Design and Status of the XFEL RF System

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for the XFEL Work Package High Power RF

Outline

- Introduction
- RF System Requirements
- RF System Main Components
  - RF Power Source
  - Modulator
  - RF Waveguide Distribution
  - Interlock
  - Other Components
  - LLRF
- Summary

Introduction

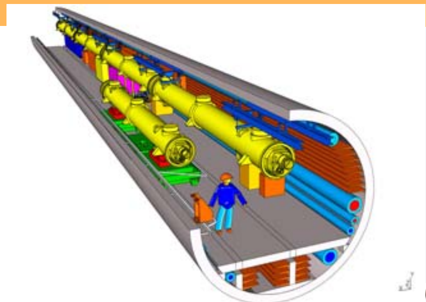
- Early 1990s start of the TESLA Collaboration
- In 1990s Tesla Test Facility (TTF) setup at DESY
- 2001 TESLA TDR of a Linear Collider with integrated XFEL
- 2002 Supplement to the TDR on a dedicated linac for the XFEL, negotiations started to build the XFEL as European project at DESY
- 2006 TDR of the European XFEL
- June 5, 2007 official launch of the project
- First beam expected for 2013

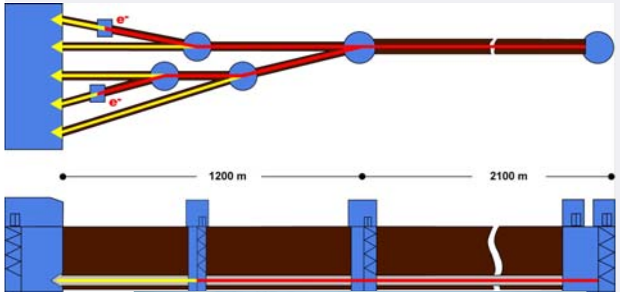
- 2004 ITRP recommended superconducting technology for a future Linear Collider

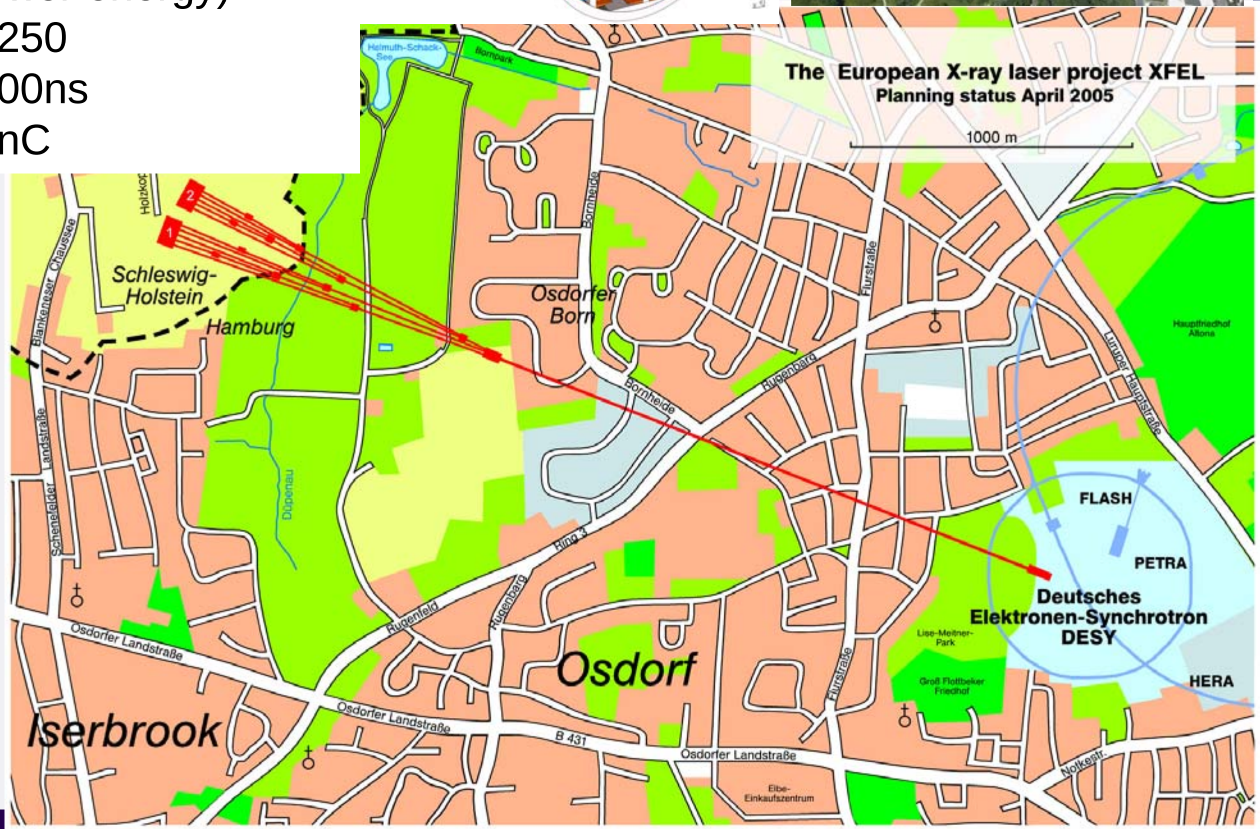
- Many of the developments for TESLA and the XFEL might be used for the ILC

Introduction

Linac energy:	17.5GeV (20GeV)
Wavelength:	down to 0.1nm
Beam pulse length:	650µs
Repetition rate:	10Hz (30Hz at lower energy)
# of bunches in pulse:	3250
Bunch to bunch spacing:	200ns
Bunch charge:	1nC

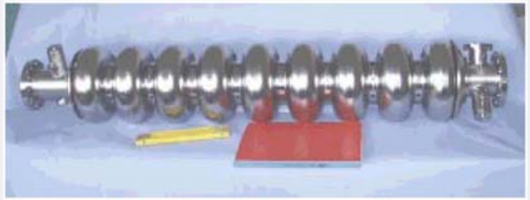


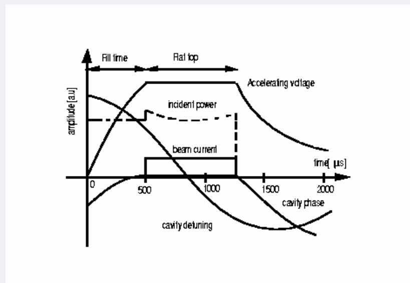




RF System Requirements

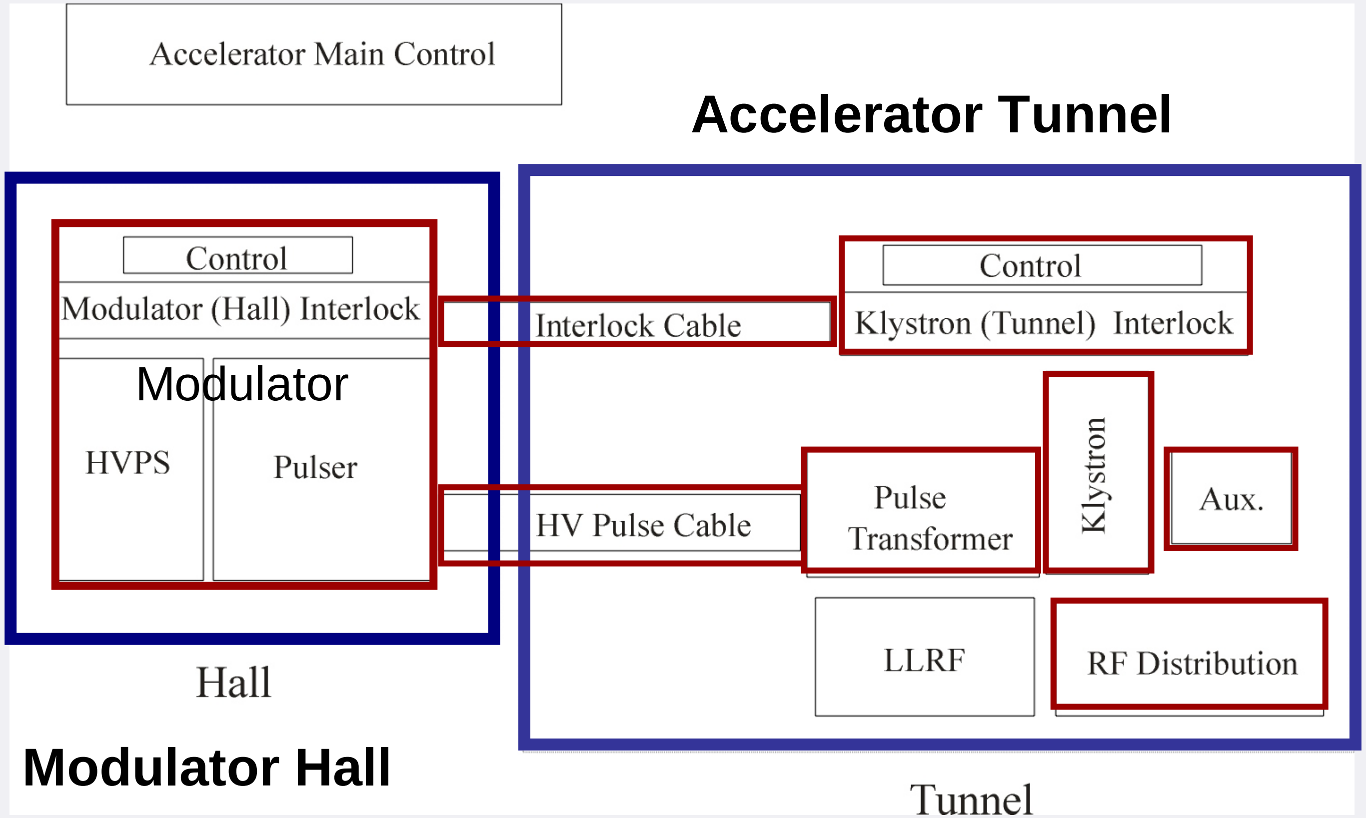
Number of sc cavities:	800 (928) total for 17.5GeV (20GeV)
Power per cavity:	122 kW
Gradient at 17.5GeV:	23.6 MV/m
Power per 32 cavities (4 cryo modules):	3.9MW
Power per RF station:	**5.2MW** (including 10% losses in waveguides and circulators and a regulation reserve of 15%)
Number of RF stations:	**25** (29), active **23** (26)
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)**





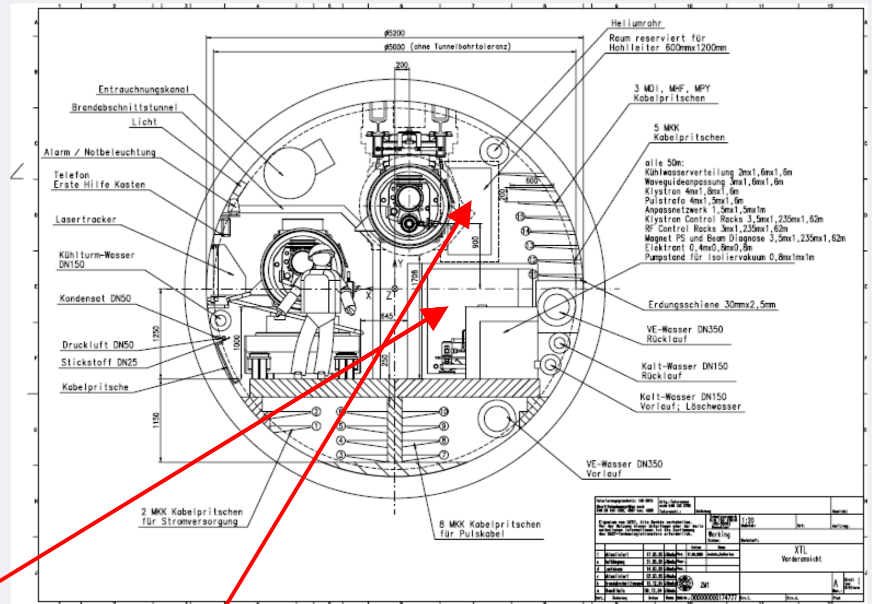
RF System Requirements

Layout of one RF Station



RF System Requirements

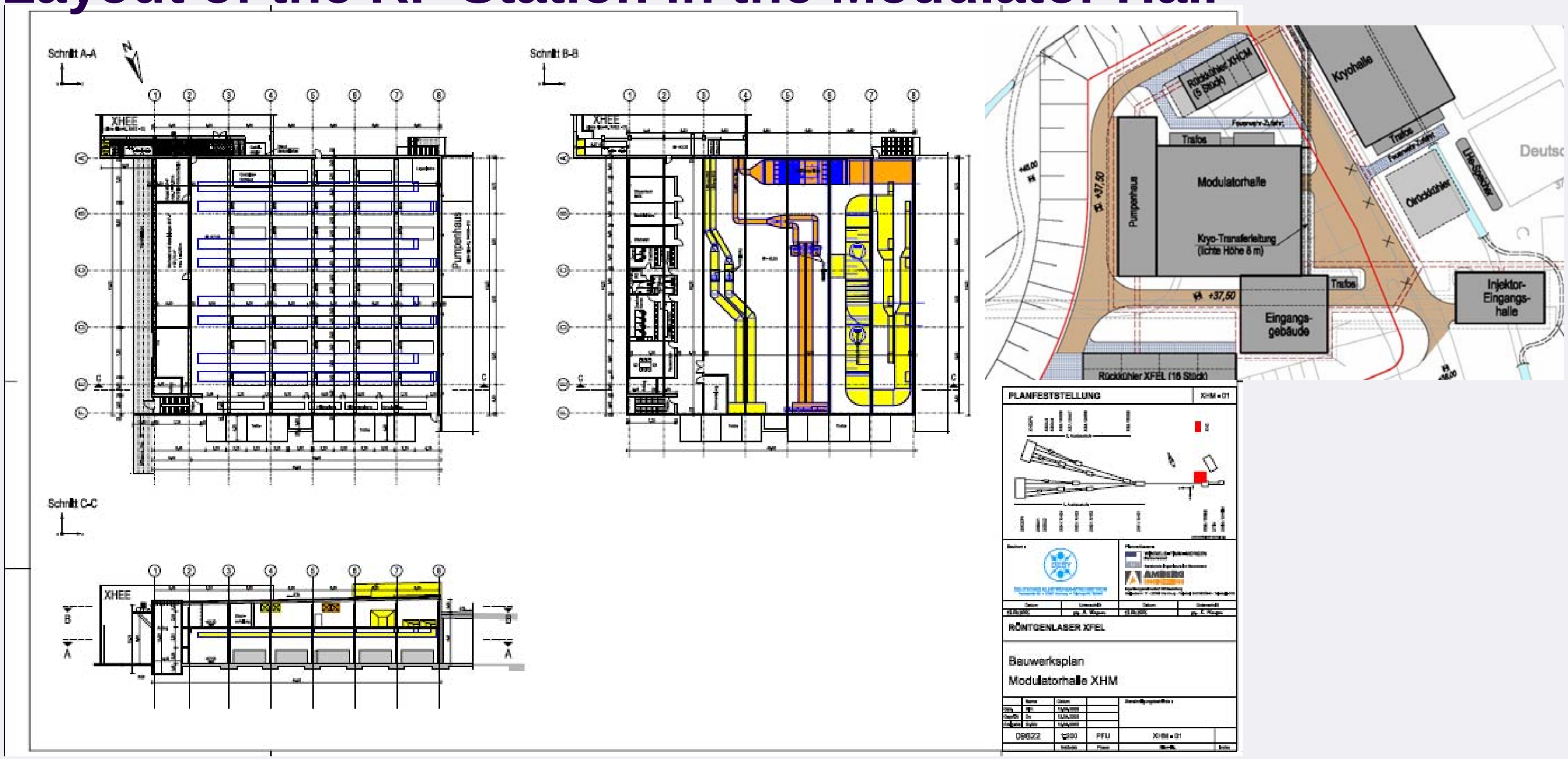
Layout of the RF Station in the Accelerator Tunnel



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

RF System Requirements

Layout of the RF Station in the Modulator Hall



•The modulators will be installed in the modulator hall.

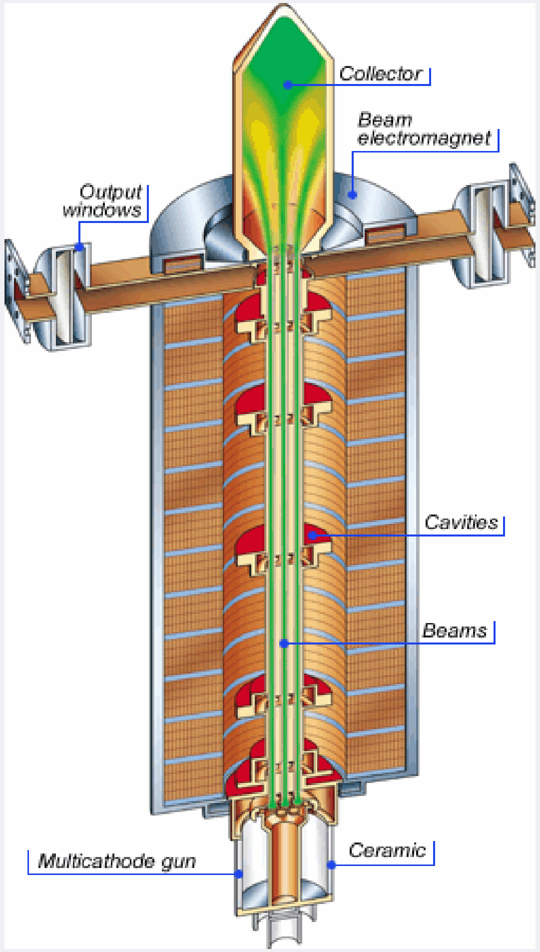
•Maintenance and repair is possible during accelerator operation.

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



RF High Power Source

3 klystron vendors have developed MBKs during the last years

THALES TH1801

CPI VKL8301

TOSHIBA E3736

RF High Power Source

Status of vertical MKB development

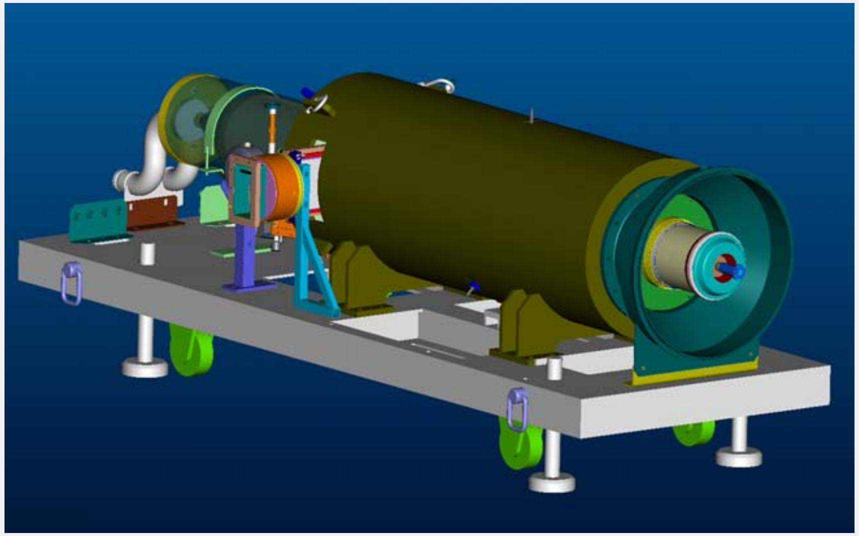
- 6 THALES TH1801 have been built, the last one has been tested successfully at THALES recently
  - best 10MW, 1.5ms,10Hz, 65% on matched load
  - typical 10MW, 1.5ms, 10Hz, 63%
  - klystrons in use at FLASH, PITZ, MBK test stand
  - several thousand hours of operation at different conditions
  - modifications have been made after early failures => no signs of degradation anymore
- 1 TOSHIBA E3736 at DESY
  - 10.4MW, 1.5ms, 10Hz, 66%
  - 750h, ~80% at full power
- 1 CPI VKL8301 at DESY
  - 8.1MW, 1.3ms, 10Hz, 53.5%

RF High Power Source

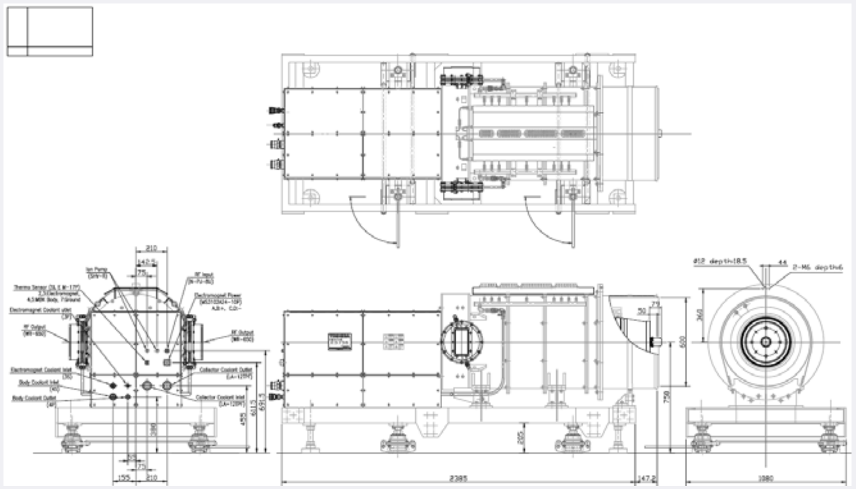
Horizontal MBK prototypes

- Horizontal versions of MBKs by all 3 vendors are under construction (THALES, TOSHIBA, CPI)
- First klystron expected for second half of 2007

THALES TH1802



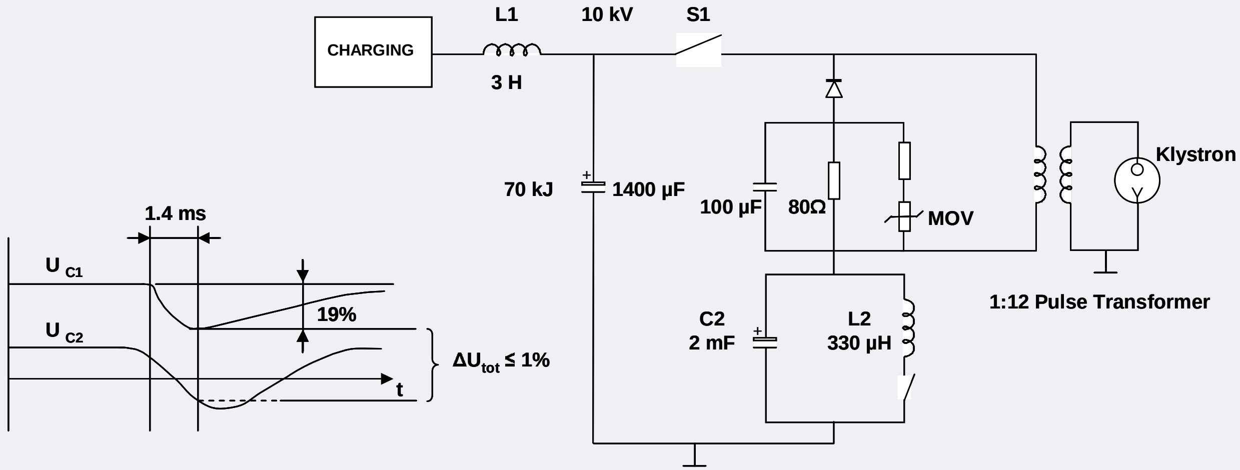
TOSHIBA E3736H



Modulator

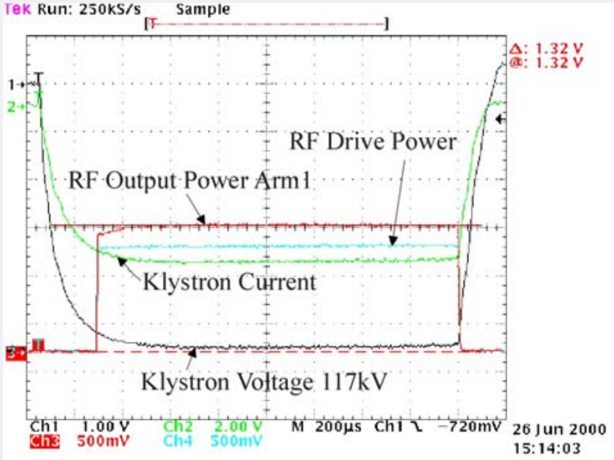
Modulator Requirements

- Modulators must generate HV pulses up to 120kV and 140A, 1.57ms pulse length and 10Hz (30Hz) repetition rate
- The top of the pulse must be flat within 1%
- The bouncer type modulator with its simple circuit diagram was chosen



Modulator

Bouncer Modulator



- 3 modulators have been developed, built and delivered to TTF by FNAL since 1994
- They are continuosly in operation at different operation conditions

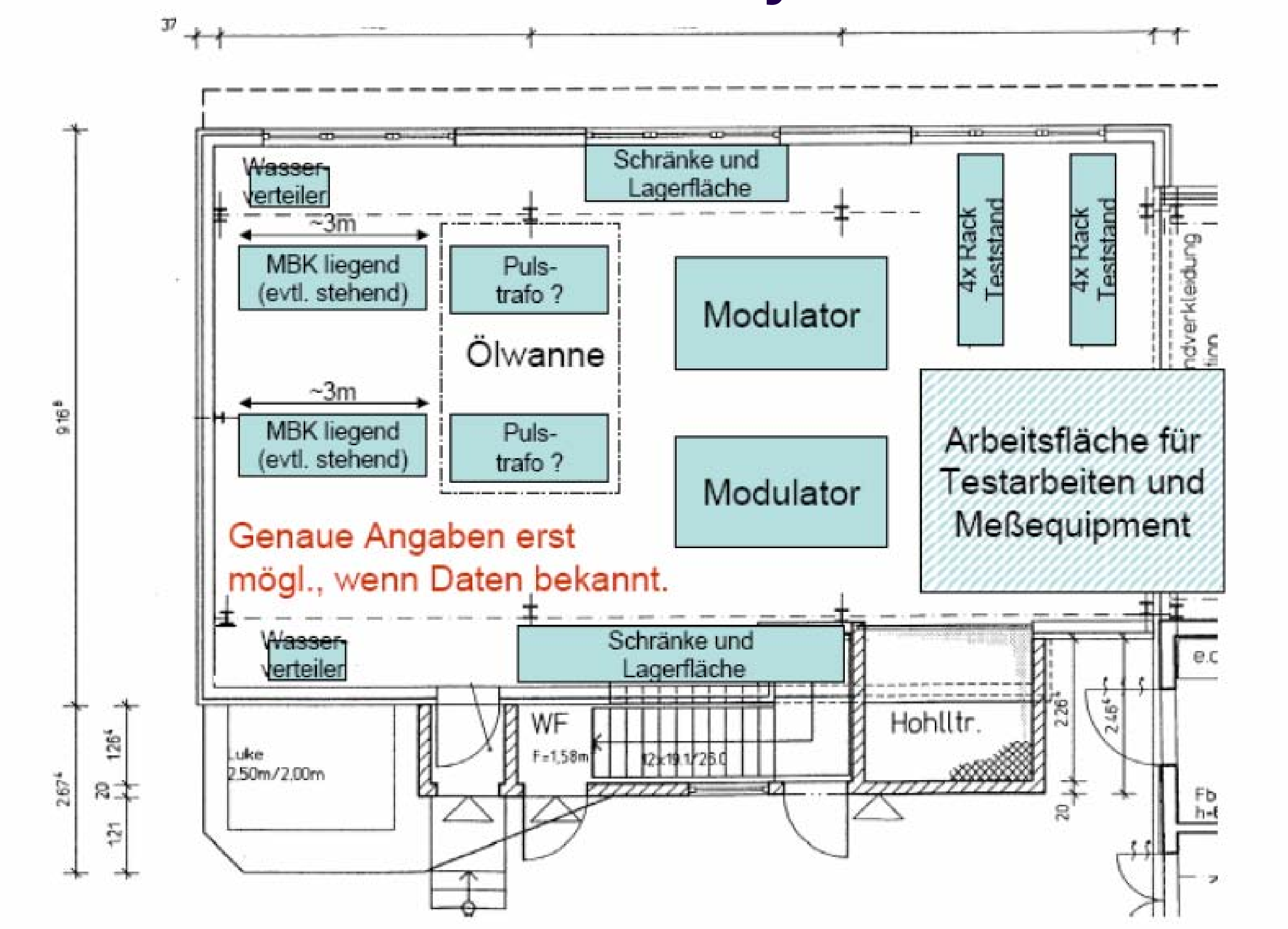
Modulator

Bouncer Modulator

- Industry made subunits (PPT, ABB, FUG, Poynting)
- Constant power power supply for suppression of 10Hz repetition rate disturbances in the mains
- Compact storage capacitor bank with self healing capacitors
- IGCT Stack (ABB); 7 IGCTs in series, 2 are redundant
- Low leakage inductance pulse transformer (ABB) L<200µH resulting in shorter HV pulse rise time of <200µs
- Light Triggered Thyristor crowbar avoiding mercury of ignitrons

Modulator

Planned Modulator Test Facility at DESY in Zeuthen

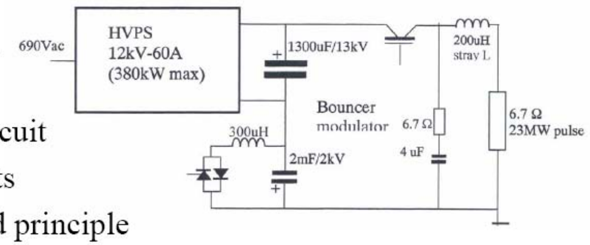


Modulator

Qualification of additional vendors

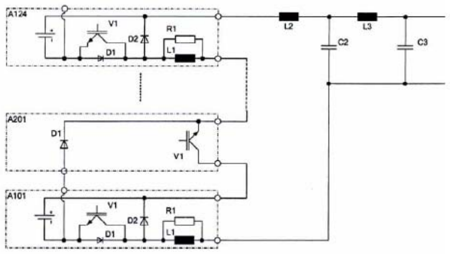
Bouncer Modulator by Imtech/Vonk

- Bouncer Type, as specified by DESY
  - 12kV HVPS
  - Bouncer 300uH/4.6kA
- 7st IGCT main switch
- Digital Regulation Circuit
- Analog In- and Outputs
- Well known and tested principle
- delivery time: 12 month



PSM Modulator by Thomson BM

- Different Type:
  - 12kV/2kA w. transformer
  - Pulse Width Modulation
  - 24 switching stages in series
  - FPGA based control
  - 2 stages for redundancy
- Slew rate and pulse shape controllable
- detailed description available, principle already successfully tested (worldwide, i.e. W7/X)
- delivery time: 14 month

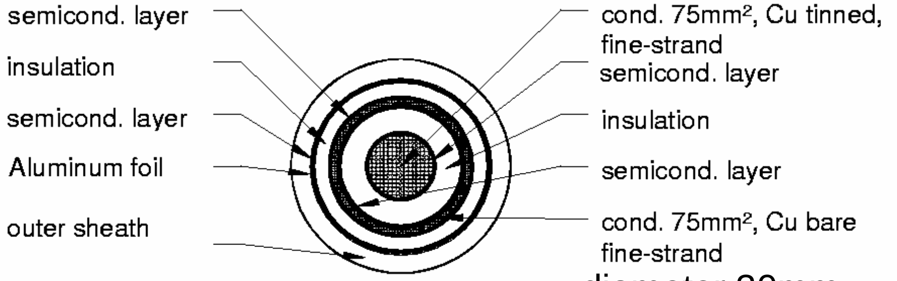


Installation at DESY, location Zeuthen, scheduled for spring 2008

Modulator

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)

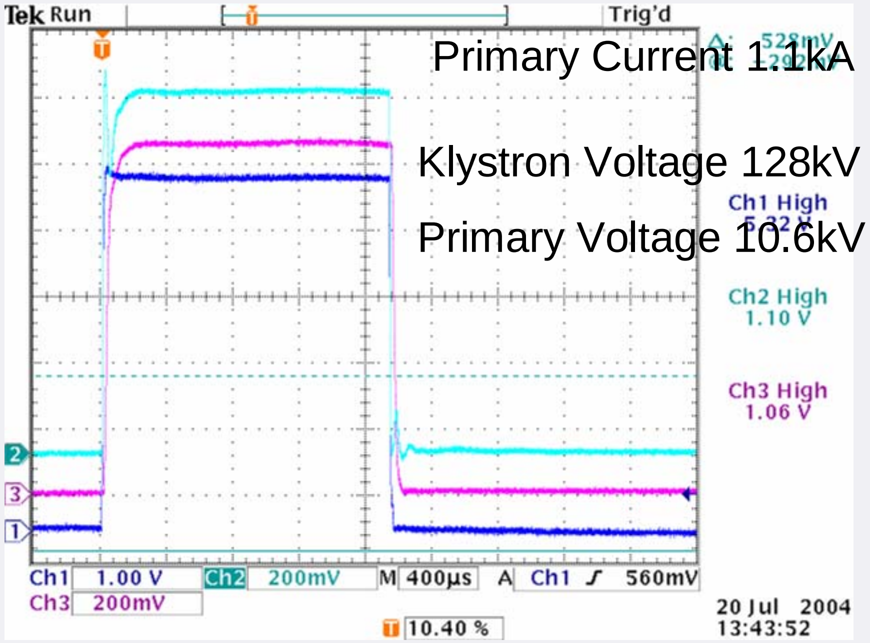


diameter 30mm
dielectric material: XLPE

Modulator

HV Pulse Cable Test

- 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 is installed at DESY hall 2 and will supply HV pulses via a 1.5km long cable to a PT/Klystron in hall 3 (FLASH) during part of the next operation period of FLASH



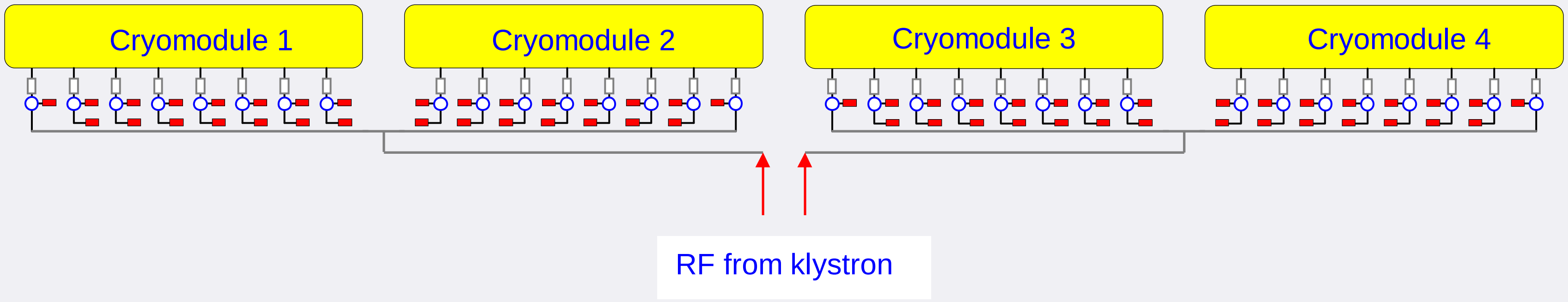
Modulator

Status Modulator

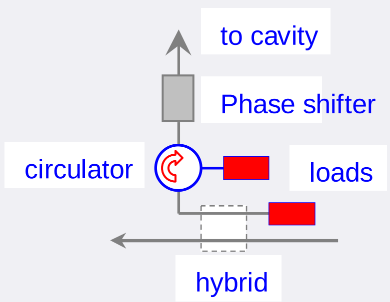
- 11 bouncer modulators have been built, 3 by FNAL and 8 together with industry
- 11 modulators are in operation (FLASH, PITZ, XFEL test stands)
- More than 10 years of operation experience
- A new modulator is installed in DESY hall 2 and connected to PT and klystron in hall 3 (Bouncer type plus improvements) and will be used for pulse cable tests
- Order for more XFEL prototypes has been placed (1 bouncer type plus 1 PSM type)
- Test of prototypes at DESY, location Zeuthen, scheduled to start spring 2008

Waveguide Distribution

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



DETAIL



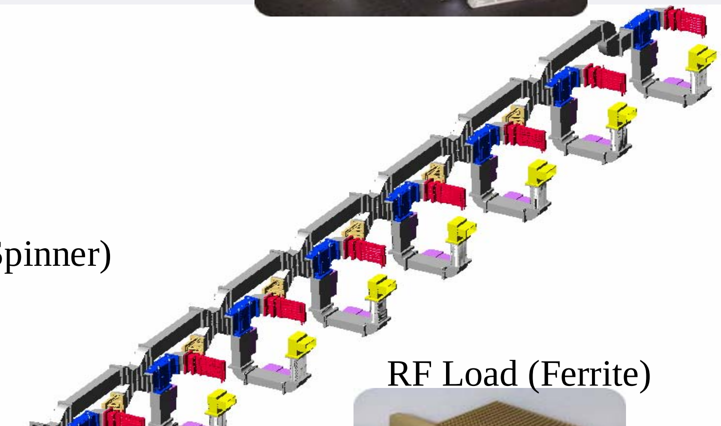
Waveguide Distribution

Many waveguide components have been developed during the last years and have been used for the operation of TTF/FLASH

3 Stub Tuner (IHEP, Bejing, China)

E and H Bends (Spinner)

Circulator (Ferrite)



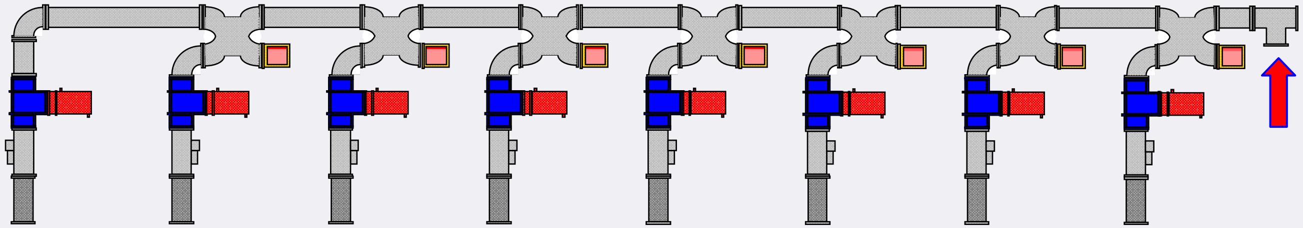
Hybrid Coupler (RFT, Spinner)

RF Load (Ferrite)

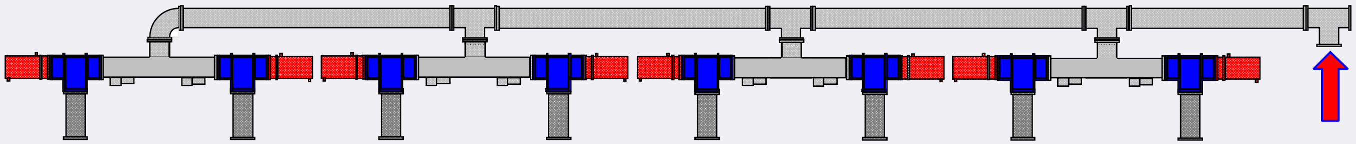
RF Load (Ferrite)

Waveguide Distribution

- Standard FLASH like distribution (linear system)

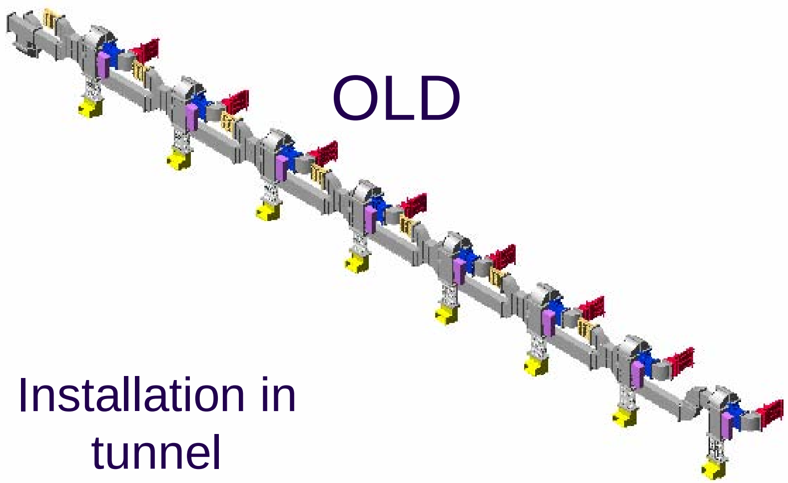


- Combined system with shunt tees (linear system with binary cells)
- Advantages: less space, less parts, less weight, lower costs

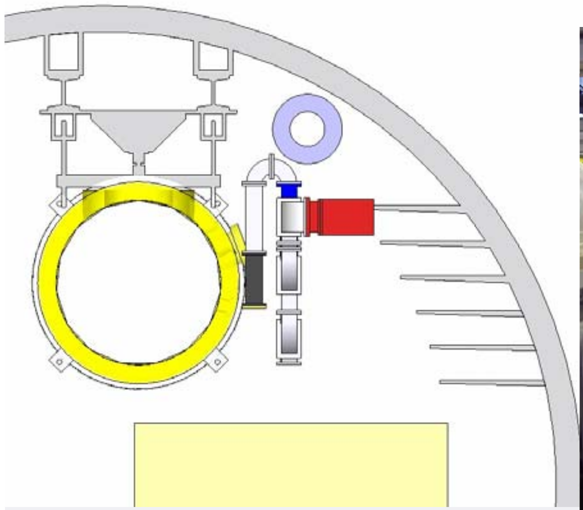


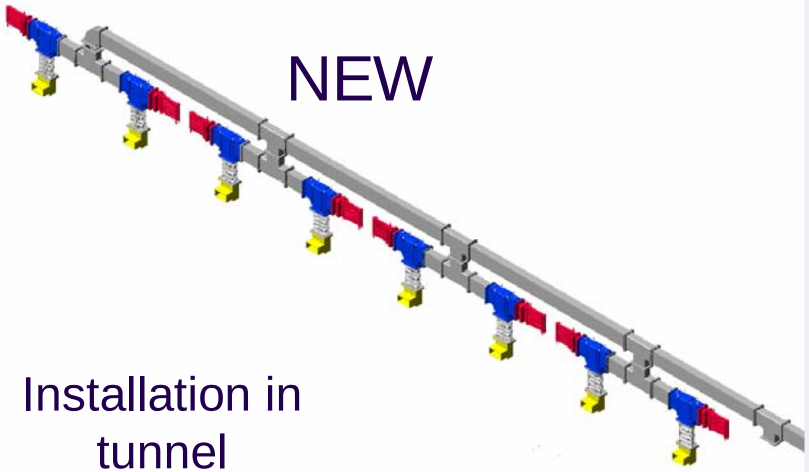
- The new distribution has been tested on a test stand at DESY and will be used with ACC6 at TTF / FLASH

Waveguide Distribution

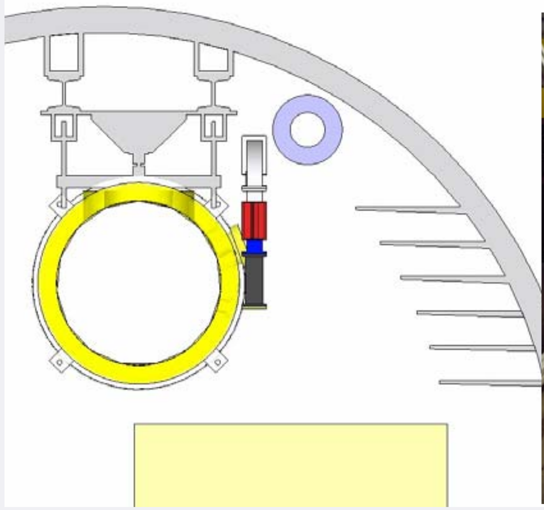


Installation in tunnel

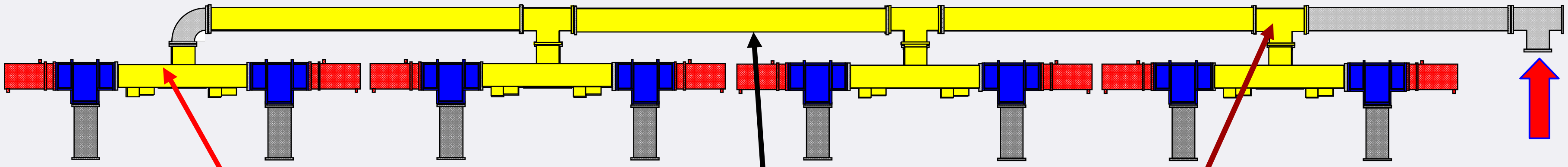




Installation in tunnel



Waveguide Distribution



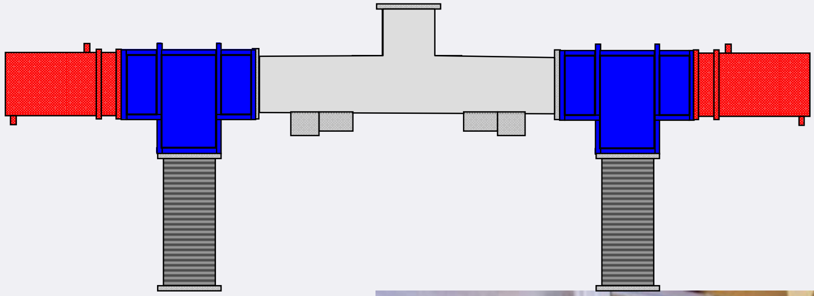
Shunt tee with integrated phaseshifters

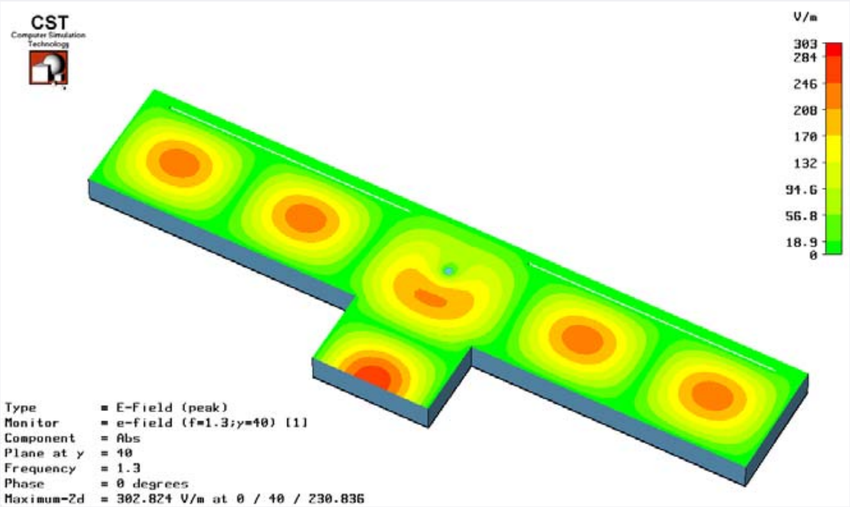
Asymmetric shunt tee 3.0 dB, 4.77 dB, 6.0 dB

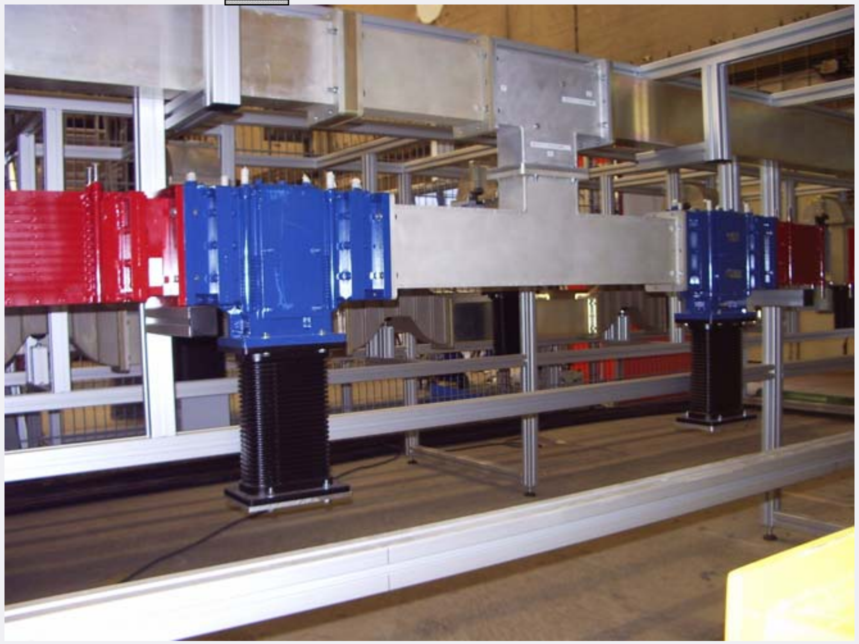
Fixed phase shifters

Waveguide Distribution

New binary cell with shunt tee with integrated phase shifter



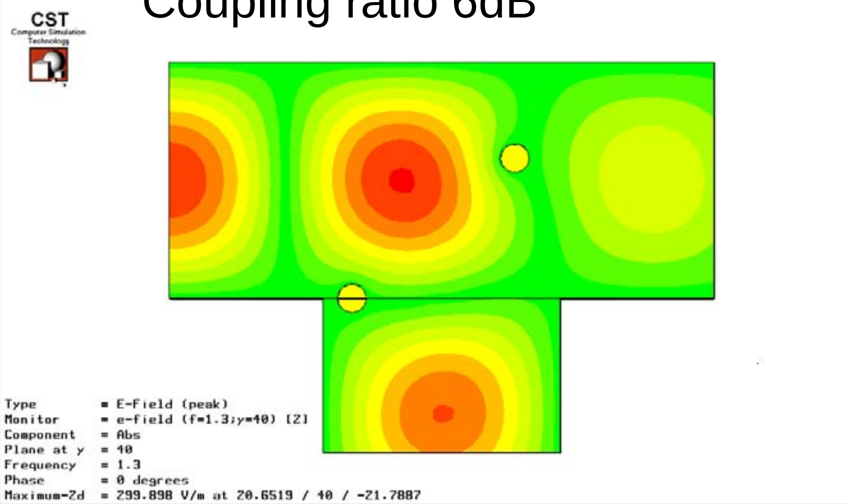


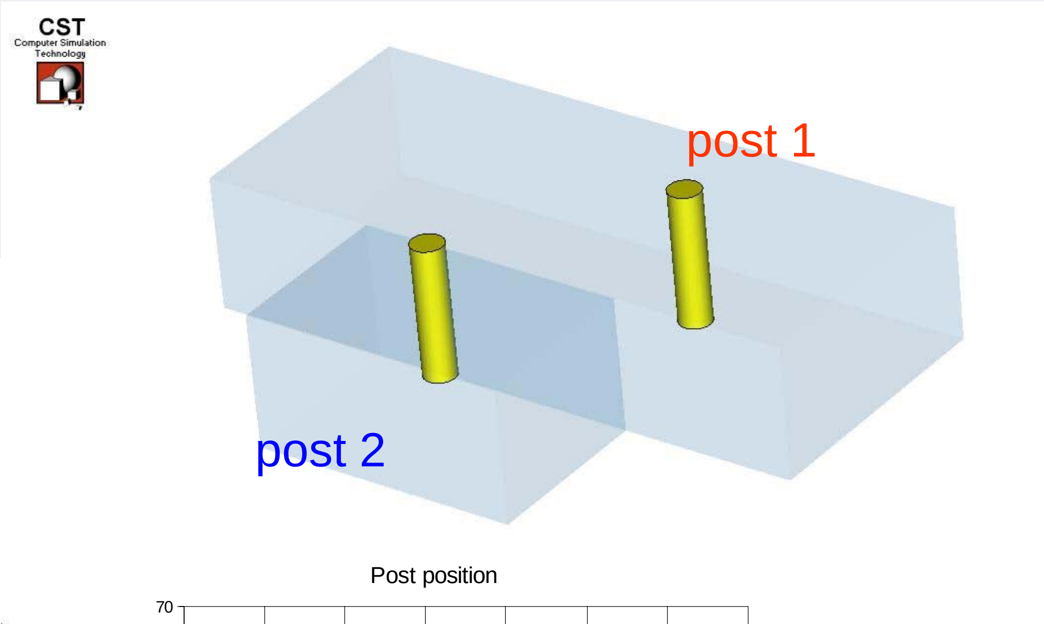


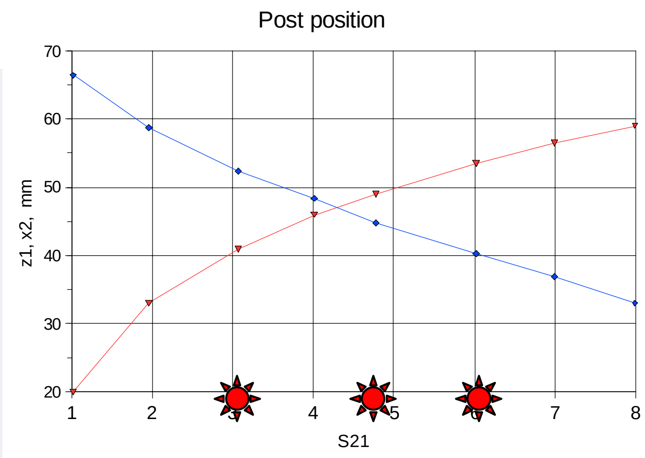
Waveguide Distribution

Asymmetric shunt tee

Coupling ratio 6dB



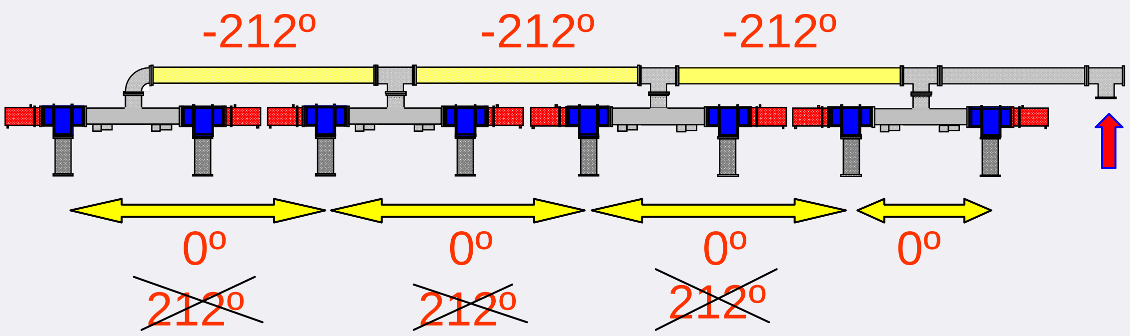


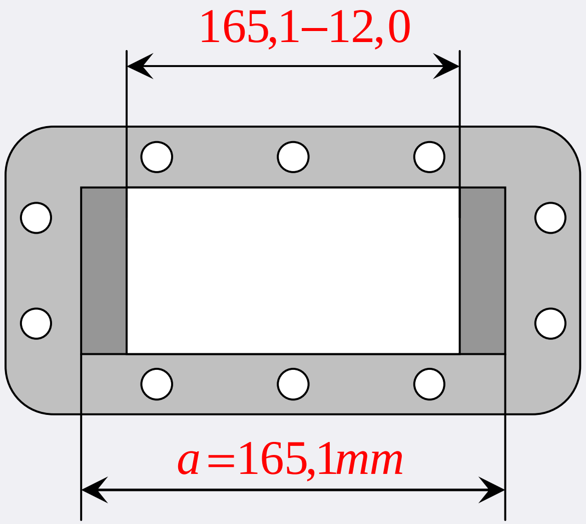


Waveguide Distribution

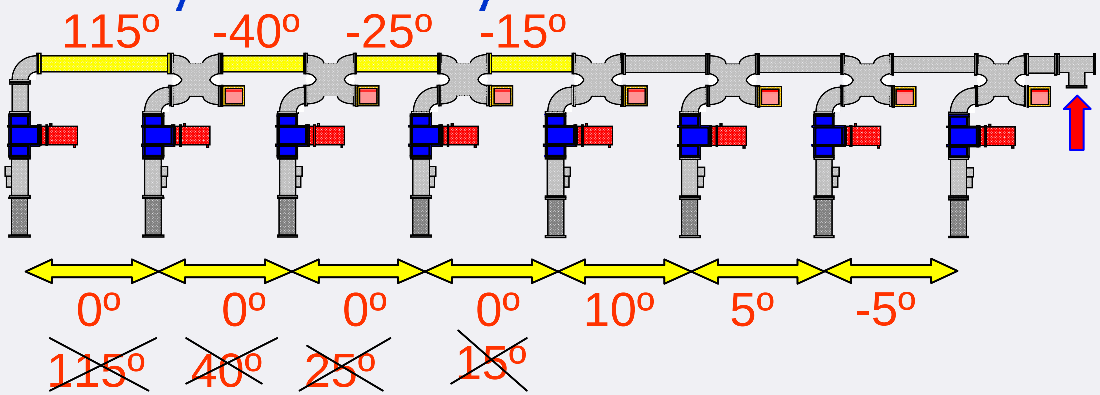
Phasing of waveguide distribution

Combined system with asymmetric shunt tees





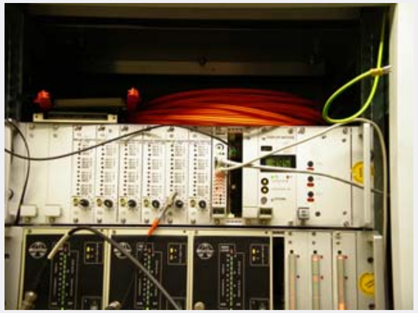
Linear system with hybrids - FLASH like



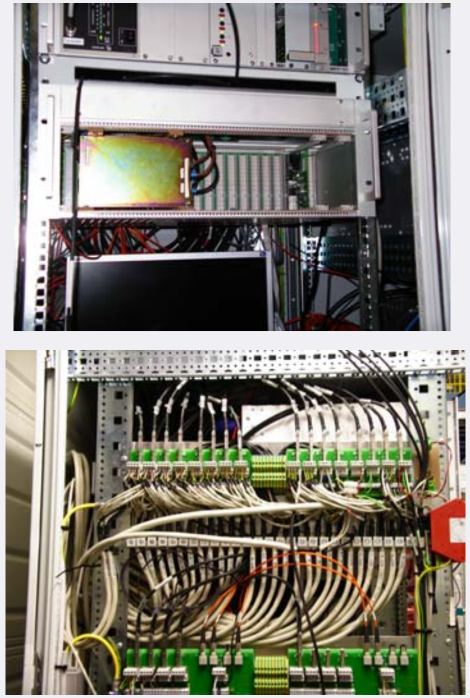
Interlock

- 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



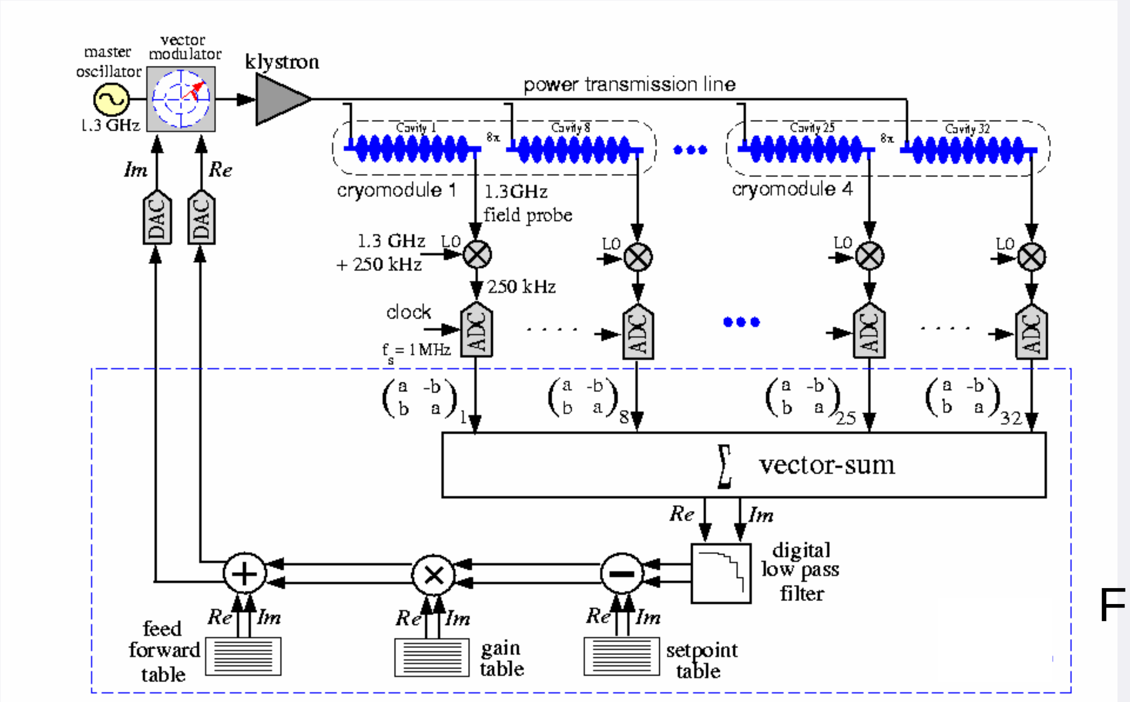
Screen shot

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

LLRF

- Digital system
- Feedback plus feedforward
- Extensive diagnostics and exception handling



FPGA System

Summary

- All components for the XFEL RF system have been designed and constructed during the last years.
- Modifications of some components allowing the installation in the accelerator tunnel and qualification of additional vendors are being continued.
- Determined by the XFEL schedule first RF system components must be delivered early 2009 for the various component test facilities.
- The components for the XFEL injector must be received only shortly after. However delivery of the major amount of all components is planned for 2010 to 2012.