XFEL RF System Overview

S. Choroba

DESY

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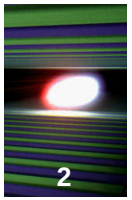
Outline



- RF System Requirements
- RF Station Layout
- Status of RF Components
  - Klystron
  - Pulse Transformer and Connection Module
  - Modulator
  - Pulse Cable
  - RF Waveguide Distribution

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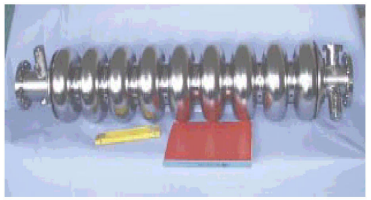
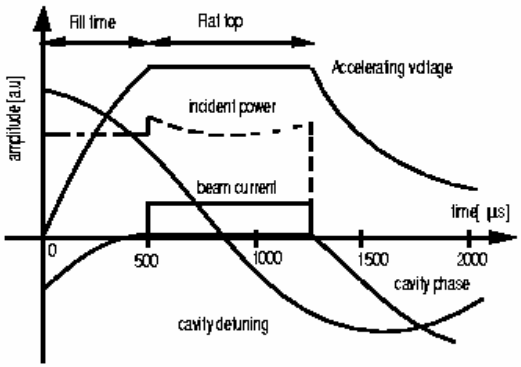
XFEL Accelerator High Power RF Requirements

- Number of sc cavities: 800 (928) total for 17.5GeV (20GeV)
- Power per cavity: 122 kW
- Gradient at 17.5GeV: 23.6 MV/m
- Power per 32 cavities (4 cryo modules): 3.9MW
- Power per RF station: **5.2MW** (including 10% losses in waveguides and circulators and a regulation reserve of 15%)



- Number of RF stations: **25**, active **23**
- Number of RF stations for injectors: **2**
- Macro beam pulse duration: 650µs
- RF pulse duration: **1.38ms**
- Repetition rate: **10Hz (30Hz)**
- Average RF power per station: **72kW (150kW)**



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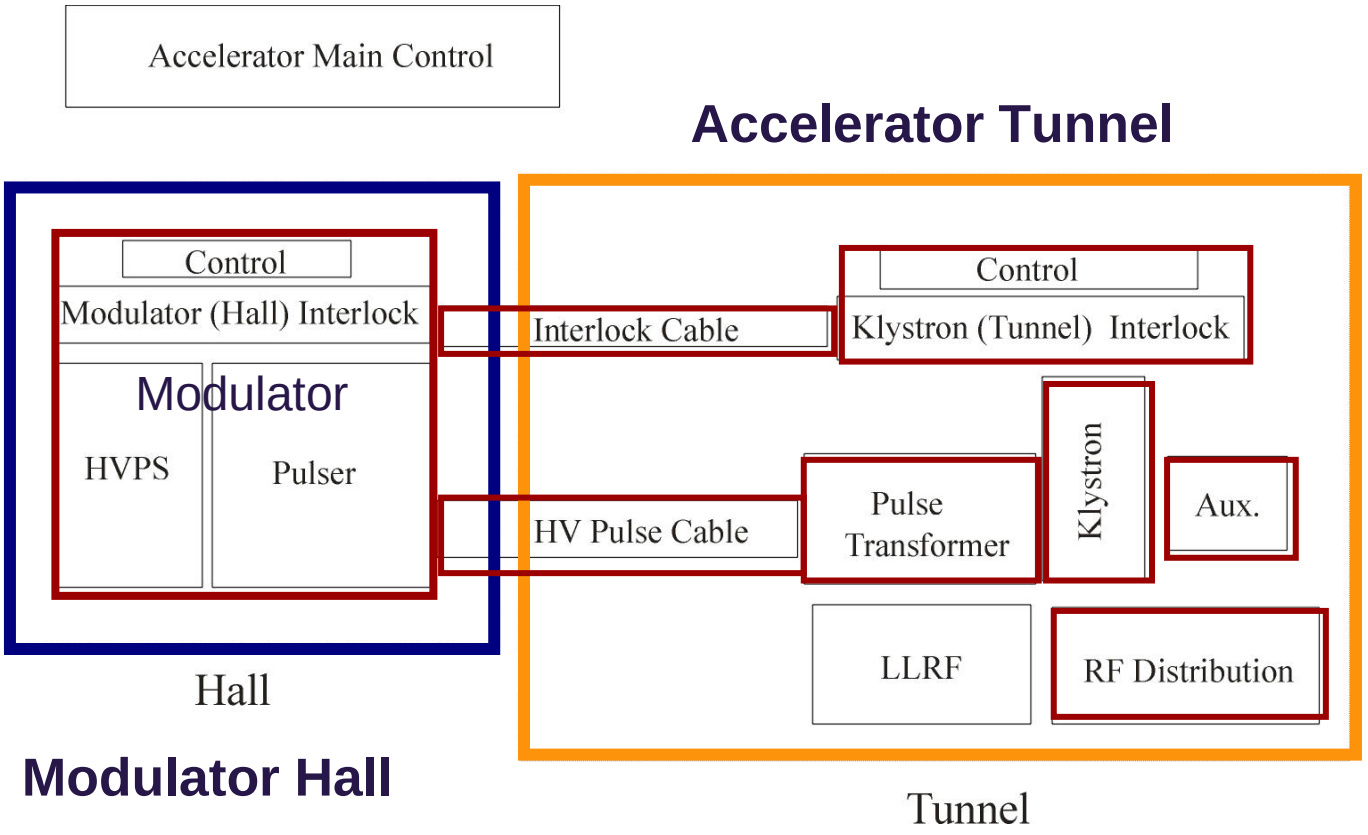
RF Station Layout

Layout of one RF Station



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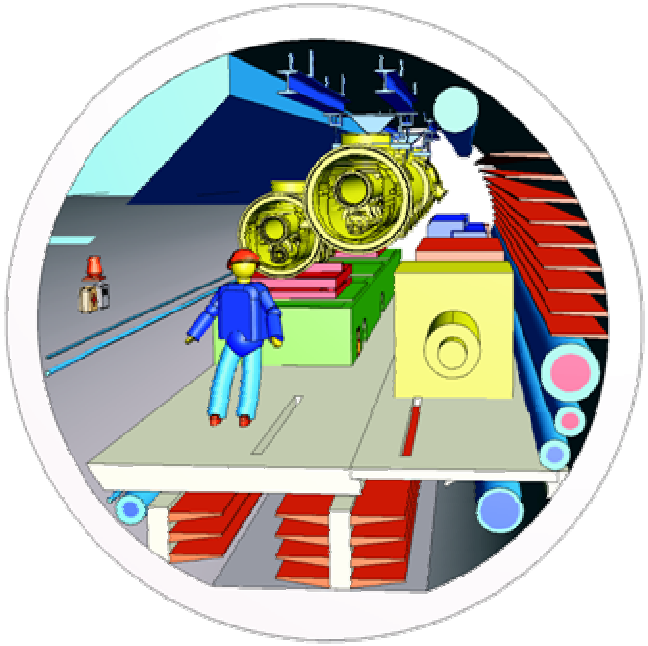
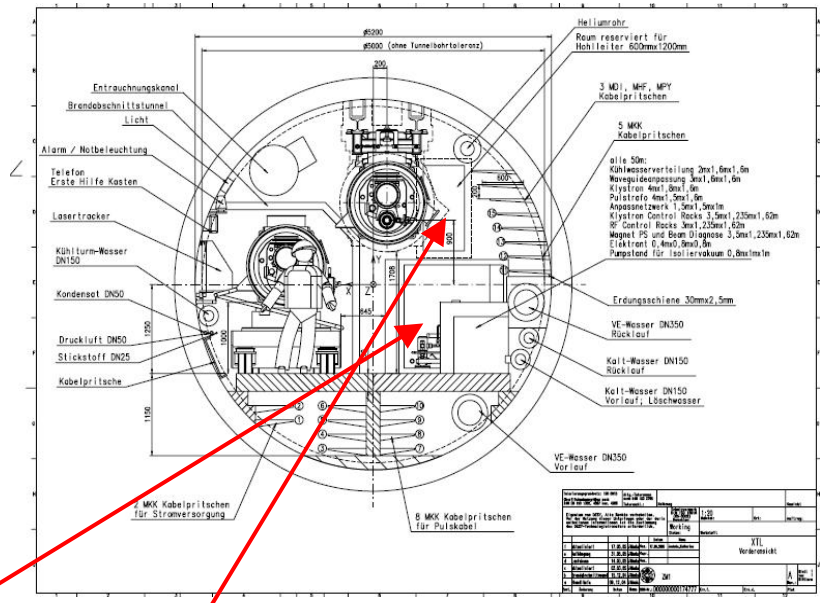
Tunnel RF Components

Layout of the RF Station in the Accelerator Tunnel





- Tunnel components (klystrons, pulse transformers, aux. power supplies etc.) will be installed underneath the cryogenic module.
- The waveguide distribution will be installed on the side of the cryo module.
- These components are not accessible during accelerator operation.

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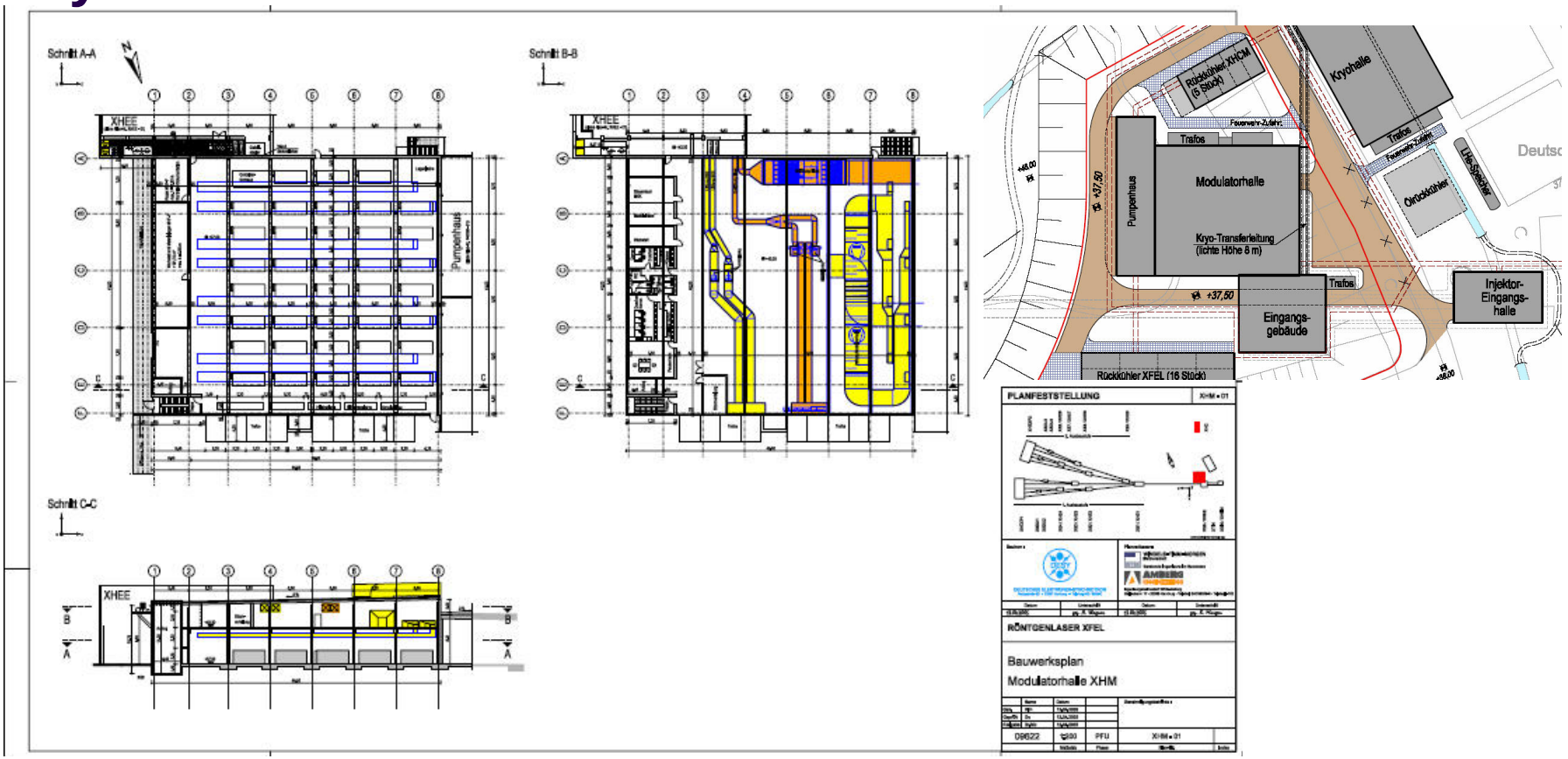
Hall RF Components

Layout of the RF Station in the Modulator Hall



- The modulators will be installed in the modulator hall.
- Maintenance and repair is possible during accelerator operation.

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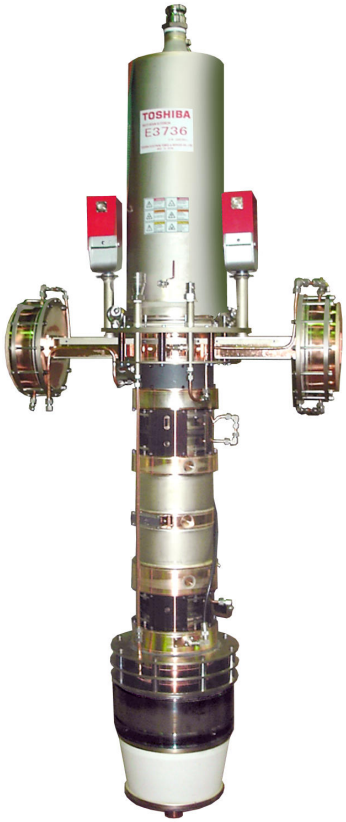
Vertical MBKs

- Three klystron vendors have developed 10MW MBKs during the last years

THALES TH1801

CPI VKL8301



TOSHIBA E3736

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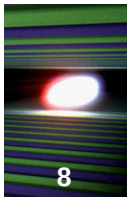
Status of vertical MBKs



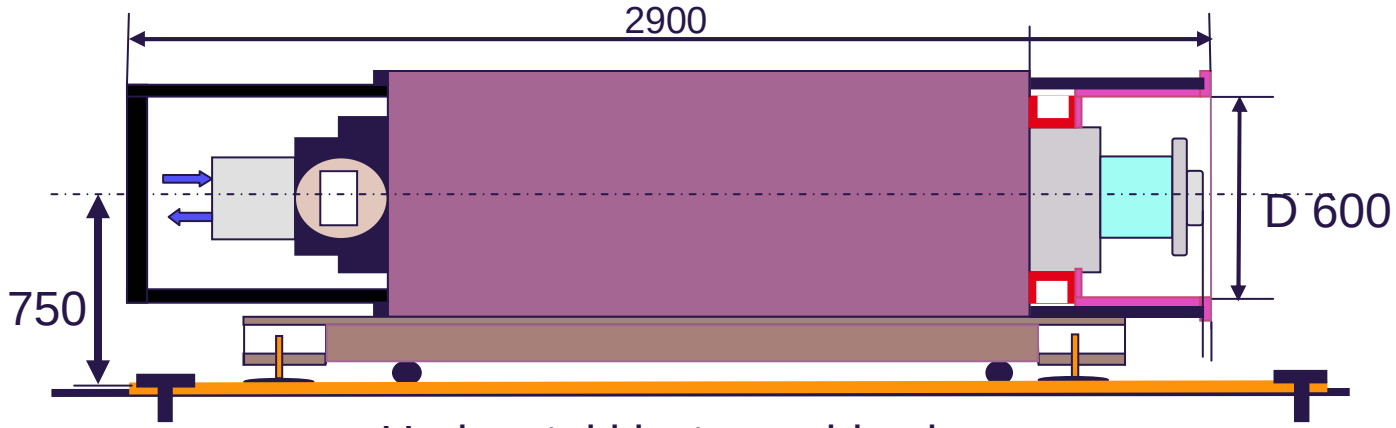
- 8 THALES TH1801 have been built
  - Prototype had been in use at Flash, now stored at DESY
  - #1 and #4 in use at PITZ for 1500h and 8700h
  - #2 did not pass acceptance test some years ago, will be rebuild as #8
  - #3 has been in use at FLASH, failure after 17000h
  - #5 in use at FLASH now for 9500h
  - #6 passed acceptance test at Thales, passed acceptance test at DESY
  - (10MW, η=61%)
  - #7 passed acceptance test at Thales, passed acceptance test at DESY
  - (10.5MW on matched load, η=62%)

- 1 TOSHIBA E3736 at DESY
  - 10.4MW, 1.5ms, 10Hz, 66%
  - 750h, ~80% at full power
  - will be used at the modulator test stand in Zeuthen

- 1 CPI VKL8301 at DESY
  - 8.1MW, 1.3ms, 10Hz, 53.5% in use at CMTB at DESY for 6000h

Horizontal MBK requirements

- Horizontal versions are required to install klystrons in the XFEL accelerator tunnel.
- All three vendors of the vertical multibeam klystrons have received contracts to develop and manufacture horizontal prototypes of the multibeam klystrons.



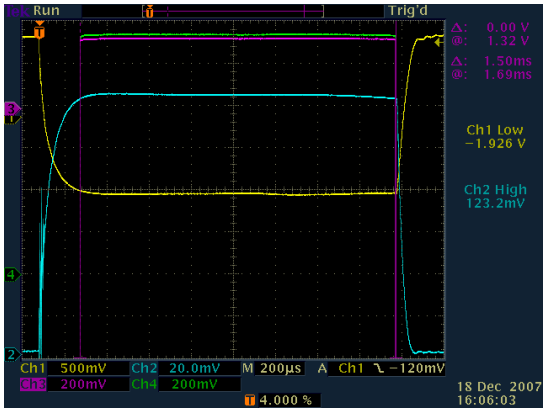
Horizontal klystron, side view

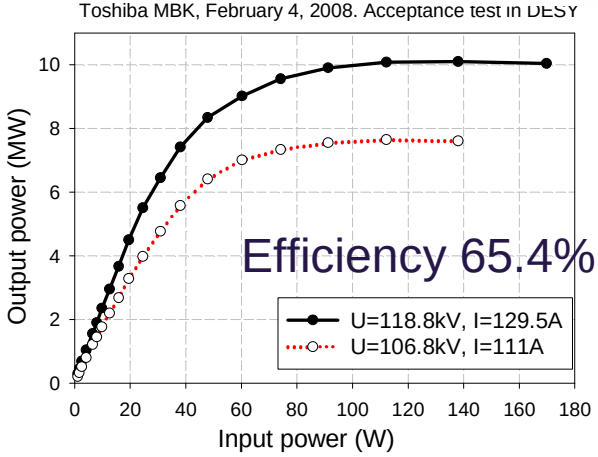
Toshiba E3736H

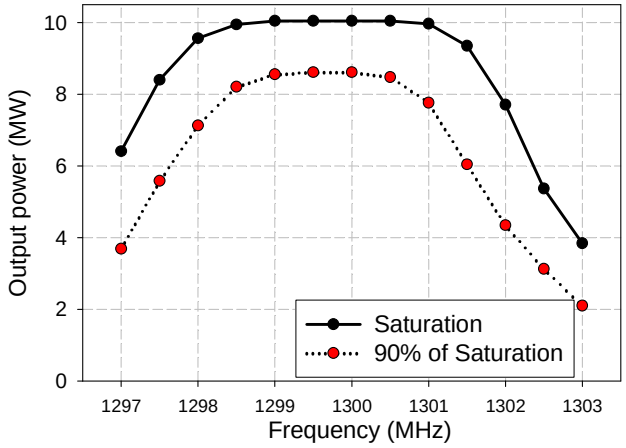
Status

- Delivered and accepted at DESY February 2008
- 10MW at 118.8kV and 129.5A

  => 65.4%
- Reliable operation







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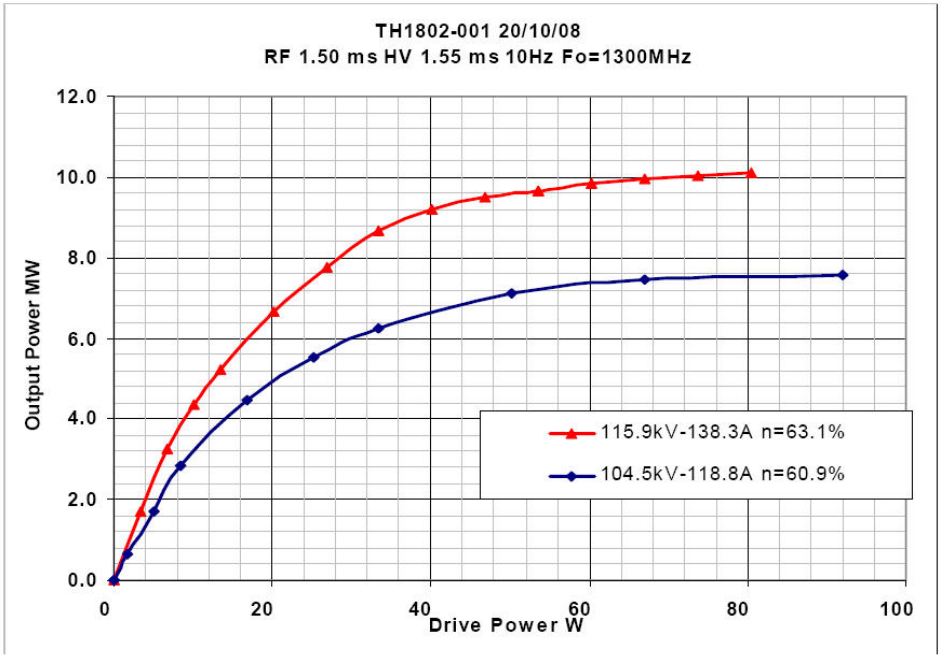
Thales TH1802

Status

- achieved 10.1MW, h=63% full pulse length in vertical test
- vacuum leak opened during test in horizontal orientation at THALES at output waveguide
- has been rebuild and is now in test at THALES
- FAT planned for Sept. 2009



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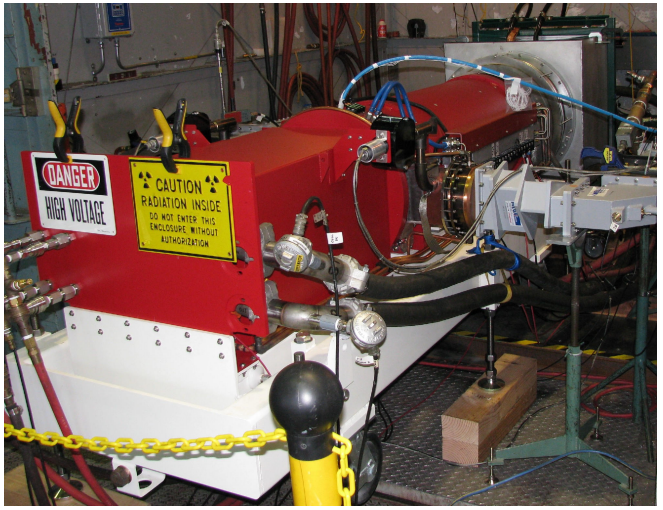
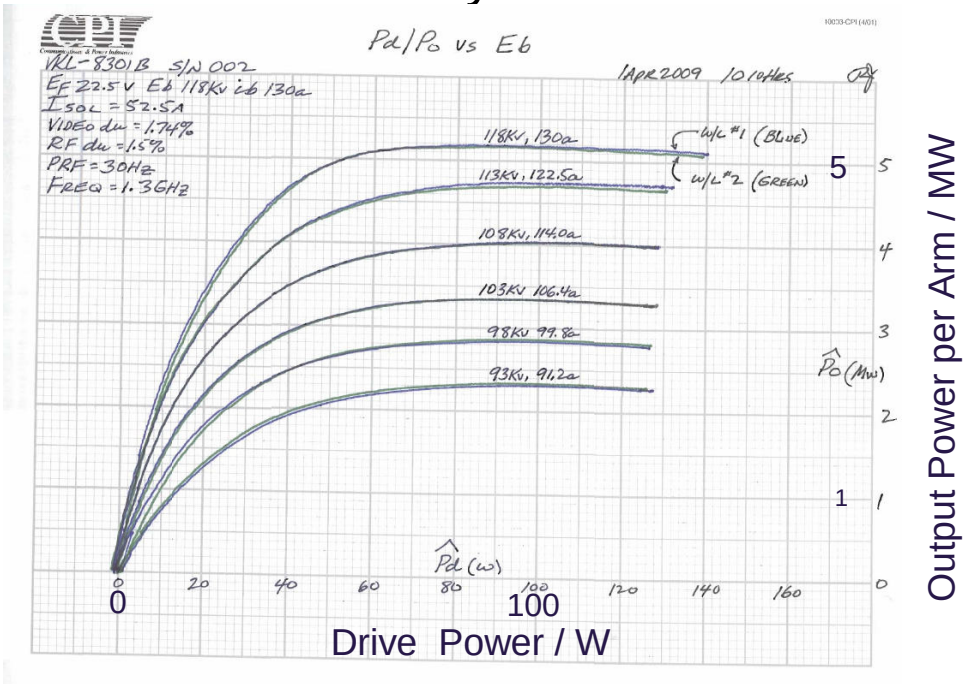
CPI VKL8301B

Status

- achieved 10.1MW, η=66% at full pulse width
- FAT at CPI April 2009
- SAT at DESY July 2009

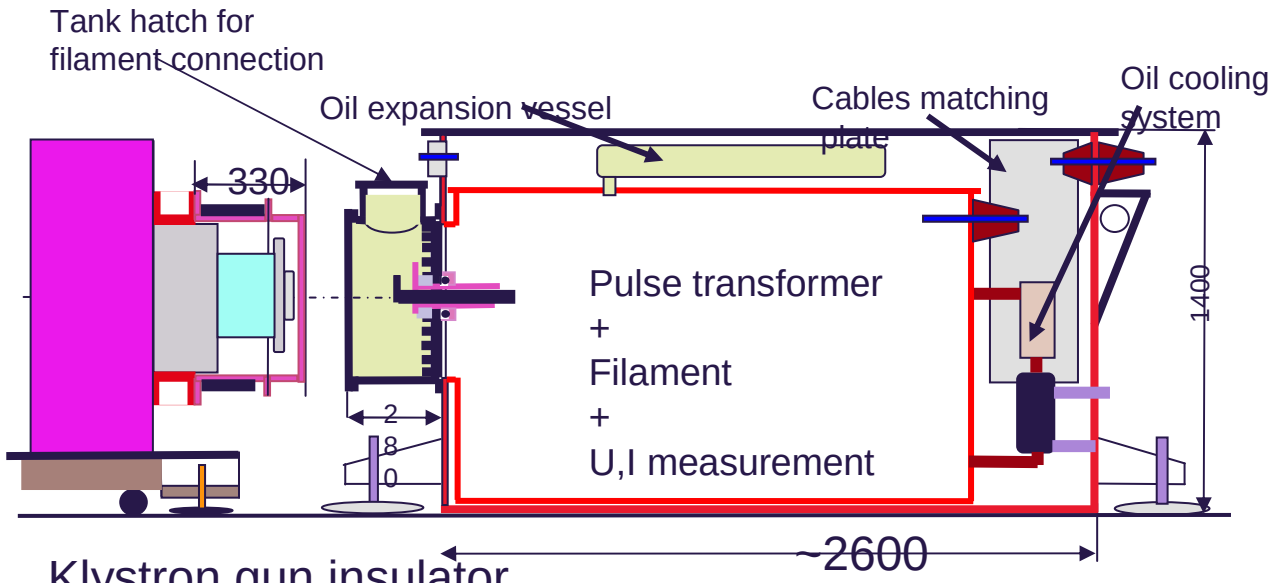




MBK to Pulse Transformer Connection

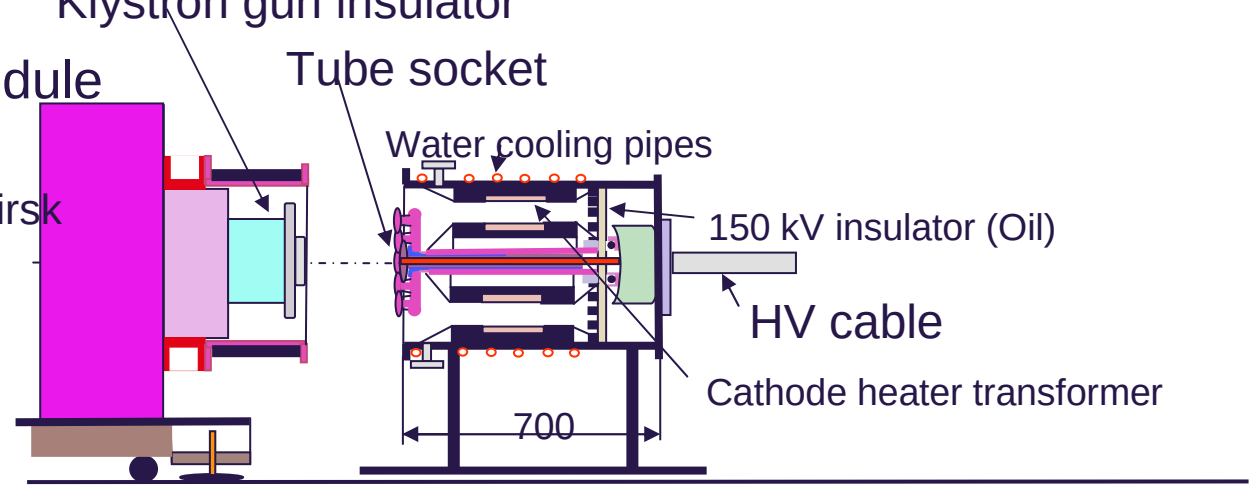
- Base line:

direct connection Klystron/PT



- Alternative:

Connection module being investigated with BINP/Novosibirsk



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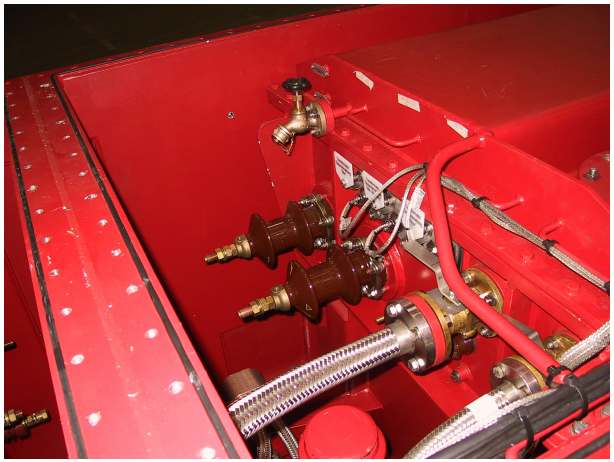
Pulse Transformer and Connection Module

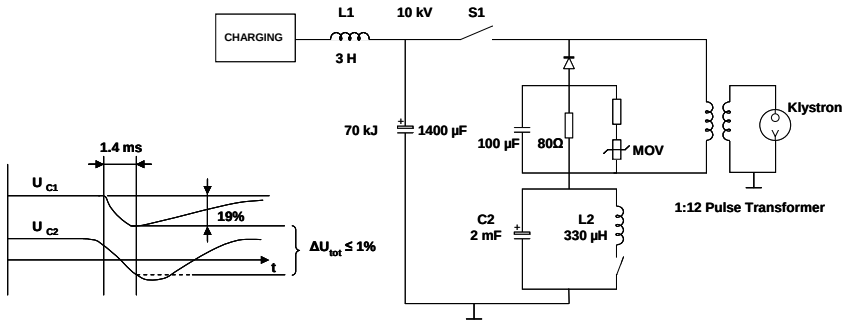


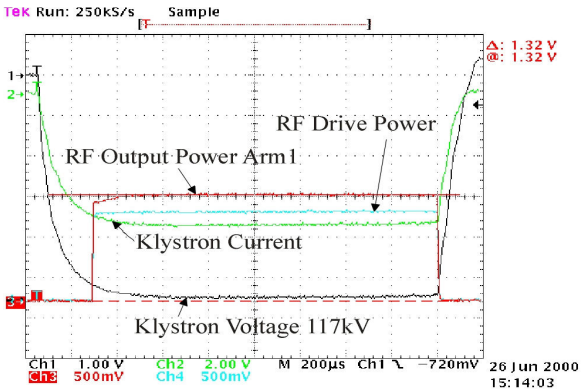
- Double wall pulse transformer (XFEL prototype) on DESY site

- Connection module will be tested with horizontal klystron.
- Cable between connection module and tank needs further investigation.

HV Pulse Modulator

- Modulators must generate HV pulses up to 120kV and 140A, 1.57ms pulse length and 10Hz (30Hz) repetition rate
- The bouncer type modulator with its simple circuit diagram was chosen as base line
- 11 bouncer type are now in operation at FLASH, PITZ and XFEL test stands since more than 15 years
- Although these work well and the vendor of the main pulse generating unit is a qualified supplier, additional suppliers are being reviewed





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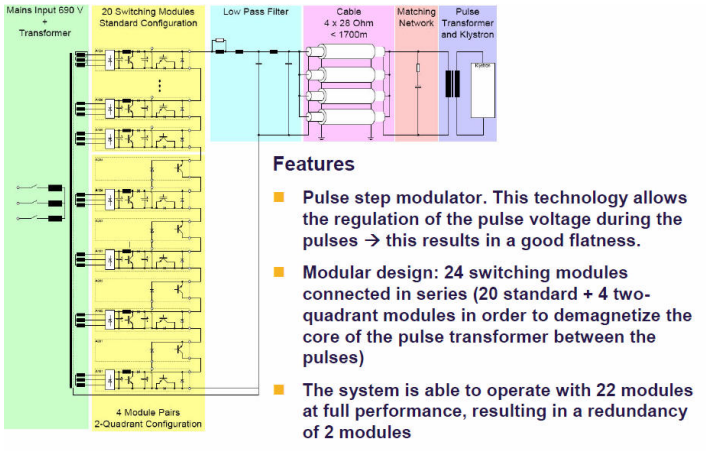
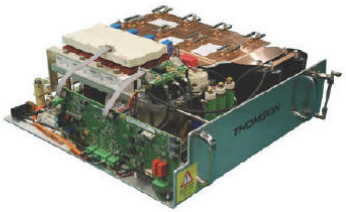
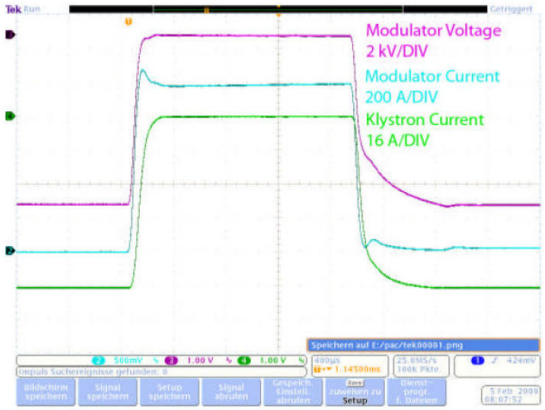
Alternative Modulators

- 1 PSM system constructed by Thomson BM in test at the MTS at DESY, Zeuthen (see pictures)
- 1 additional bouncer modulator still in development/construction at Imtech/Vonk





Nominal Pulse



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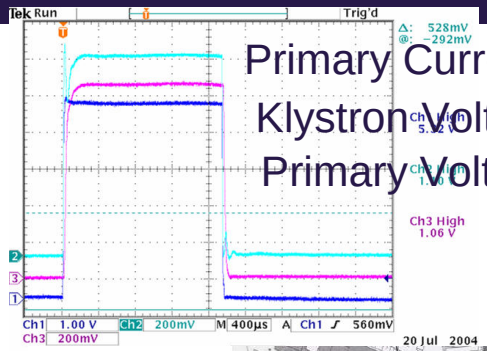
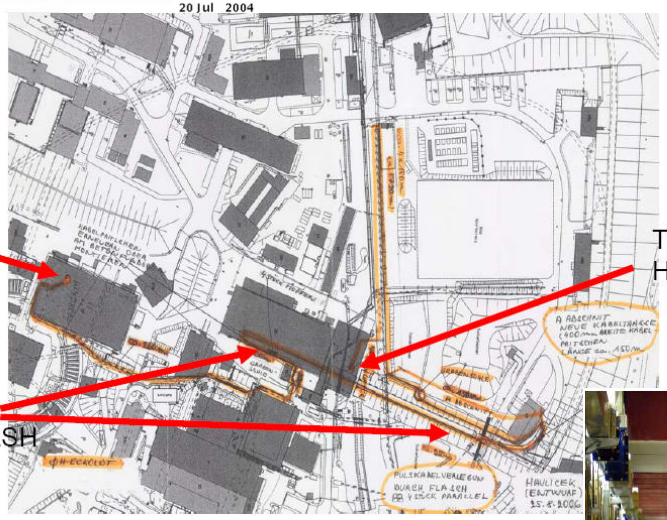
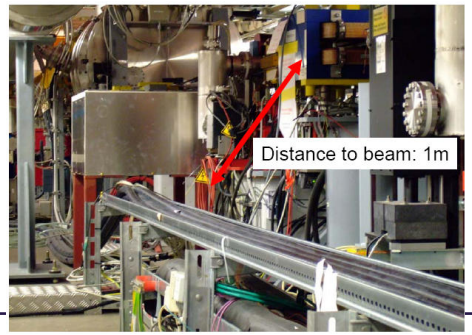
HV Pulse Cable

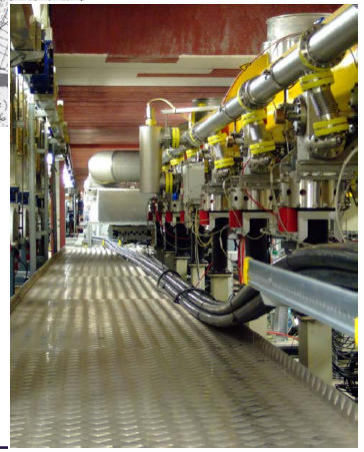
- Pulse transmission has been tested successfully at TTF/FLASH Modulator 5.
- EMI caused by cable required modification of modulator internal layout (lower leakage inductances, EMC cabinets, bouncer at high voltage potential).
- New modified modulator has been installed at DESY hall 2 and supplied HV pulses via a 1.5km long cable to a PT/Klystron in hall 3 (FLASH) during part of the 2007/08 operation period of FLASH, test has been successful.



Primary Current 1.1kA
Klystron Voltage 128kV
Primary Voltage 10.6kV







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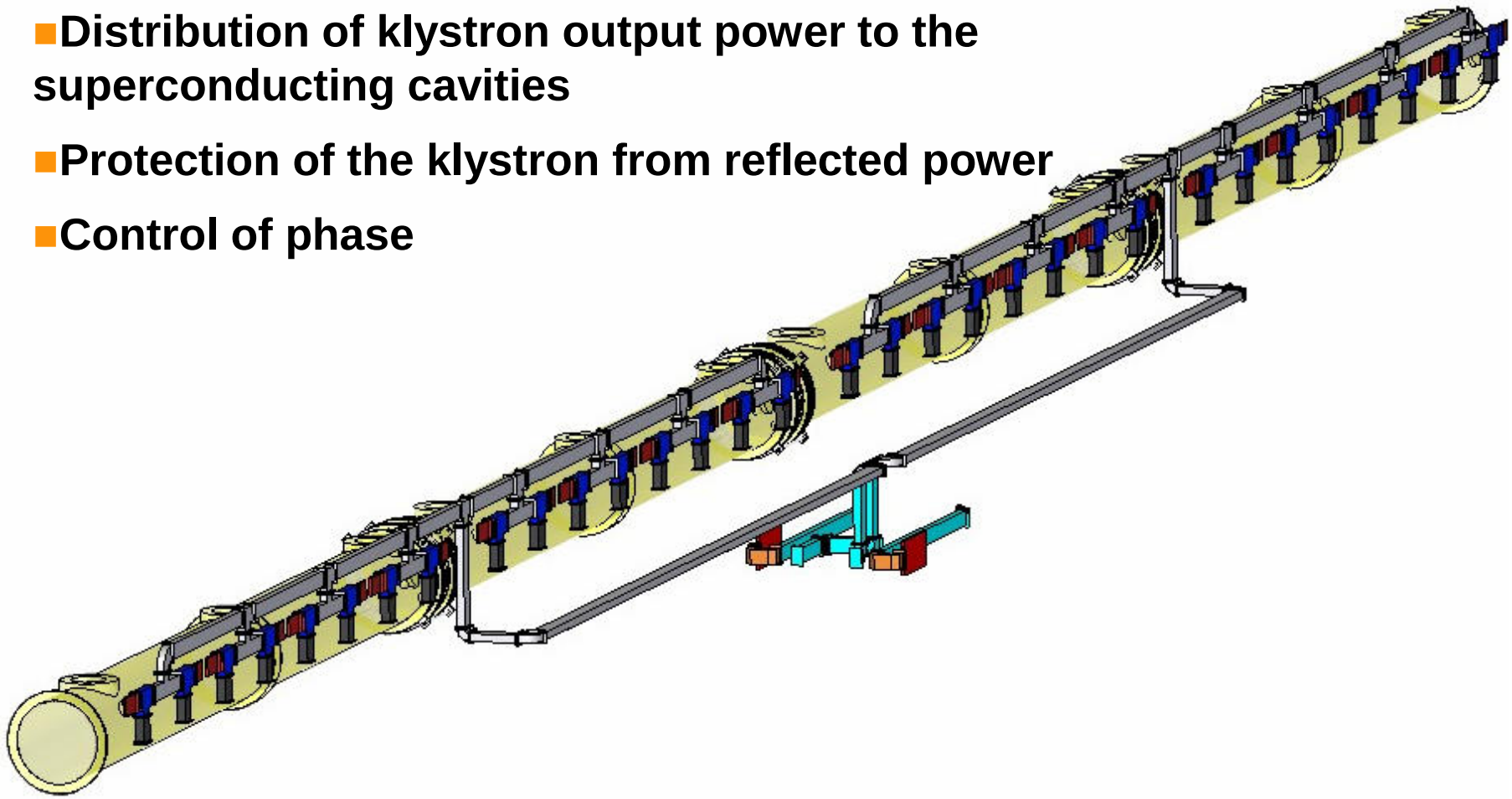
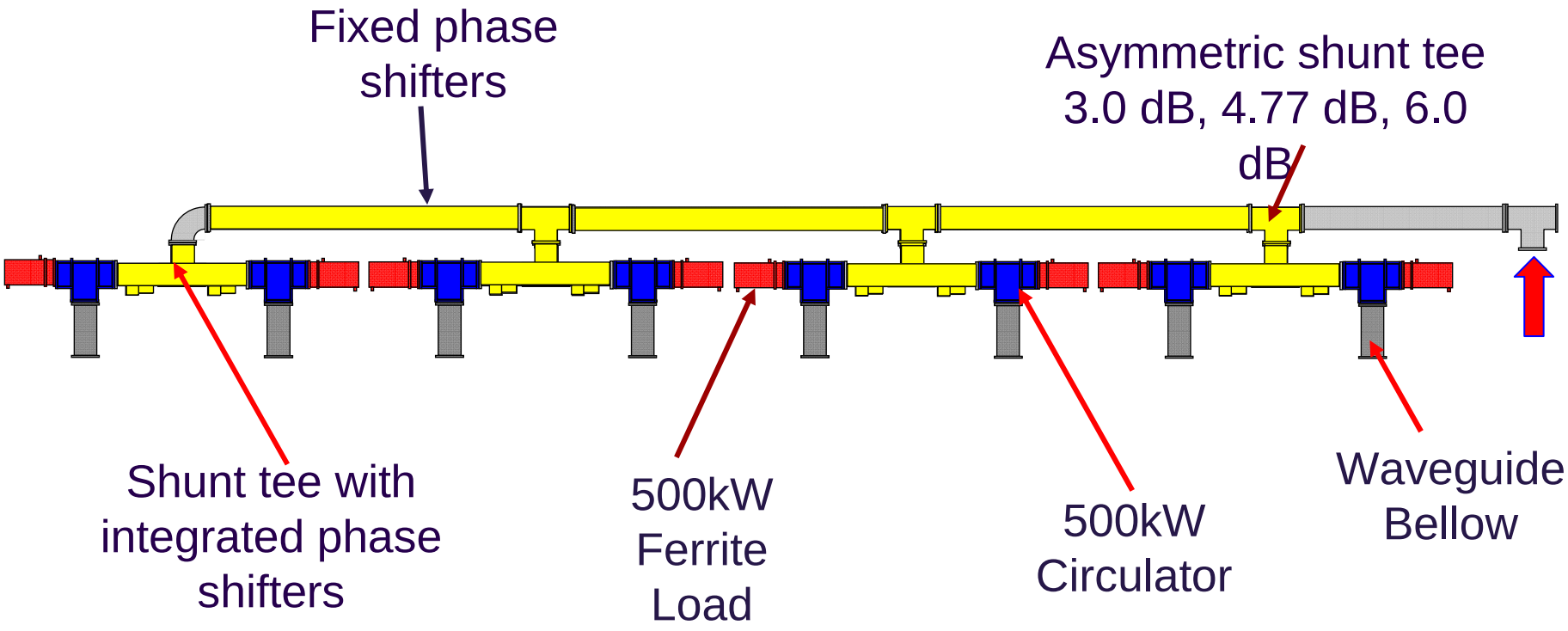
Waveguide Distribution

- Distribution of klystron output power to the superconducting cavities
- Protection of the klystron from reflected power
- Control of phase



Module Waveguide Distribution



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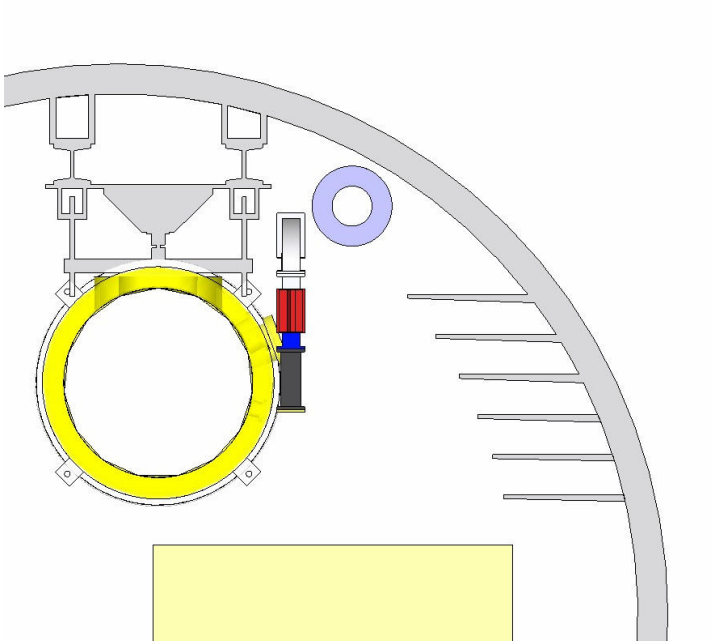
Test of XFEL distribution at FLASH

Waveguide in the XFEL Tunnel



XFEL type distribution at FLASH

XFEL type distribution at Mockup

- FLASH ACC7 will be XFEL module and equipped with XFEL type waveguide distribution.

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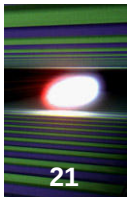
Appendix



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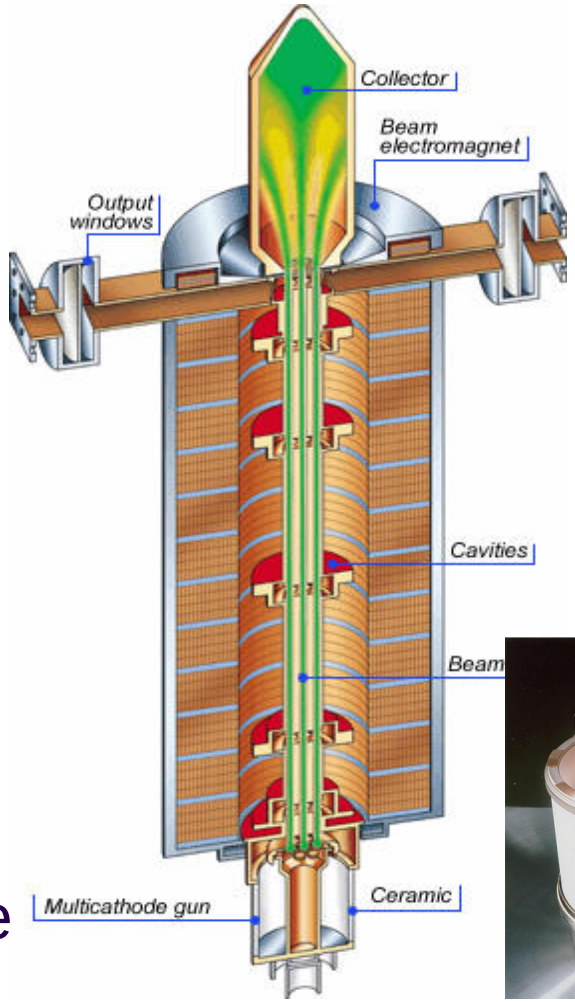
RF High Power Source

Requirements

- Operation Frequency: 1.3GHz
- Cathode Voltage: < 120 kV
- Beam Current: < 140 A
- Max. RF Peak Power: 10MW
- RF Pulse Duration: 1.5ms
- Repetition Rate: 10Hz
- RF Average Power: 150kW
- Efficiency: 65%
- Solenoid Power: < 5.5kW
- Length: 2.5m



Multibeam Klystrons (MBK) have been chosen

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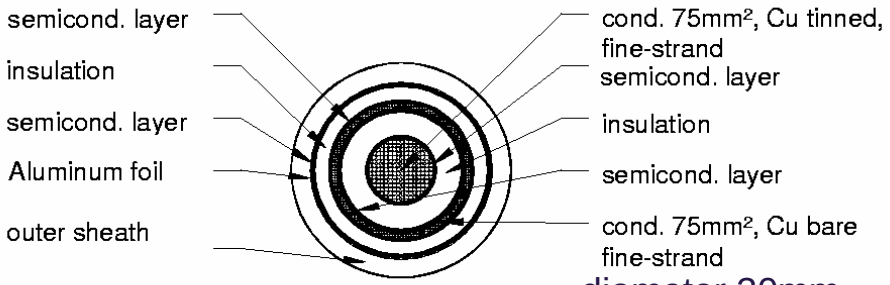
Horizontal MBKs

- With the exception of the RF gun klystrons, all MBKs shall be operated with air at atmospheric pressure at output window.
- Open point: Will the horizontal MBKs work reliable at 2 x 5MW with air at atmospheric pressure at output window? E_{max} at window is 14kV/cm at 2 x 5MW, $E_{airbreak}$ is 30kV/cm. Problem to test klystrons with loads in air at test stand.
- It seems that 3.5-4MW is reliable, this (7-8MW) is enough for the FEL (5.2MW). But our goal was 10MW.
- Alternative: e.g. flow of dry air with small overpressure (200mbar) from klystron to modules in waveguide.

HV Pulse Cable

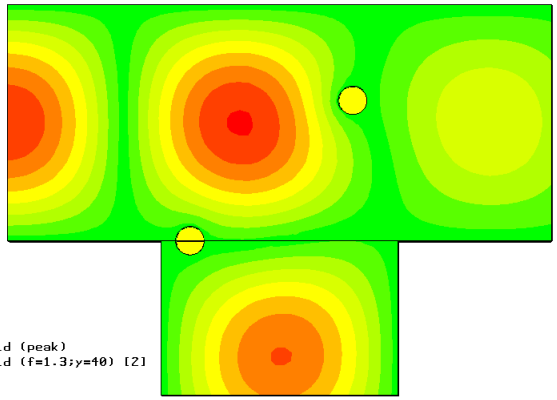
- Transmission of HV pulses (10kV, 1.6kA, 1.57ms, 10Hz (30Hz)) from the pulse generating unit (modulator hall) to the pulse transformer (accelerator tunnel)
- Maximum length 1.5km
- Impedance of 25 Ohms (4 cables in parallel will give 6.25 Ohms in total) to match the klystron impedance
- Triaxial construction (inner conductor, middle conductor, outer conductor at ground)



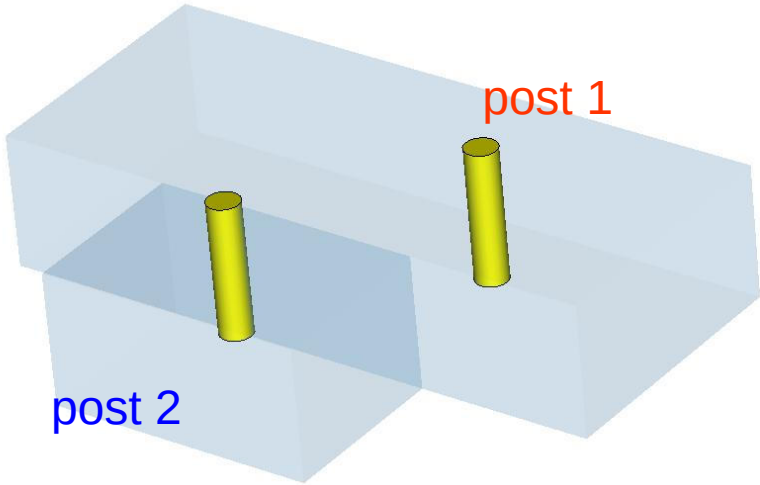
diameter 30mm
dielectric material: XLPE

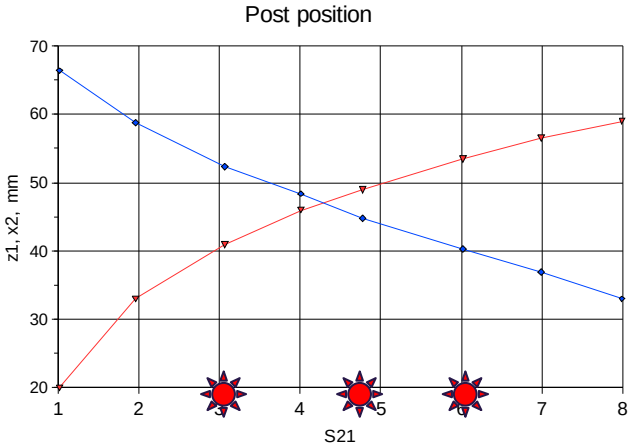
Asymmetric shunt tee

Coupling ratio 6dB



```
Type        = E-Field (peak)
Monitor     = e-field (f=1.3;y=40) [2]
Component   = Abs
Plane at y  = 40
Frequency   = 1.3
Phase       = 0 degrees
Maximum-2d  = 299.898 V/m at 20.6519 / 40 / -21.7887
```

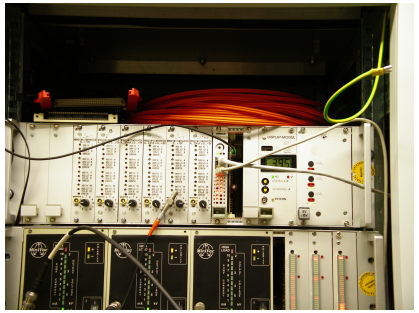




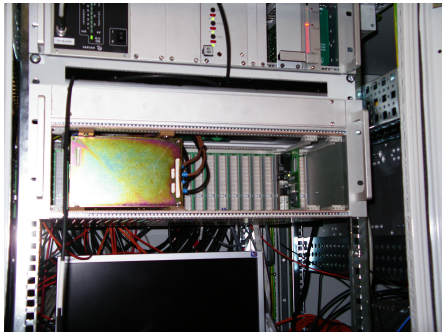
Interlock

- Modulator interlock is integral part of the modulator
- RF interlock is a DESY Zeuthen/HH development
- Both parts are connected by glass fibers
- FPGA based
- Version #2 in use at FLASH at present
- Version #3 installed at PITZ and module test facility, will be installed at FLASH too
- Version #3 allows setting of interlocks remote controlled
- The interlock will be installed in shielded racks in the accelerator tunnel

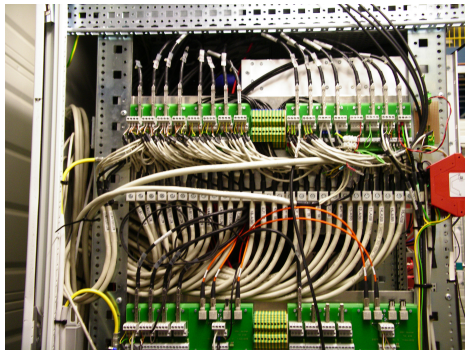
Front view



Rear view



Screen shot



Other Components

- Off the shelves PS will be used for the klystron solenoid, filament, vacuum pumps and pulse transformer core bias
- A semiconductor preamplifier will be used for amplification of the LLRF signals up to the klystron input level
- Components will be installed in shielded racks in the tunnel