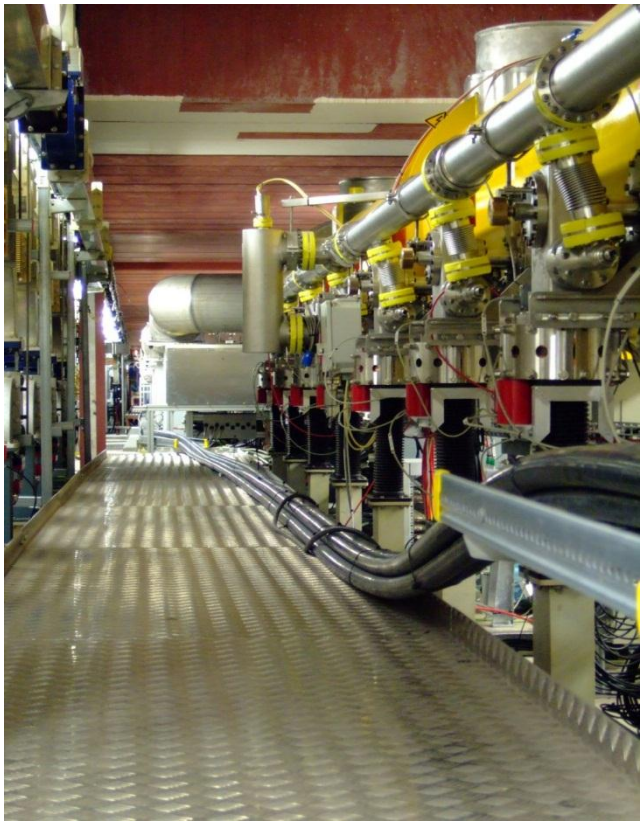
Cables near Kryomodule



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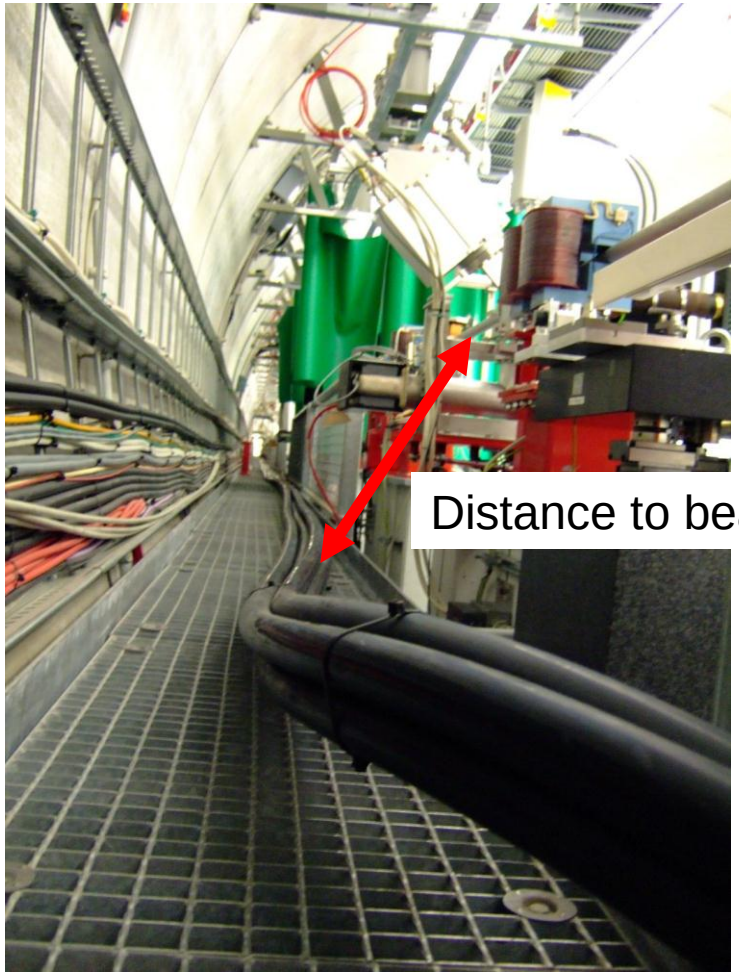
Warm Beamline



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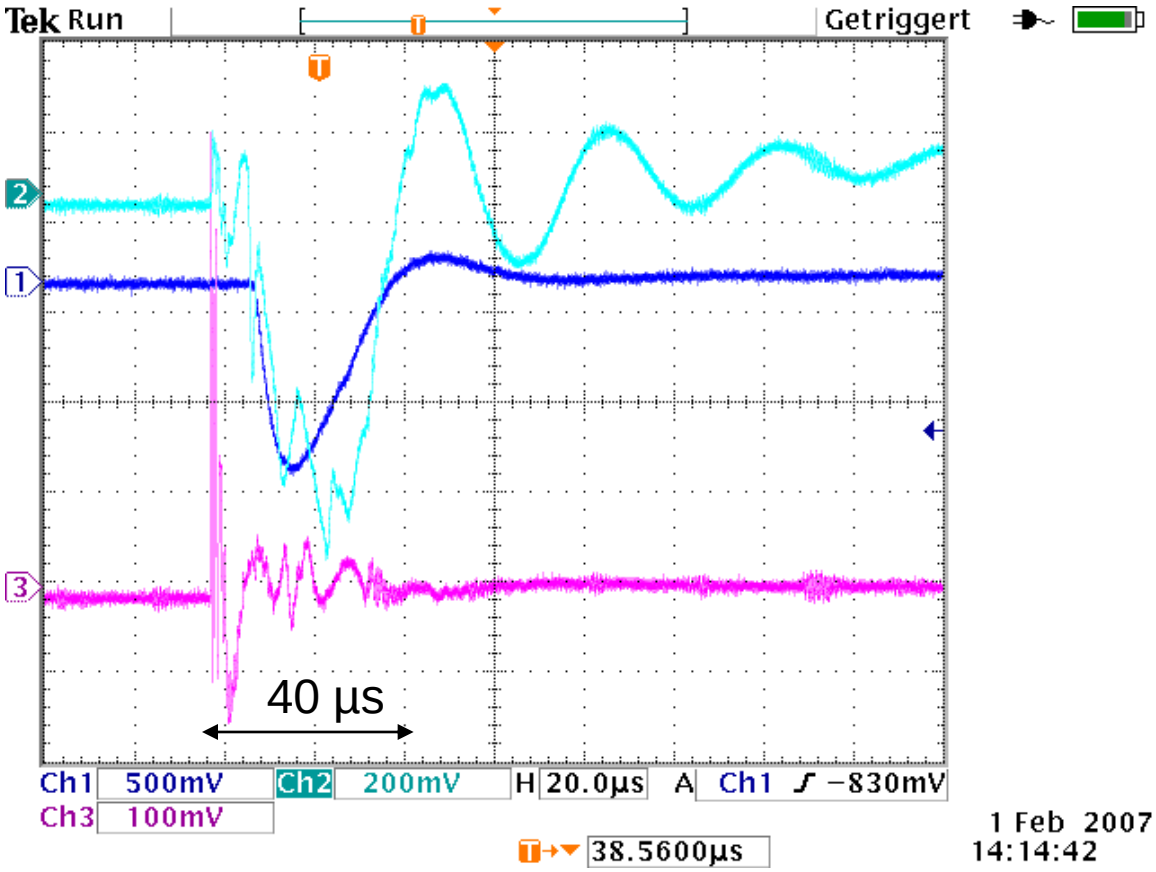
Old PPT-Modulator

- U Modulator = 10,8 kV
- Old PPT-Modulator



Kanal 1: dunkelblau: Hauptstrom in AN-Schrank	500A/V
Kanal 2: hellblau: Strom im schirm (Hinter AN-Schrank)	100mv/A
Kanal 3: lila: Strom über 3 Kabel (Anfang des Kabels)	50mV/A

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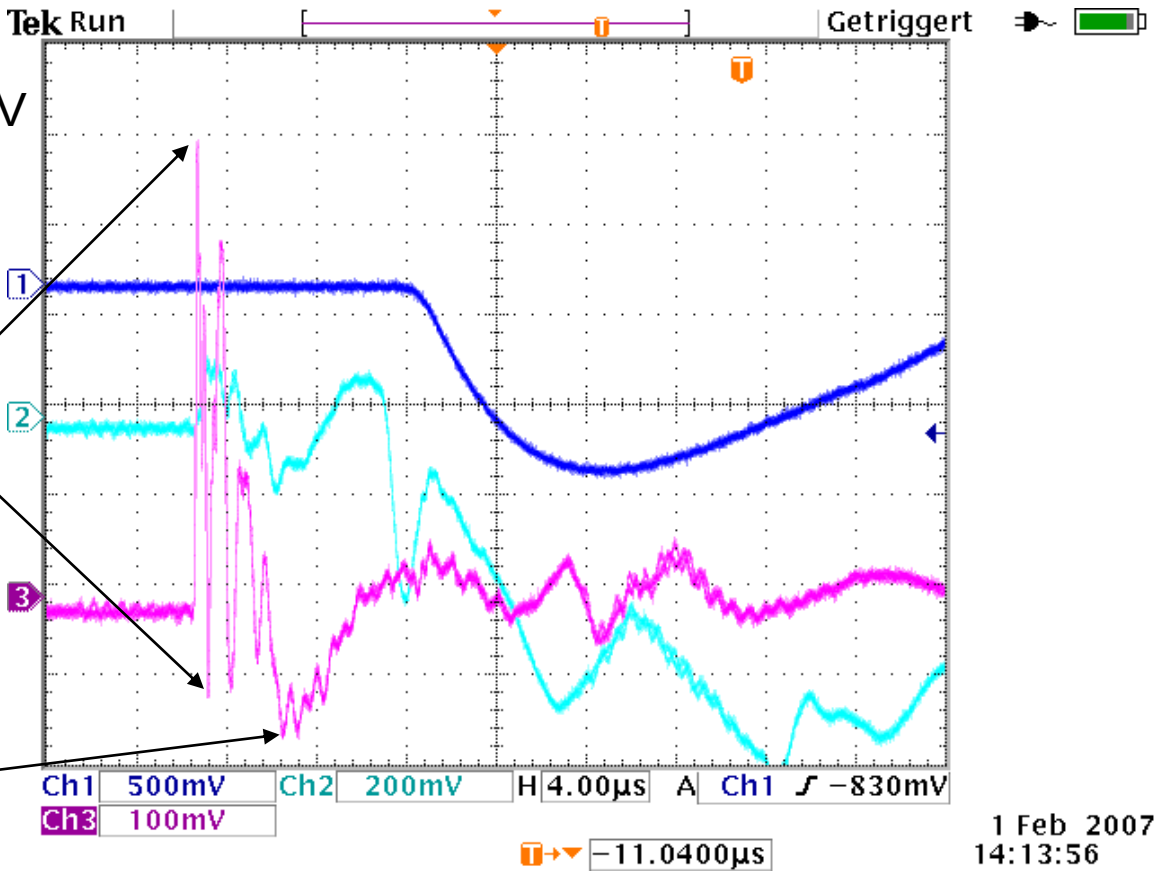
Old PPT-Modulator

- U Modulator = 10,8 kV
- Alter PPT-Modulator

12 A peak-peak

2.8 A



Kanal 1: dunkelblau: Hauptstrom in AN-Schrank	500A/V
Kanal 2: hellblau: Strom im schirm (Hinter AN-Schrank)	100mv/A
Kanal 3: lila: Strom über 3 Kabel (Beginning of the cable)	50mV/A

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New Modulator

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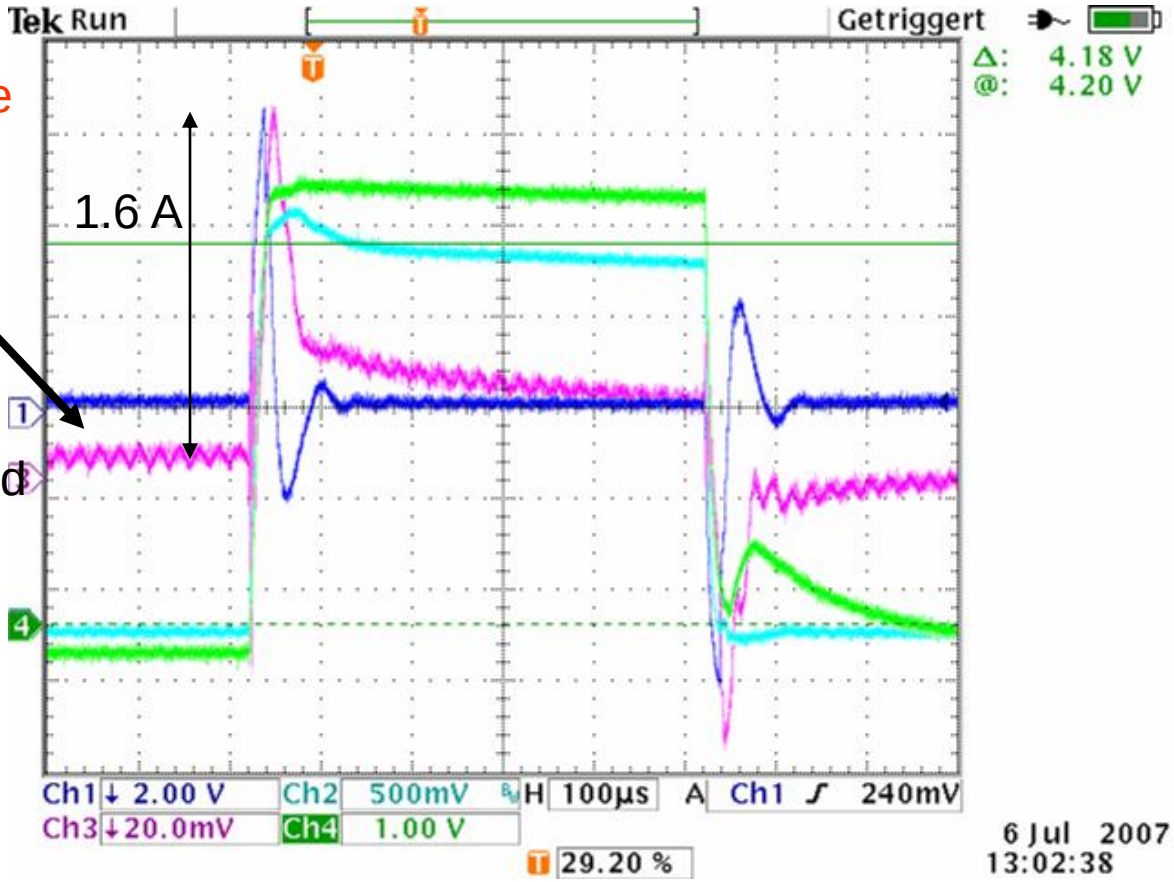
New PPT-Modulator

Please look at purple curve

- U Modulator = 11 kV
- new PPT-Modulator
- Shield connected to ground



Kanal 1 : Darkblue:	**Current in shield**	**100 mV/A**
Kanal 2 : Lightblue:	**Voltage across busbar between middle lead and shield**	**1/10**
Kanal 3 : Violet:	**Current of pulse cable (Beginning of cable)**	**50 mV/A**
Kanal 4 : Green:	**Modulator output voltage**	**1/2000**

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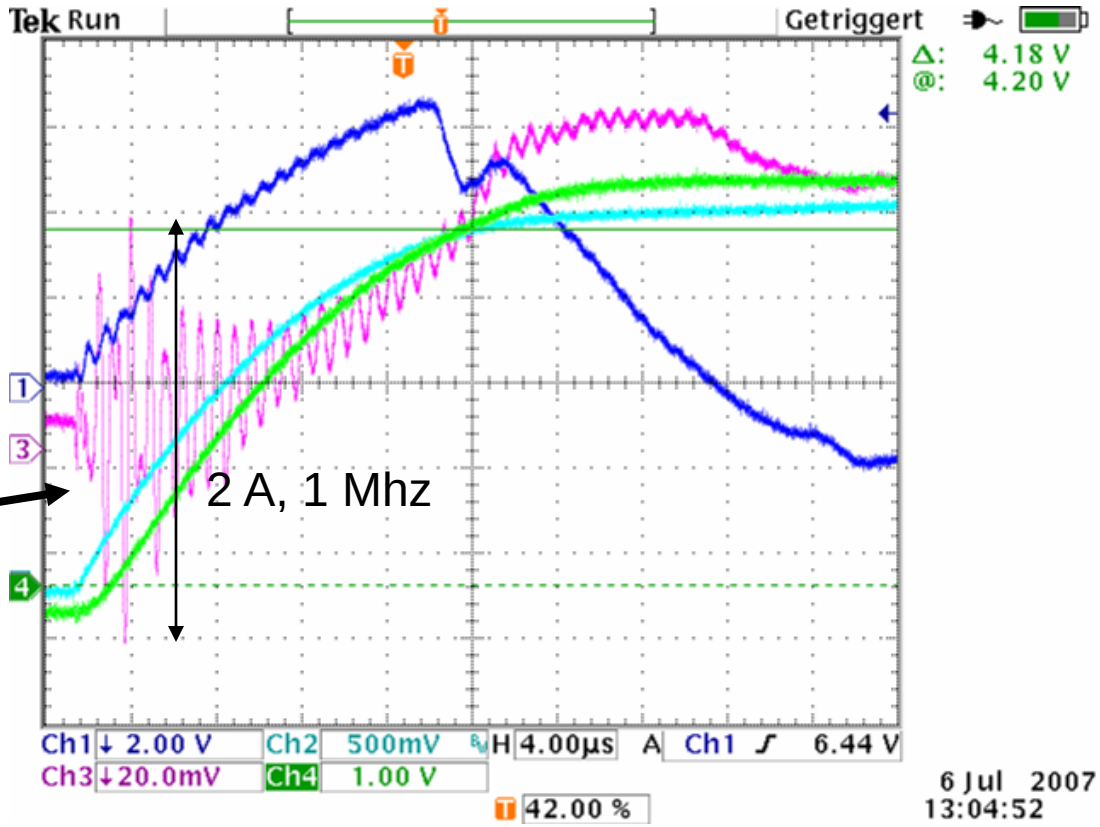
New PPT-Modulator

- U Modulator = 11 kV
- neuer PPT-Modulator
-

Please look at purple curve



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Kanal 3 : Violet:	**Current of pulse cable (Beginning of cable)**	**50 mV/A**
Kanal 4 : Green:	**Modulator output voltage**	**1/2000**

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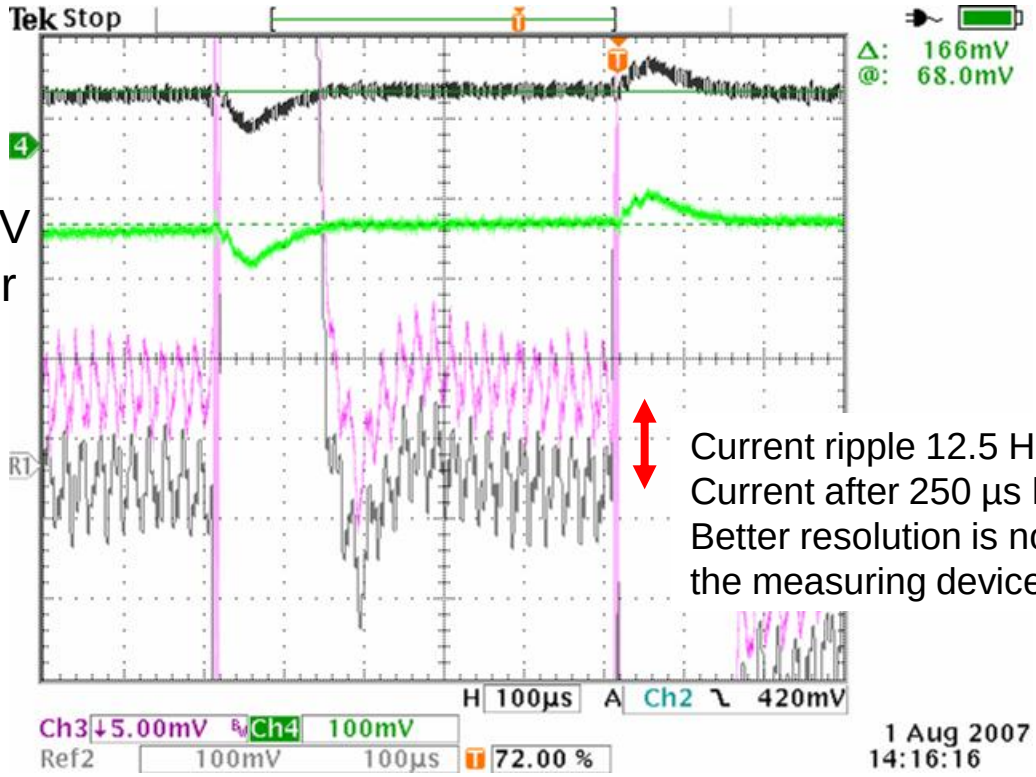
Current ripple, Integral current

- U Modulator = 11 kV
- new PPT-Modulator
- 12 Ω parallel 2,5µ
- Final installation



Current ripple 12.5 Hz < 50 mA
Current after 250 µs less than 50 mA
Better resolution is not possible due to the measuring device

Ref 1:	**Gray:**	**current of pulse cable (End of cable)**	**100mV/A**
Channel 3:	**Violet:**	**Current of pulse cable (End of cable)**	**100mV/A**
Channel 4:	**Green:**	**current of parallel ground cable cable**	**50mV/A**

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EMI problems due to bad installation

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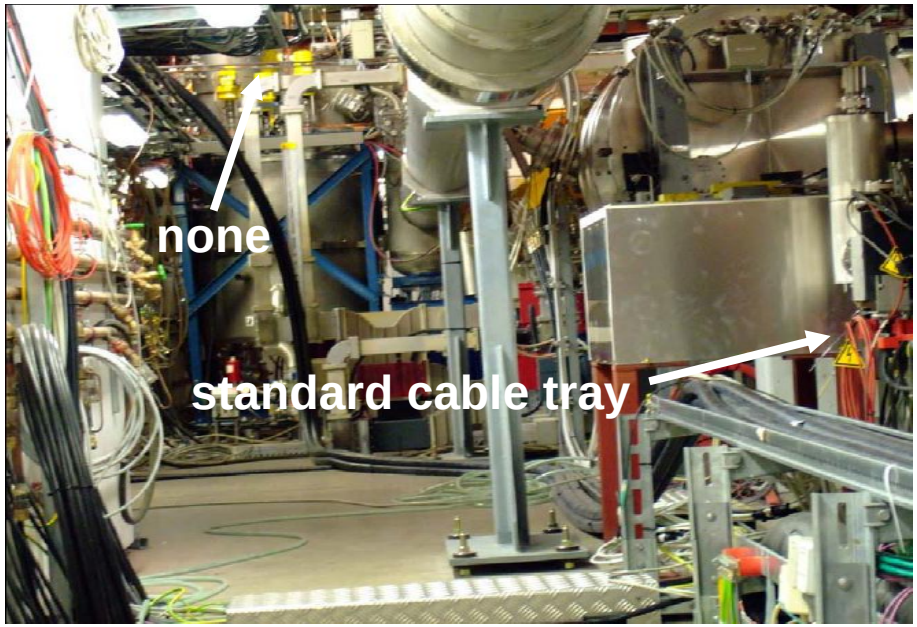
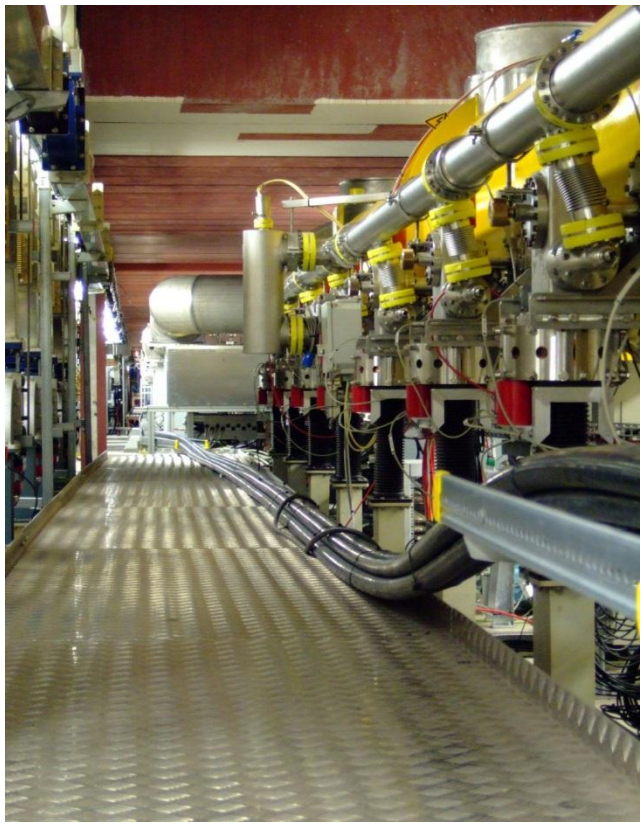
Different pulse cable supports in the FLASH tunnel



Cables entering tunnel at gun area

We'll see in a minute what difference this makes...



Cables behind ACC module

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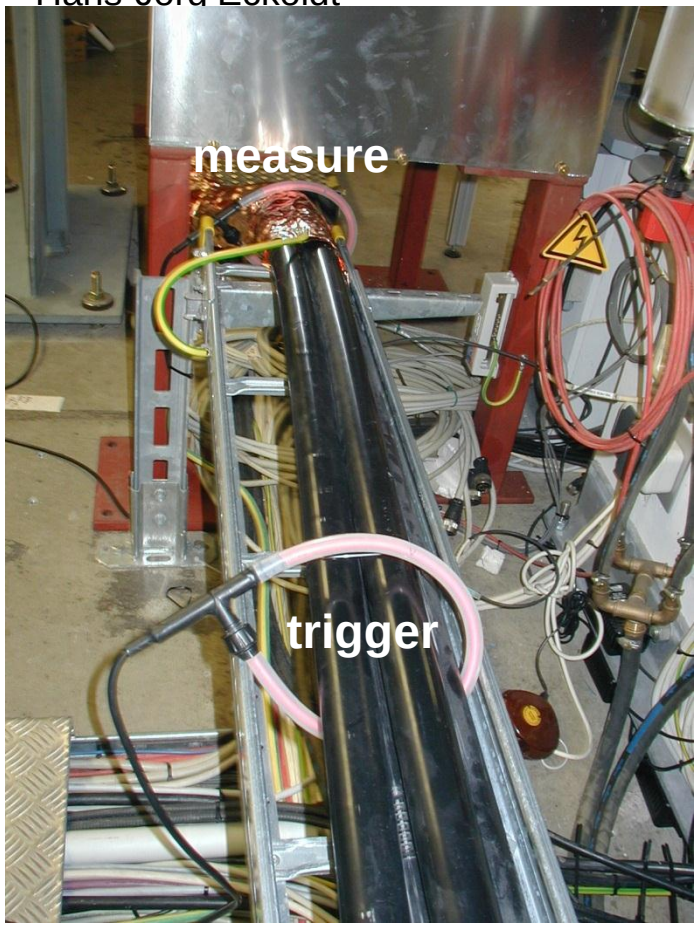
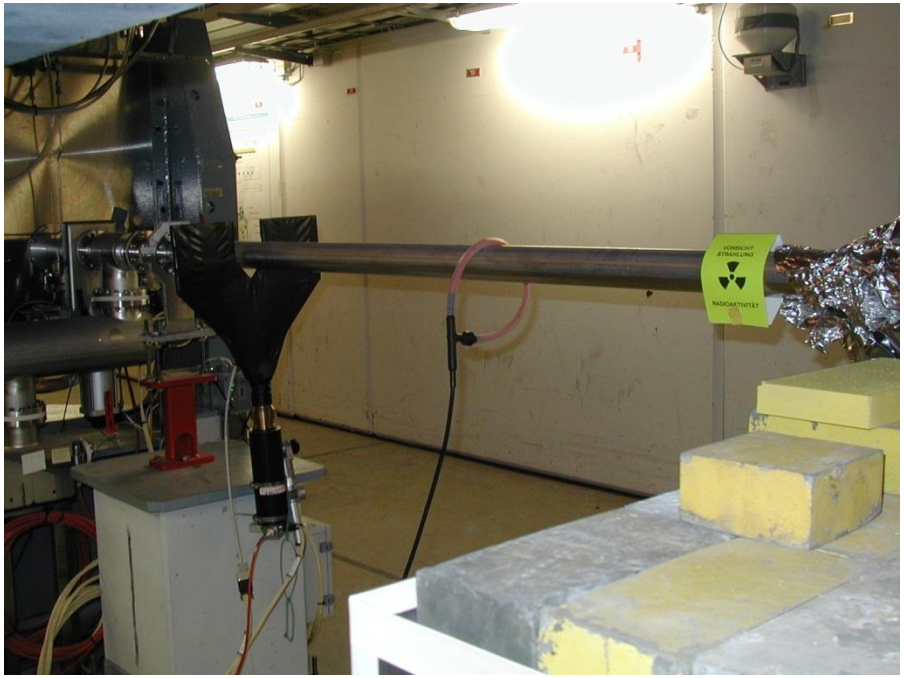


Rogowski coils in action
trigger: 100 mV/A
measure: 50 mV/A

- **Currents on the beam pipe**

Beam tube section before BC2 (z=17 m)



Measurement by H. Kapitza (DESY-FLA)

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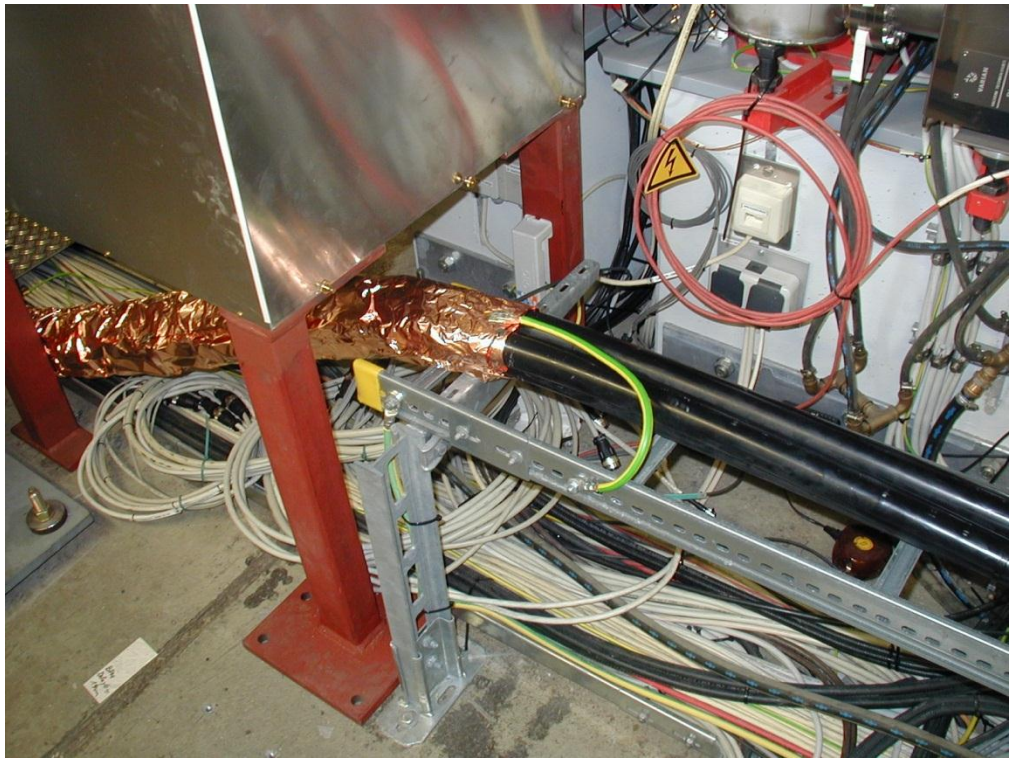
Provide a better path for stray current return:
Wrap cables with 0.1 mm Cu foil and connect through.



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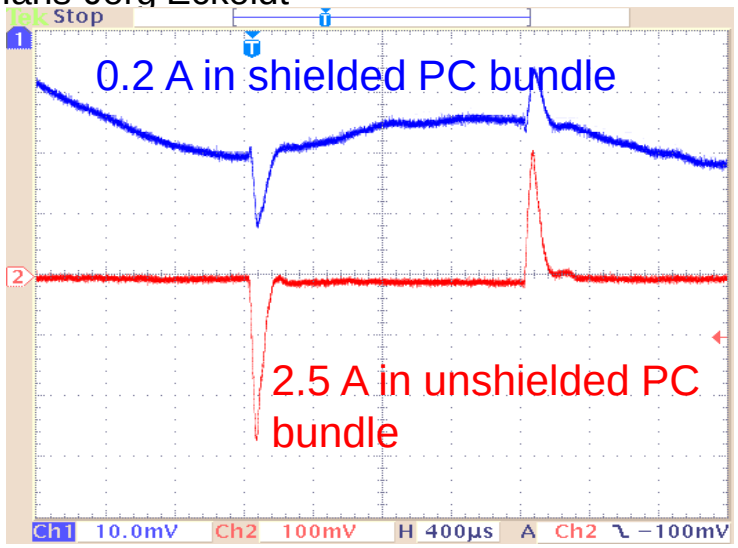

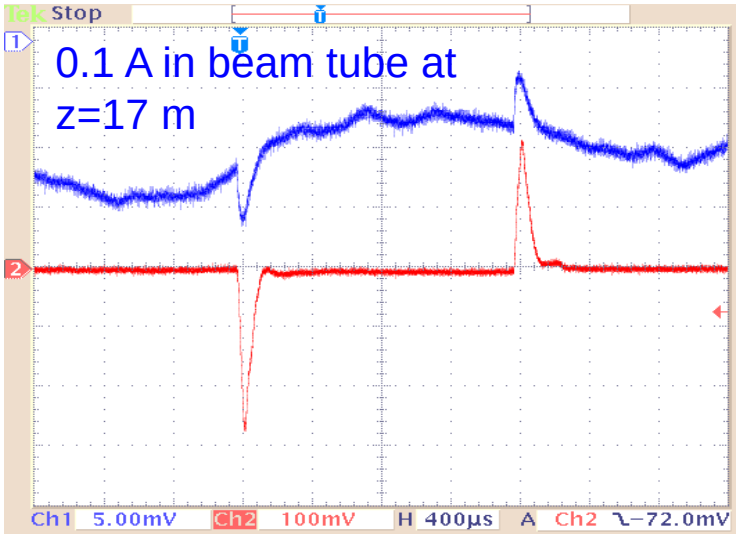

- The cable shielding (= ground plane continuation) absorbs > 90 % of the stray current from the environment.
- At FLASH the beam pipe is a very attractive current route.
- Reason: The FLASH tunnel is composed of isolated concrete blocks and floor slabs. This makes a very poor facility ground.
- This is an example for fixing an EMI problem in a long grown non-optimal environment.

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2007

Conclusion in the year ~~2004~~:

The pulse cables behave in the way it is foreseen.

The functionality is now **proven** for XFEL

~~Shortly after this conclusion.~~

~~A lot of problems occurred with EMI~~

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DESY
MKK

Thomson Modulator

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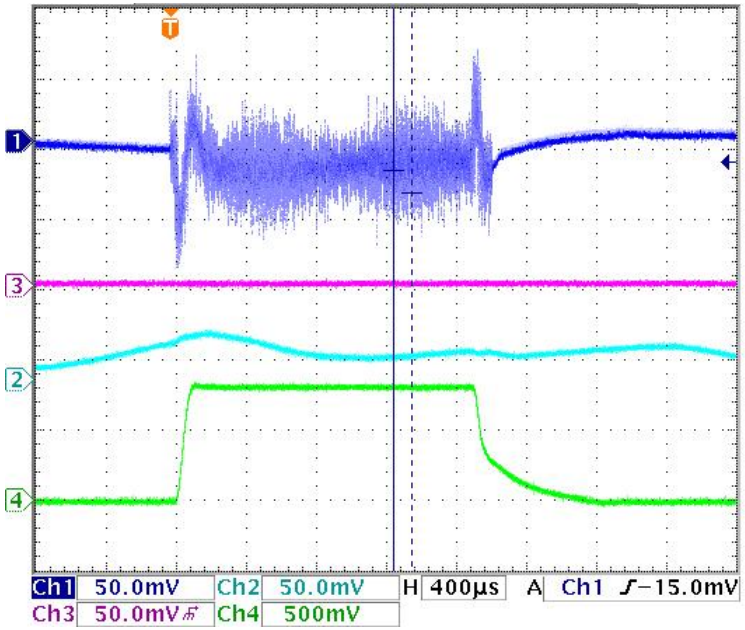
Messungen Thomson Modulator



Noise **during** the pulse

Channel 1: Dark blue : Integral current of all Pulsce cable (100 mV/A)
Channel 2: Light blue: Strom im PE-Leiter des Modulator (50 mV/A)
Channel 3: Lila :
Channel 1: Green: Modulatorvoltage V_{out}

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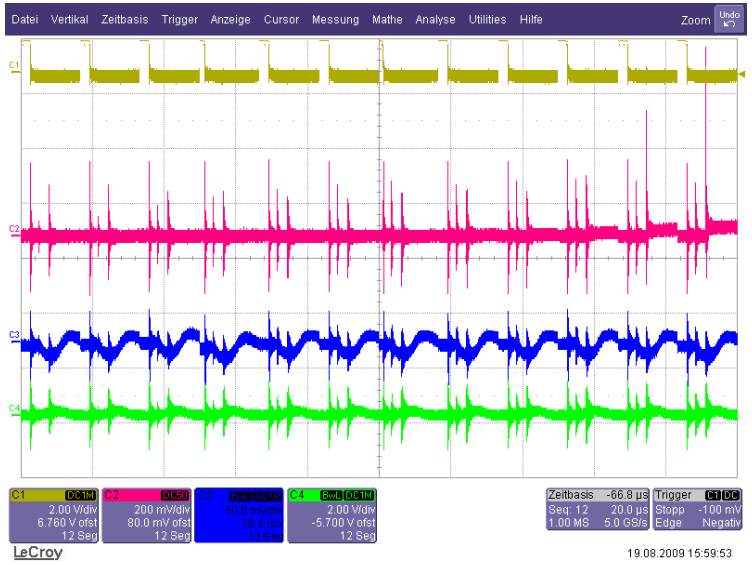
Messungen Thomson Modulator
Loading of capacitances of transformer



Noise **during** switching

For measurement purpose special pulse pattern

Channel 2: Light blue:	Current in the Transformer shield	(50 mV/A)
Channel 3: violett :	Integral current of all Pulsce cable	(100 mV/A)

DESY Experience pulse cable, EMI, power, grounding

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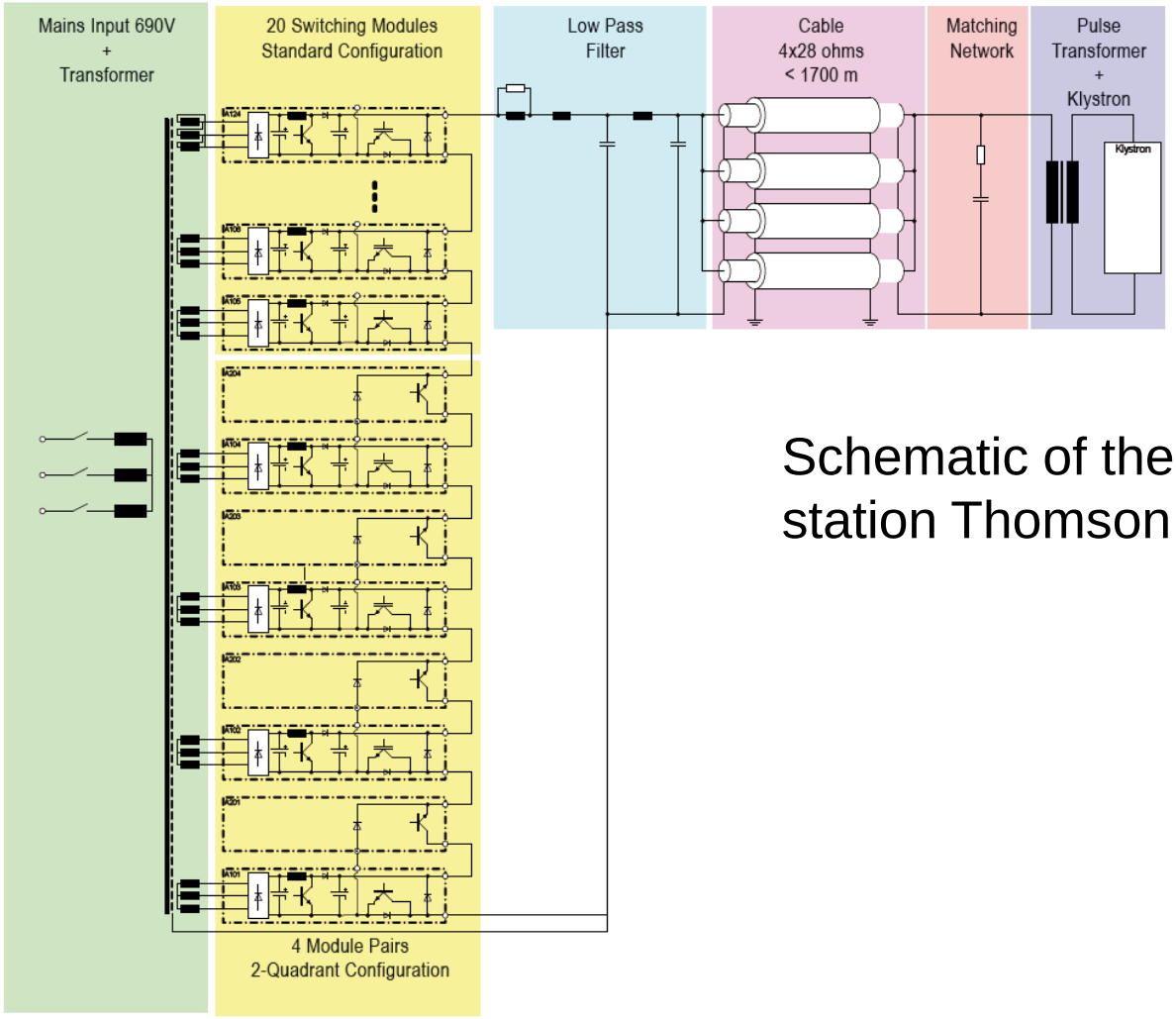

Schematic of the entire RF-station Thomson modulator

DESY Experience pulse cable, EMI, power, grounding

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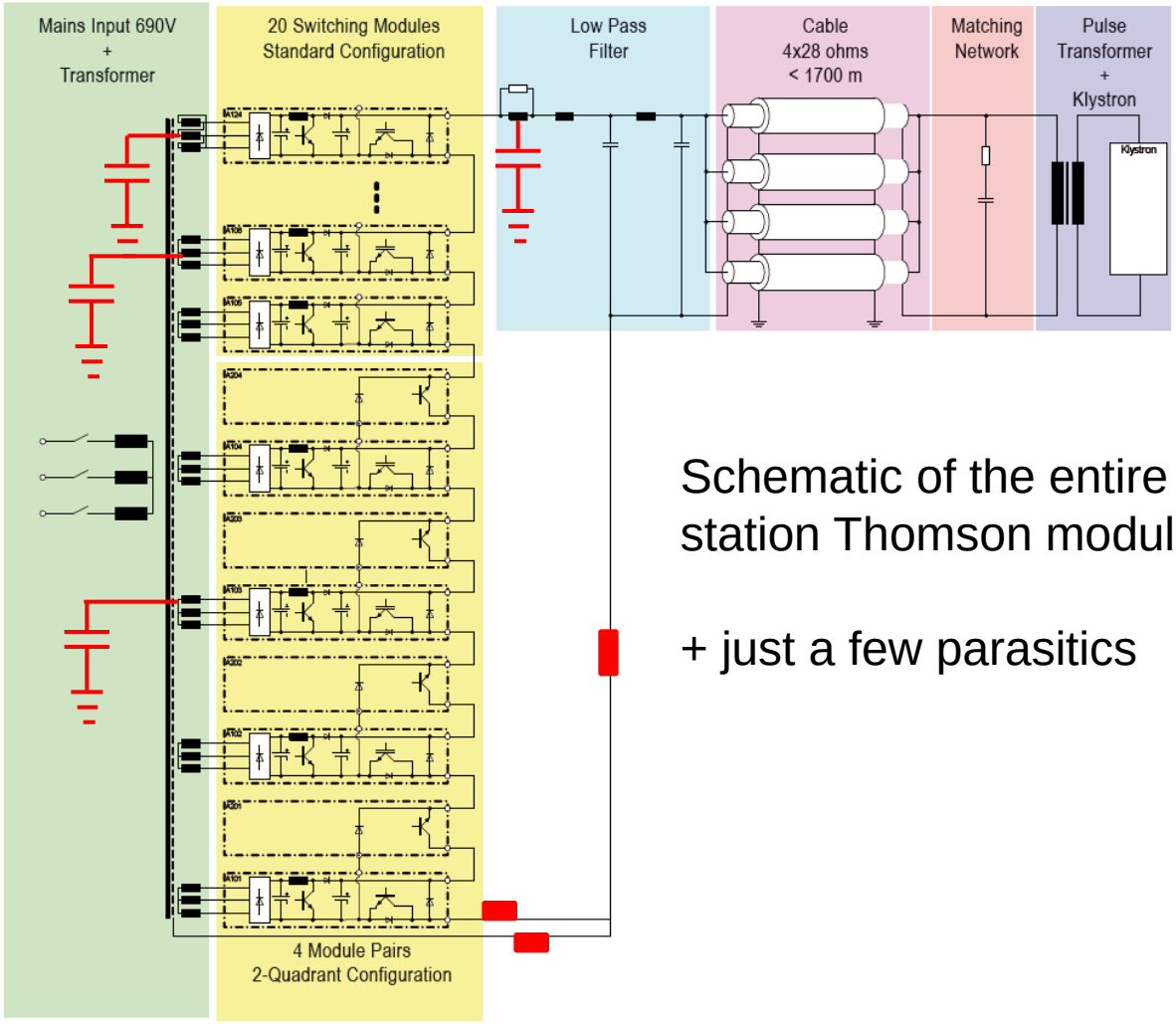

Schematic of the entire RF-station Thomson modulator

+ just a few parasitics

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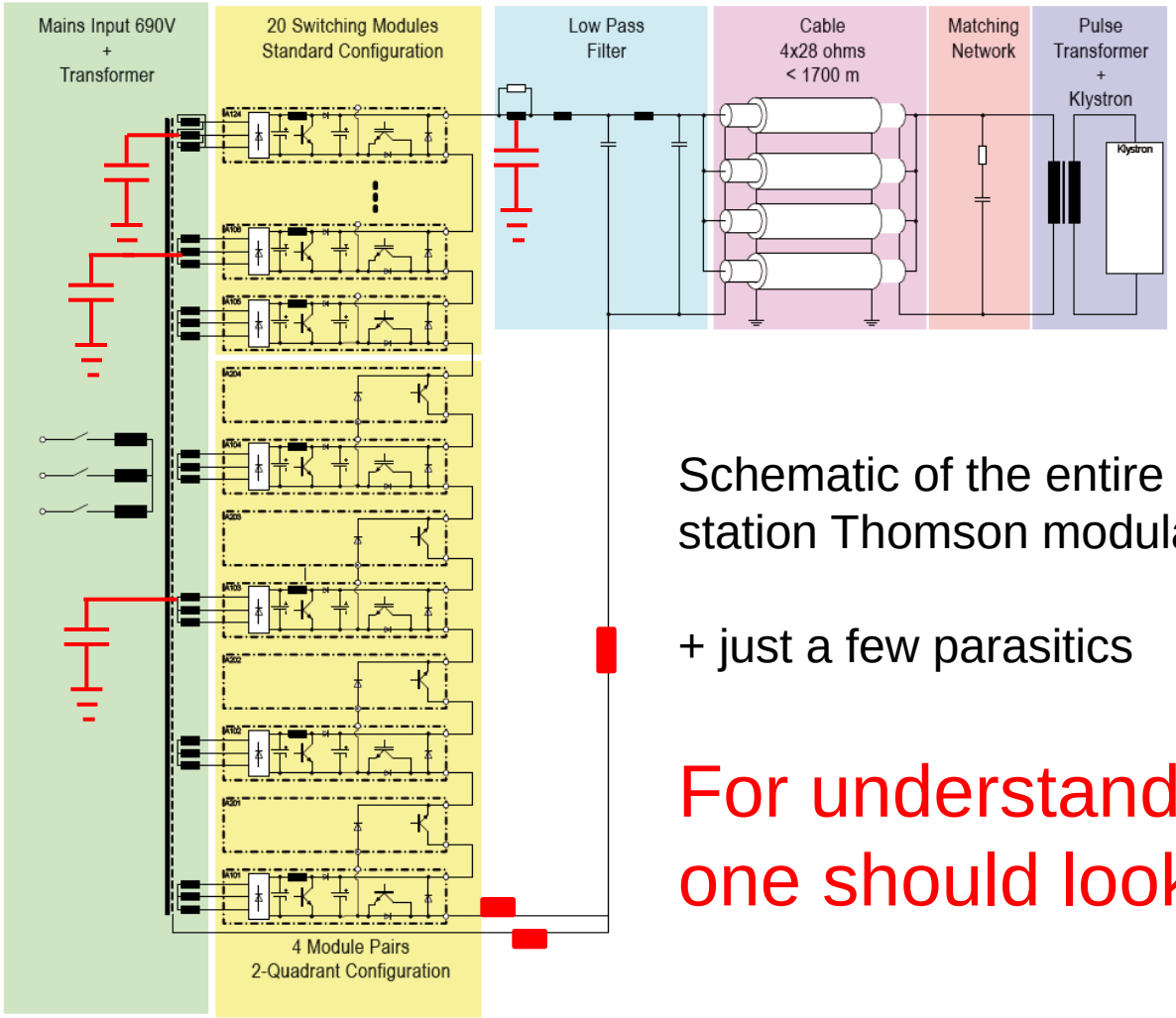

Schematic of the entire RF-station Thomson modulator

+ just a few parasitics

For understanding EMI one should look at these!

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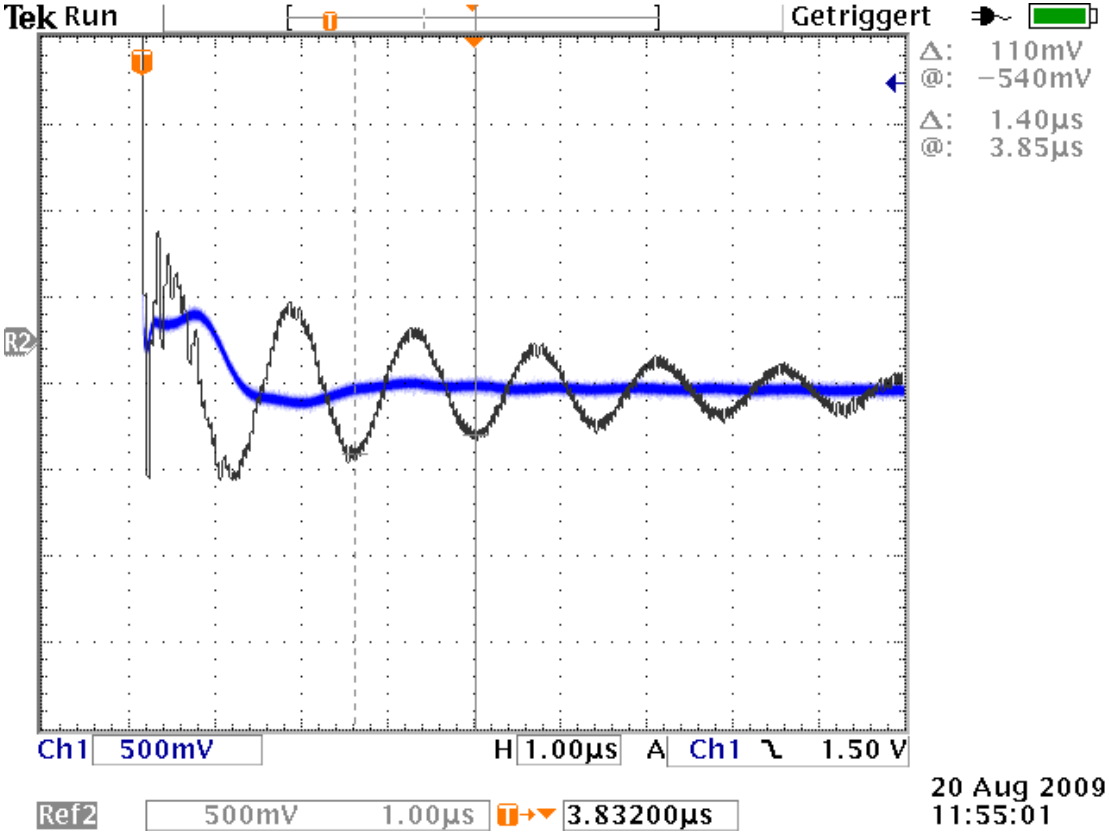
Damping of transformer oscillations with 4 ferrites



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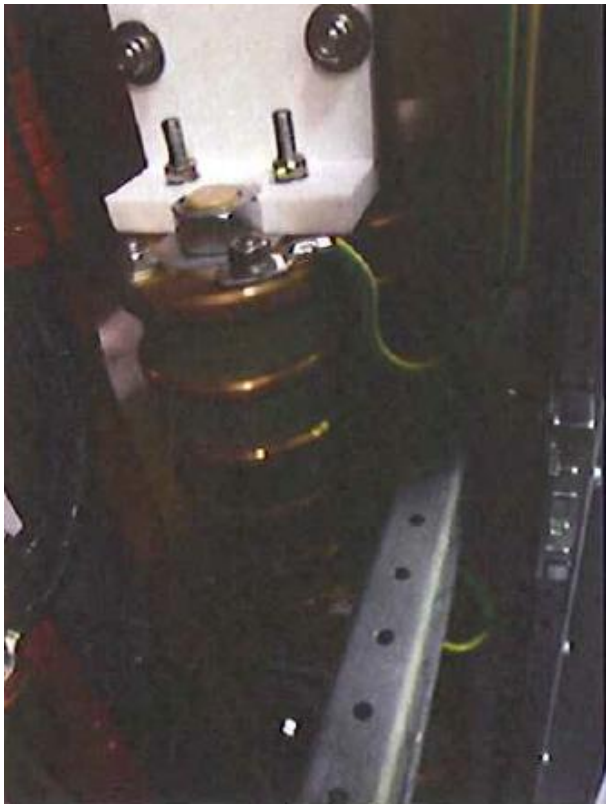
Combination of ferrites and resistors at the output



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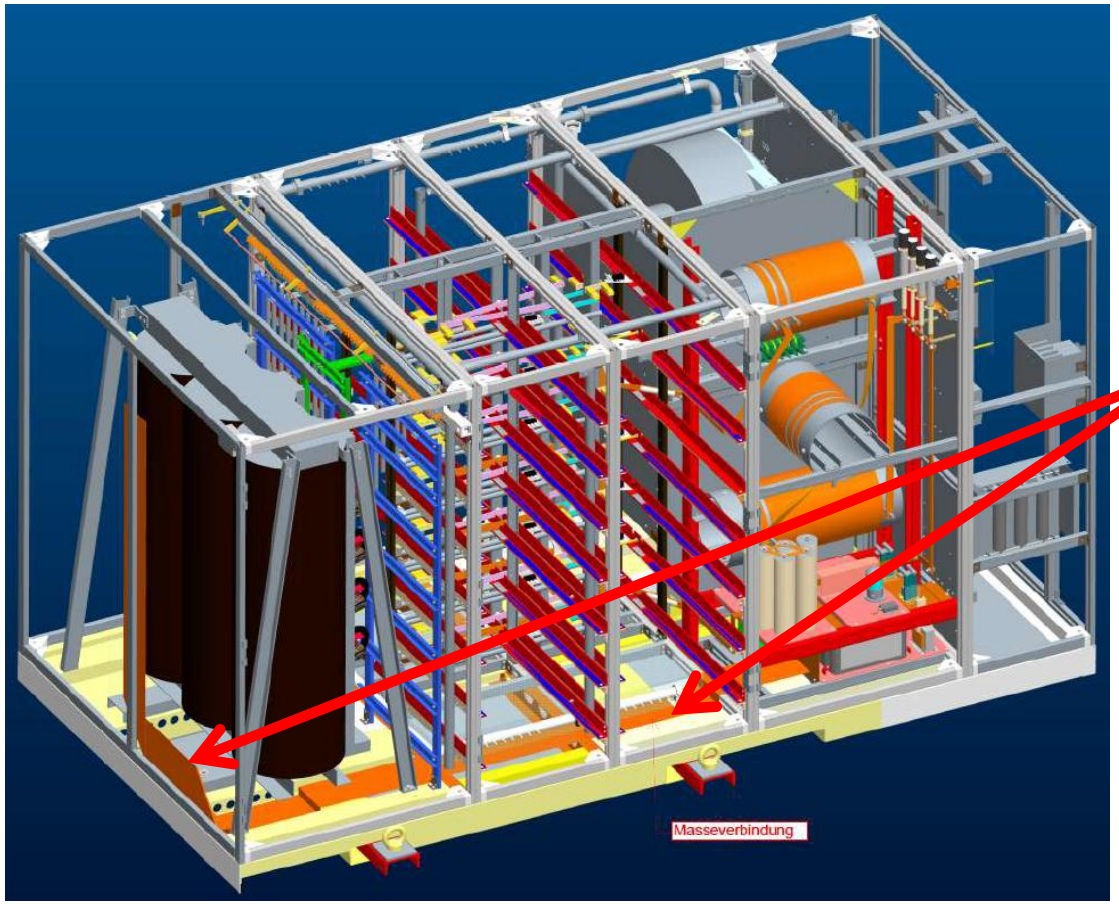
Improved internal grounding



Copper sheet through the entire housing

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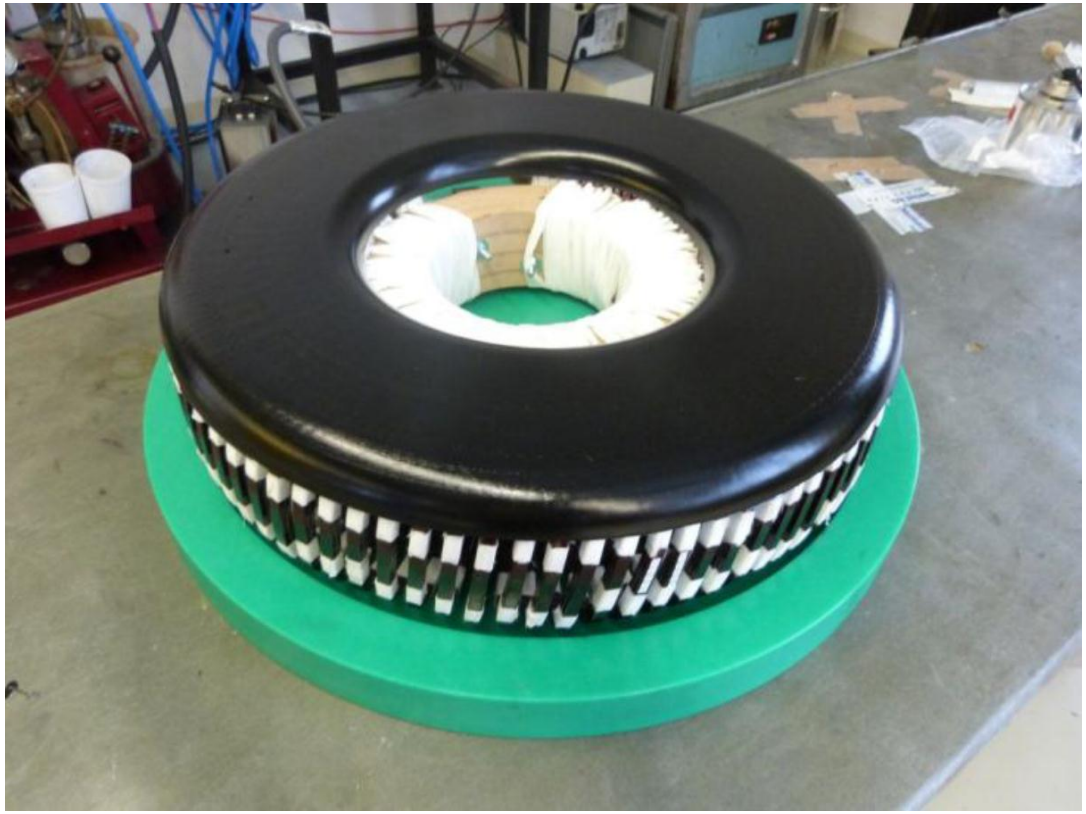
Coils with closed magnetic path due to toroidal construction



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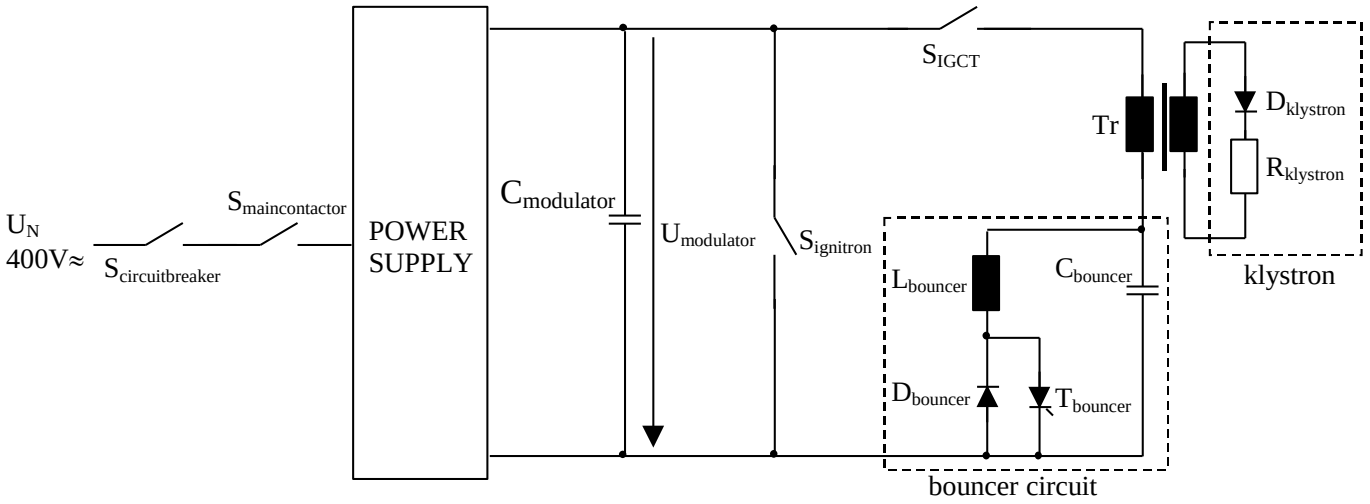
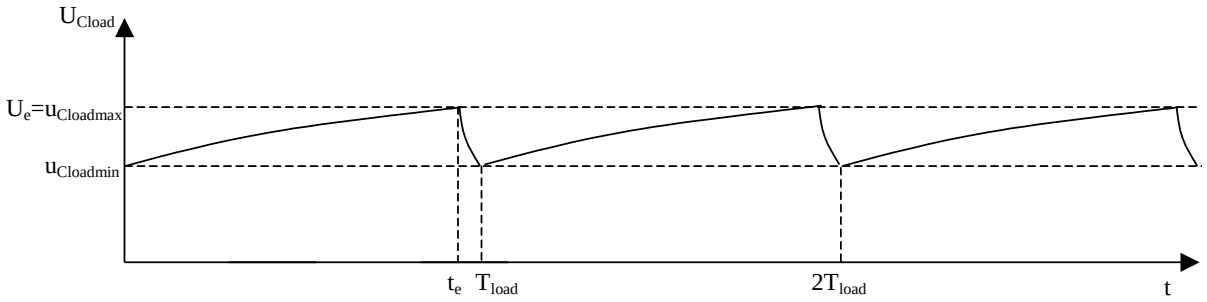
What does it mean putting a pulsed machine to the mains?

Hans-Jörg Eckoldt

Bouncer Modulator





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Disturbances to the mains

The amount of allowed disturbances is defined in the German standard VDE 0838, IEC 38 or the equivalent European standard EN 61000.

No energy consumer is allowed to produce more distortions than 3% of the voltage variation of the mains.

For low frequencies in the visual spectrum this value is even more restricted. The low frequencies are called flicker frequencies. The human eye is very sensitive to changes in light intensities in this frequency domain.

It is defined as changes of a square wave per minute.

This is not to be confused with the frequency since a change is from top to bottom and vice versa = 2*f*60

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

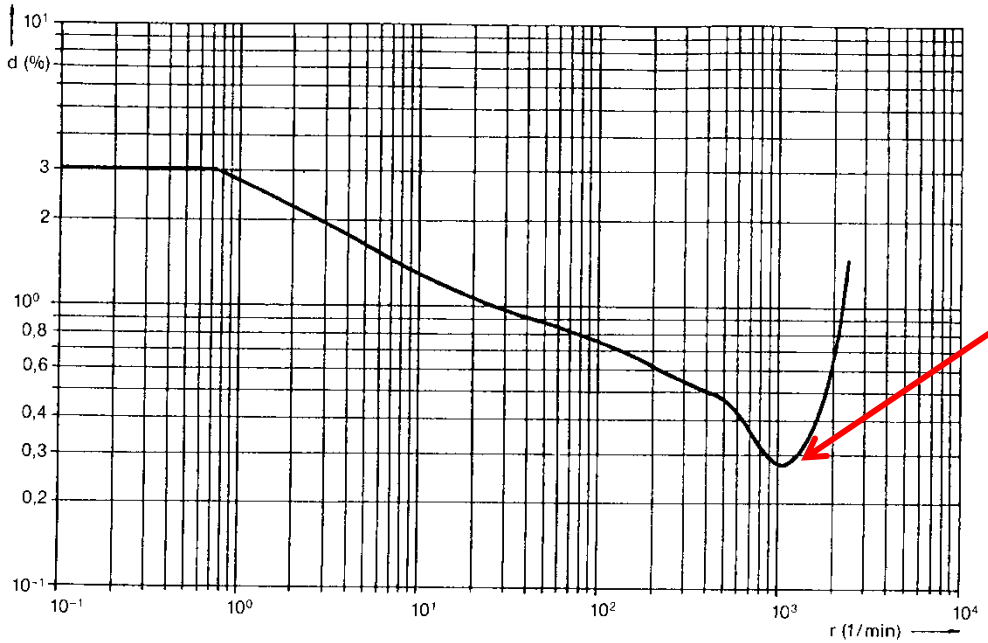

Bild 5-2: Verträglichkeitspegel für regelmäßige rechteckförmige Spannungsänderungen

Operation point of
XFEL 10 Hz
d ≈ 0.28 %

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Disturbances to the mains

$$d = \frac{\Delta S}{S_{sc}} = \frac{\Delta U}{U_n} = 0.28\ \%$$

d= allowed distortion of the voltage

ΔS = variation in apparent power

Ssc = short circuit power

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DESY mains and specification

- At DESY the intermediate voltage is 10 kV.
- The short circuit power of the mains station to which the modulators are connected is 250 MVA.
  - 250 MVA * 0,28%=700 kVA
- The first assumption was that max. 35 modulators could be in operation.
  - Budget of 20 kVA/Modulator
  - This budget was cut by two since other components in the machine are assumed to be more critical than the human eye specified 10 kVA per modulator

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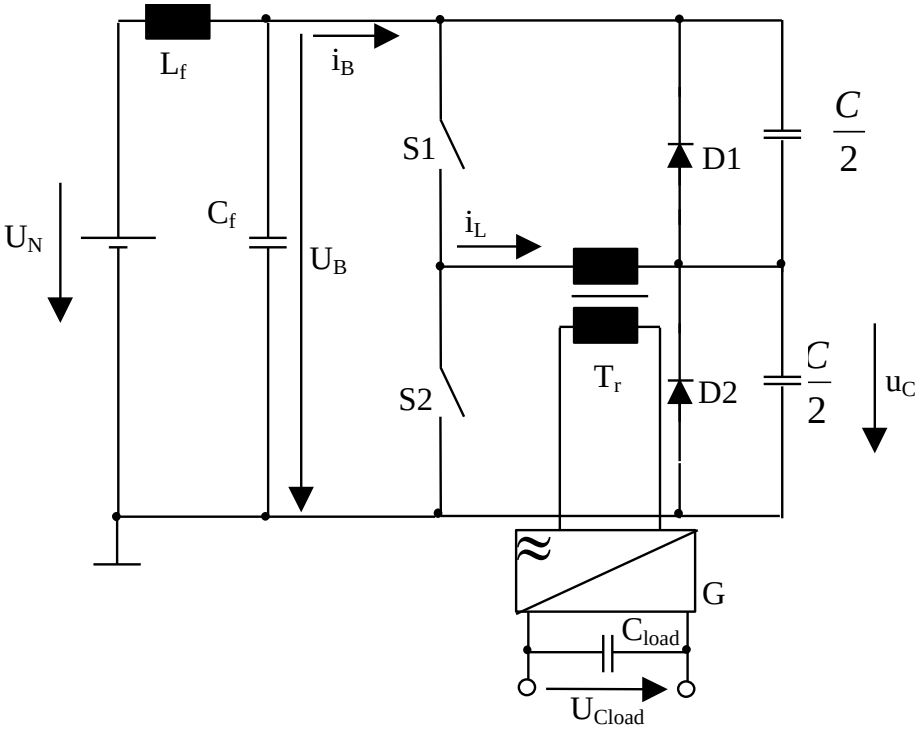
300 kW-Switched mode supply for constant power (research of a Master thesis)



G	Rectifier
i_B	supply current
i_L	primary current of the transformer
u_C	voltage of the resonance capacitor
U_{Cload}	output voltage to the switch of the klystron
i_{Bt1}	current i_B at the time t1
L	primary stray inductivity of the transformer
f	resonance frequency of the resonant circuit of L and C
n	gear ratio of the transformer and rectifier
T	period time of the switching frequency of S1 and S2
C	resonance capacitor
U_B	supply voltage
U_N	line voltage
C_f	filter capacitor
L_f	filter inductance

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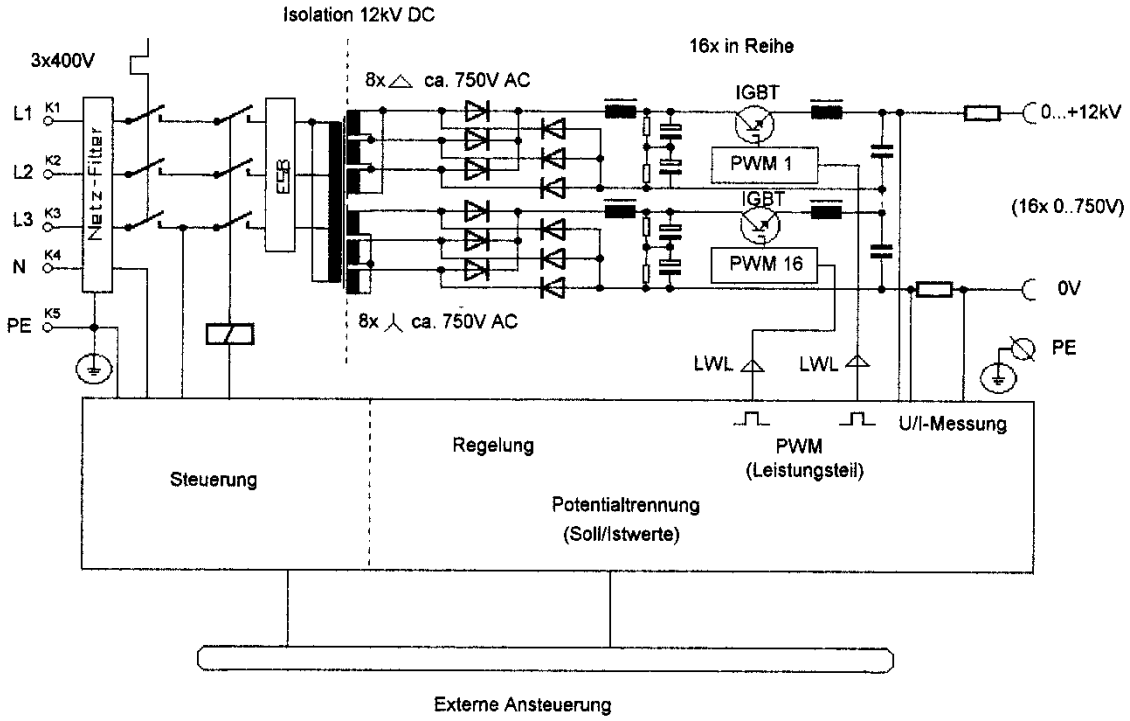
Series connection of buck converters FuG solution



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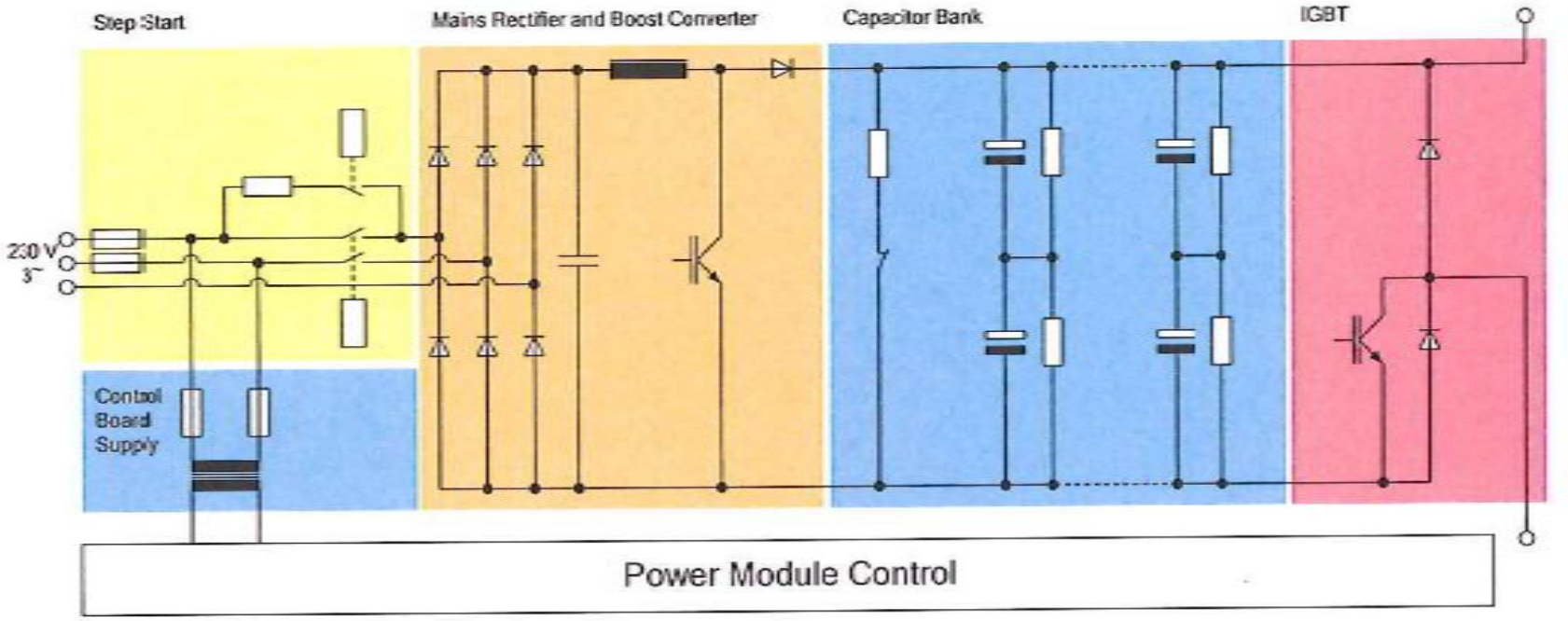
Thomson Power Module



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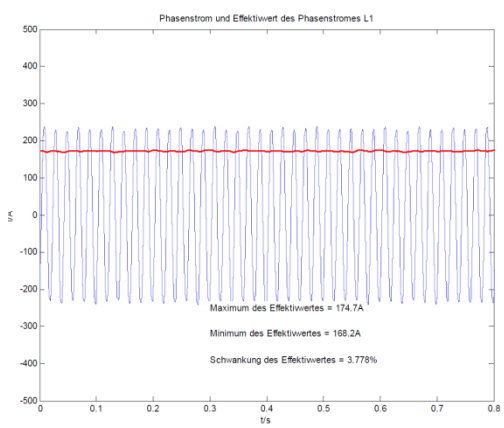
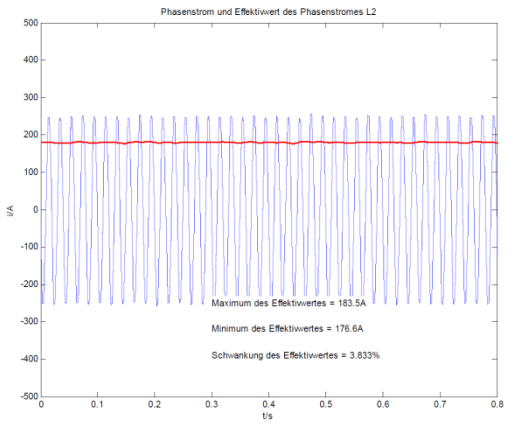
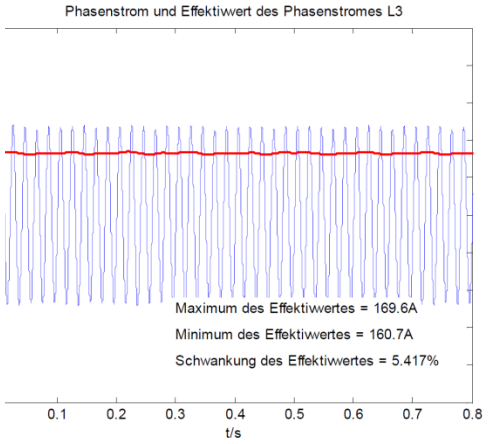
Variation of the mains current Thomson modulator







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

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Grounding in the civil construction

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Grounding of buildings

- „Good old starpoint grounding“ is not possible for large scale plants
- In modern civil construction all metallic structures are included into the grounding
- This is well in combination with the lightning protection

- For pulsed application combined with precision measurement the grounding should be even improved

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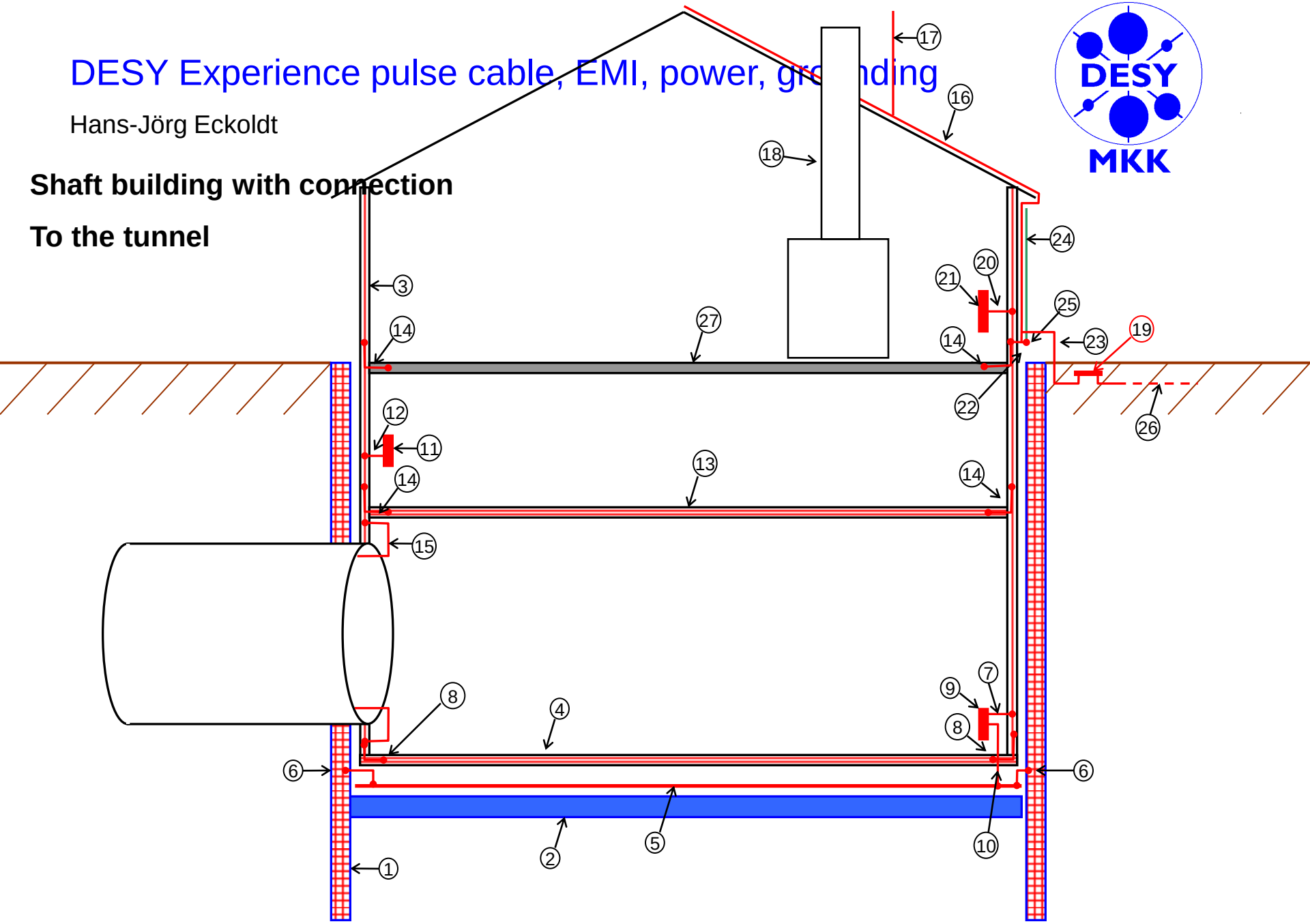
Shaft building with connection

To the tunnel



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Interesting:

- **Kapitza**
- http://xfel.desy.de/project_group/work_packages/control_and_operation/wp_39_emc
- **Ott**
  - Electromagnetic Compatibility Engineering
  - Noise reduction techniques in electronic systems
- Power supplies for TESLA-Modulators by Eckoldt/Heidbrook TESLA Report 200-36