C-band linac progress: rf source

Accelerator Laboratory

KEK –High Energy Accelerator Research Organization
Accelerator Laboratory

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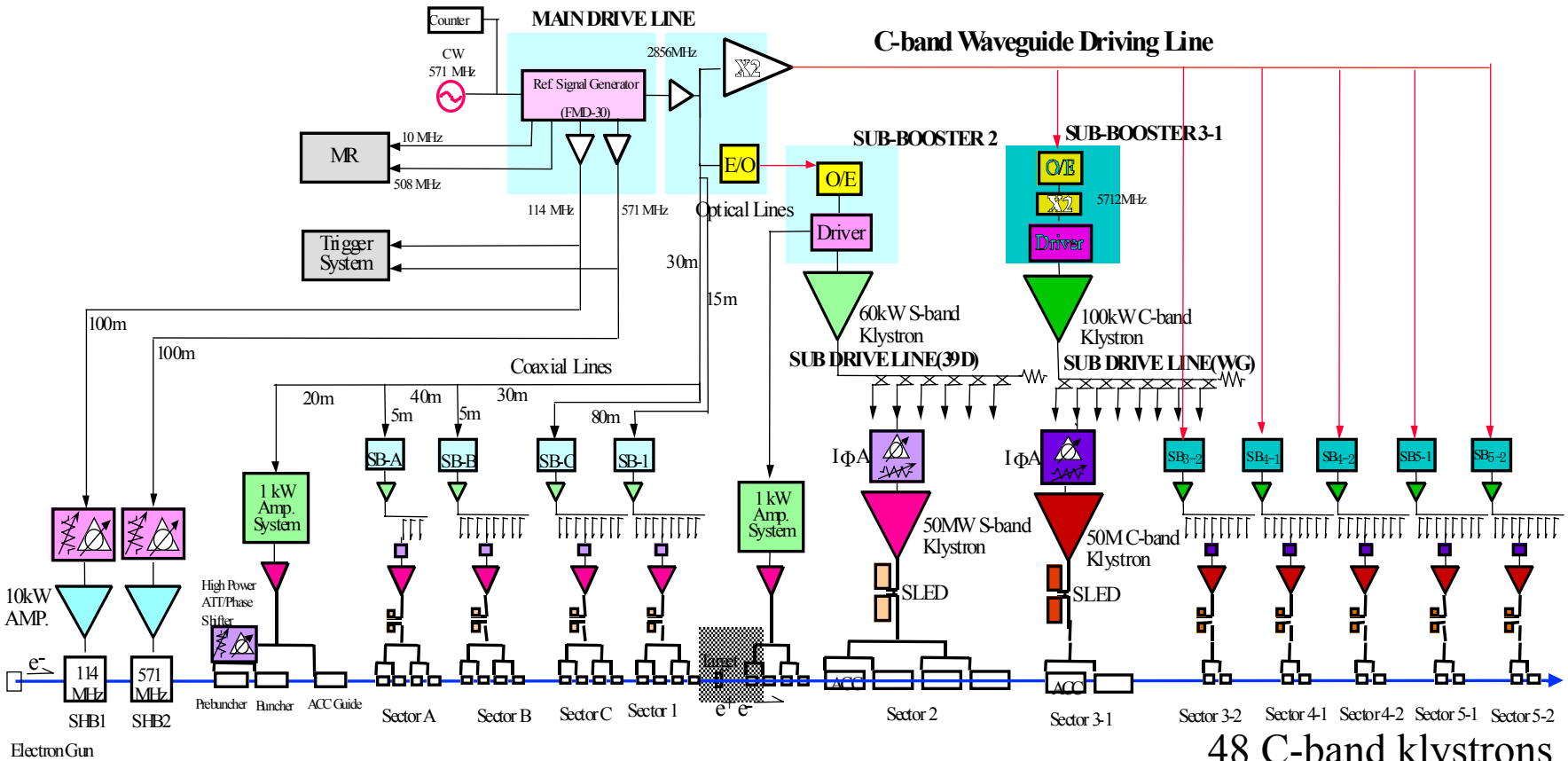
- ✧Overview of C-band rf system
- ✧Rf system
  - ✧LLRF
  - ✧Driver klystron (Subbooster:SB)
  - ✧High power klystron
  - ✧Compact modulator
  - ✧RF window / resonant ring
- ✧Performance at KG #44
- ✧Future works

Overview of C-band rf system

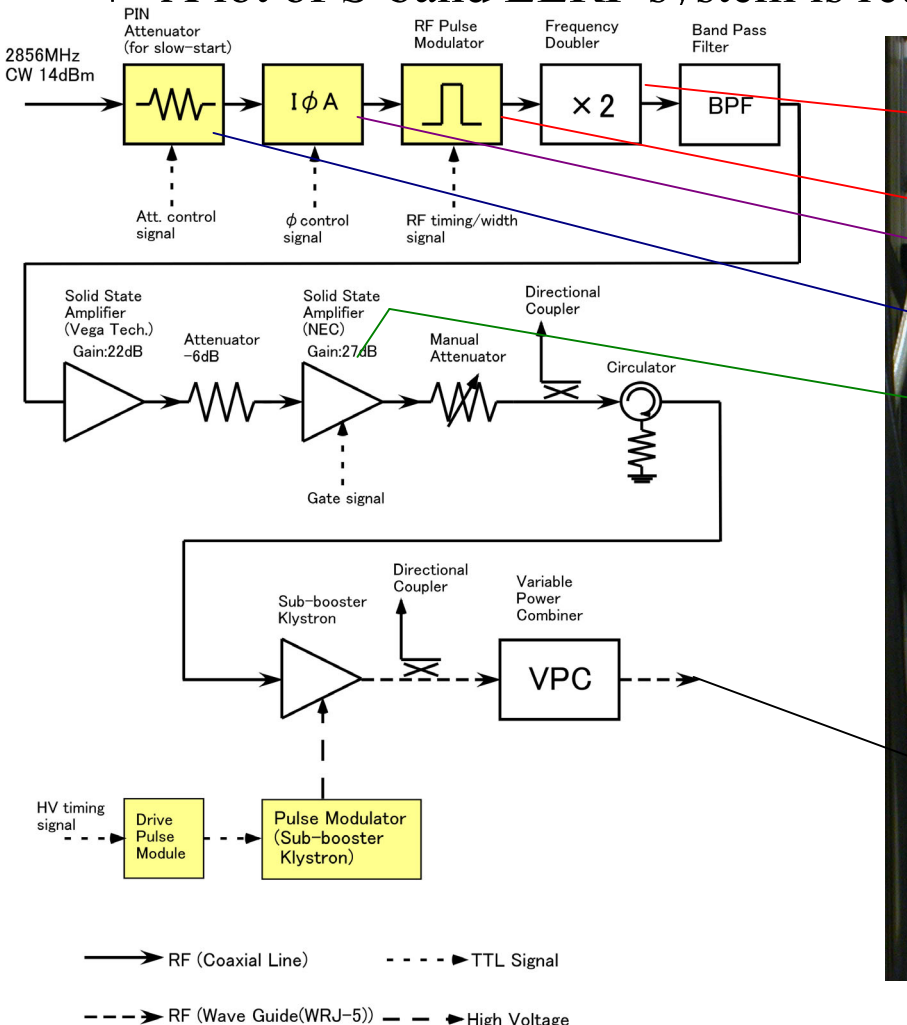
- C-band rf system from #3 to #5 sector
- Forty eight klystrons are installed (instead of 24 S-band klystrons)

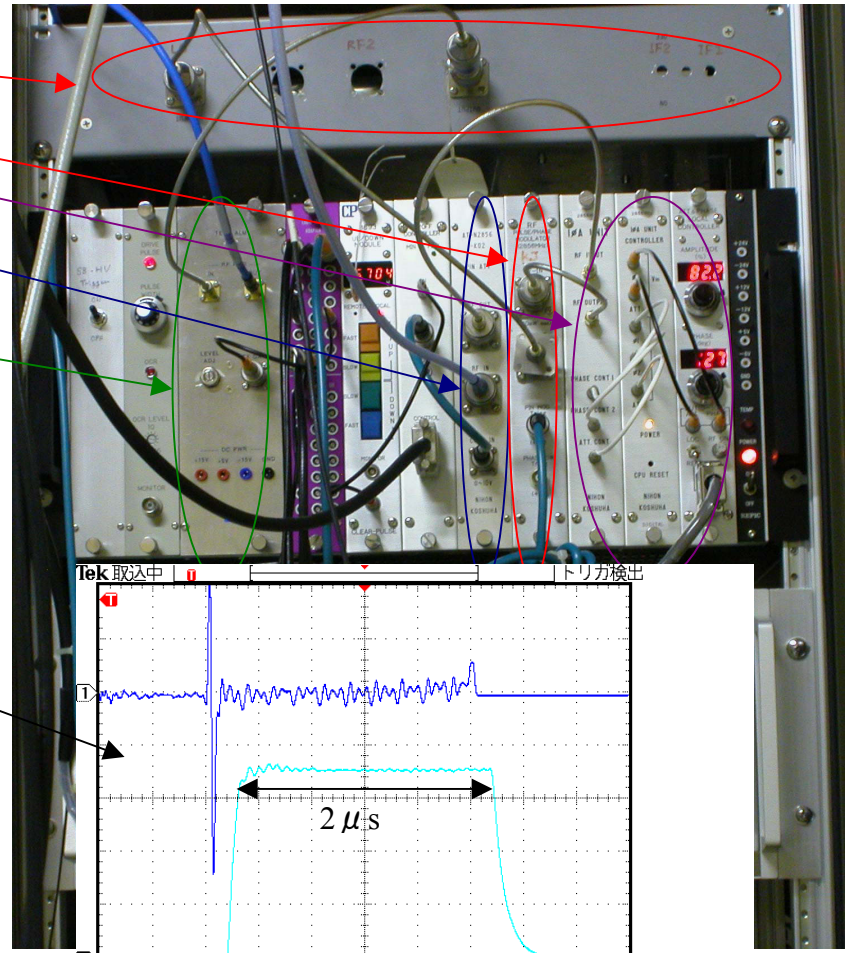
RF System Diagram C-band Plan(example)



LLRF system

- S-band -> (frequency doubler) -> C-band
- A lot of S-band LLRF system is reused. (pulse modulator, trigger,….)





SB klystron

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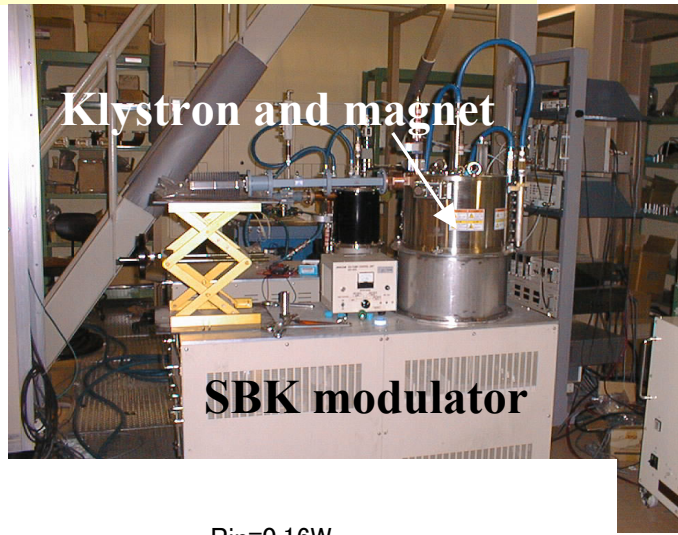
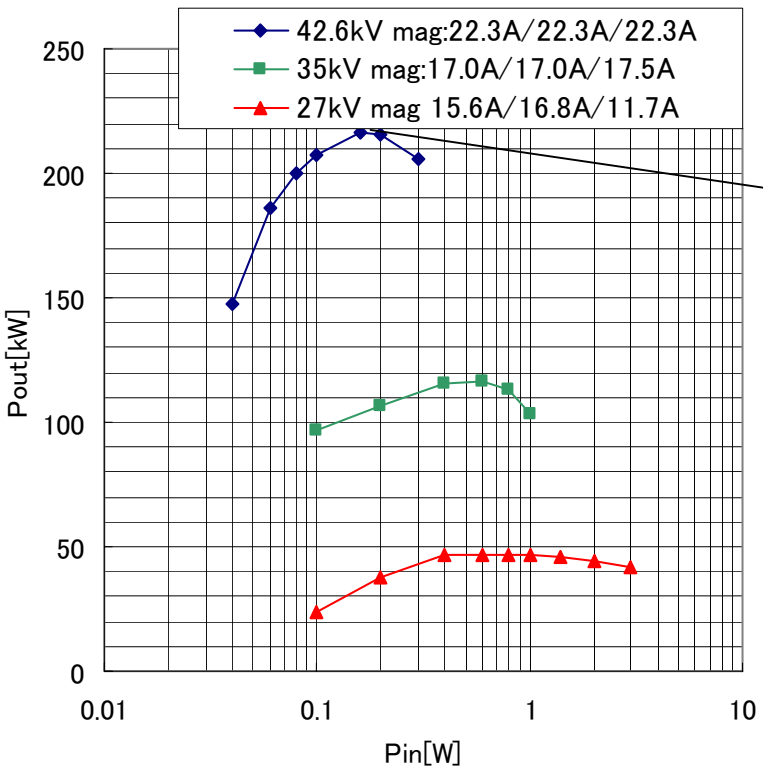
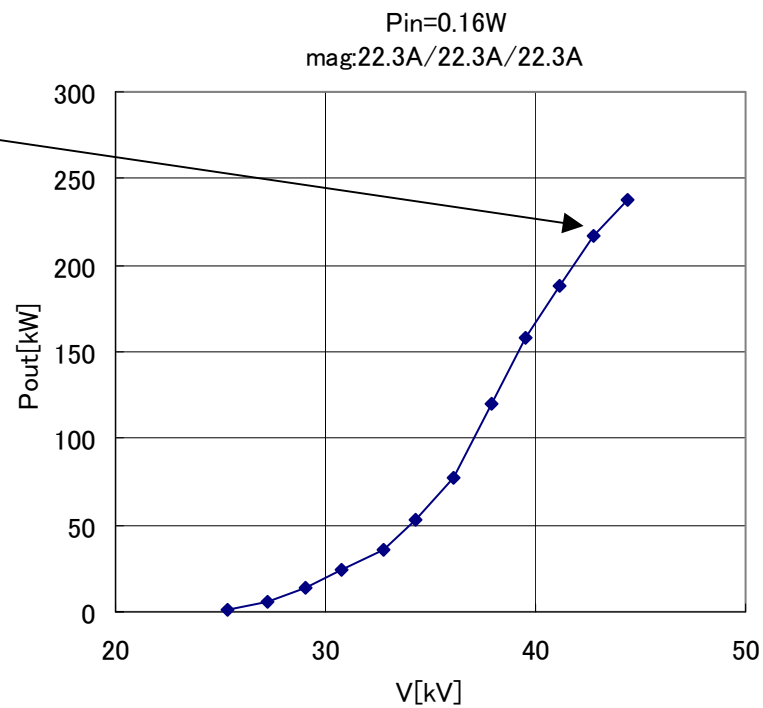


- Retune the existing C-band 200 kW klystron for weather observation station (MELCO).
- Driver klystron (SB) can deliver >100 kW (35 kV).
- Same modulator and HV supply to S-band system is used.





Toshiba E3746 klystron assembly

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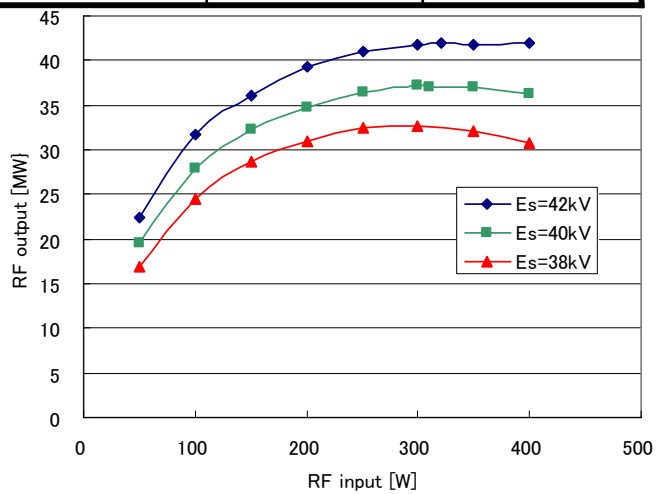
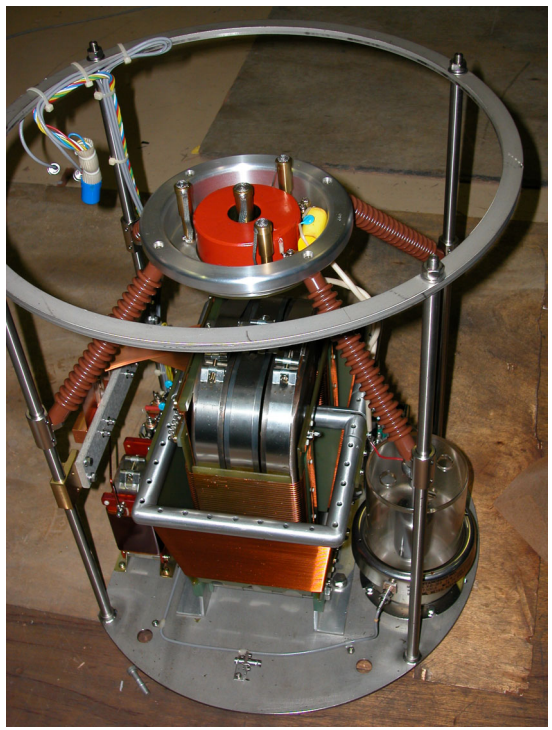
- Toshiba E3746 klystron (50MW) is adopted.
- Conventional 1:15 pulse-transformer (used at klystron gallery) is reused.

Requirements for rf source

	S-band	C-band
RF output	41 MW	40 MW
Typical charging voltage	42 kV	41 kV
Typical applied voltage	290 kV	325 kV
Pulse duration	4 μ s	2 μ s
Accelerating gradient	(21 MV/m)	(42 MV/m)

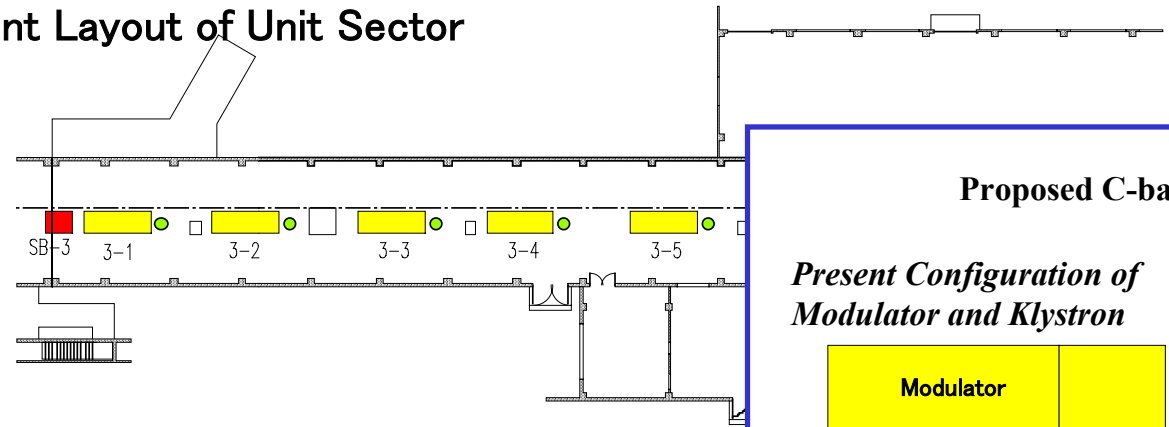




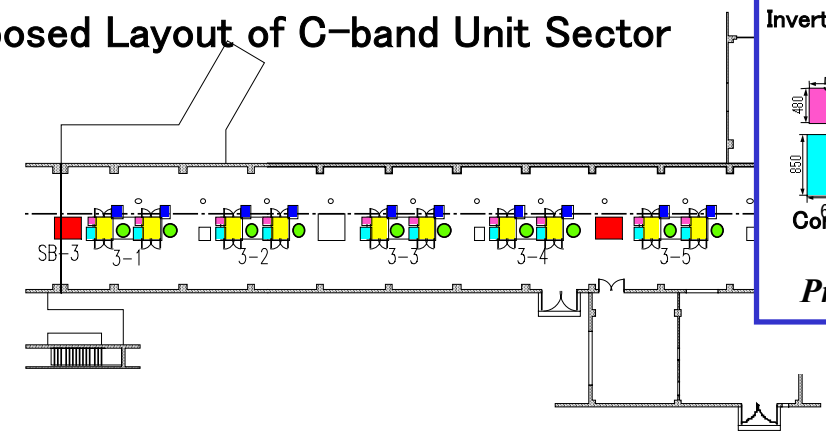
Compact modulator (1)

✧ Compact modulator is necessary to install 48 units.

Present Layout of Unit Sector

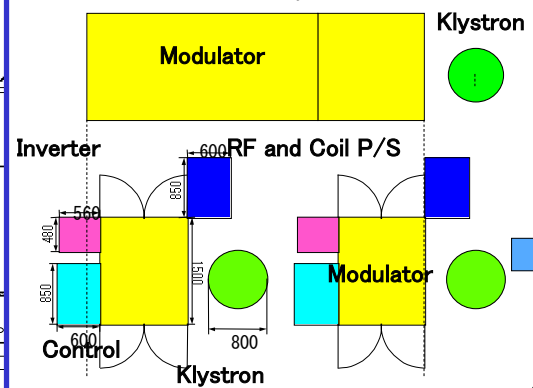


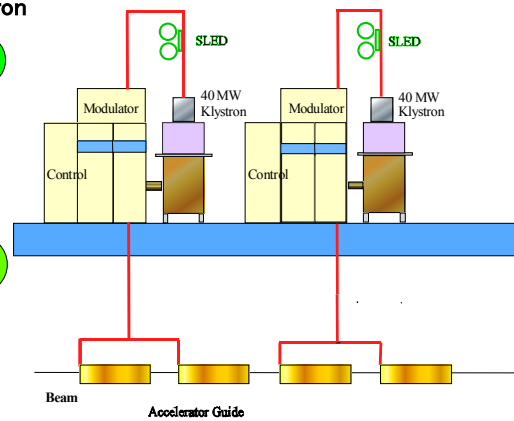
Proposed Layout of C-band Unit Sector



Proposed C-band Modulator Configuration

Present Configuration of Modulator and Klystron

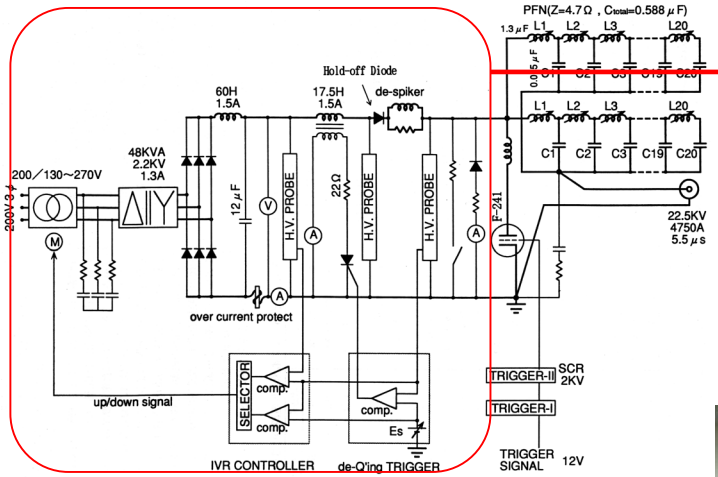


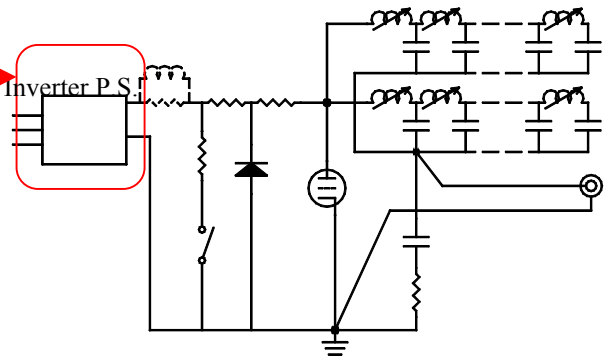


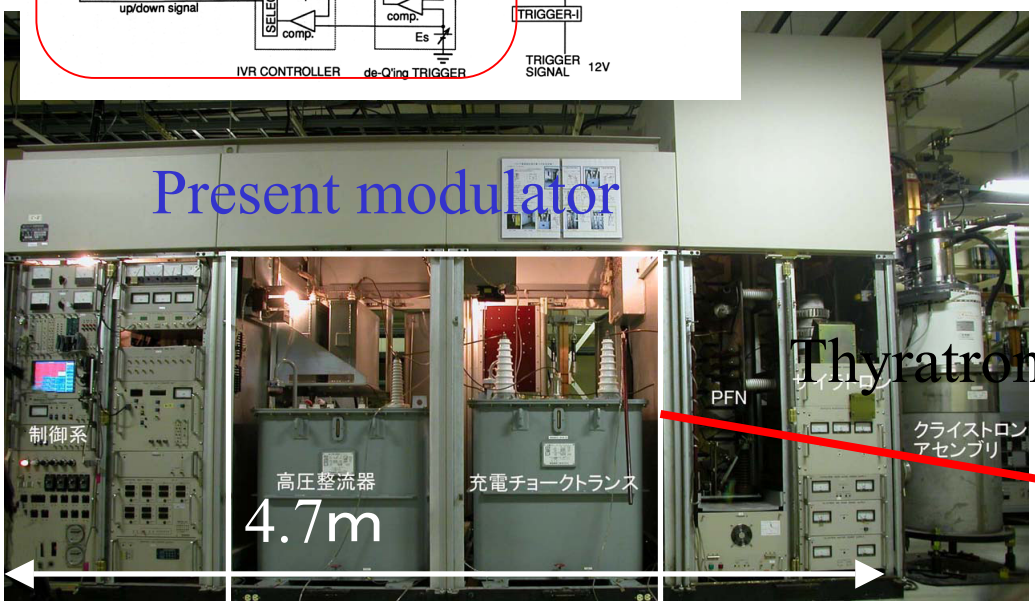
Proposed Configuration

Compact modulator (2)

- By using invertor P.S., the modulator size can be 1/3 (4.7 m->1.8 m).
- Present PFN and Thyratron are reused at new modulator.



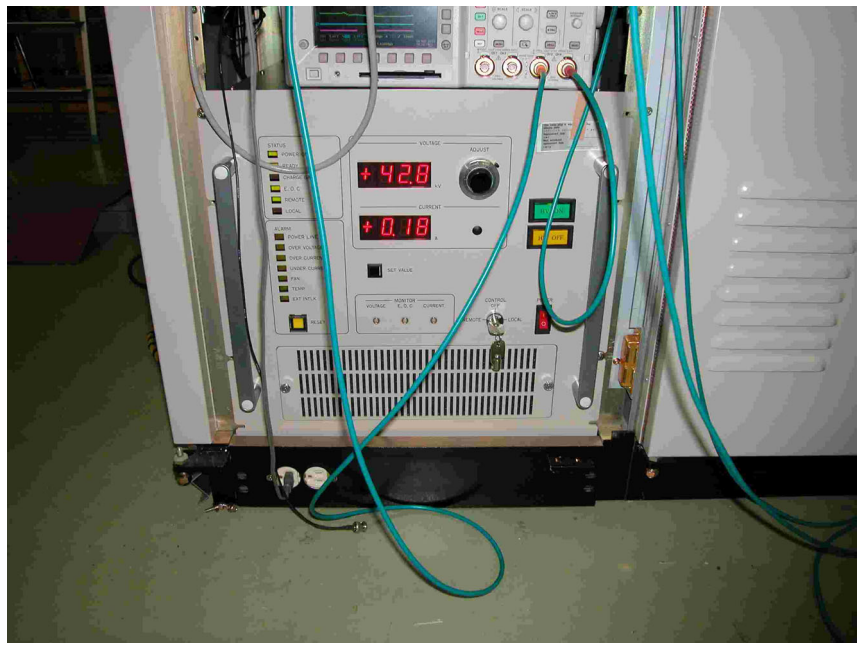




Inverter Power Supply Development

Specifications

• Output voltage	50 kV(max.)
• Output power	30 kJ/s
• Voltage regulation	±0.1%
• Efficiency	89%
• Power factor	86%
• Switching frequency	33 kHz
• Input voltage	420 V, 3 Phase, 50 Hz, AC
• Cooling	Water, 4.5 liters/min.
• Weight	170 Kg
• Size	19” rack mount
	449mm(H), 480mm(W), 630mm(D)



Switching Power Supply (TDP)

Inverter Power Supply Development-2

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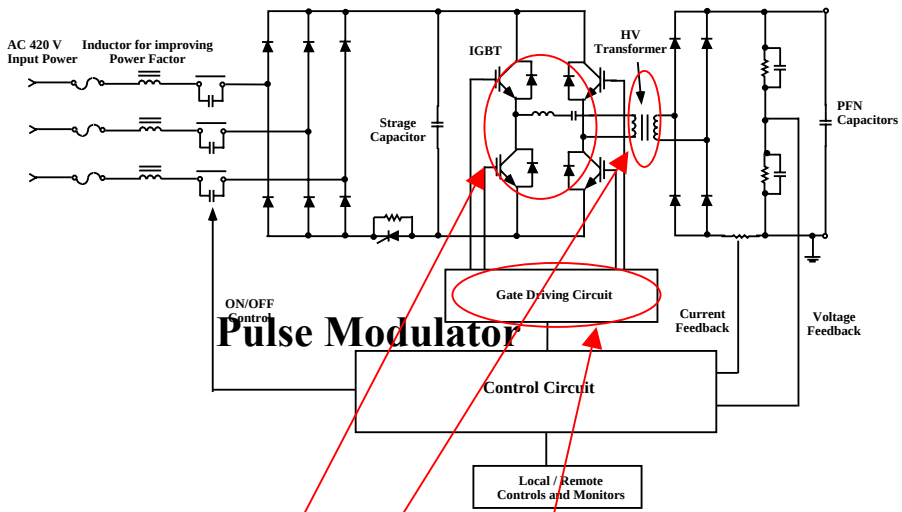
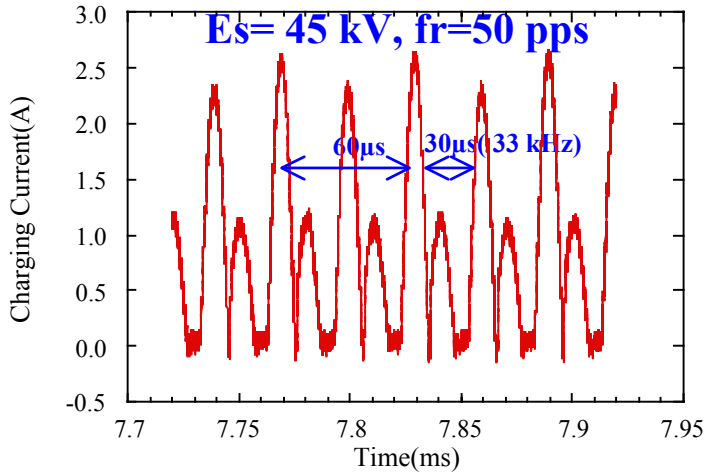


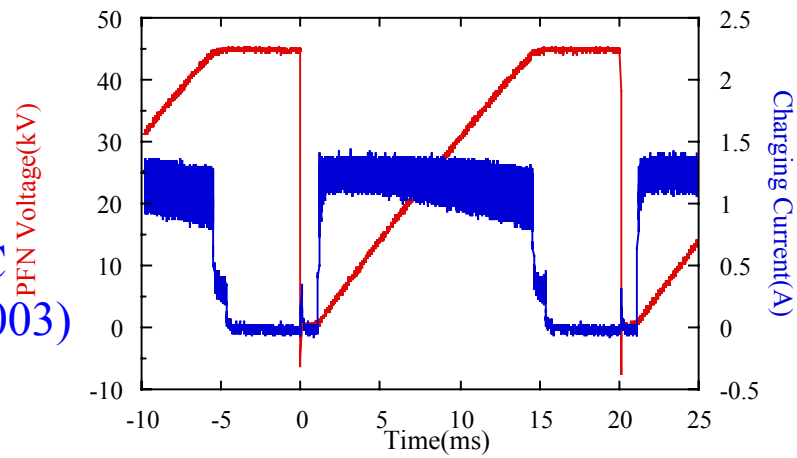
Block Diagram of Switching Power Supply



Problem

1. Heating of HV tank
   - Cooling improvement
   - Reduction of ohmic loss(winding wire)

   Tank temperature over 130˚C ----> below 90˚C
2. IGBT breakdown due to dual trigger pulse (Nov.,2003)
   - Redesign the IGBT gate driving circuit



Applied pulse waveform

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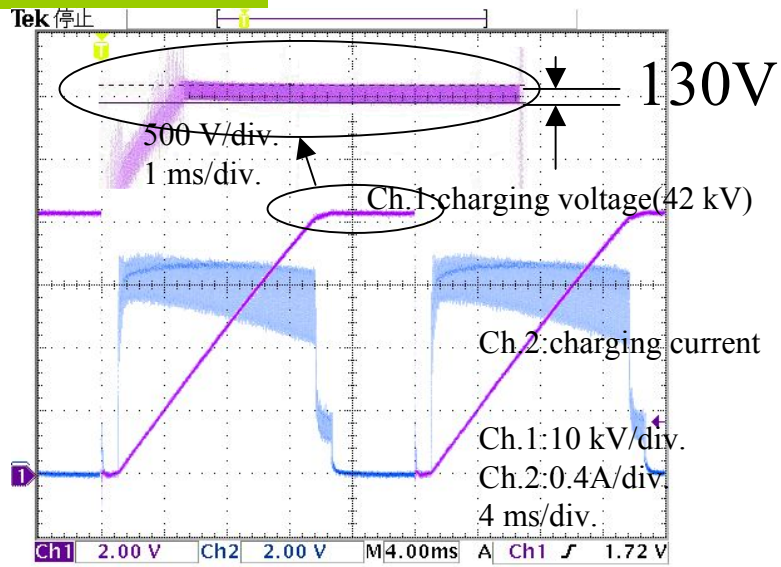
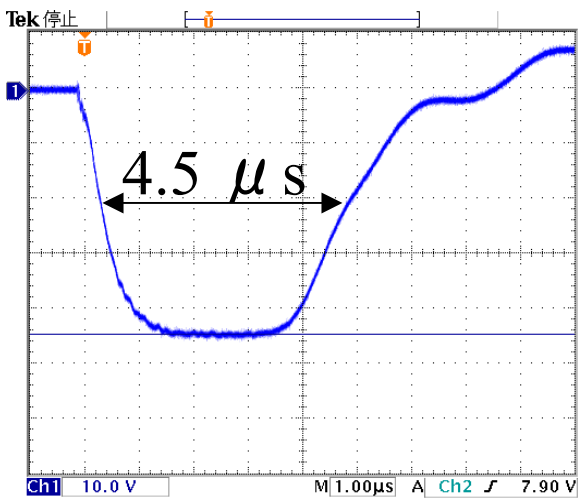
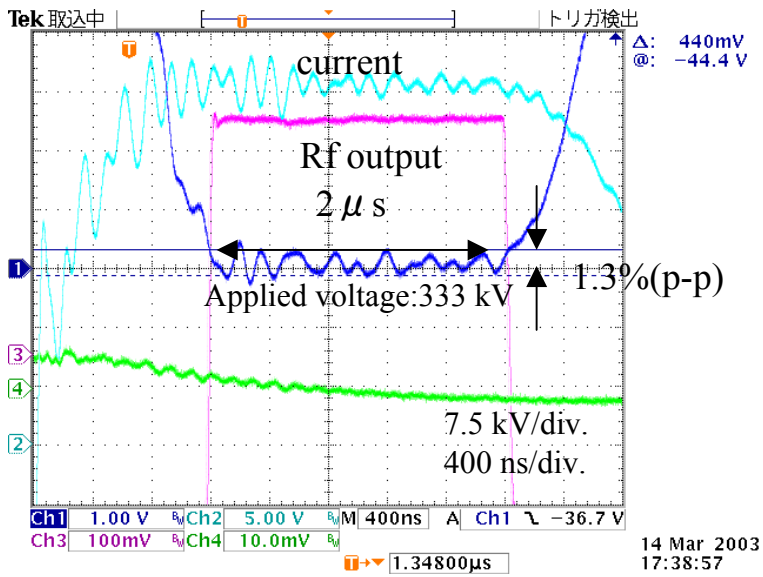
- Flat top: 2 μ s,
- PFN Impedance: 5 ohms
- Pulse-transformer 1:15
- 350 kV at maximum
- Measured flatness 1.3%(p-p)
- Stability $\pm$0.15%

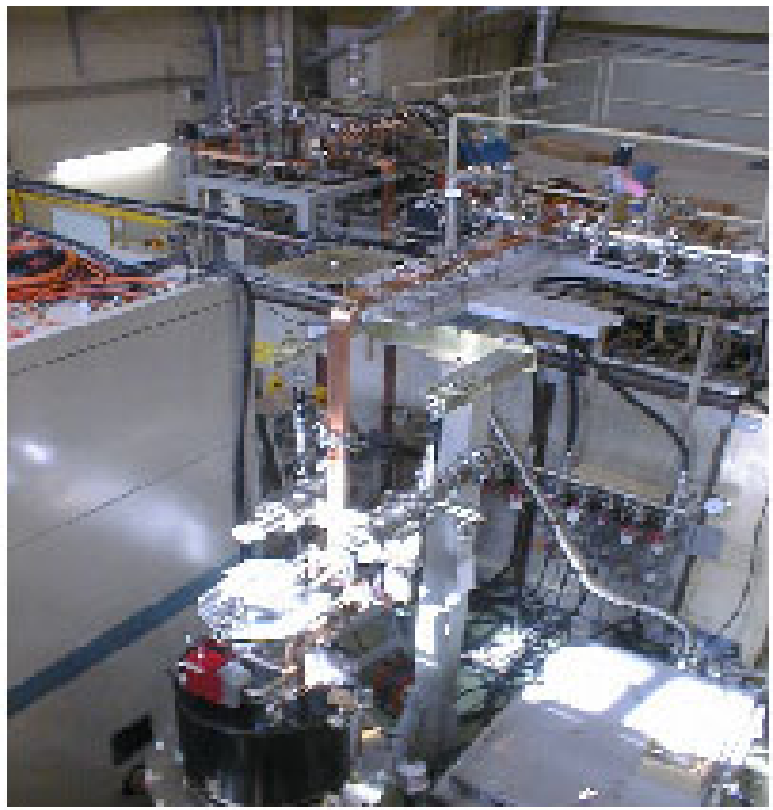






Test stand

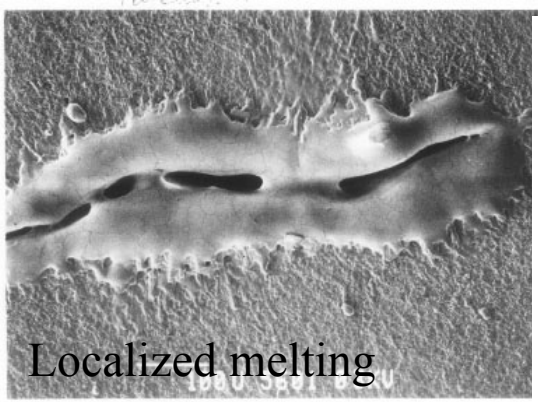
- C-band system is installed in the test stand.
- RF window, dummy load and acceleration structure were tested.

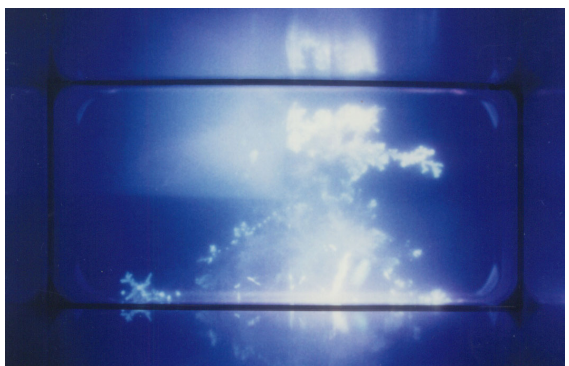


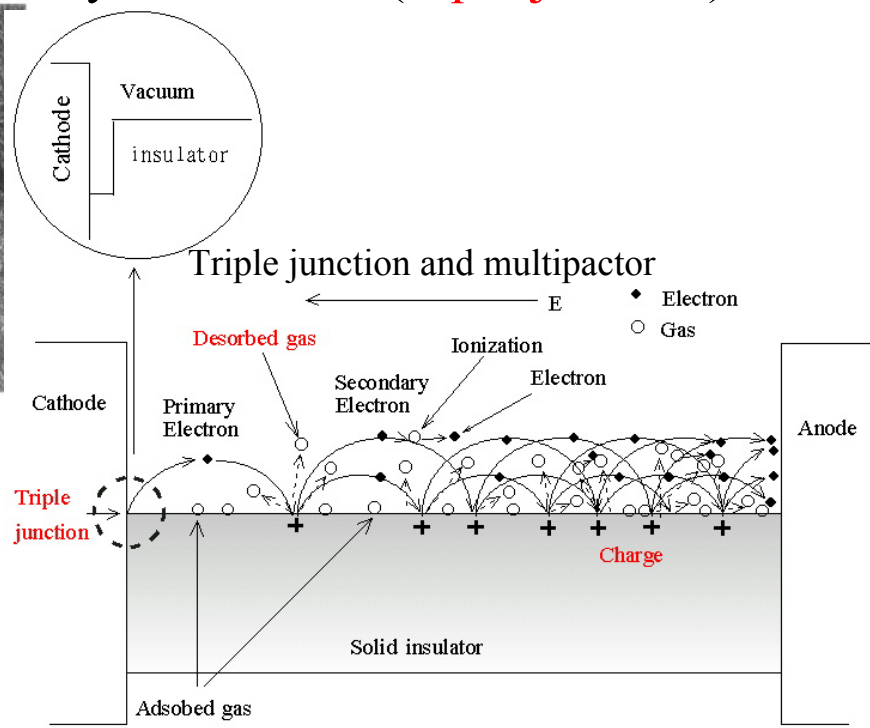
Breakdown of rf window

- Breakdown of the rf windows induces
  1) vacuum leak to the acceleration structure
  2) rf reflection at the window
- High reliability is required for the rf window.
- The breakdown is initiated by the edge-emission of the ceramics.
  → Lower the electric field at periphery of ceramics (triple-junction).

Broken window


Localized melting

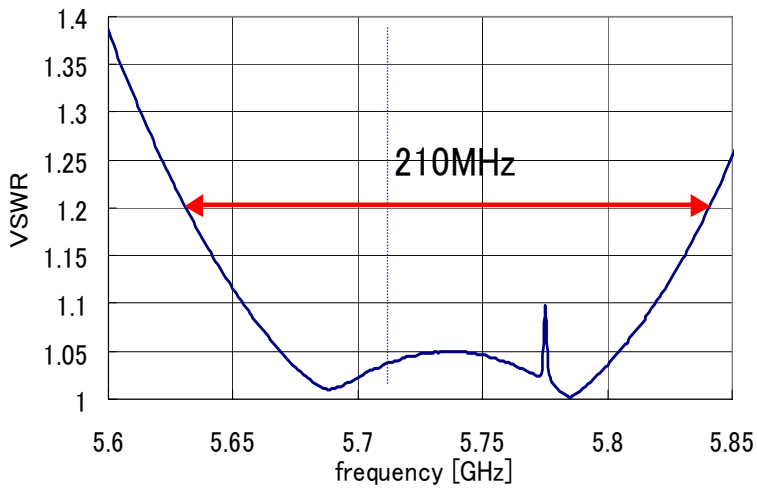

Surface discharge



R&D of c-band rf window

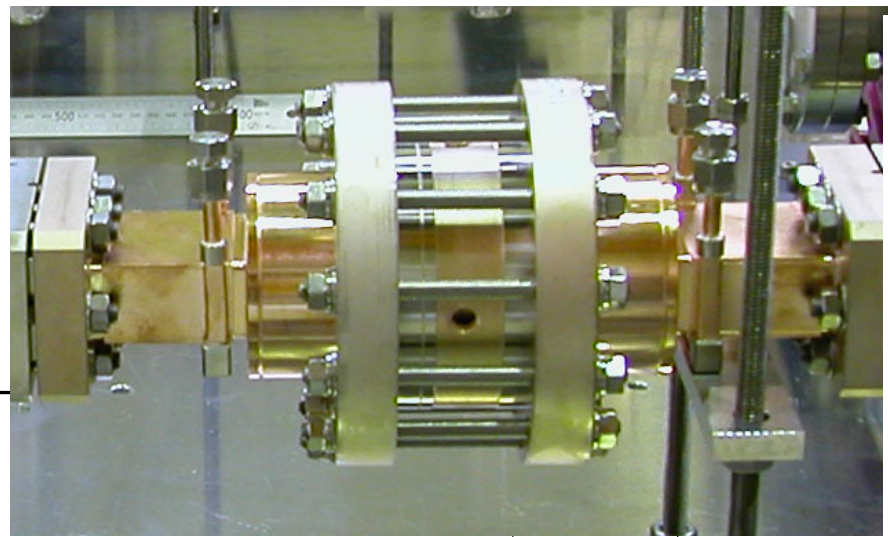
- About Sixty S-band rf windows are successfully operated in KEKB linac. (MTBF > 40,000 h.)
- Electric fileds should be less than rf windows used in S-band linac.
- Mix-mode window (TE11+TM11) enables to lower the edge electric field.
- Five parameters are optimized for lower electric fields and traveling wave in ceramic.

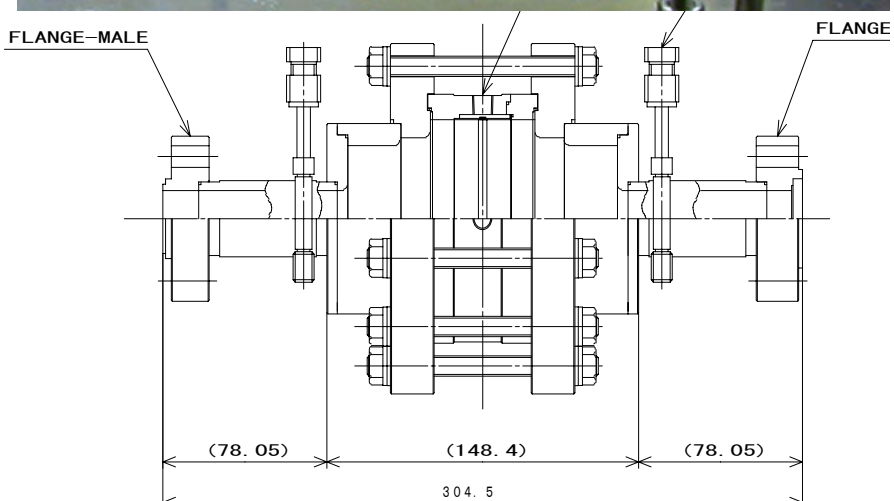
	S-band	C-band
Electric field at center of the ceramics [MV/m@50MW]	3.7	3.1
Electric field at edge of the ceramics [MV/m@50MW]	1.7	***0.8***
Maximum electric field on the ceramics [MV/m@50MW]	5.5	3.7
Band width [MHz] (VSWR<1.2)	600	210

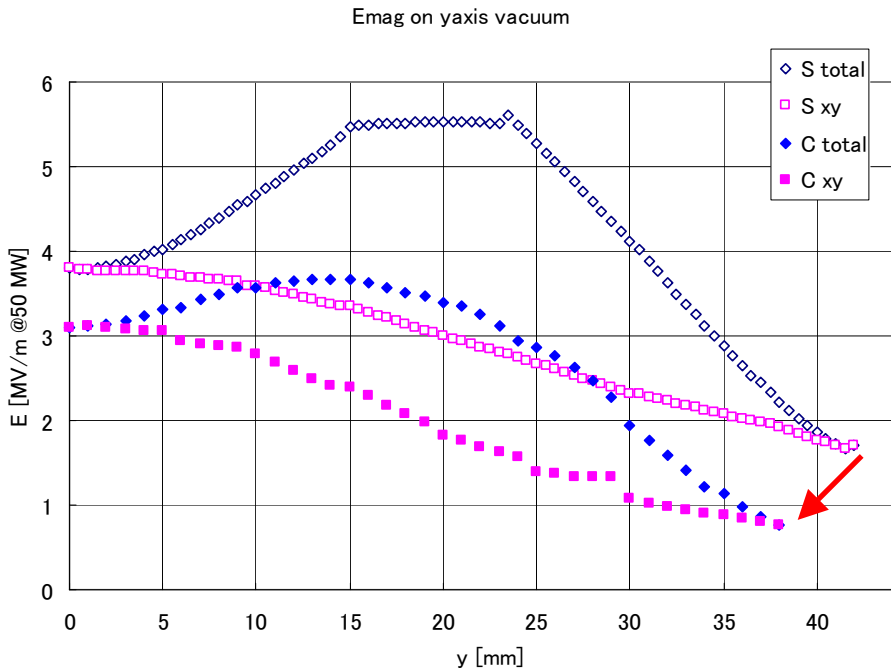


Mix-mode rf window

- Mix-mode (TE11+TM11) window with traveling wave in ceramic.
- The electric field at the periphery is half of the S-band window.

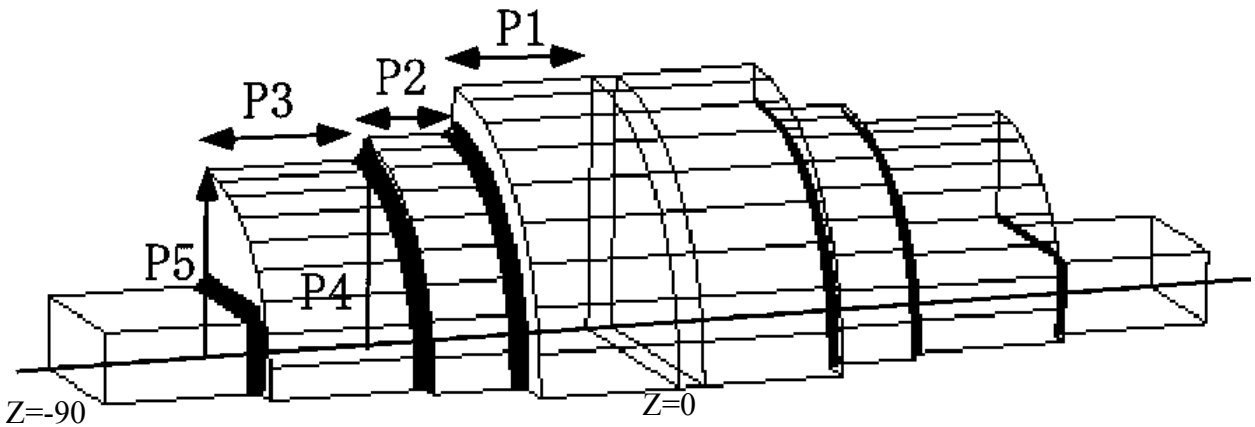


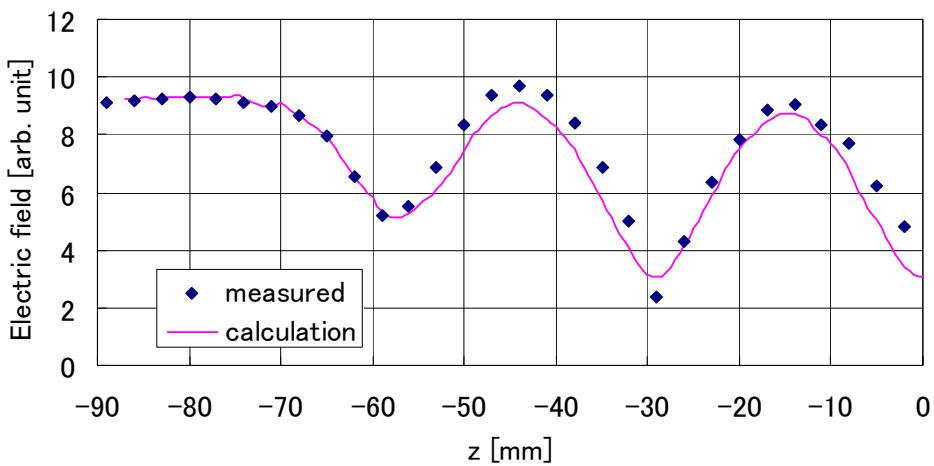




Low level measurements

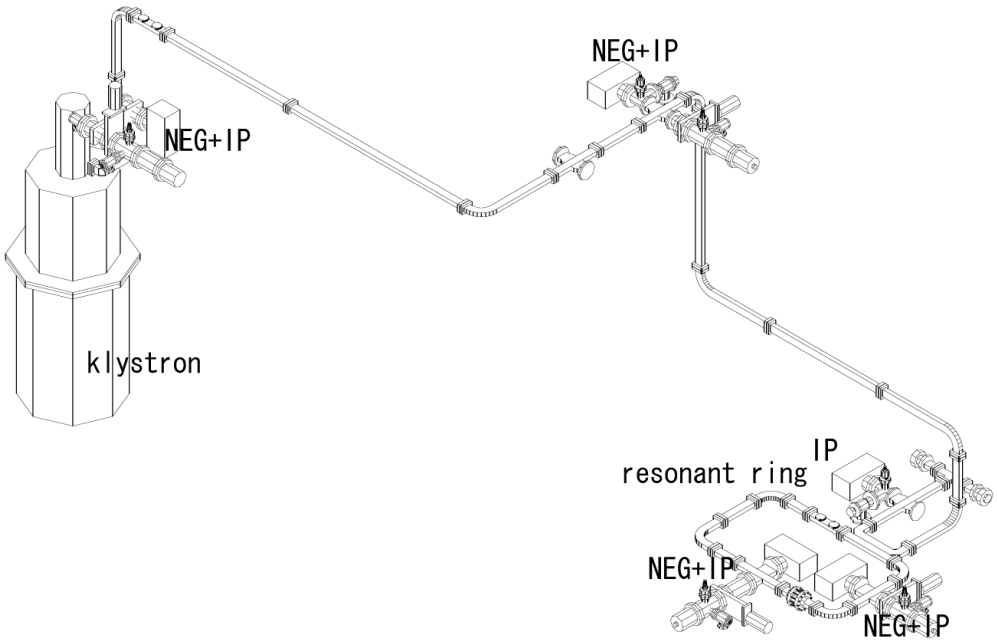
- The low power measurements are carried out by bead perturbation method.
- The electric fields measured are similar to calculation.

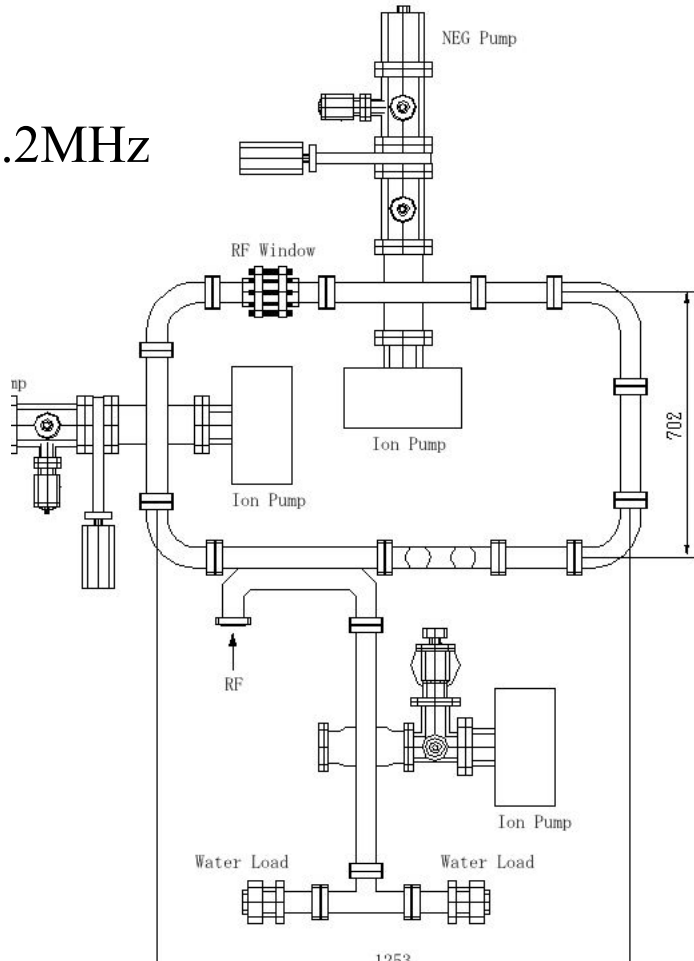




Resonant ring

- In order to examine the rf window, resonant ring is assembled.
- Resonant ring consists of hybrid (14dB) and waveguides.
- Power multiplication ratio is about 18.
- Rough tuning: spacer in the ring (±5mm)
- Fine tuning: frequency (±5MHz)
- Operation frequency for rf window test is 5710.2MHz (5712MHz-1.8MHz).
- Evacuated by NEG and ion pumps. (<10^{-6} Pa)

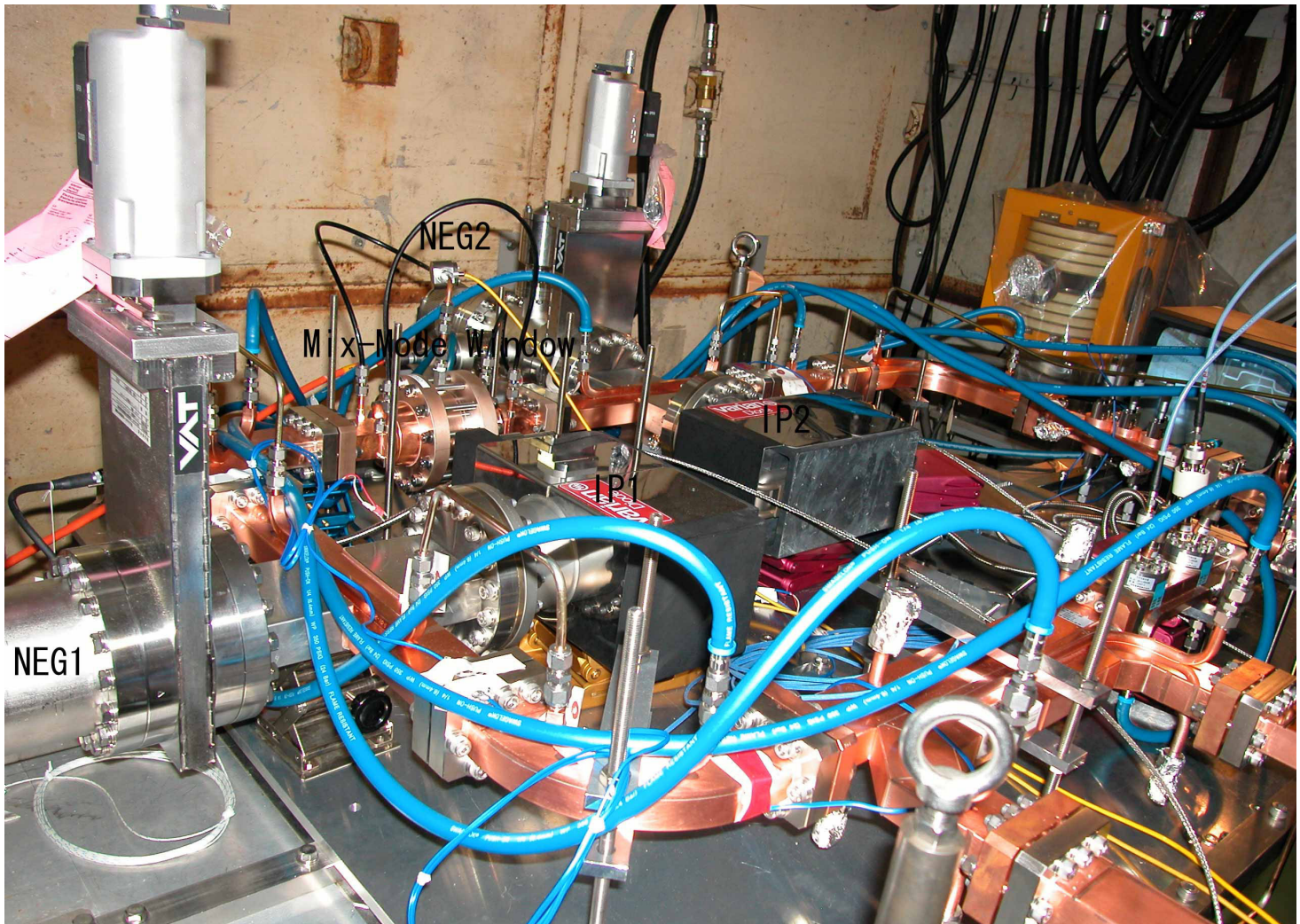


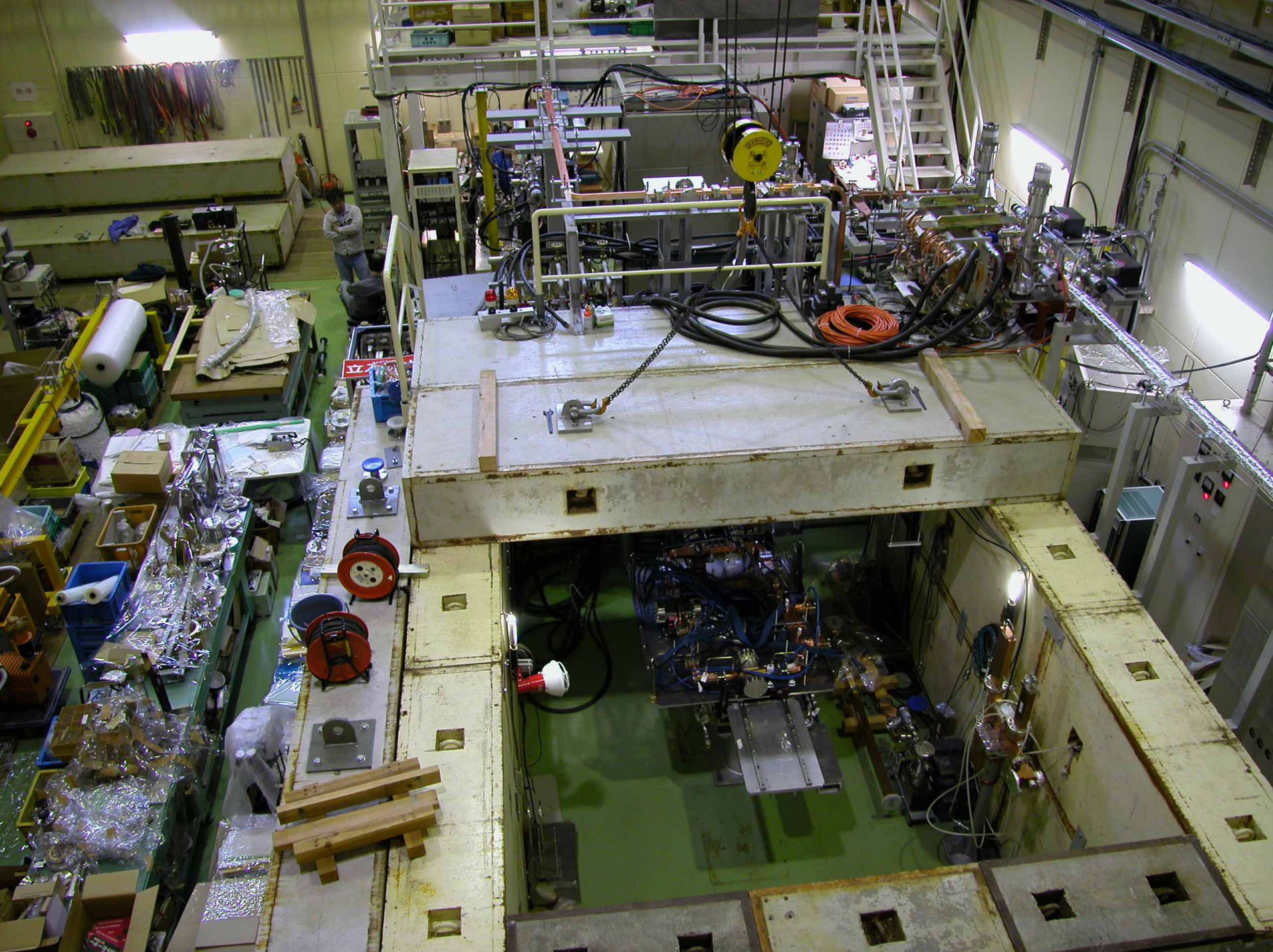


Assembly of resonant ring

Resonant ring in the shield

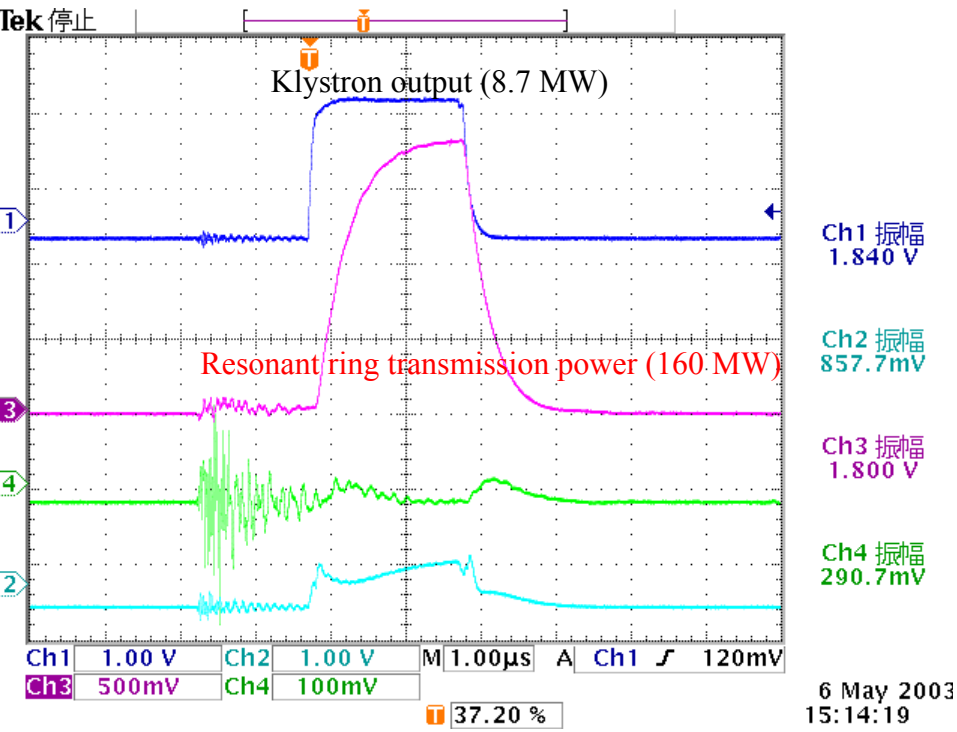
✧ Both sides of rf window are evacuated with NEG and ion pumps.

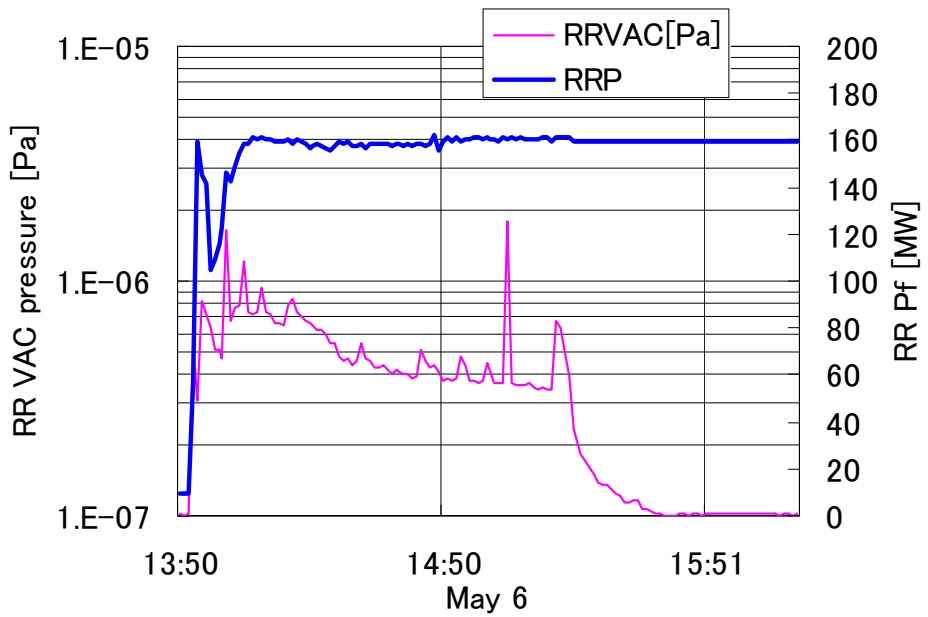




Results at resonant ring (1)

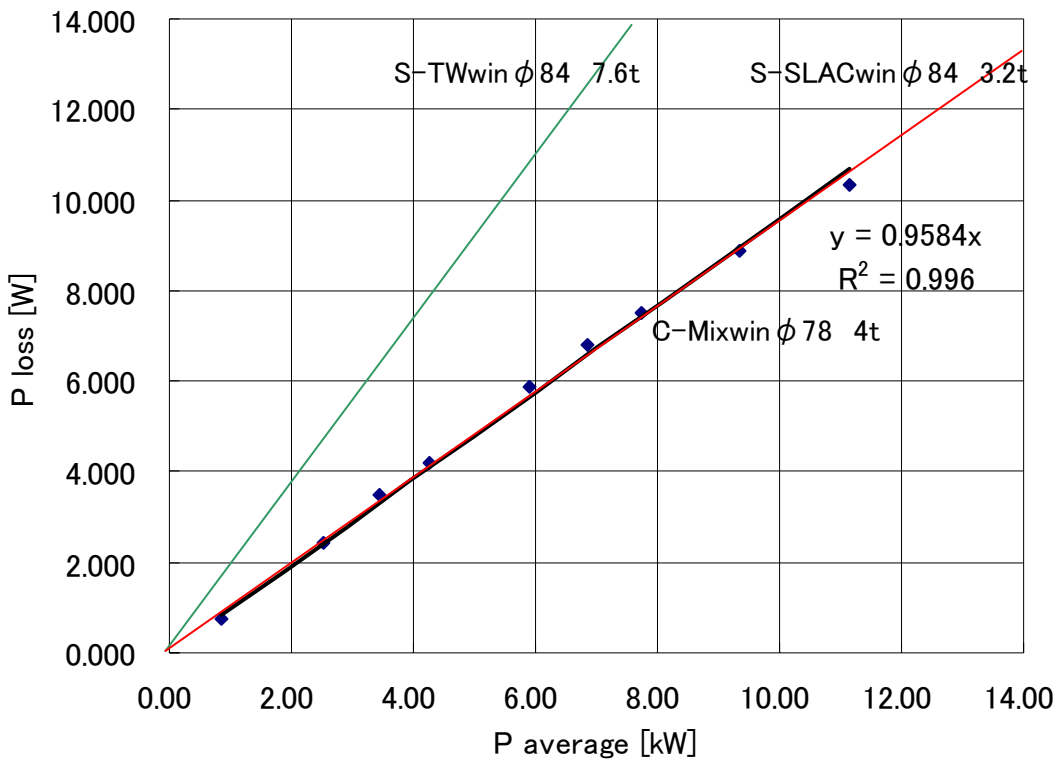
- Maximum operation power of 160 MW (2 μs), corresponding to full reflection from the load at the rf power of 40 MW.
- Radiation level is <1 μSv/h, much less than S-band window.



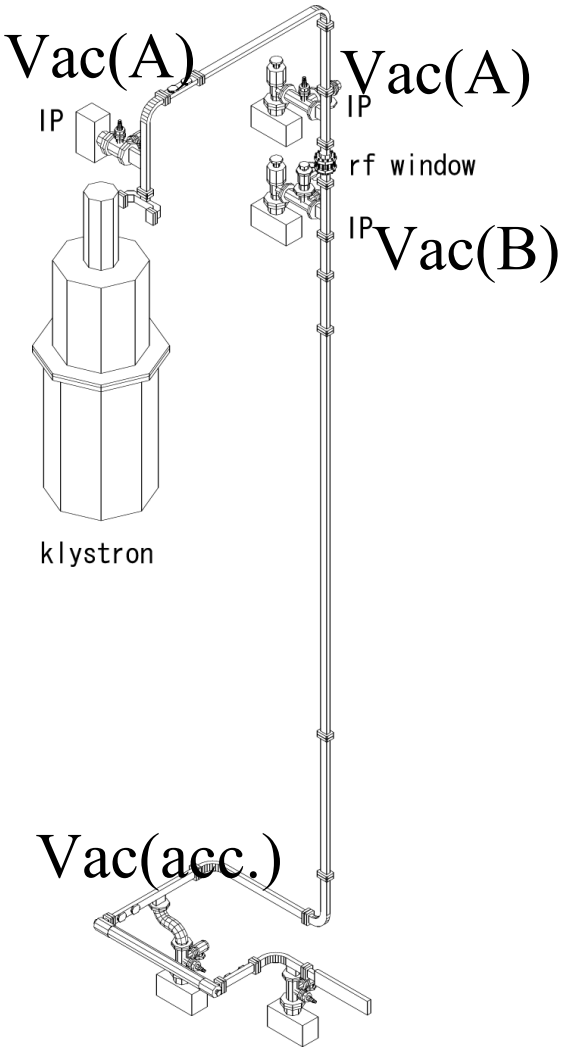


Results at resonant ring (2)

- RF losses at rf window are measured.
- The loss is almost same to the S-band window.
- The C-band window ceramics is 25% thicker than S-band ceramics.
- 50 MW 2 μ s,50 pps operation will be safe from the view point of heating.



Installation to klystron gallery (#44)



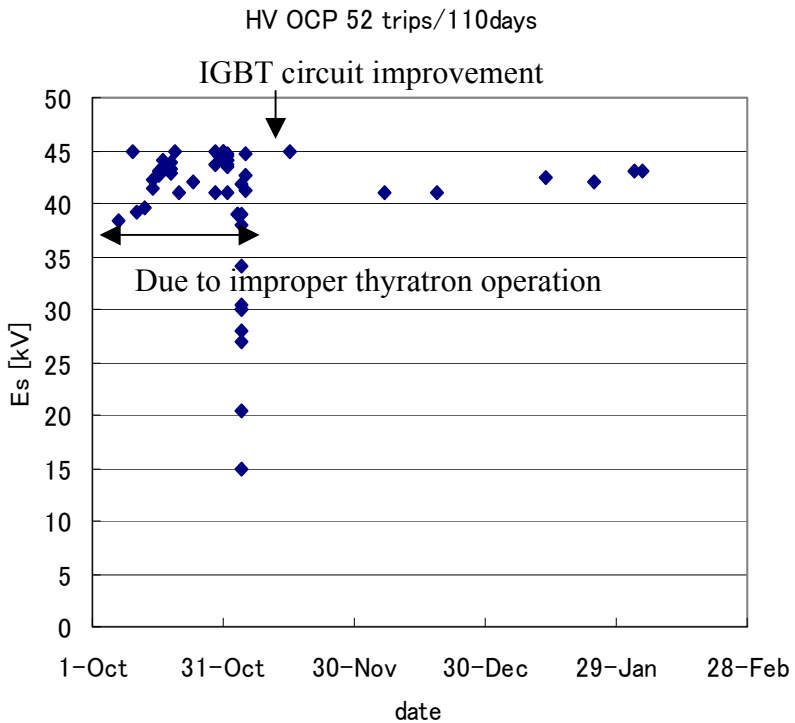
- RF system moved to klystron gallery on Sep.,2003.
- Vacuum pumps are located near the rf windows. (klystron / mix-mode window)

Operation status @ #44

- RF operation continues more than 100 days.
- Trips caused by the modulator are 52 for 110 days operation.
- After the exchange of thyratron, the stability increases drastically (Nov.3,2003).
- Inverter PS is exchanged on Nov.5,2003 in order to improve the IGBT gate driving circuit.
- After that the modulator runs rather stably. (but under development)

Due to conditioning

	Number of trips (Sep.30,2003-Feb.11,2004)
VSWR	11,346
Vacuum (A)	20
Vacuum (B)	14
Vacuum (acc.)	147
modulator	52



Future works

- 2nd klystron assembly has been tested since Jan.,2004.
- The conventional oil tank (for S-band) is reused.
- Since the outer diameter is same to the magnet, reinforcement is required.
- High power test (upto 50 MW) for the klystron assembly (pulse transformer, dielectric insulator, capacitive divider (max.350kV) ….) will continue.
- High power resonant ring test will be carried out upto 200 MW. (next April)