



5kHz Modulation of 170 GHz Gyrotron with Anode-Cathode Short-Circuited Switch

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Outline



- Introduction of 5kHz modulation methods of the present gyrotron.
- Introducing Cathode-Anode Short-Circuited switch (Anode switch).
- A 5kHz modulation experimental results.
- Proposing a new circuit configuration and a new Anode Power Supply (APS) in JAEA test stand.
- Summary.

Introduction of the 5kHz modulation strategies



5kHz on/off power modulation is required for NTM suppression for ITER 170GHz gyrotron.

Main switch on/off (>40A / 50kV) modulation.

Body power supply or anode power supply partial voltage (~20mA/5kV) modulation.

Heat load on the switch is too high for 5kHz modulation.

Electron beam is injected collector without dumping energy during turn off phase.

Heat load on the collector is too high if RF is completely turned off.

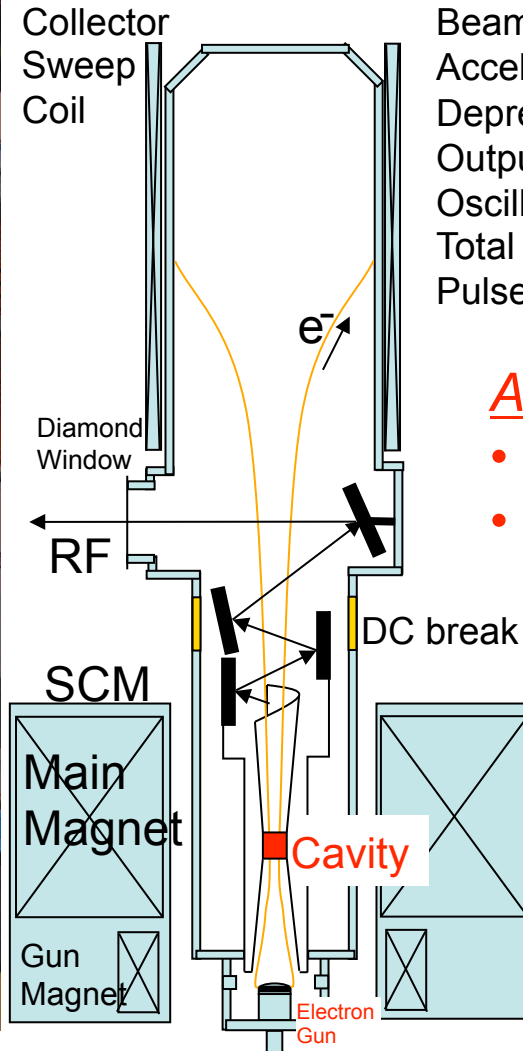
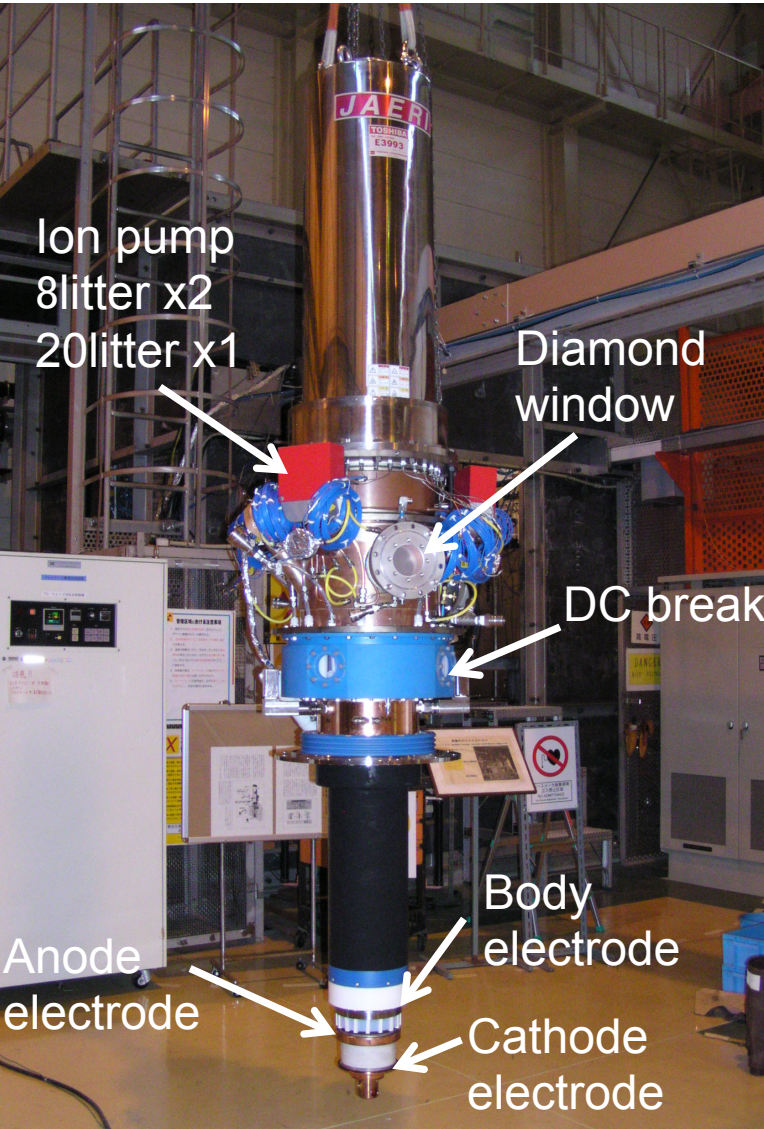
1kHz modulation

50-100% power modulation

ITER current decision

1kHz 0-100% power modulation.
5kHz 50-100% power modulation.

Gyrotron



Parameters for 1MW operation

Beam current: 38A
 Acceleration voltage: 73kV
 Depressed collector voltage: 25kV
 Output power: 1MW
 Oscillation efficiency: 37%
 Total efficiency: 55%
 Pulse length: 800s

Achievements

- 1MW / 800 s / 55%
- 0.8MW / 3600 s / 55%

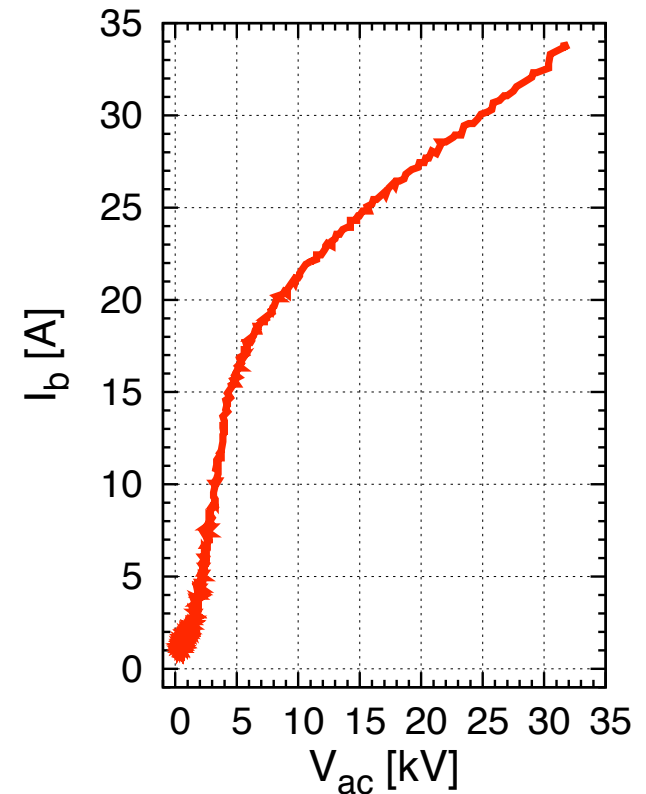
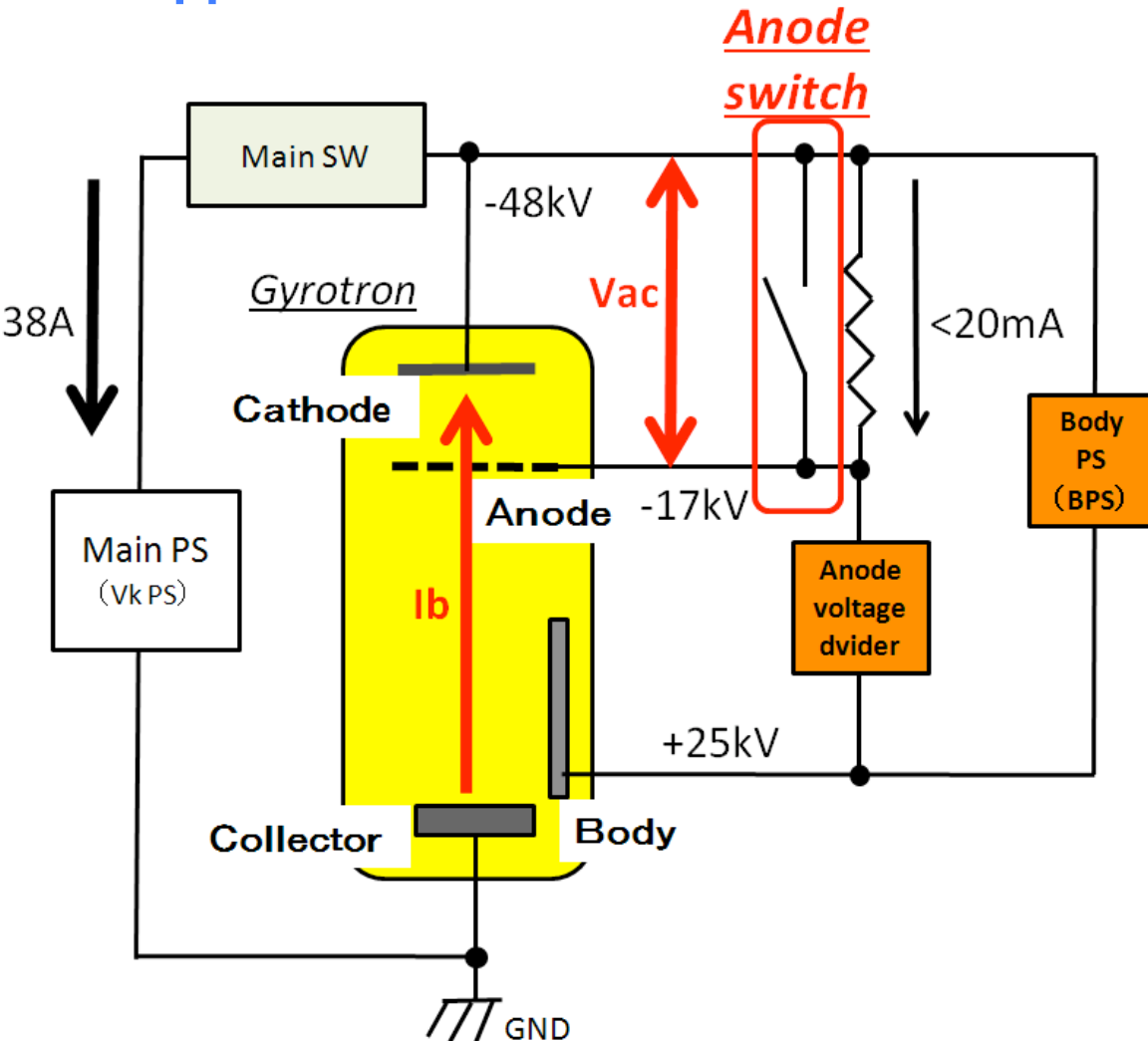
Specifications

Frequency: 170GHz
 Oscillation mode: TE_{31,8}
 Triode Magnetron
 Injection Gun (MIG)

Introducing the Anode-cathode short-circuited switch



- Anode-cathode short-circuited switch (anode switch) is installed to suppress the beam current for the modulation.



Advantage of the anode switch on/off modulation



5kHz on/off power modulation is required for NTM suppression for ITER 170GHz gyrotron.

Anode switch on/off modulation.

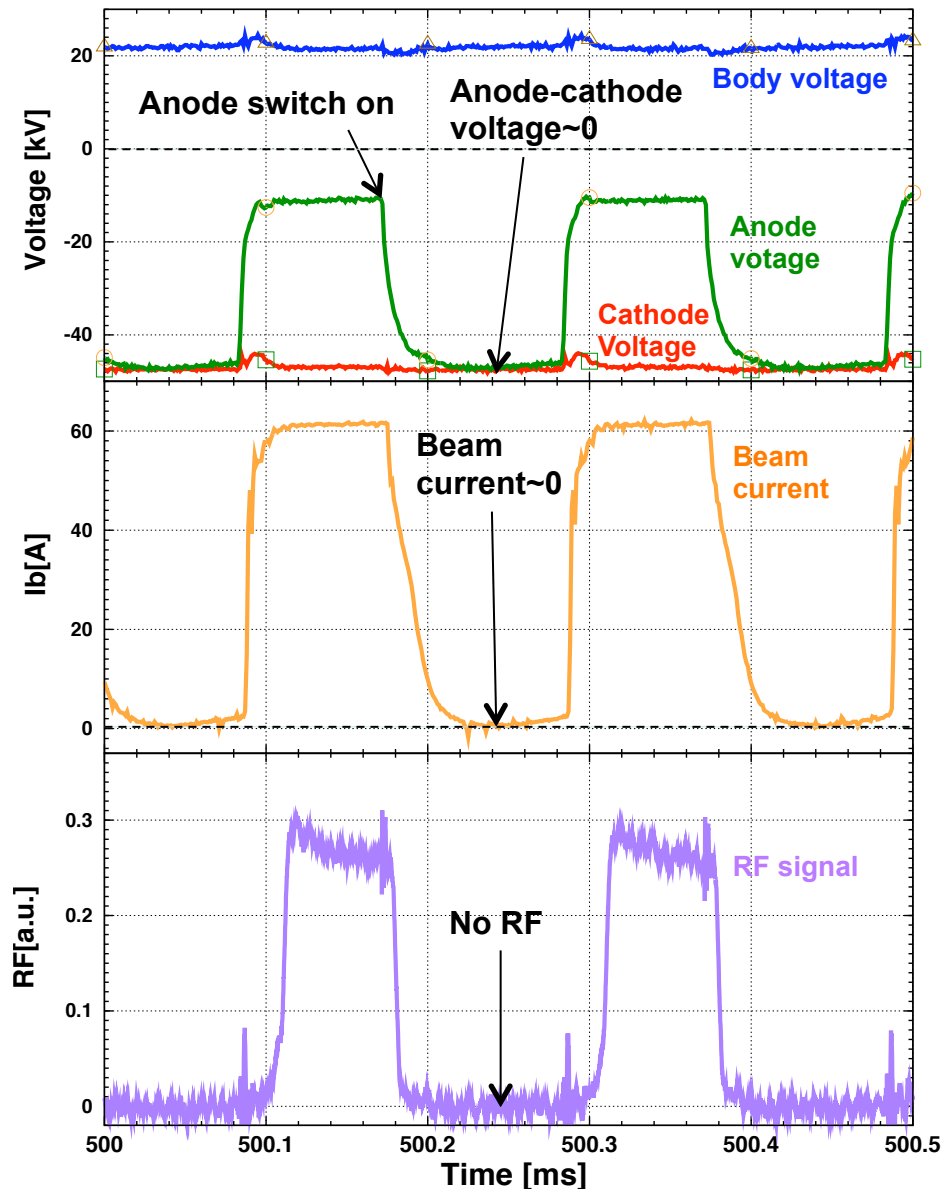
1. Complete suppression of the beam current
 - **No heat load on the collector during turn off phase**
2. Unlike the main switch, anode switch does not need to turn on/off 40-50A (less than 1A).
 - **It is possible to operate with 5kHz modulation.**

Heat load on the cavity and the collector is about half

5kHz modulation
0-100% power modulation

Higher power operation (more than 1MW) with 1MW designed gyrotron

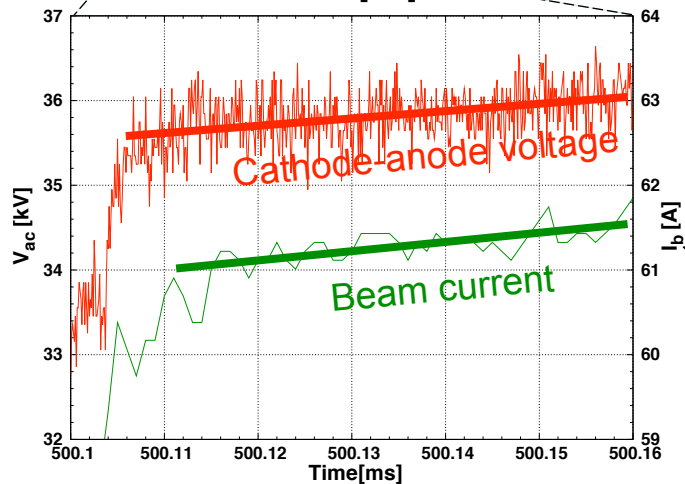
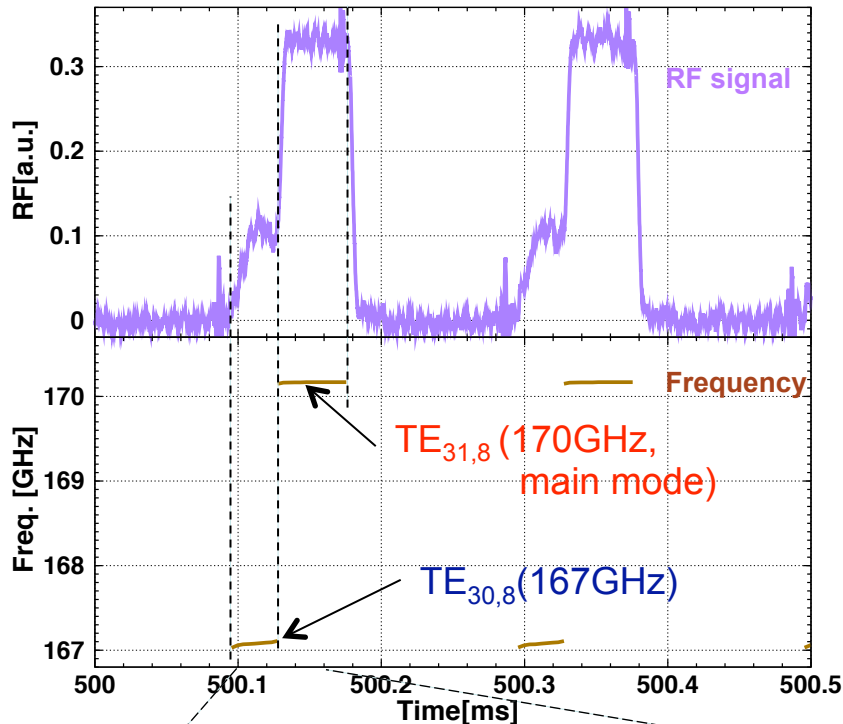
Typical waveform of 5kHz modulation



- By using the anode switch
 - ✓ 5kHz Modulation
 - ✓ Complete suppression of beam current
 - ✓ Complete suppression of RF
 - ✓ More than 1MW output power (Next slide)

*A part of 550ms 5kHz modulation shot.
Duty 45% shot.

High power and high efficiency operation



Achievement

Power : 1.16MW

Pulse width : 40s (can be extended)

Efficiency : 48%

Beam current: 57A

Depressed collector voltage : 24kV

Acceleration voltage : 67kV

$TE_{30,8}$ (167GHz) mode appeared at the beginning of the turn on phase for **high efficiency operation**.

The duty cycle of the main mode is decreased.

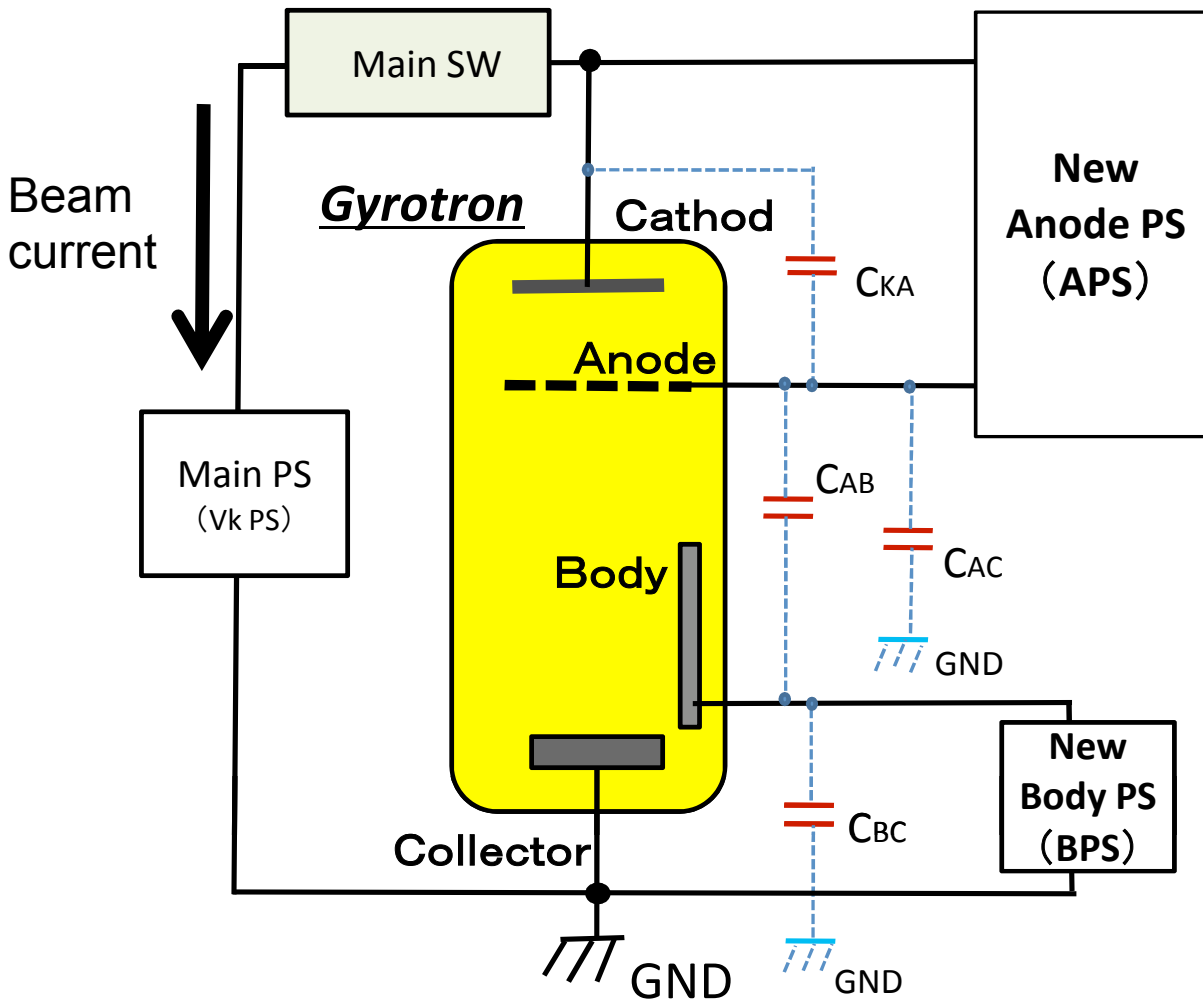
Heat load on the collector is increased.

It may be caused by slight drift of beam current or/and cathode-anode voltage at flat top period.

New configuration



- Instead of the anode voltage divider, an Anode Power Supply controls the Anode-Cathode voltage directly.



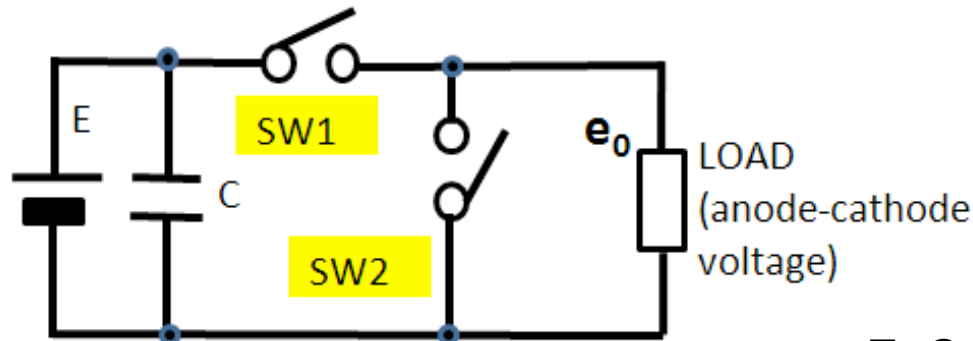
Purpose:

- More stable operation during flat top phase.
- Faster turn on/off for further decrease of collector heat load.
- Introduce small BPS.

Development of the APS for high speed modulation



- Small DC power supply can charge the capacitor bank during turn off period of 5kHz modulation.
- High speed voltage rise/fall time can be realized.

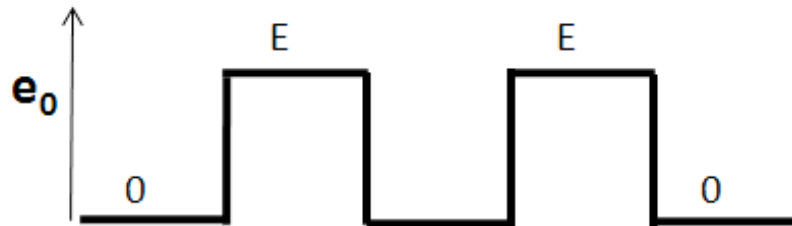


E : Commercial available DC power supply

C : Capacitor bank

$SW1$ and $SW2$: semi-conductor high speed switch (IGBT)

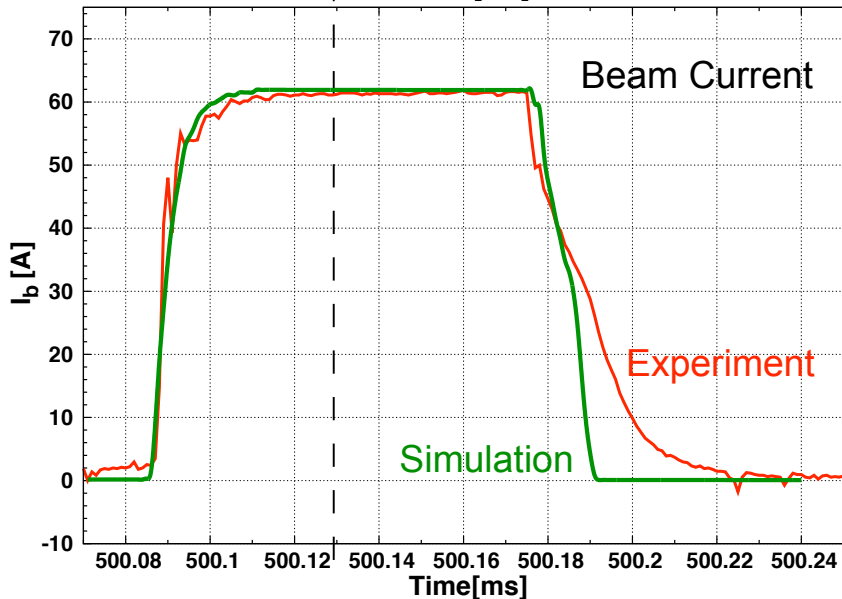
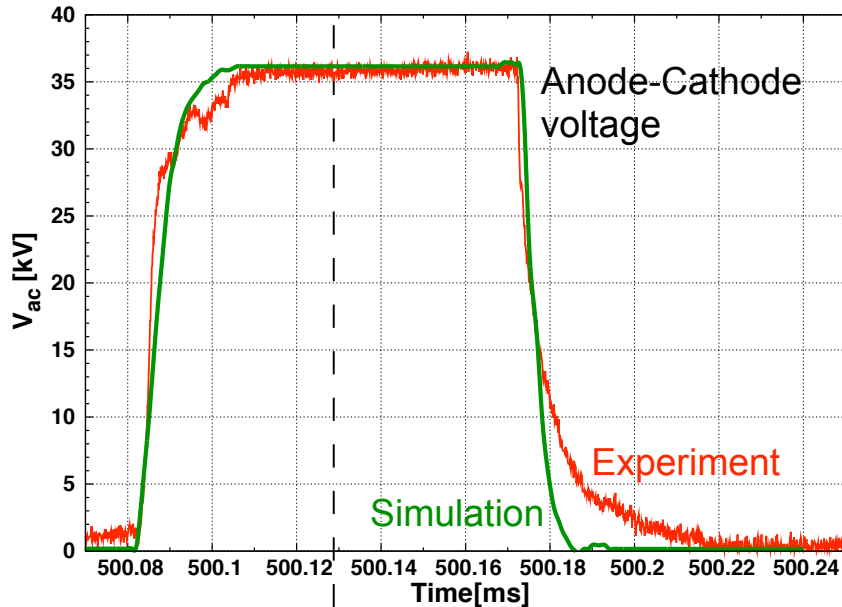
e_0 : Modulation output voltage to Gyrotron anode electrode .



SW1	ON	OFF	ON	OFF
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SW2	OFF	ON	OFF	ON
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Electrical circuit simulation result



- Electrical circuit simulation includes...

- The new APS concept
- Actual cable capacitance
- Actual I-V characteristic curve (beam current – between the anode and cathode voltage)

- **Simulation result**

- ✓ Fast current ramp down
- ✓ Stable flat top

Expecting for the new configuration...

Lower collector heat load.



Higher power operation.

Summary



- A new modulation concept (beam on/off modulation by controlling the anode-cathode voltage) is proposed for the triode gyrotron. It realizes the high frequency modulation with low collector heat load (lower than CW). That means the higher power operation is possible.
 - **The 5kHz modulation with complete beam current suppression during the turn off phase is achieved.**
 - The high power operation of 1.16MW / 40 s / 48% was achieved.
 - For the high efficiency operation, TE_{30,8} was appeared at the beginning of the turn phase instead of the main mode, which may be caused by the slight drift of the beam current and/or cathode-anode voltage.
- The new circuit configuration with the new Anode Power Suppl (APS) is proposed. The new APS will control anode-cathode voltage directory.
 - The simulation shows high speed ramp down and stable flat top is expected.
 - The further reduction of the heat load on the collector will be envisioned for higher power operation.

Specification of the developed APS



1. Output

- **Output voltage: 0~-50kV**
- **Output current: DC480mA (average), 8Ap (peak)**
- Output duty: 0~100%
- **Frequency: DC~5kHz**
- **Rise time t_r , Fall time t_f : within 20 μ s (0~100%)**
- Output voltage ripple: within 1%p-p
- Stability :
regulation: within 0.5%
reliability of output : within 0.5%

2. AC input

- 3phase. 400V \pm 10%. 50/60Hz. 30kVA

3. Load circuit

- Resistance : 100kohm~10Mohm
- Stray capacitance : within 1000pF

4. Size

- DC HV power supply \Rightarrow W1800 \times D1200 \times H2000mm
- HV SW oil tank \Rightarrow W1400 \times D1200 \times H800mm
- Control unit rack \Rightarrow W600 \times D600 \times H1800mm (included BPS)