

Experience of Klystron Operation at J-PARC LINAC

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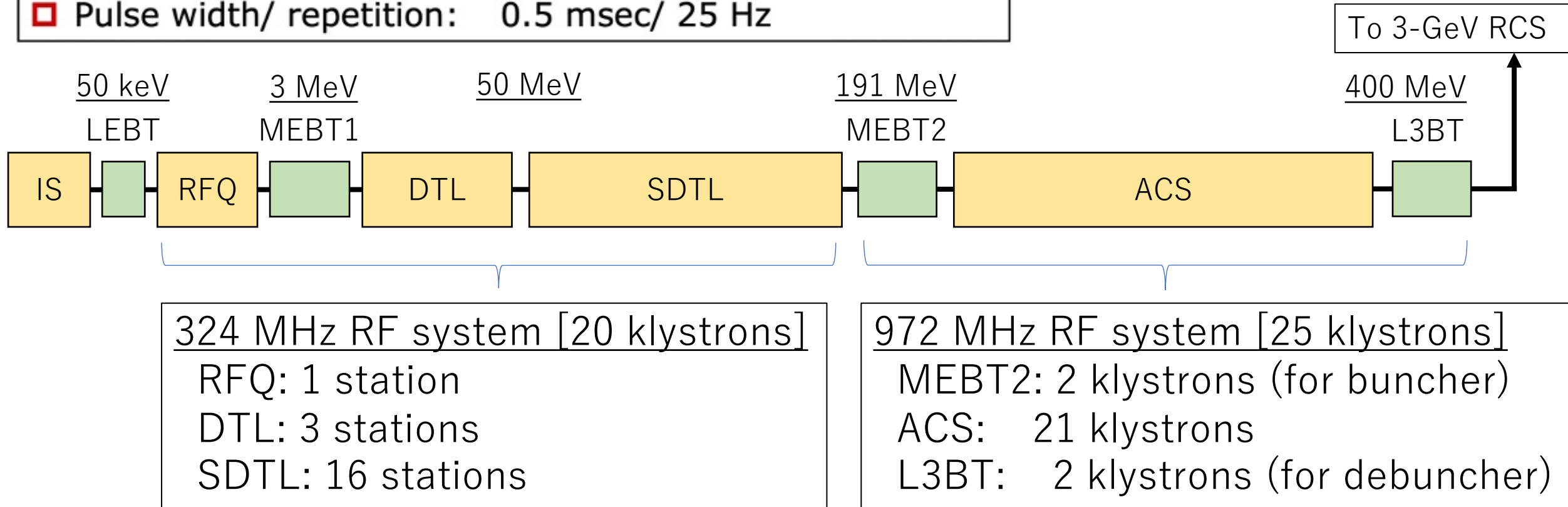
- Overview of klystrons system in J-PARC LINAC
- Operation Experience of klystrons at J-PARC
- Operation Experience of klystron HVDC power supply
- Summary

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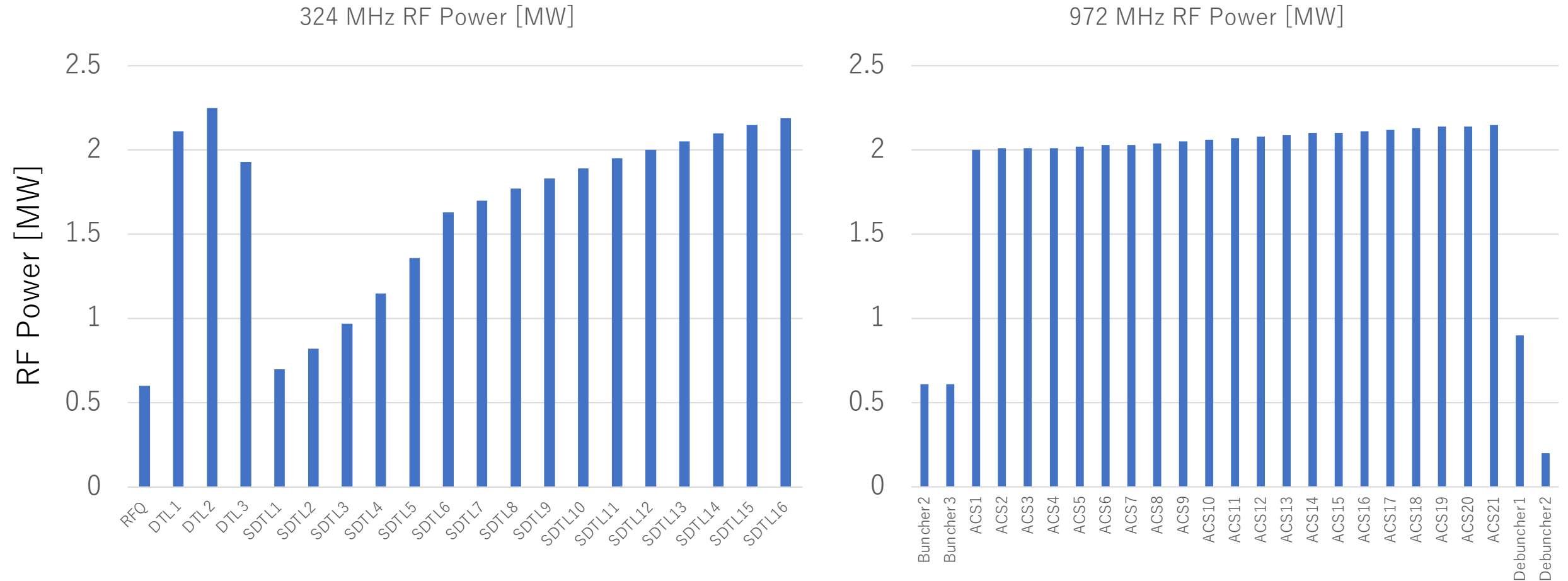
J-PARC LINAC

- Acceleration particle: Negative hydrogen ion (H^-)
- Energy: 400 MeV
- Peak current: 50 mA
- Pulse width/ repetition: 0.5 msec/ 25 Hz



In total, 45 klystrons are operated in J-PARC LINAC.

RF Power required for J-PARC LINAC



The required peak power per klystron is 2 MW or more.

* Above graphs show designed parameters. Actual RF power is depended on operation condition.

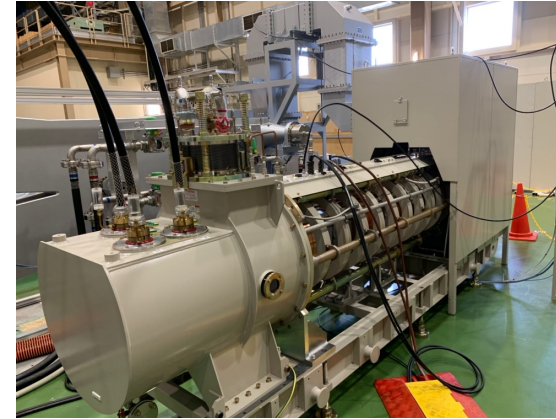
Klystrons for J-PARC LINAC

324 MHz klystron

E3740A (Canon Electron Tubes & Devices)

972 MHz klystron

E3766A (Canon Electron Tubes & Devices)



CETD E3740A

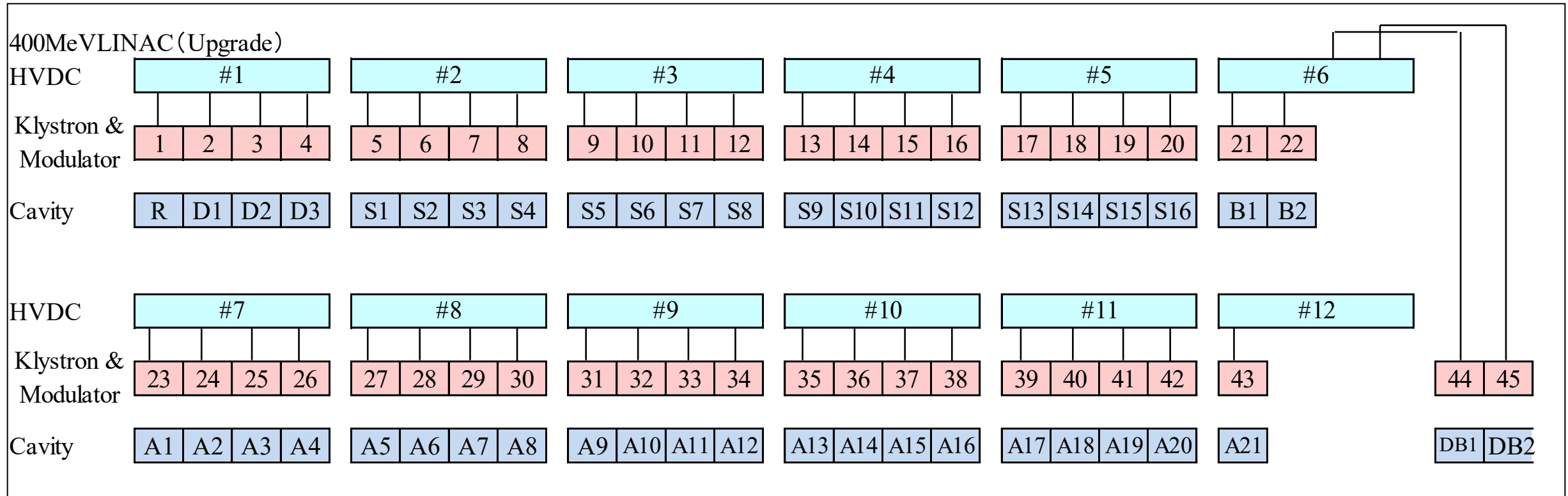


CETD E3766A

Specification of klystrons

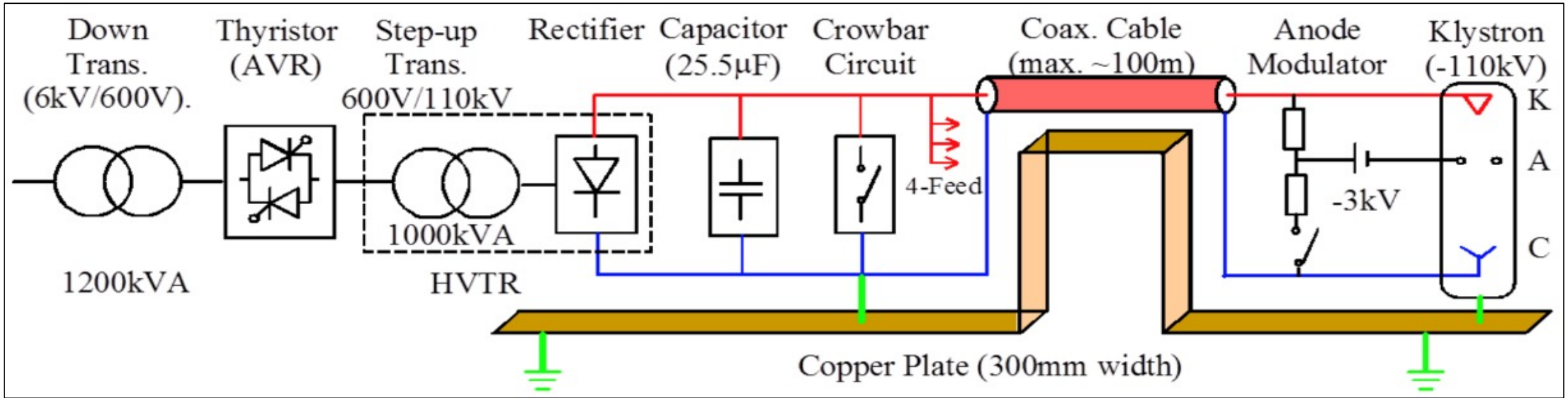
Frequency:	324/972 MHz
Peak Power:	3 MW (Averaged Power: 93 kW)
Gun type:	Anode-Modulating type
Pulse Length:	620 micro-sec.
Repetition Rate:	50 pulses per second (operated with 25 pps in J-PARC LINAC)
Beam Voltage:	110 kV
Beam Current:	50 A
Efficiency:	55%

Configuration of High Power RF Sources



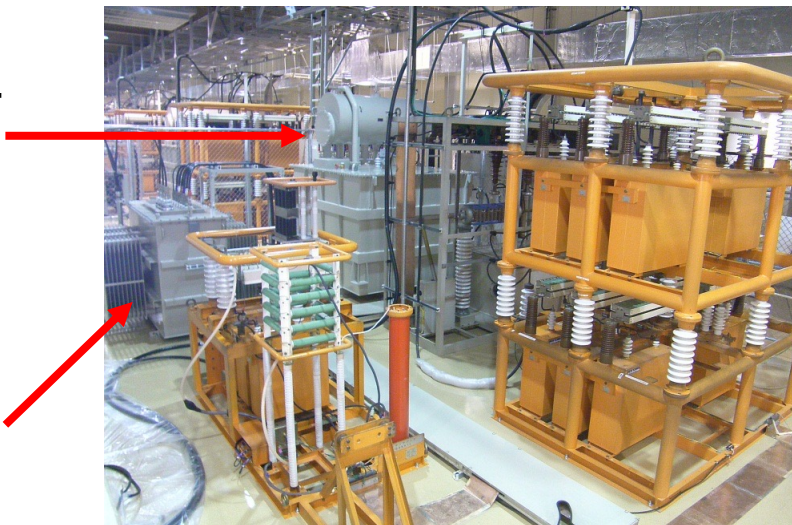
Four tubes of klystrons are connected to a single High-Voltage DC Power Supply. Each klystron is accompanied by an anode modulator which switches klystron beam pulses.

Klystron High Voltage Power Supply

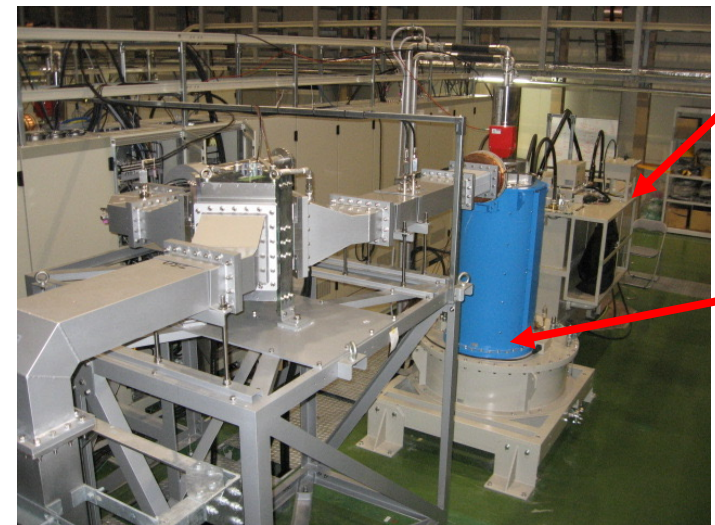


Step-up Trans. & Rectifier

Down Trans.



Capacitor



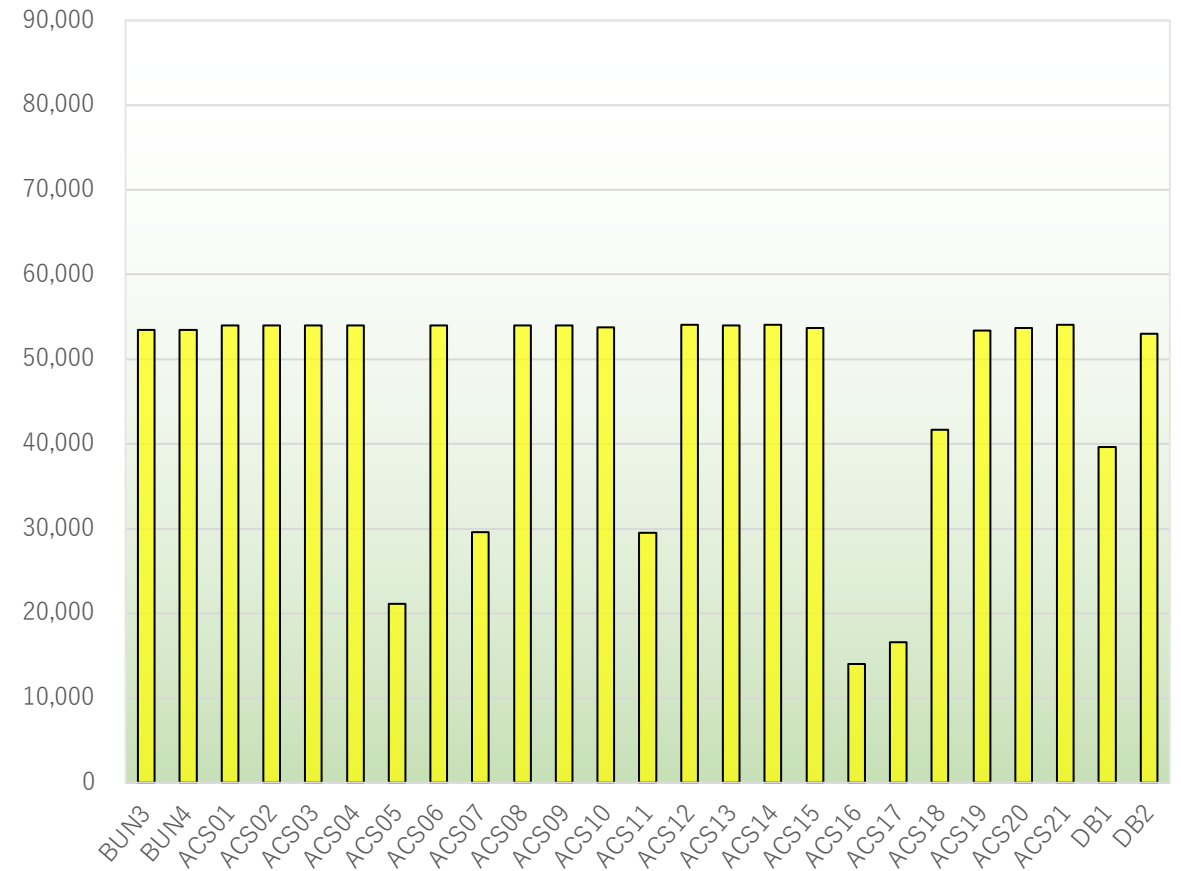
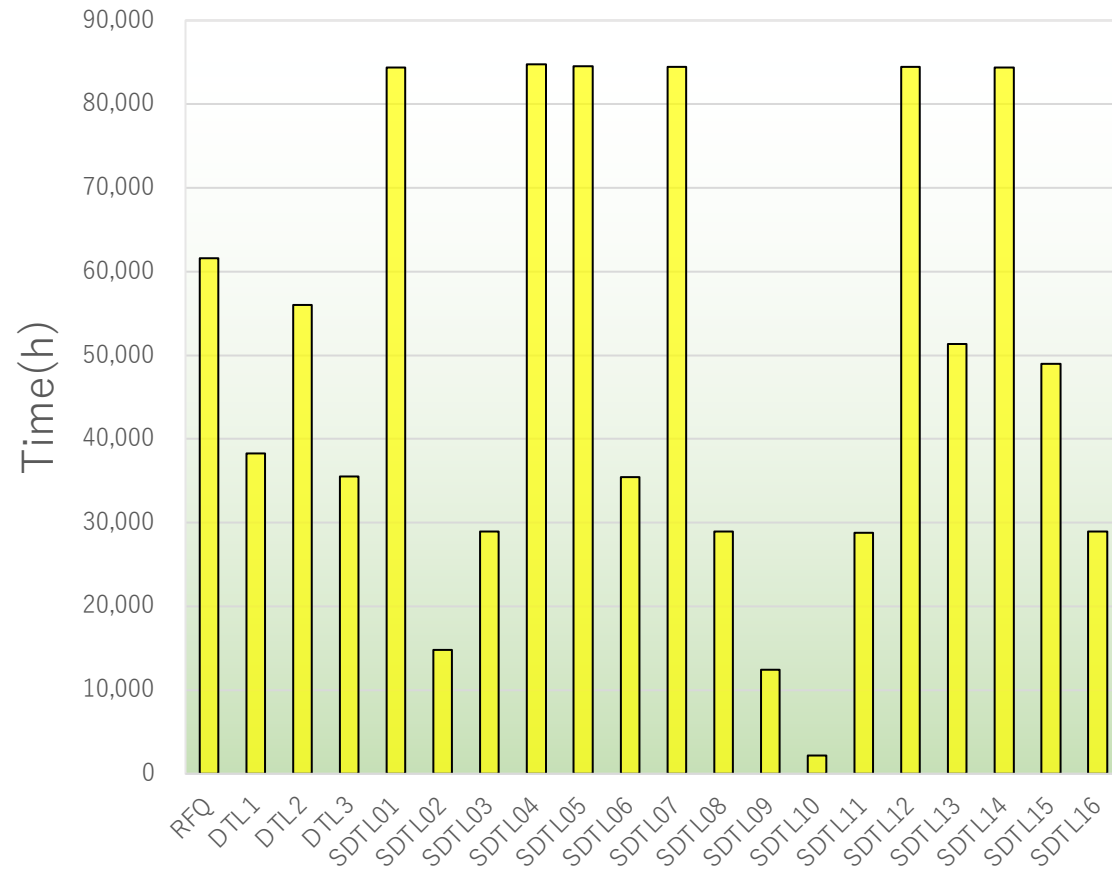
anode modulator

klystron

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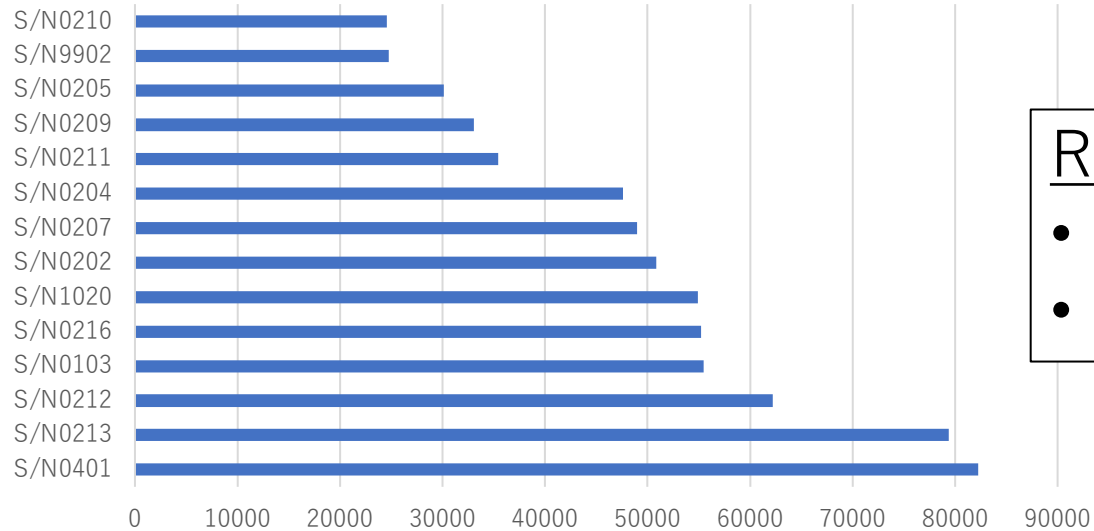
Operation Time of Klystrons (July 2022)



The 324-MHz klystron, which has been in use since 2006, has reached 84,000 hours of operation. The 972-MHz klystron, which has been used since 2014, has reached 54,000 hours of operation.

Lifetime of klystrons

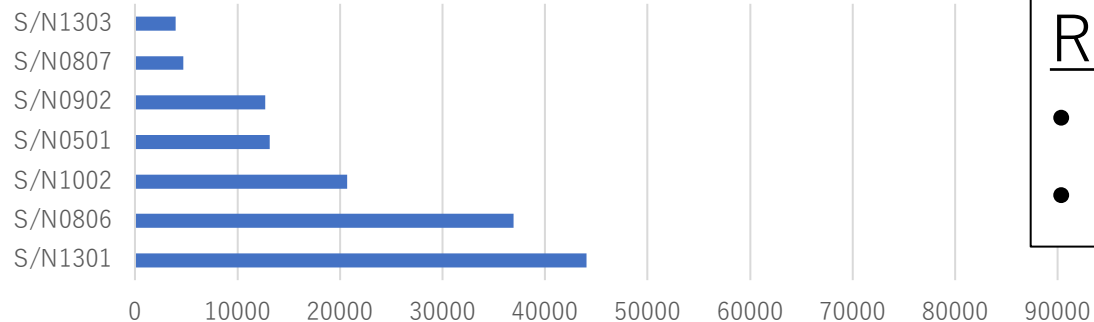
324-MHz klystrons: 14 tubes were retired during 16 year operation



Reason for Termination of use [324-MHz KLY]

- Discharge at electron gun (13 tubes)
- Degradation of vacuum in tube (1 tube)

972-MHz klystrons: 7 tubes were retired during 8 year operation

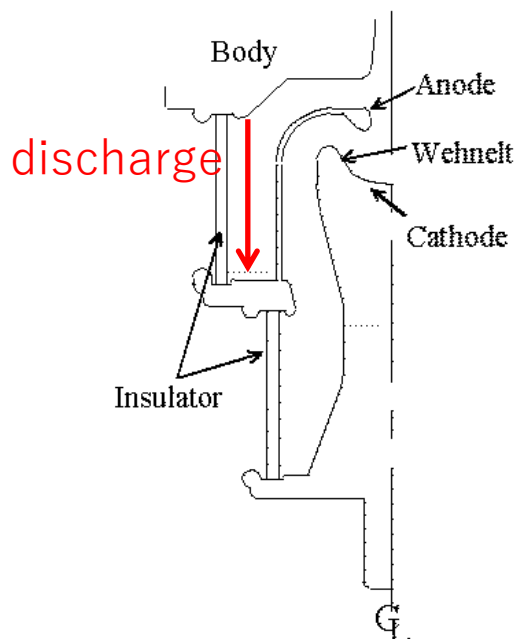


Reason for Termination of use [972-MHz KLY]

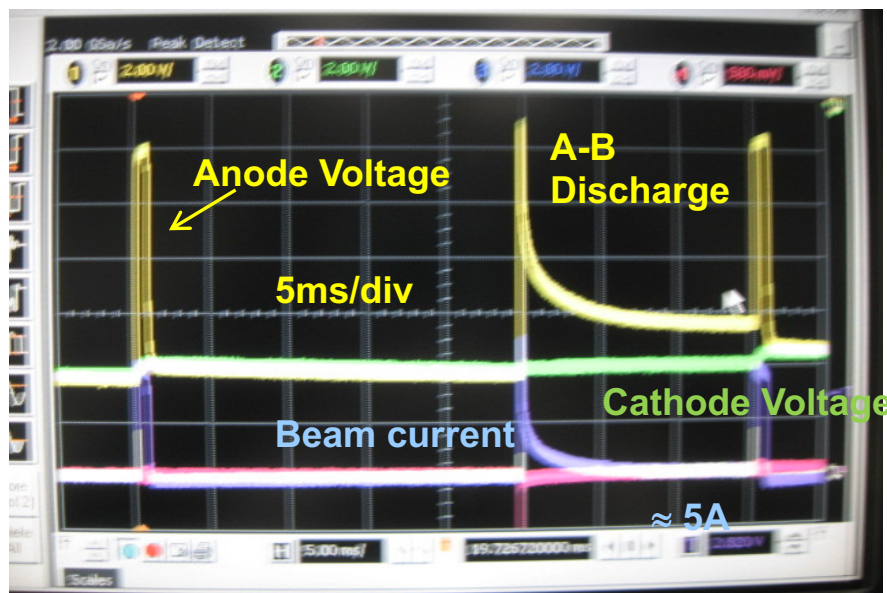
- Discharge at electron gun (5 tubes)
- Water leak (2 tube)

Discharge at klystron electron gun

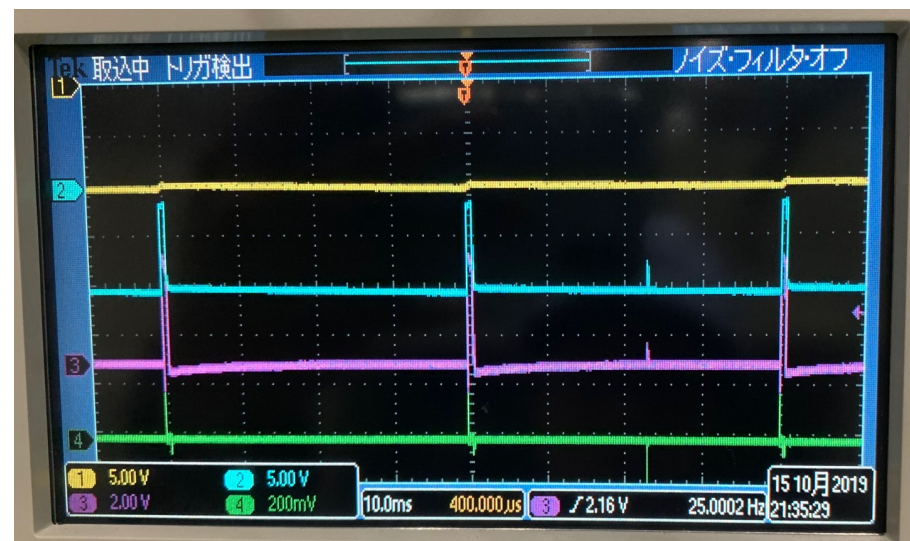
The klystrons for J-PARC have electron gun with a triode configuration, so the distance between the gun electrode is short. Therefore, the electric field on the electrode surface is relatively large, and discharges are likely to occur.



Cross section of electron gun



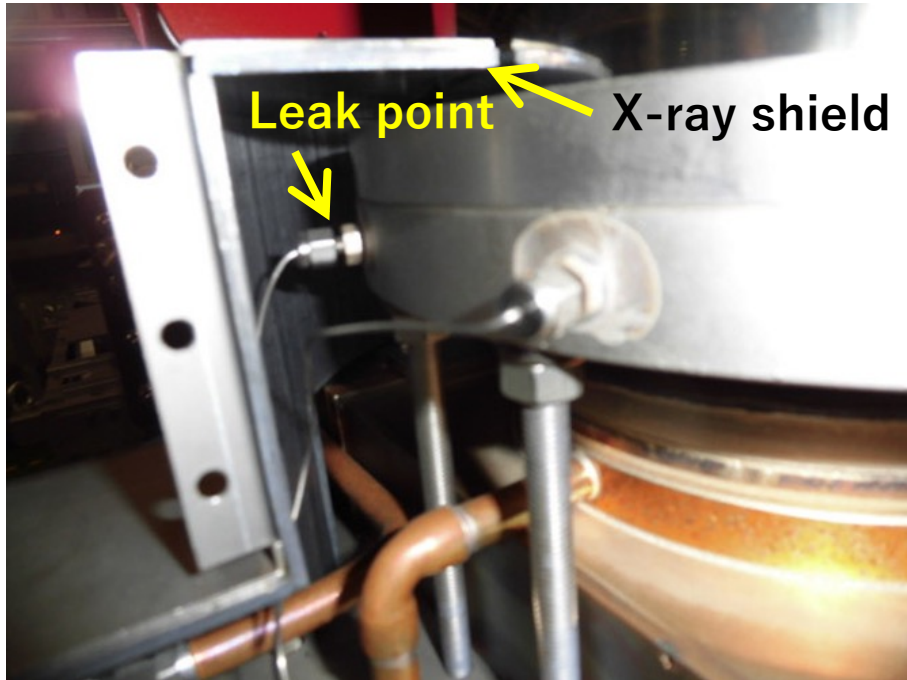
↑ discharge event in 324-MHz KLY



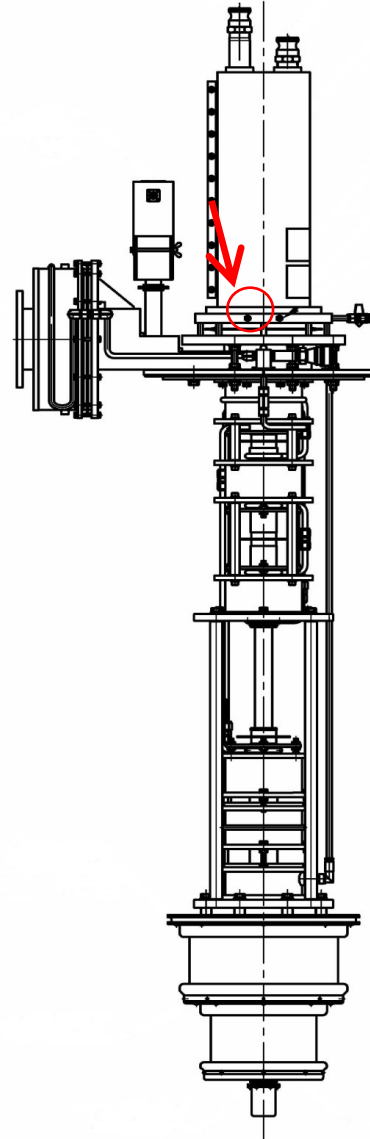
↑ discharge event in 972-MHz KLY

To reduce the risk of discharge, the voltage of the klystron high-voltage power supply is set to the minimum required voltage, which is lower than the rated value of 110 kV.

Leakage of Klystron Cooling Water



Leak point: brazed part between the flange and the thermocouple socket.



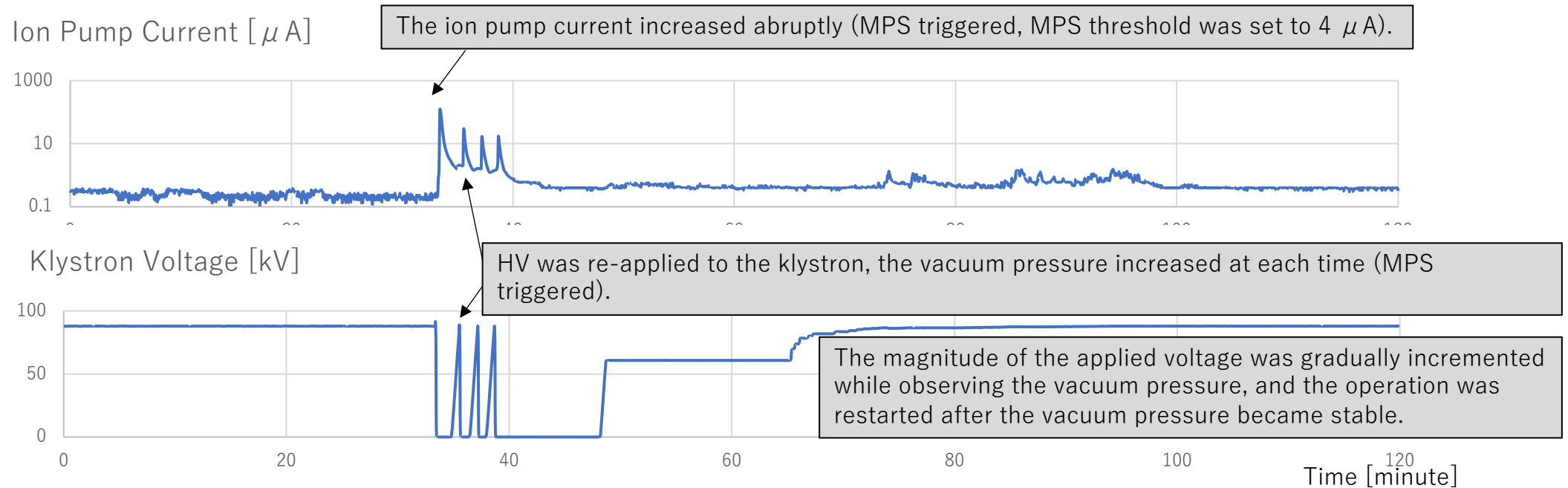
Exposed to high humidity for a long time.

Causes of water leakage

The X-ray shield hit the thermocouple socket, when installing the shield in J-PARC.

Deterioration of Vacuum in Klystron

- One 324-MHz klystron was replaced due to deterioration of vacuum pressure. (A typical vacuum failure event show below.)



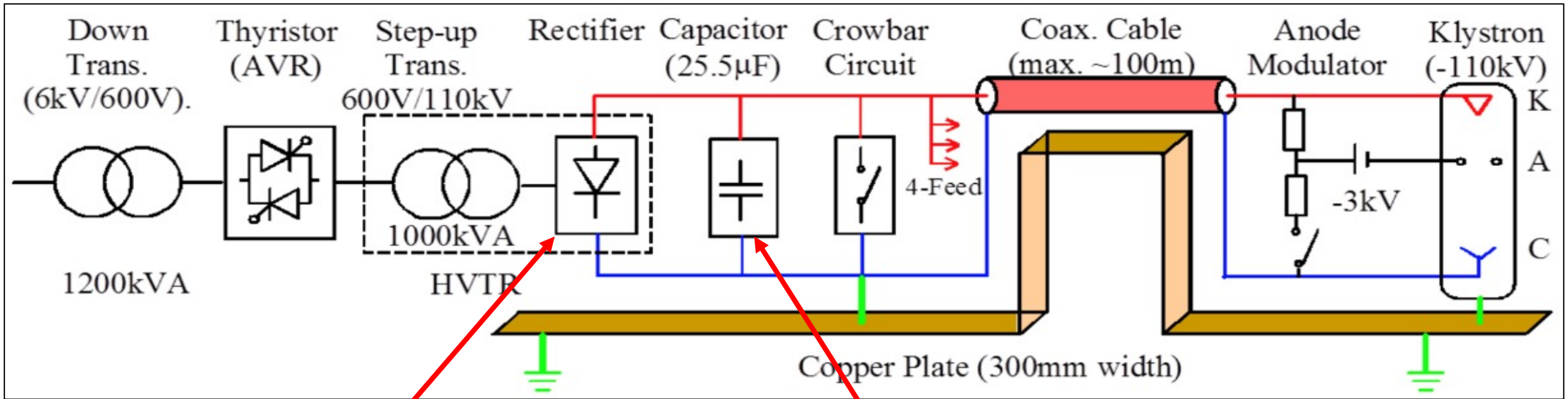
- **Similar events have been occurring with lower frequency for several years, however, the number of such events has increased in the last operation period (11 events occurred from Nov. 2020 to Jul. 2021).**

- The operating time of the klystron tube is over 80,000 hours, which is much beyond the tube life presumed by the manufacturer (50,000 hours).
- We assessed that this vacuum deterioration was due to the end of klystron's life and decided to replace it.

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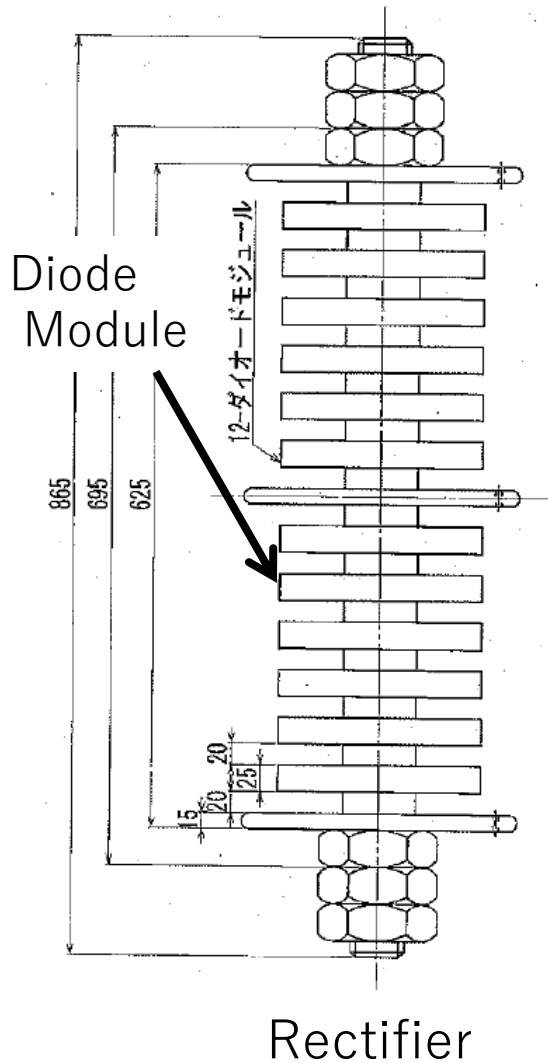
Major Trouble on HVDC Power Source



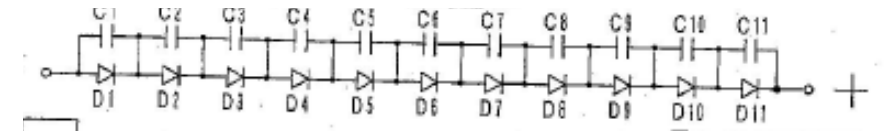
1. Breakdown of HV Rectifier

2. Oil Leak from HV Capacitor

Breakdown of HV Rectifiers



Diode Modules in the klystron HVDC power supply were broken due to over voltage.



Causes of breakdown

Parallel capacitors in diode elements has temperature dependence and elements near the input terminals were heated.

-> An imbalance in voltage dividing and breakdown occurred.

Oil Leakage from Capacitor

Oil leak from one of the capacitor package in Capacitor Bank(C-Bank) have found on high voltage power supply system #3 in summer maintenance of 2019.

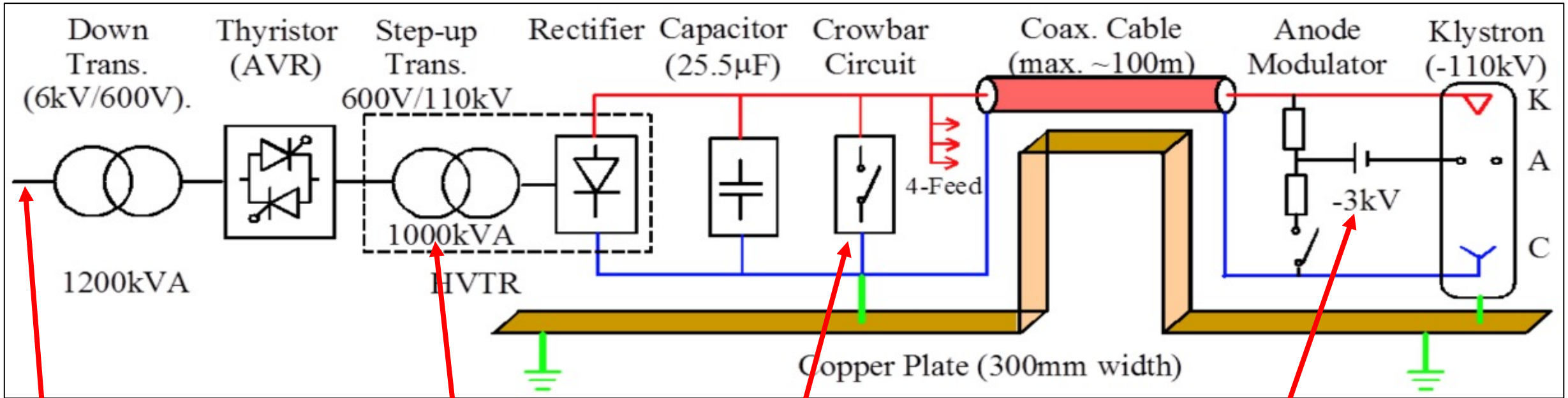
There was a slight defect in the welded area, which led to oil leakage after a long operating time.

Although no other damaged capacitors have found, many C-Bank have been **operated for over 15 years**.

To ensure safety, replacement of the C-Bank with new model has been going on since 2020.



Components with Age-Related Deterioration



6600-V Vacuum Circuit Breaker

Step-up Transformer

Ignitrons in Crowbar

Bias Power Supply for Modulating Anode

More than 15 years have passed since the start of operation, and many components have begun to show age-related deterioration. A long-term plan for replacement is needed to assess the trend of component deterioration.

Summary

- A total of 45 klystrons and 12 HVDC power supplies are used to operate the accelerator at the J-PARC LINAC.
- Klystrons were replaced due to discharge at electron gun region, water leakage, and vacuum deterioration.
- In the high-voltage DC power supply, some components in use are deteriorating over time and are being replaced.