Fourth CW and High Average Power RF Workshop

Coaxial switch, high power load and higher harmonic absorber for PROSCAN

Markus Schneider, RF power amplifier

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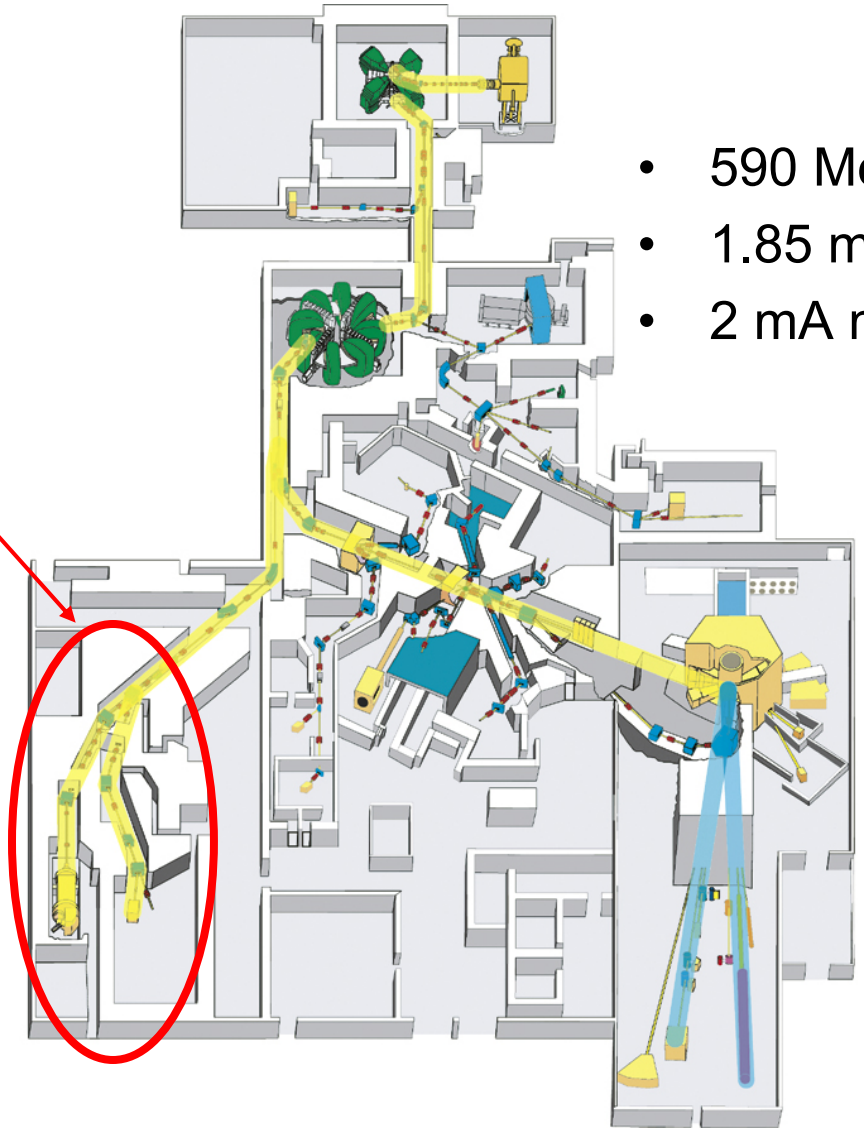
Proton accelerator facility

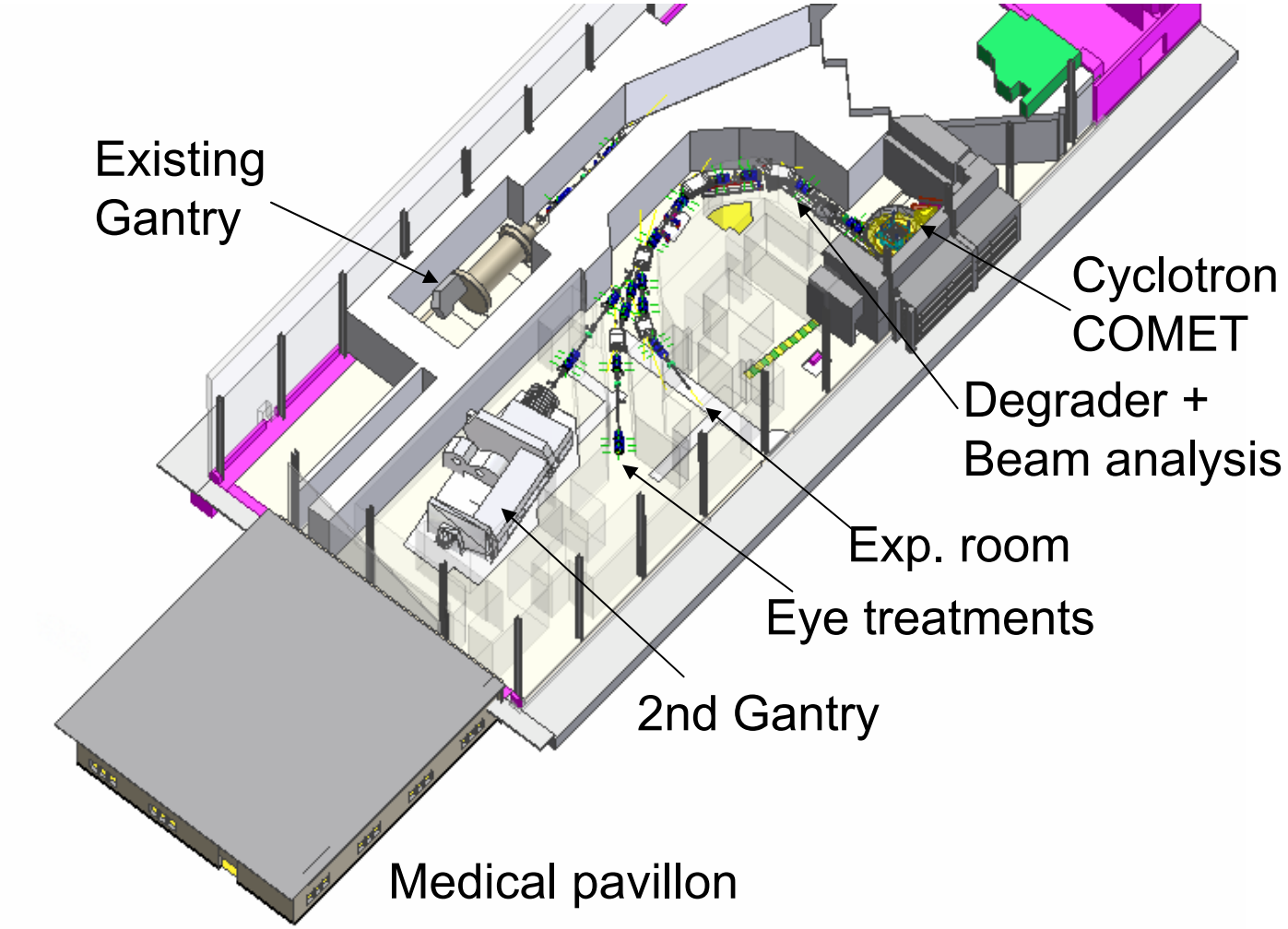


- 590 MeV proton beam
- 1.85 mA operational beam current
- 2 mA max achieved beam current

Protons beam

Neutrons beam

PROSCAN

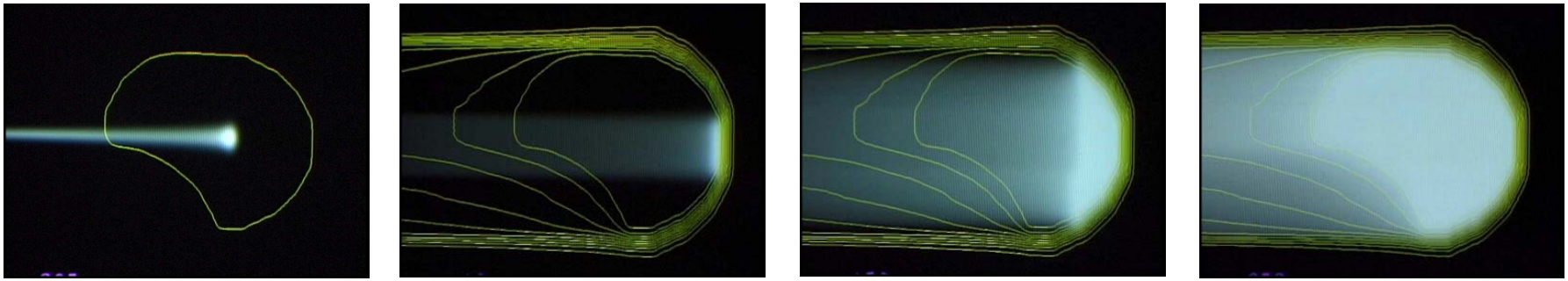

Existing
Gantry
Cyclotron
COMET
Degrader +
Beam analysis
Exp. room
Eye treatments
2nd Gantry
Medical pavillon

PROSCAN

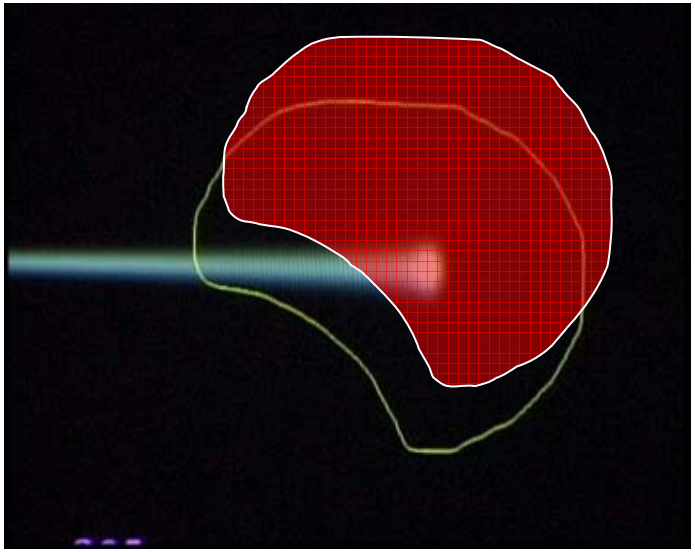
Existing Gantry

Medical pavillon

Spot scanning technique at PSI



Proton pencil beam scans the tumor in 3 dimensions → 3D : lateral + depth



Dynamical treatments

Danger to underdose and overdose

PROSCAN approach:

Maximum flexibility for research of strategies

- Multiple scans of tumor
- increase scan speed
- intensity modulation

COMET Cyclotron

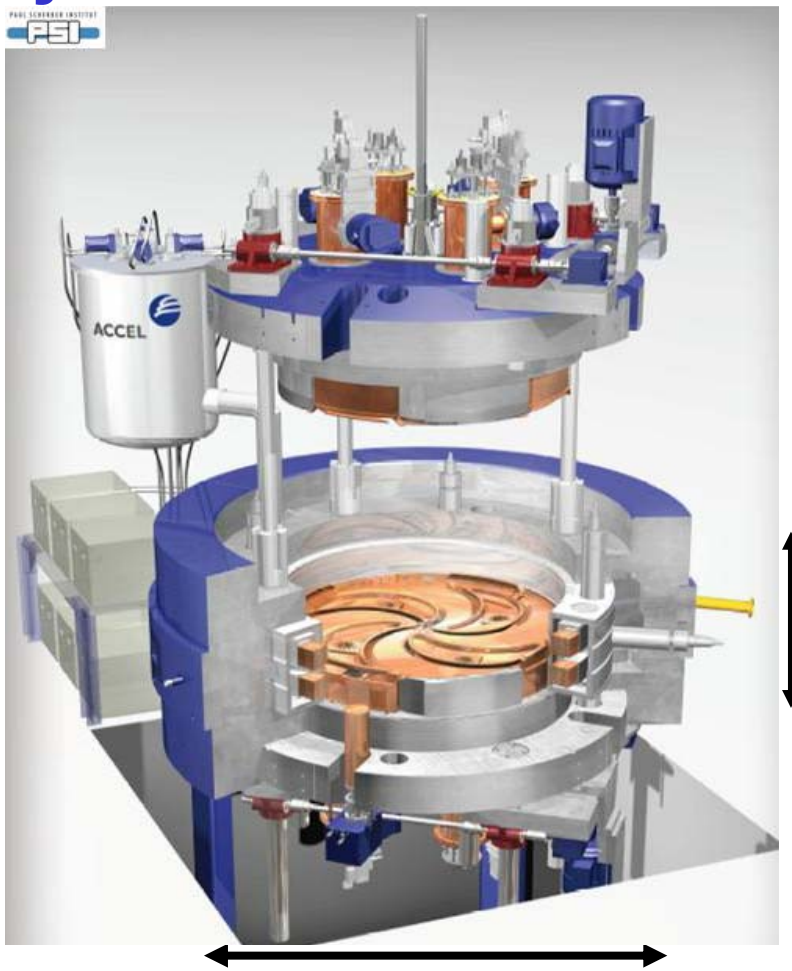
new cyclotron for proton therapy: 250 MeV, 500 nA

superconducting coils

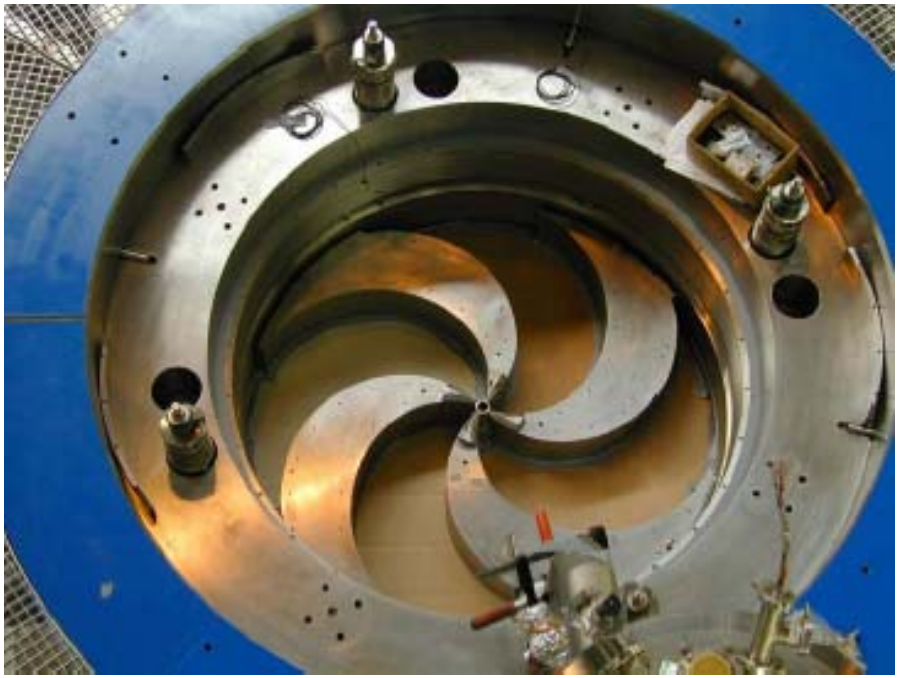
basic design: NSCL (H. Blosser)

manufactured by

ACCEL



COMET Cyclotron



Magnet sectors

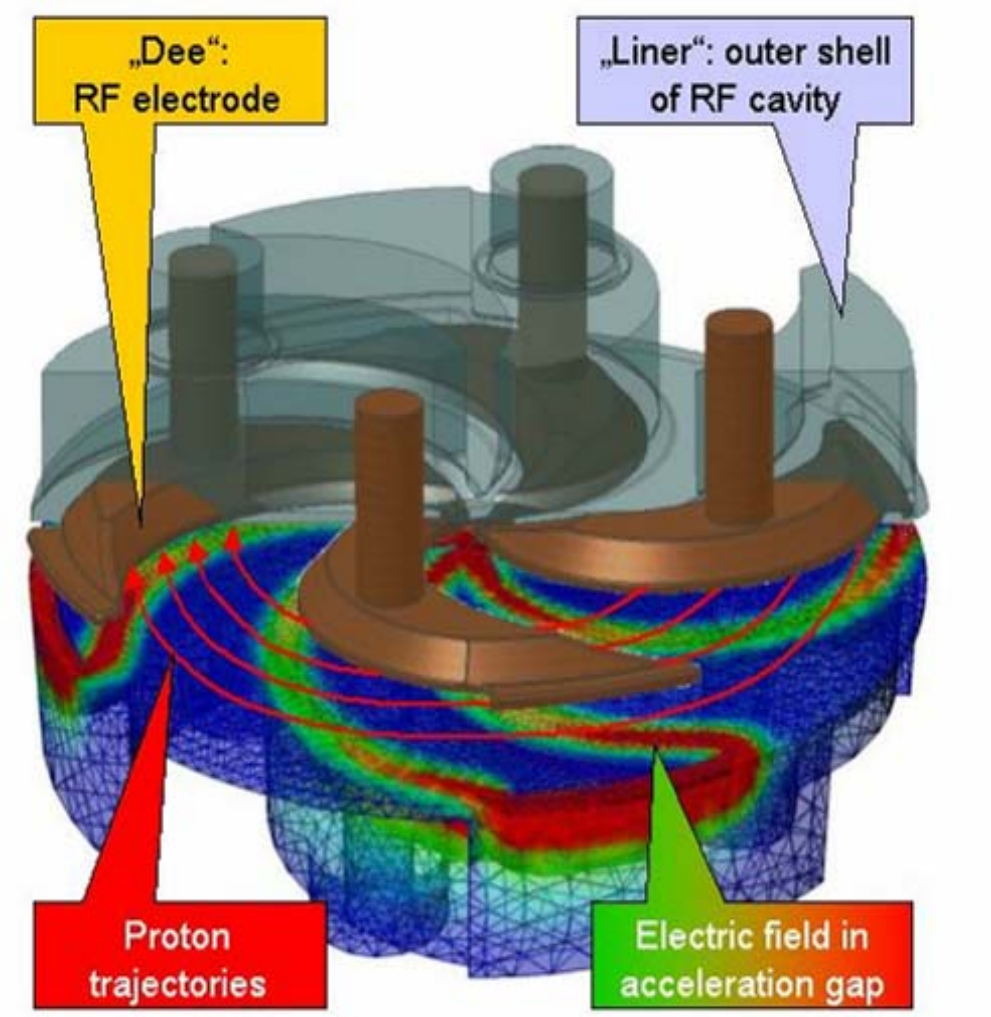
Iron yoke

- Outer diameter 3.1 m
- Height 1.6 m
- weight 90 t

Magnet

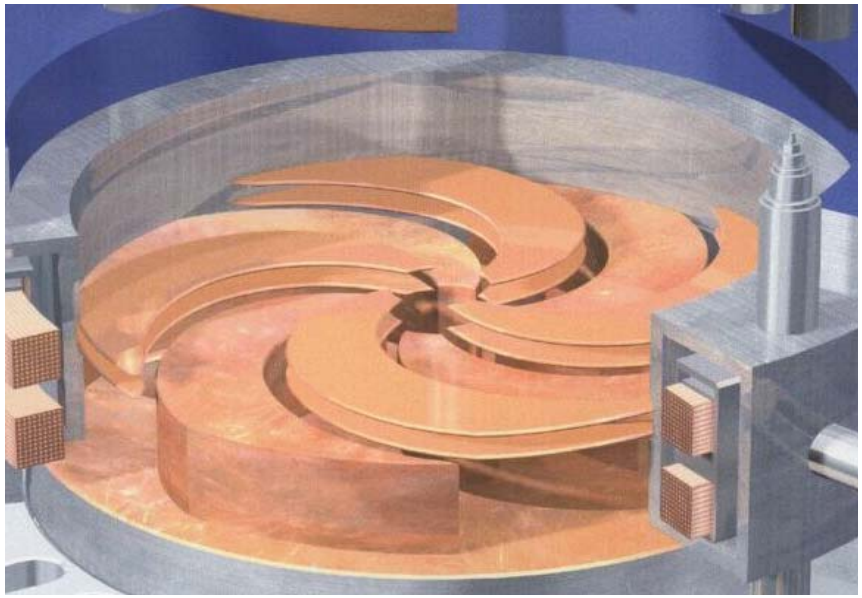
- Superconducting coils
- Magnetic Field 2.4 – 3 T
- Operating current 160 A
- Rated power cryocoolers 40 kW

COMET Cyclotron



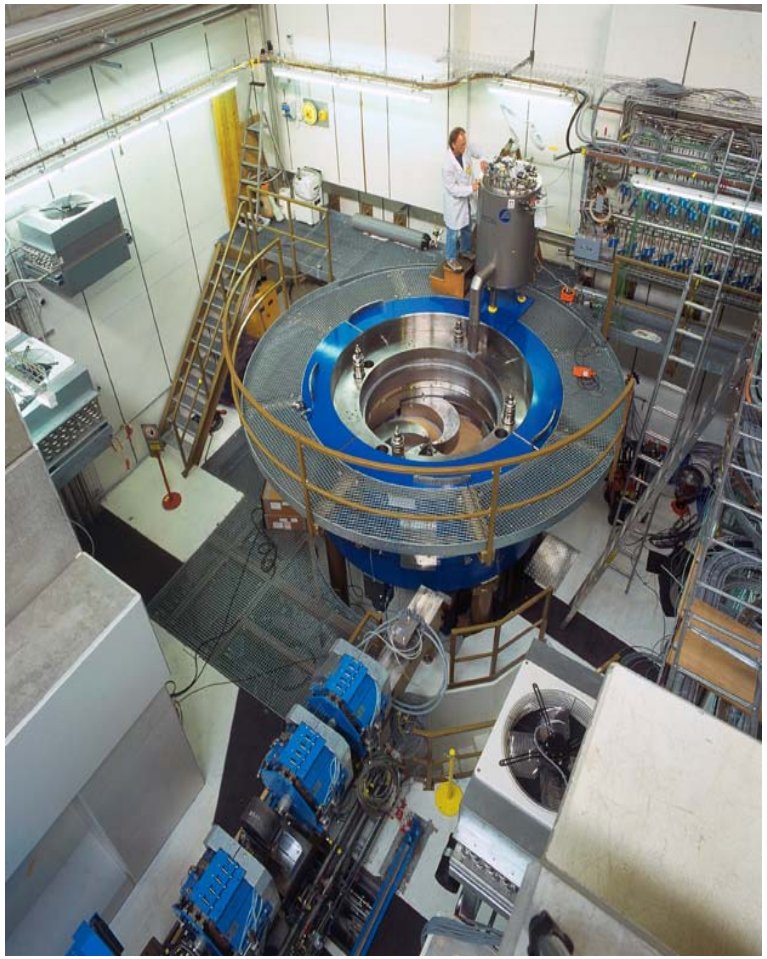
Electromagnetic field model; shown are:
- *Upper half: structure of Dees & liners*
- *Lower half:* ***mesh, E-field in gaps***

COMET Cyclotron



- Frequency 72.8 MHz (2nd harmonic)
- Voltage Source to Puller 80 kV
- Voltage @ extraction radius 130 kV
- RF-Power 120 kW

COMET Cyclotron



1. April 2005 first beam extracted

2005 / 2006

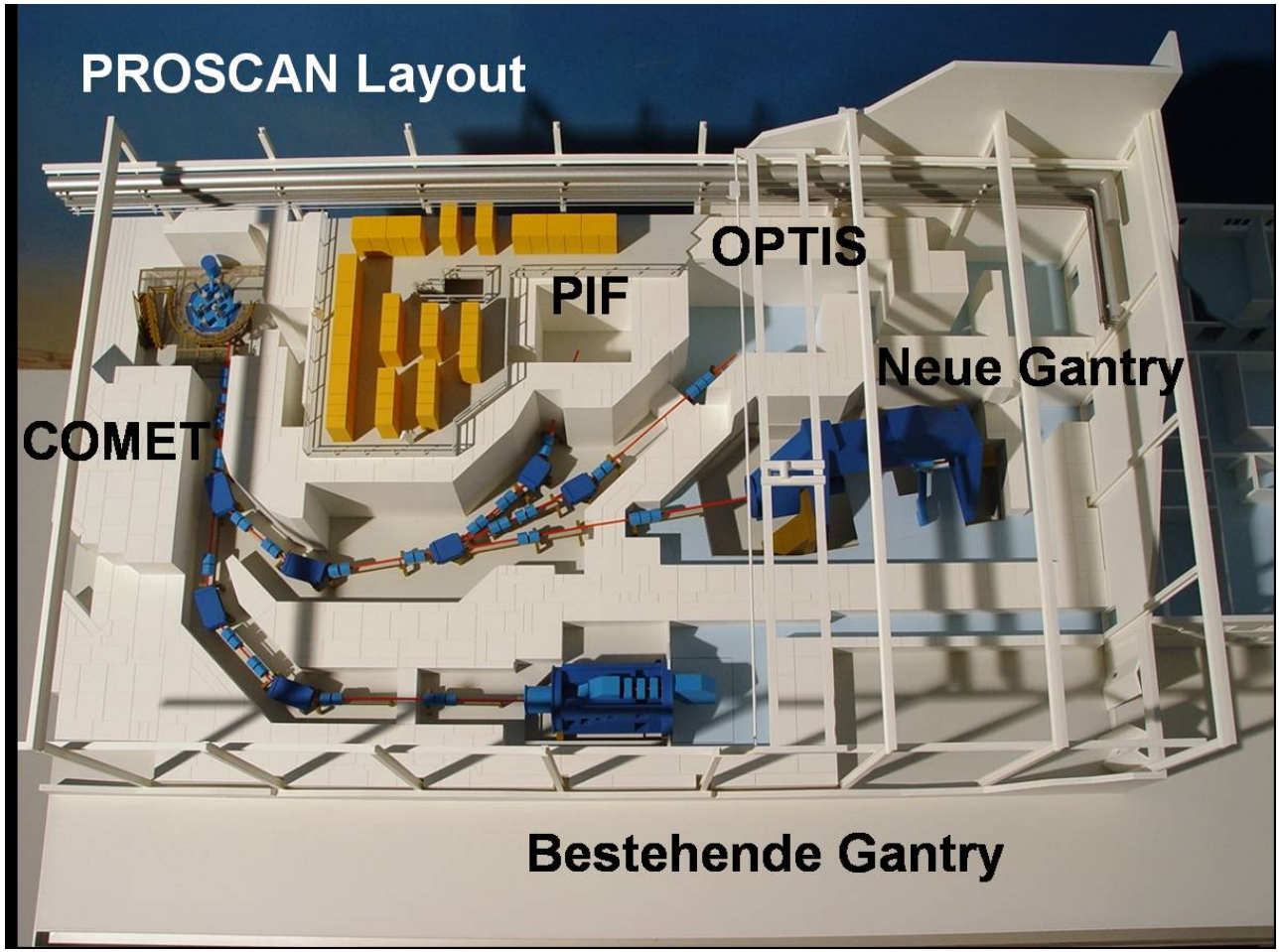
- 500 nA Beam current
- Extraction efficiency 80%

Now connecting Gantry 1 to Cyclotron

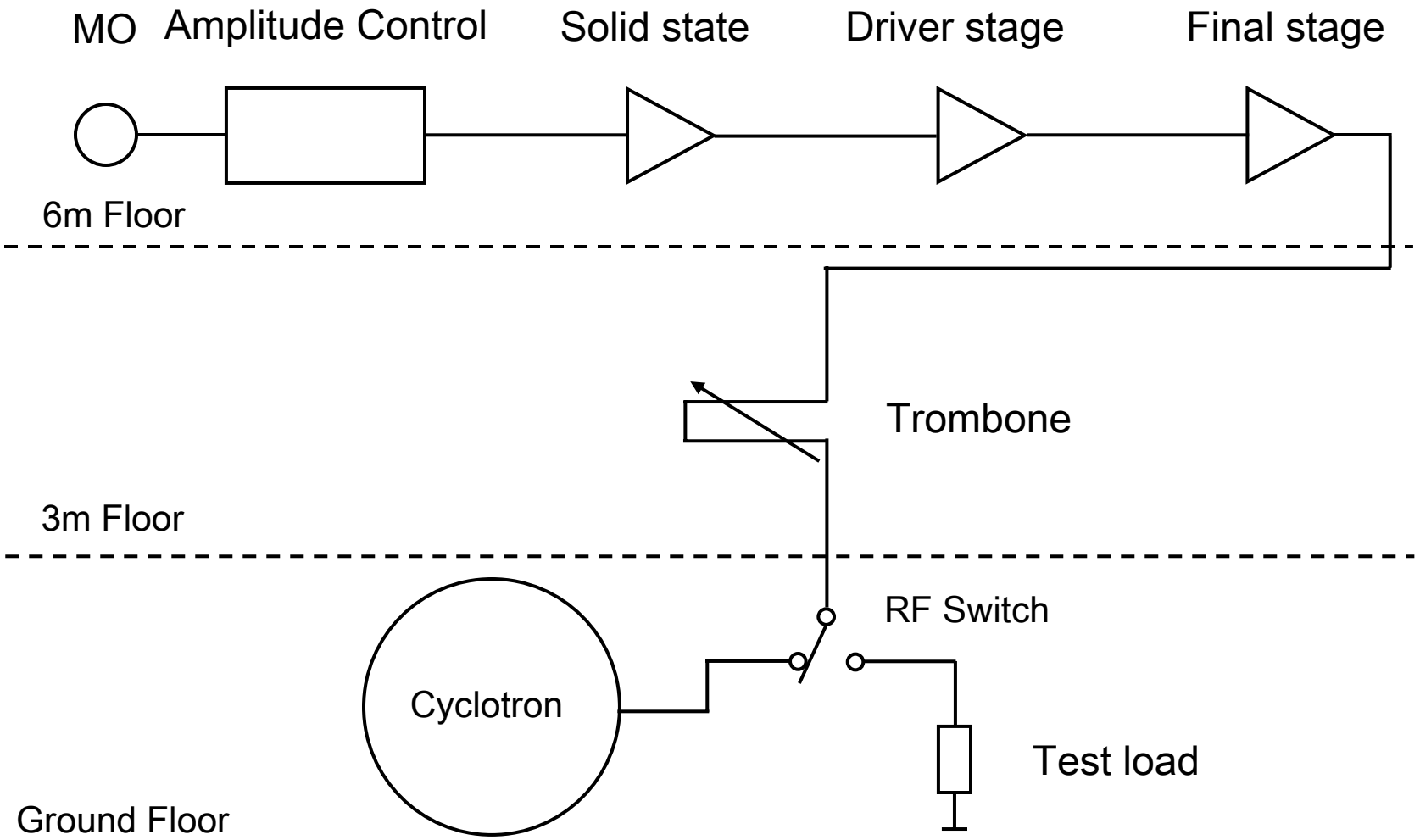
OUTLOOK

- June 2006 first beam to Gantry 1
- In fall 2006 first patient treatment in Gantry 1

PROSCAN


PROSCAN Layout
OPTIS
PIF
Neue Gantry
COMET
Bestehende Gantry

RF System of PROSCAN



Amplifier for PROSCAN

- 150 kW CW amplifier at 72 MHz
- Designed and manufactured by Bertronix, Munich
- 300 W solid state
- 8 kW driver stage
  Tetrode TH 561 SC
- 150 kW final stage
  Tetrode TH 781
- Water cooled tubes from Thales

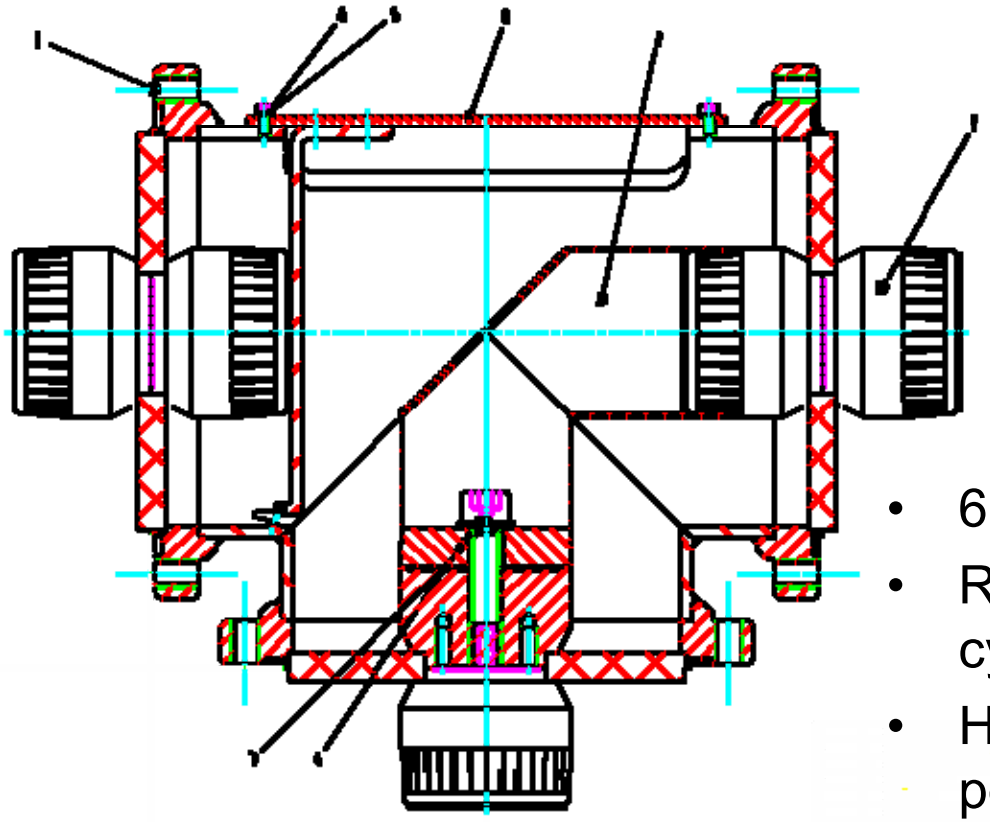
6 1/8 " EIA coaxial transmission line 3m floor

- 6 1/8 " EIA transmission line with trombone
- Manufactured by Spinner
- Installed by PSI

6 1/8 " EIA coaxial transmission line ground floor

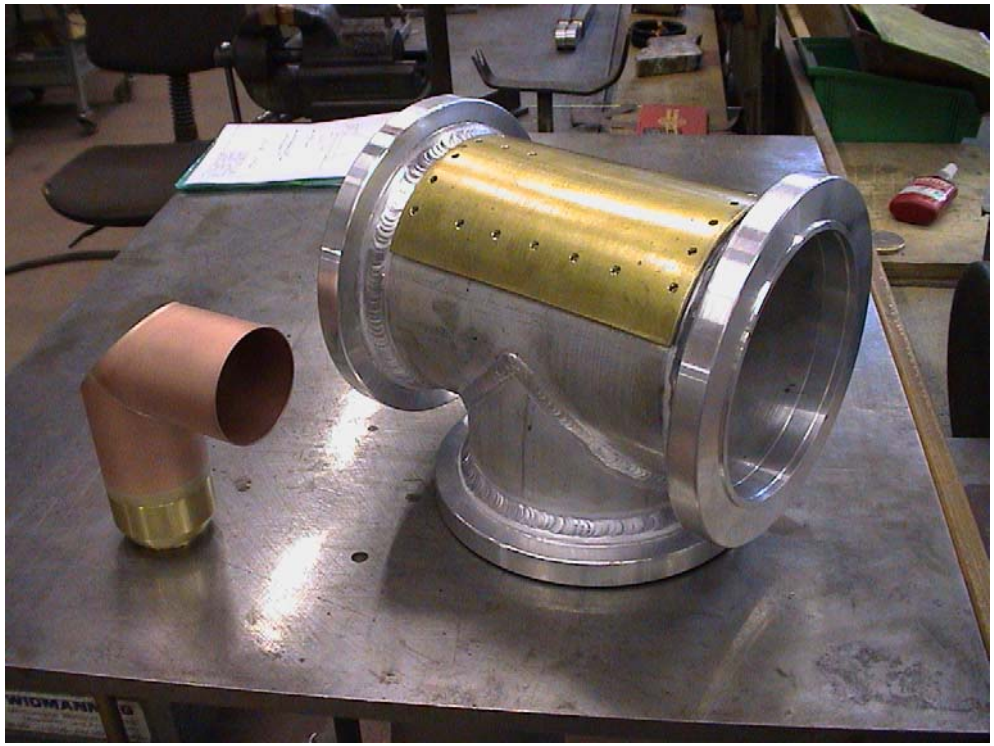
- Coaxial Switch
- Absorber
- Transmission line to cyclotron

Coaxial Switch



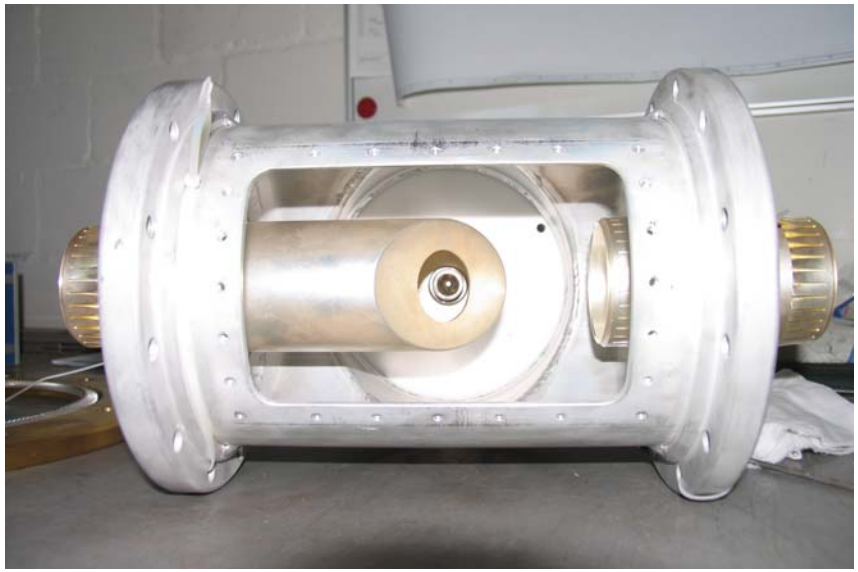
- 6 1/8 " EIA flange
- Run amplifier on cyclotron or load
- High isolation to disconnected port
- Same size as 90° bend

Coaxial Switch



- Coaxial switch in the machine shop
- Outer conductor made of aluminium
- Cover of switching window made of brass
- Inner conductor made of copper and brass
- Finally inner conductor and cover will be silver plated

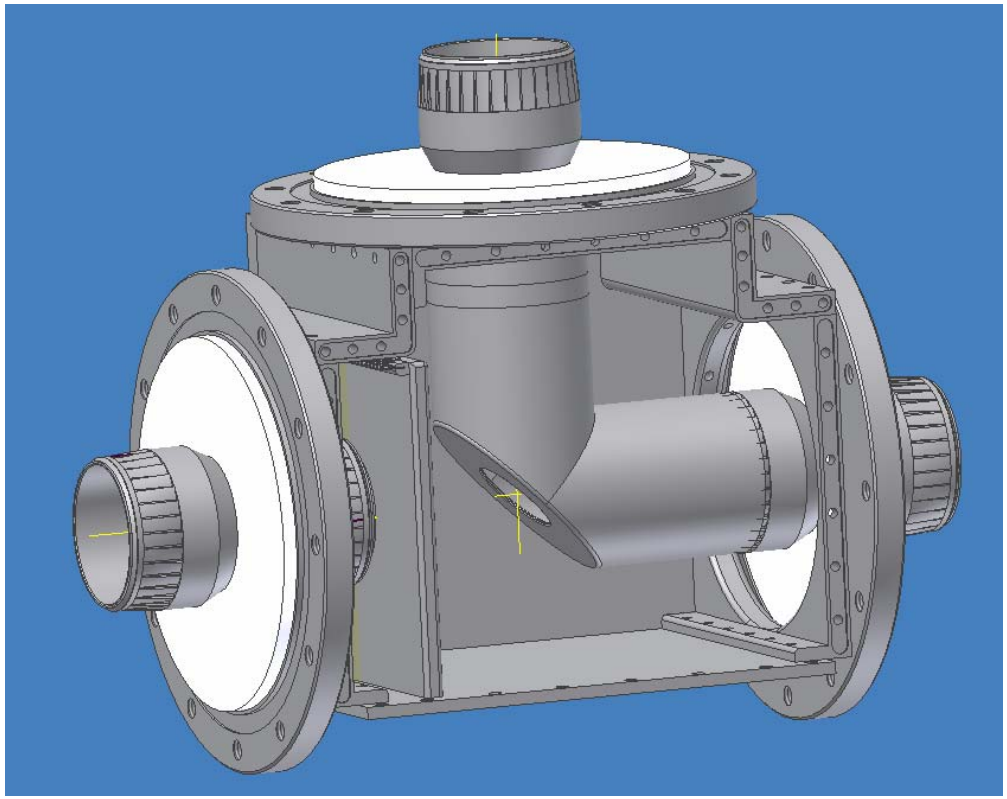
Measurements of Coaxial Switch



RF Switch with window opened

- Port 1 connected to port 2
- Measured at 72 MHz
- Matching Port 1 - 40 dB
- Isolation to Port 3 52 dB

New Design of Coaxial Switch

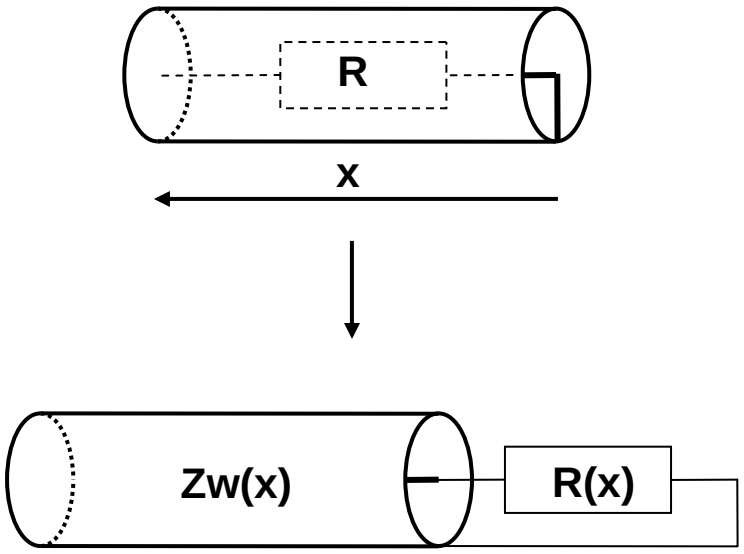


- Better RF - shielding
- Higher isolation to disconnected port
- Easier to manufacture

300 kW RF Power Load

- For commissioning, acceptance test and maintenance of the PROSCAN amplifier a high power 50 Ω load was needed.
- The maximal output power of the amplifier was rated at 200 kW. To allow for some margin, the decision was made to build a 300 kW load.
- To handle this power water cooling is needed. A solution of sodium carbonate in water acts as absorbing material and as cooling medium at the same time.
- The operating frequency of the amplifier is 72 MHz.
- Design of a wideband load with VSWR < 1.15
- 6 1/8 “ EIA coaxial line connector

300 kW RF Power Load



Simplified electrical schematic of the absorber

- Wideband Load Zw(x) = R(x)
- Coax transmission line
  D = outer Diameter
  d = inner Diameter

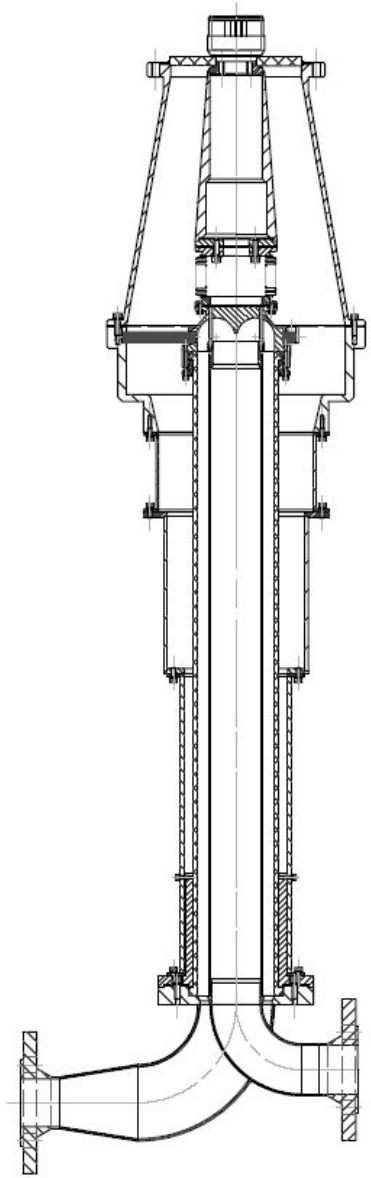
$$Zw(x) \approx 60\ \Omega \cdot \ln\left(\frac{D(x)}{d}\right)$$

- Resistor
  l = length of Resistor

$$R(x) = R_0 \cdot \frac{x}{l} = 50\ \Omega \cdot \frac{x}{l}$$

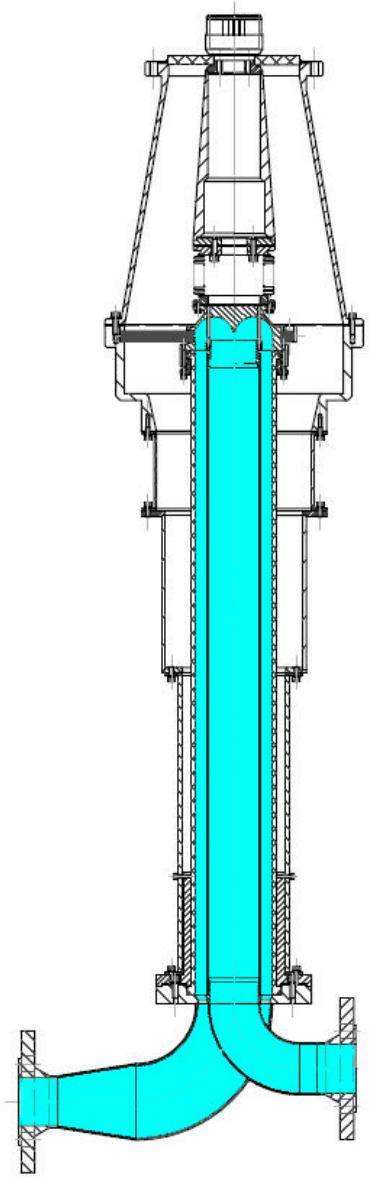
- Ideal Absorber outer diameter

$$D(x) = d \cdot e^{\left(\frac{50\ \Omega}{60\ \Omega} \cdot \frac{x}{l}\right)}$$



Design of Load

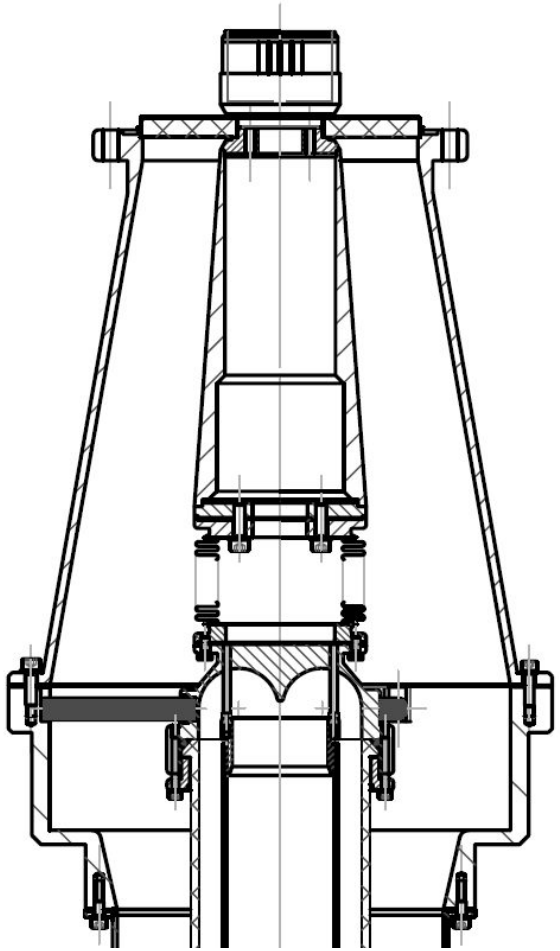
- Resistor: two polypropylene pipes filled with a solution of sodium carbonate in water



Design of Load

- Resistor: two polypropylene pipes filled with a solution of sodium carbonate in water
- Outer conductor in form of exponential curve.
  Approximated with 5 pieces of silver plated brass or copper pipes.

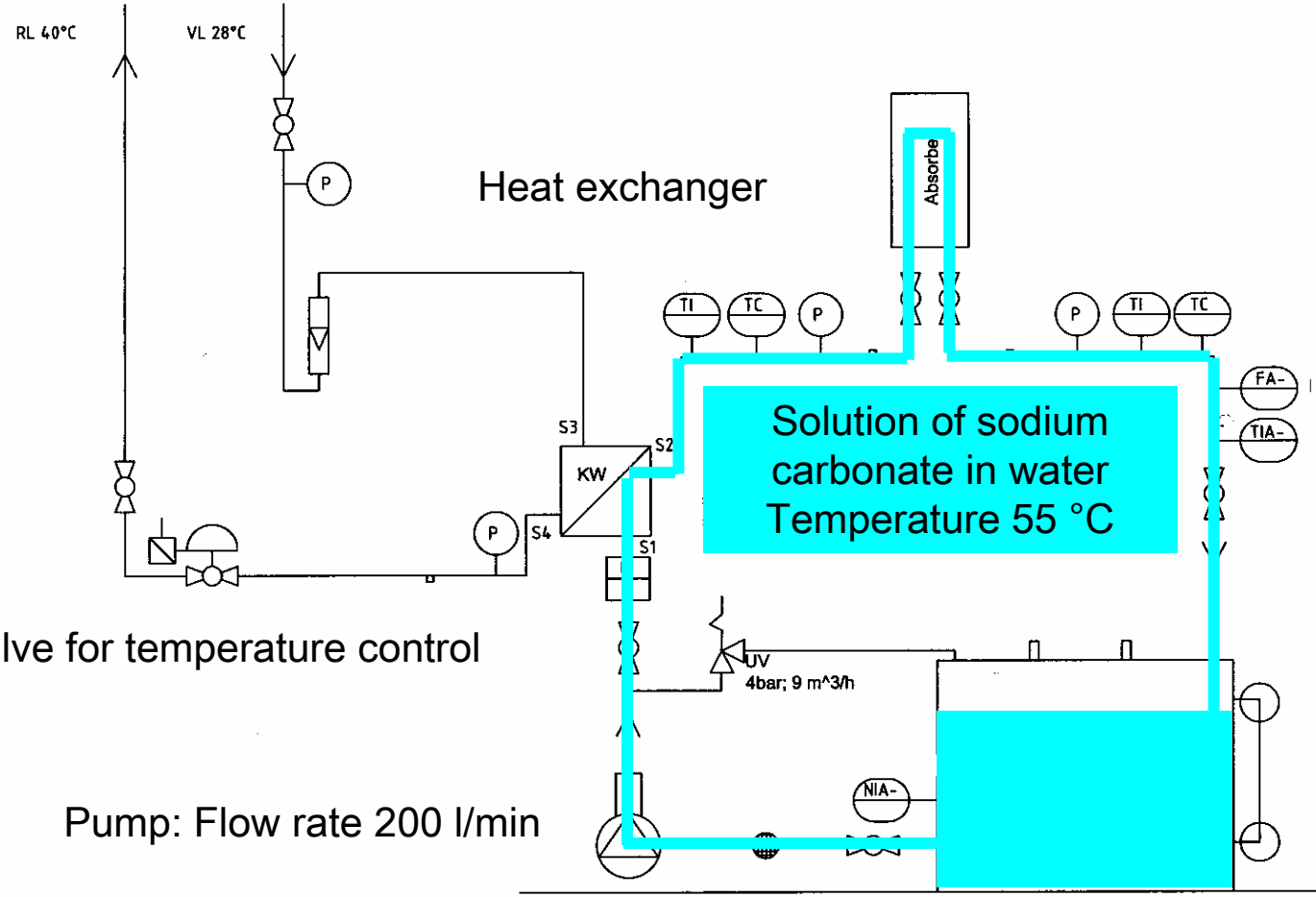
Design of Head of Absorber



- 6 1/8 “ EIA coaxial line
- Cone
- Bellows to avoid mechanical forces
- 3 Isolators to center the inner conductor
- Turning head for water

Water Circuit

City water for cooling



Interlock on:
Flow
Temperature

Valve for temperature control

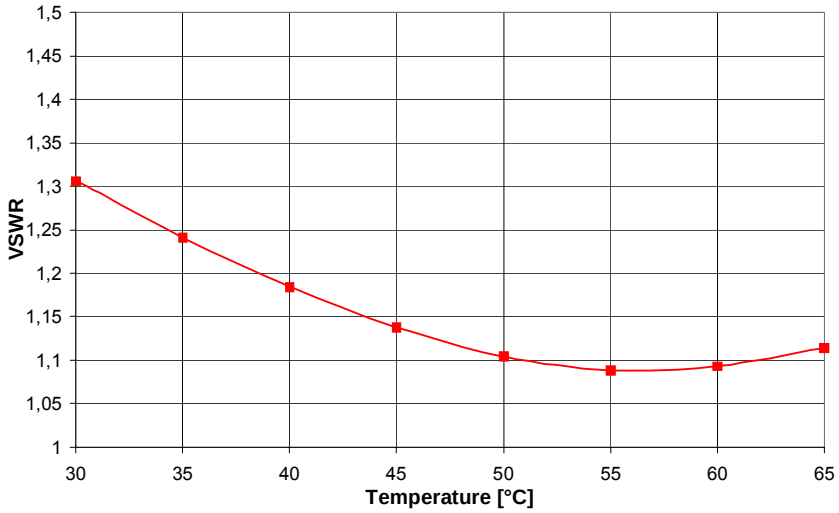
Pump: Flow rate 200 l/min

Tank level

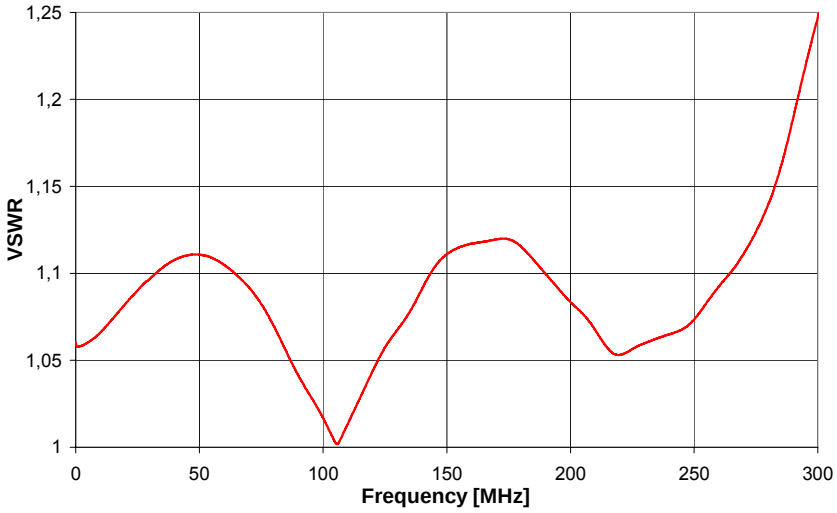
Control System of Load

- Temperature of coolant is controlled within 3° C
- PLC for Interlock handling
- Calorimetric calculation of dissipated power

Measurement of 300 kW RF Power Load



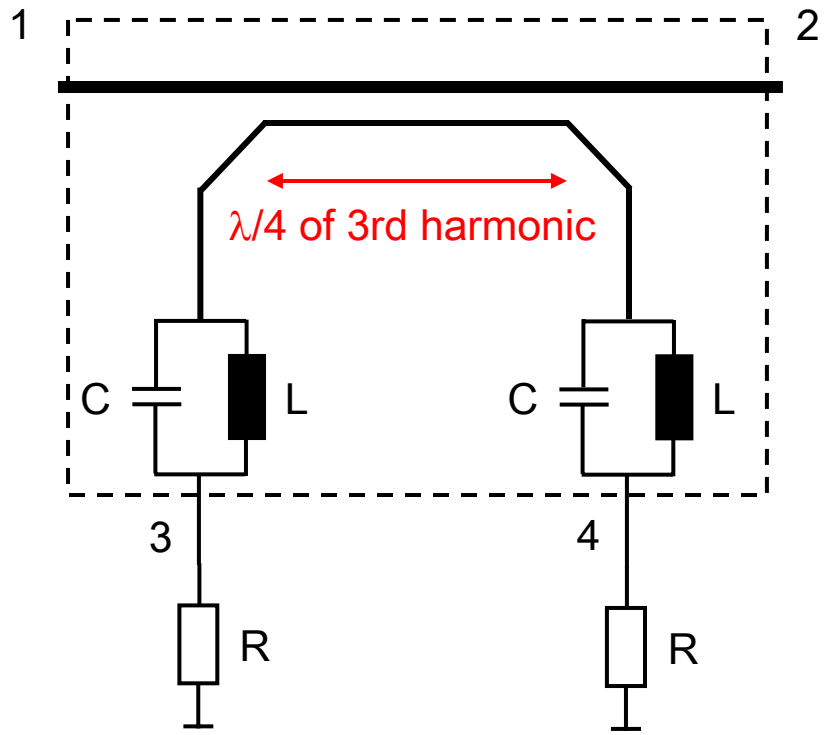
Measurement of the VSWR versus the temperature at 72 MHz



Measurement of the VSWR in function of the frequency

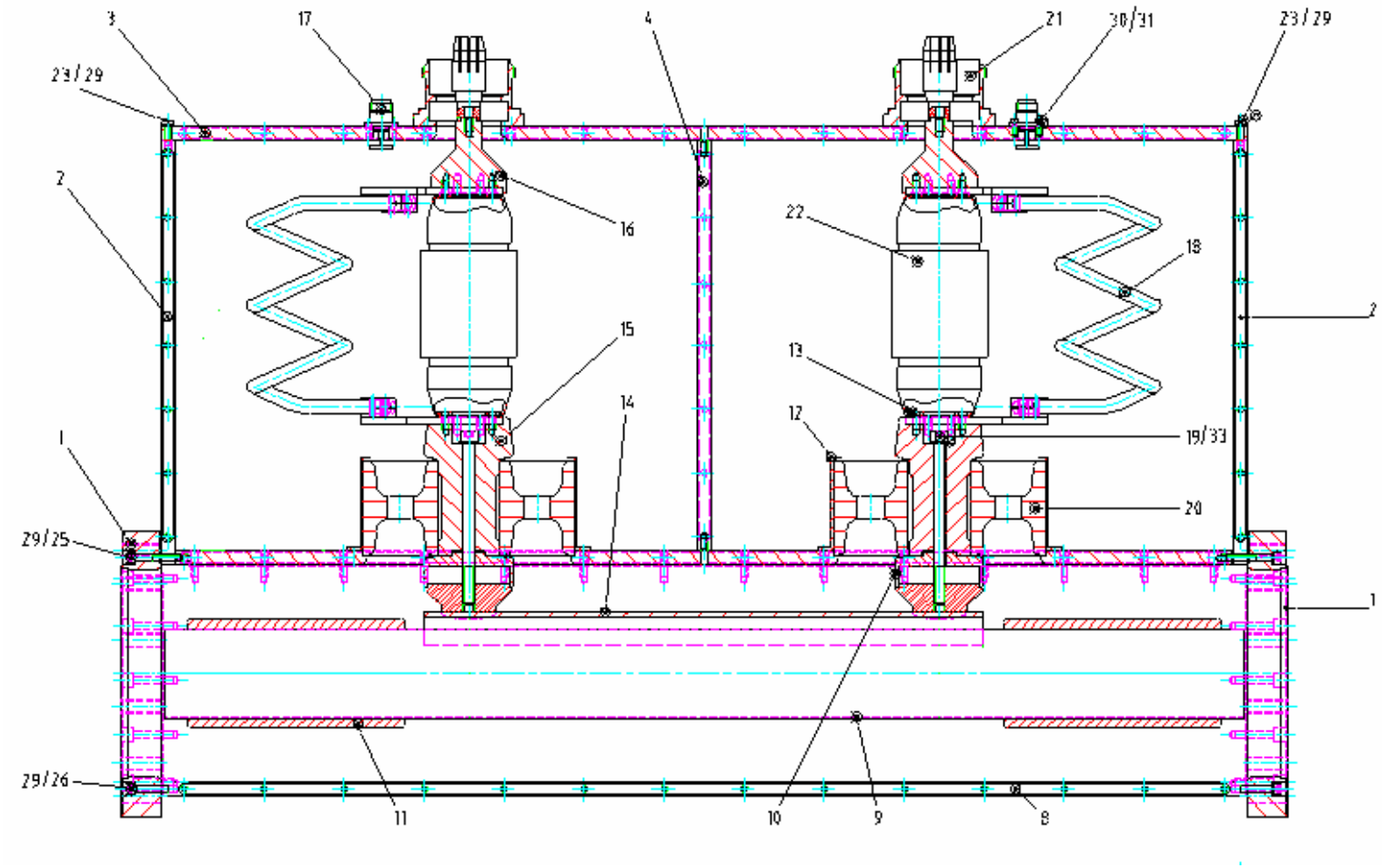
During commissioning, acceptance tests and troubleshooting of the amplifier in 2005 / 2006, up to 150 kW of RF power were dissipated in the load without any problems.

Higher Harmonic Absorber

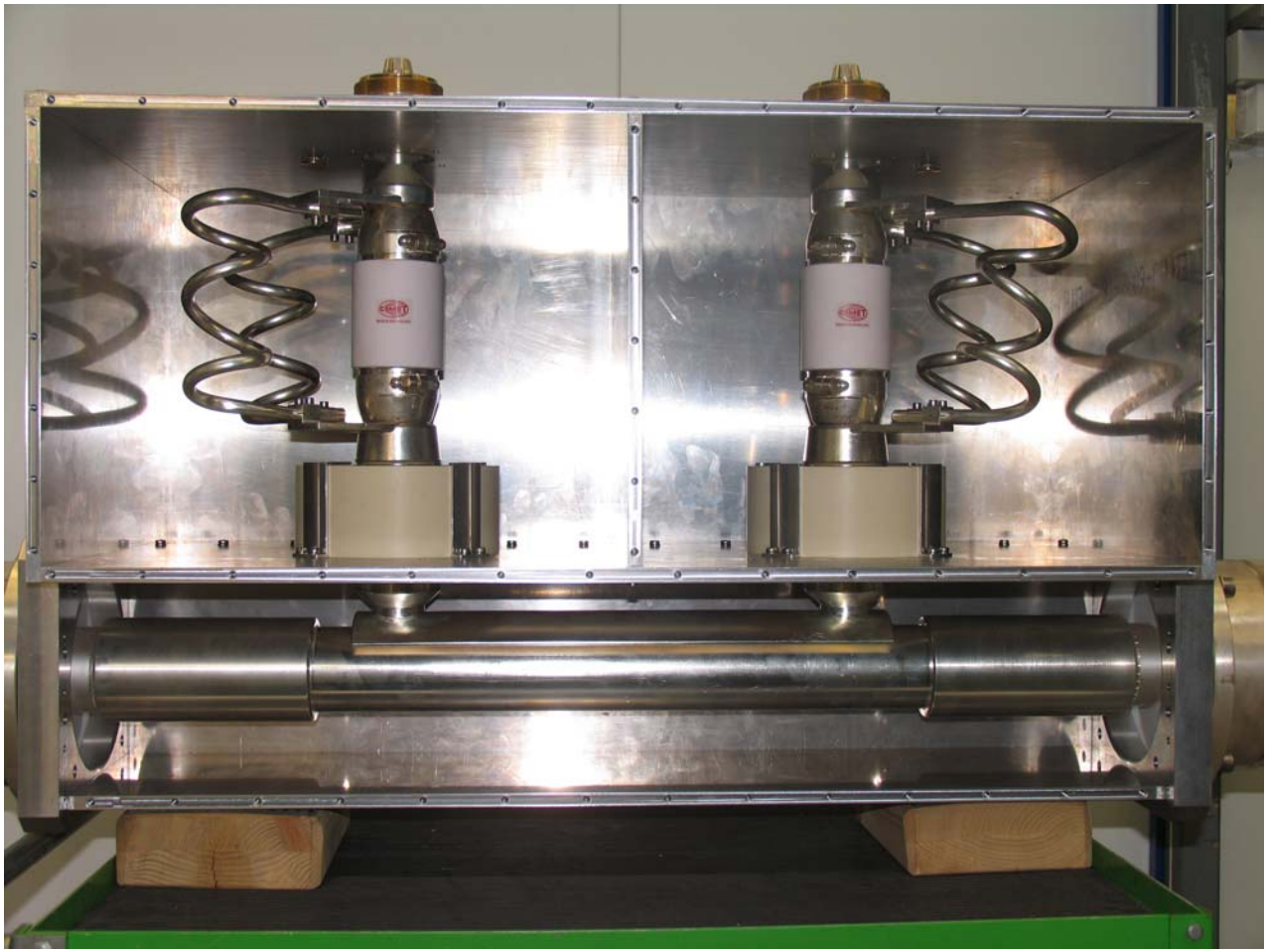


- 3 dB directional coupler at λ/4 of third harmonic frequency
- Stop band filter for fundamental frequency
- 50 Ω Load

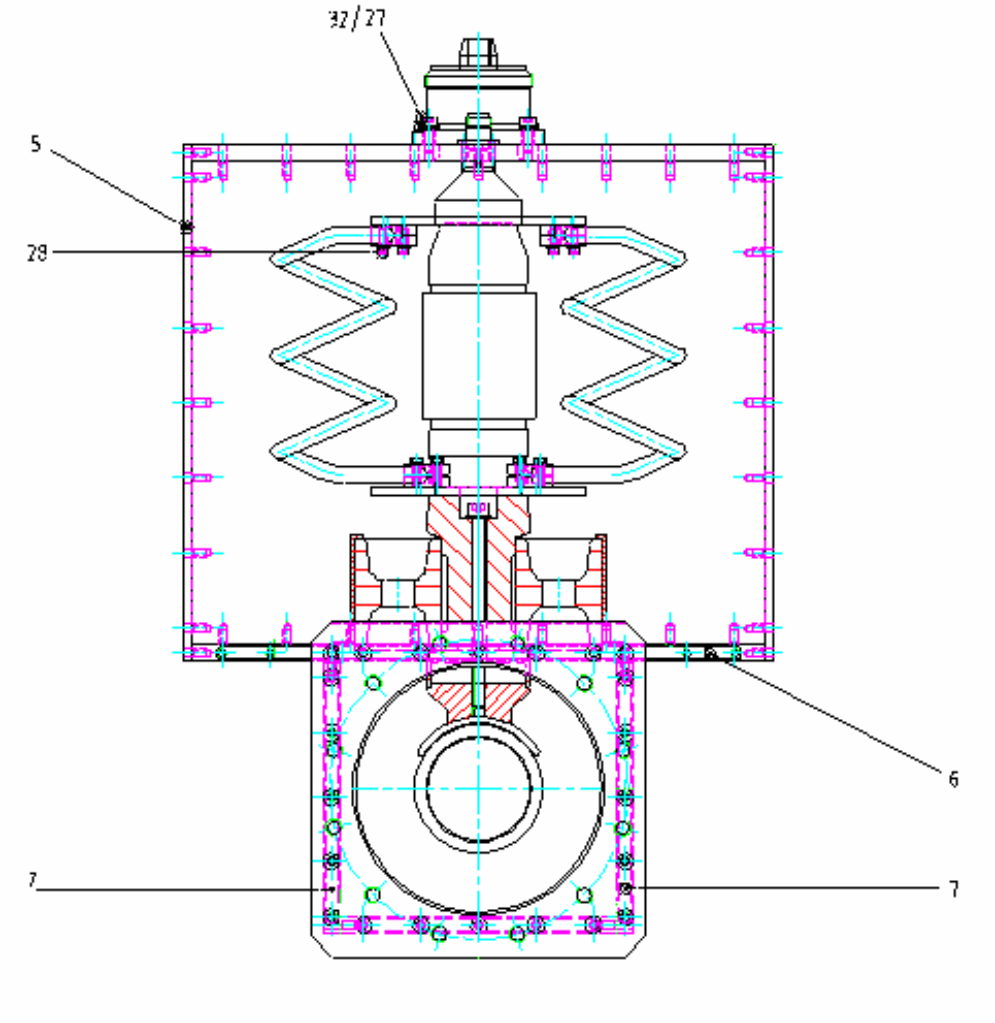
Cross Section of Higher Harmonic Absorber



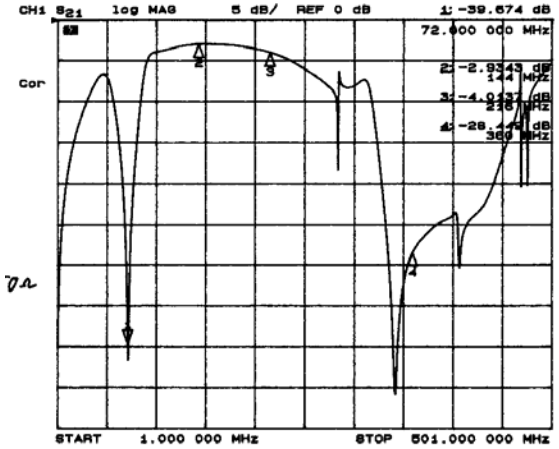
Cross Section of Higher Harmonic Absorber



Cross Section of Higher Harmonic Absorber



Measurements of Higher Harmonic Absorber

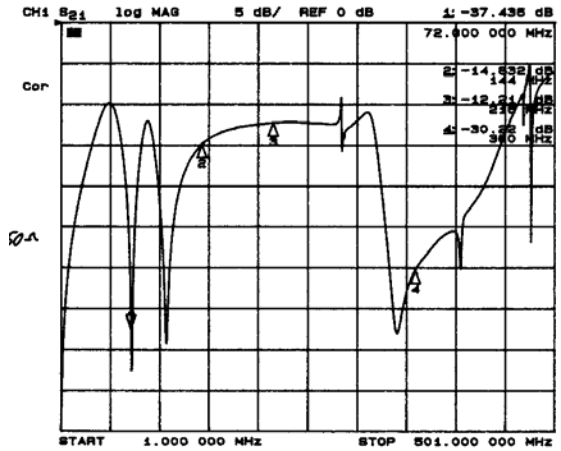


Measurement S31

Fundamental: - 39 dB

2nd harmonic: - 2.9 dB

3rd harmonic: - 4.0 dB



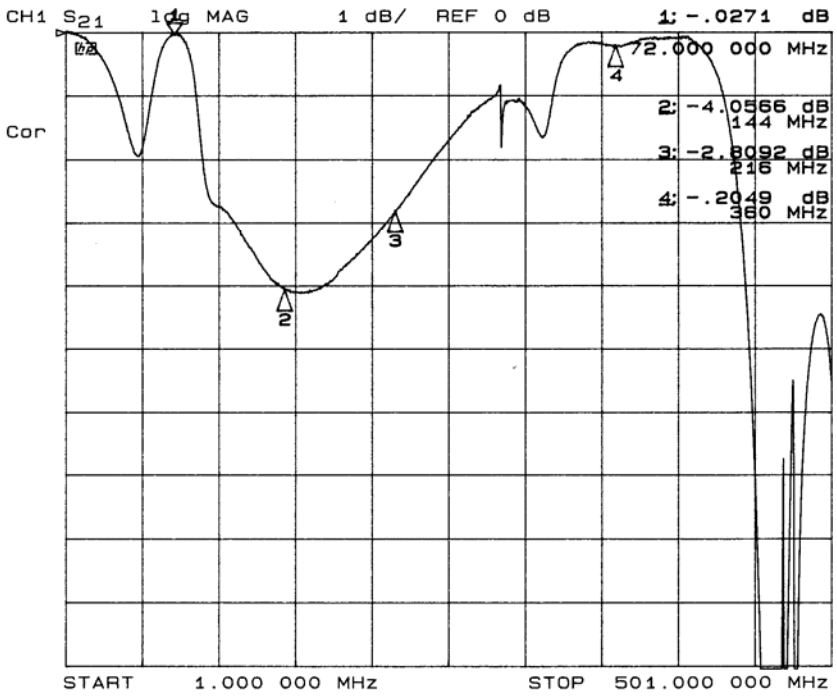
Measurement S41

Fundamental: - 37 dB

2nd harmonic: - 14 dB

3rd harmonic: - 12 dB

Measurements of Higher Harmonic Absorber



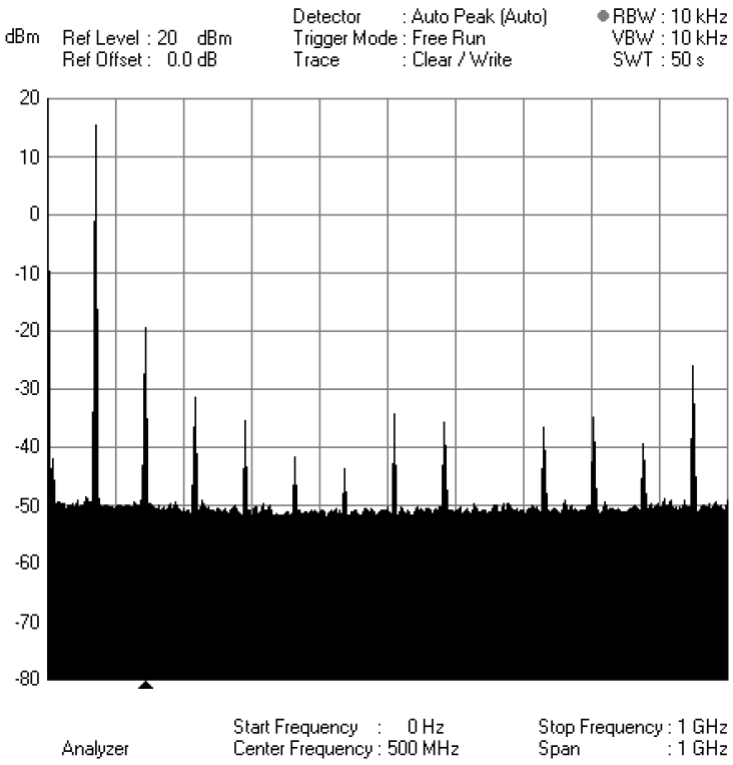
Measurement S21

Fundamental: **- 0.02 dB**

2nd harmonic: **- 4 dB**

3rd harmonic: **- 2.8 dB**

Conclusion



Spectrum of amplifier

- Higher harmonic absorber works as expected. 2nd and 3rd harmonic are reduce by 3 dB. No influence on fundamental frequency
- Due to the fact, that all harmonics of the amplifier are 30 dB below the fundamental frequency, the higher harmonic absorber is not installed up to now.
- Within 15 minutes the amplifier can be switched form cyclotron to the load. This was done several times during commissioning without of problems.