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Progress on performance tests of ITER-gyrotrons and design of dual-frequency gyrotron for ITER staged operation plan

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Summary :

- ◆ Fabrication of 8 gyrotrons and the performance tests for first 4-gyrotrons were completed. It is ready to be delivered to ITER for the First Plasma.
- ◆ Design of 104 GHz/170 GHz dual-frequency gyrotron for ITER is successfully completed and the proto-type dual-frequency gyrotron is fabricating.

Completion of performance tests for 4 gyrotrons

Features : Magnetron injection gun of triode type
Cavity oscillation mode of $TE_{31,11}$ mode

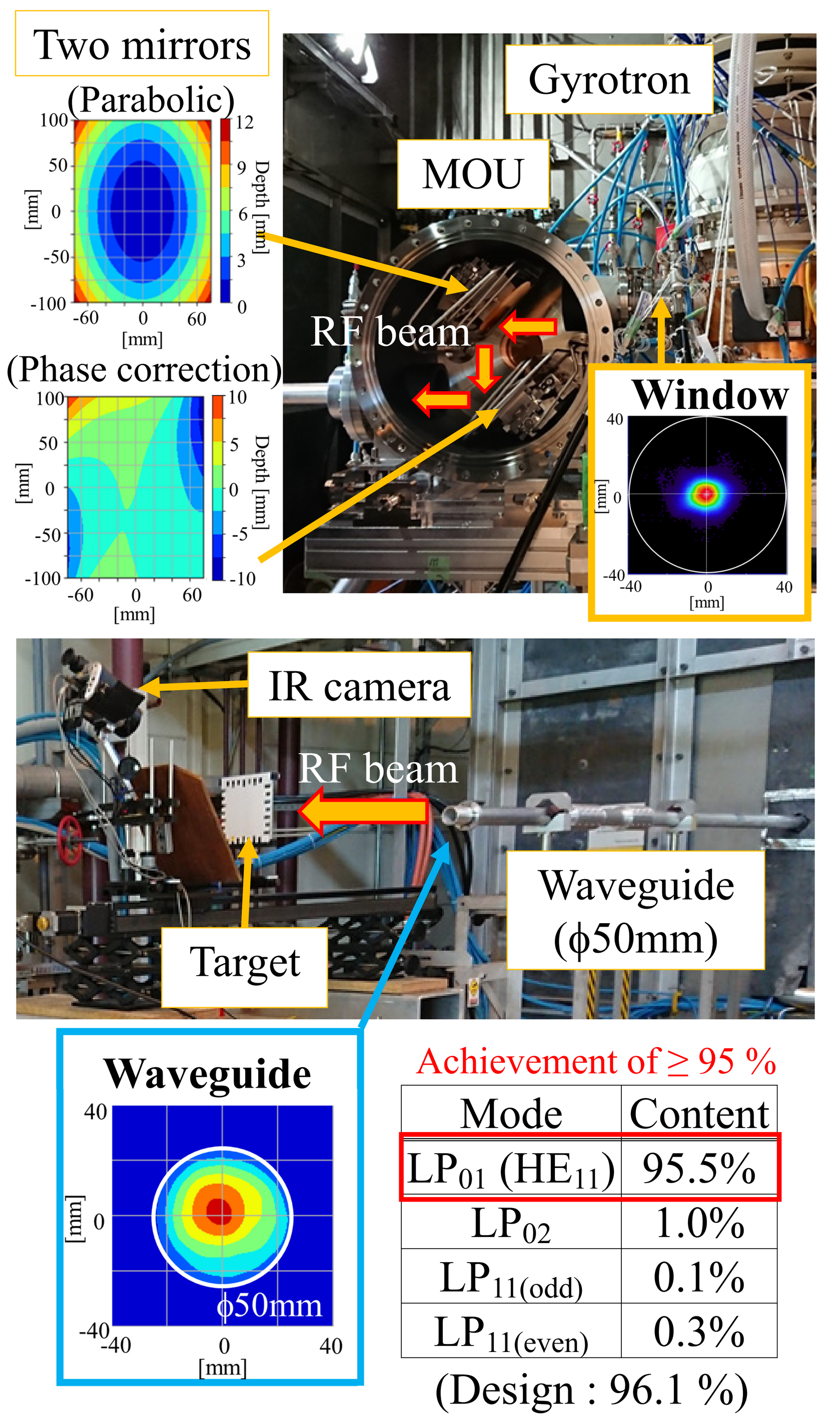
Summary of performance tests for four ITER gyrotrons

No.	Frequency (170 ± 0.3 GHz)	MOU outlet power (≥ 0.96 MW)	Cathode voltage / Beam current Total efficiency	Full-power modulation (≥ 0.8 MW, ≥ 60 s)	HE_{11} mode at waveguide -in (≥ 95%)
#1	169.85 GHz	1.01 MW	45.6 kV / 45.3 A 50.3 %	1 kHz/0.89 MW/200 s, 3 kHz/0.87 MW/200 s, 5 kHz/0.90 MW/200 s	96.9 % (63.5 mm WG)
#2	169.85 GHz	1.02 MW	43.6 kV / 47.8 A 50.4 %	1 kHz/0.91 MW/60 s, 3 kHz/0.96 MW/60 s, 5 kHz/0.90 MW/60 s	96.5 % (63.5 mm WG)
#3	169.91 GHz	1.00 MW	43.8 kV / 47.8 A 50.0 %	1 kHz/0.90 MW/60 s, 3 kHz/0.89 MW/60 s, 5 kHz/0.85 MW/60 s	95.6% (50.0 mm WG)
#4	169.90 GHz	1.00 MW	43.9 kV / 46.6 A 51.1 %	1 kHz/0.81 MW/200 s, 3 kHz/0.80 MW/200 s, 5 kHz/0.82 MW/200 s	95.4% (50.0 mm WG)

Progress on performance tests of ITER-gyrotrons

Introduction : Performance tests should be conducted using the actual components (gyrotrons, matching optics units and superconducting magnets) based on ITER test-requirement before delivery to ITER.

Beam coupling test to waveguide



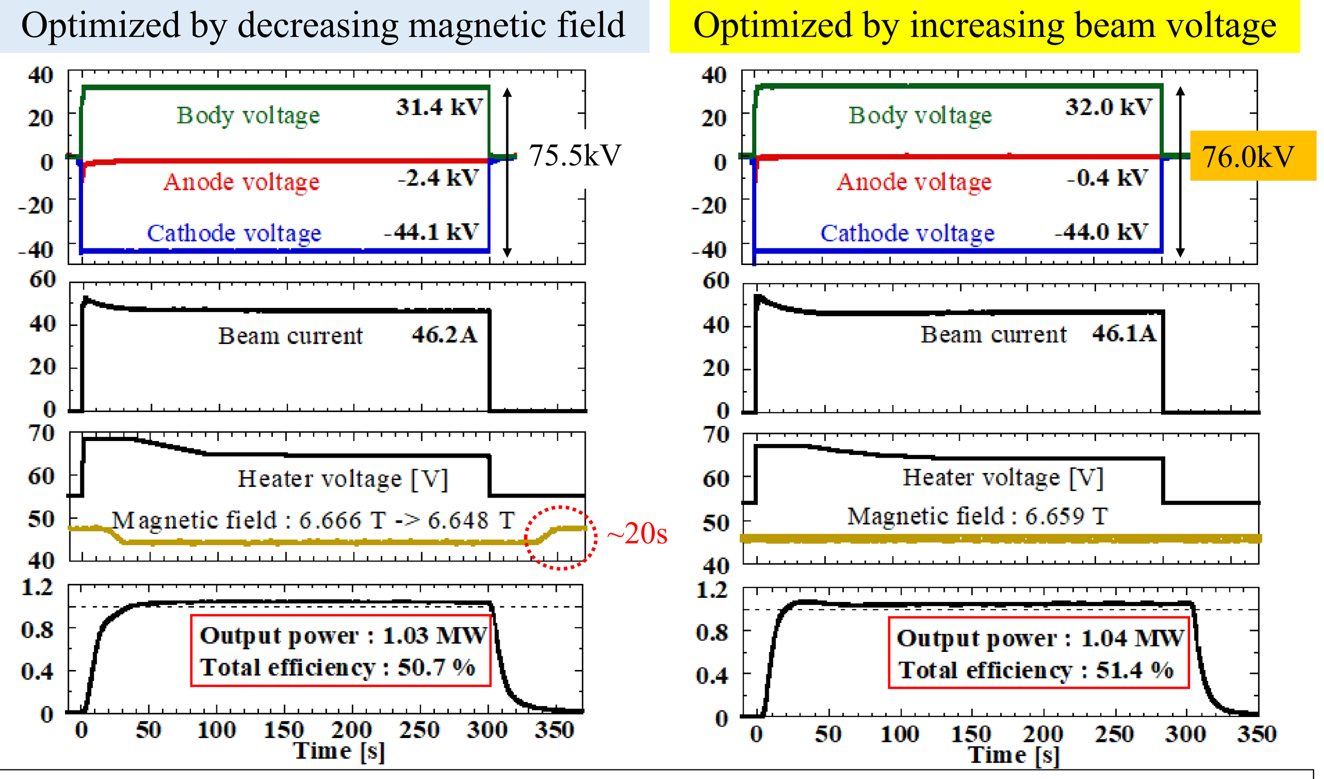
Achievement of ≥ 95 %

Mode	Content
LP_{01} (HE_{11})	95.5%
LP_{02}	1.0%
$LP_{11(odd)}$	0.1%
$LP_{11(even)}$	0.3%

(Design : 96.1 %)

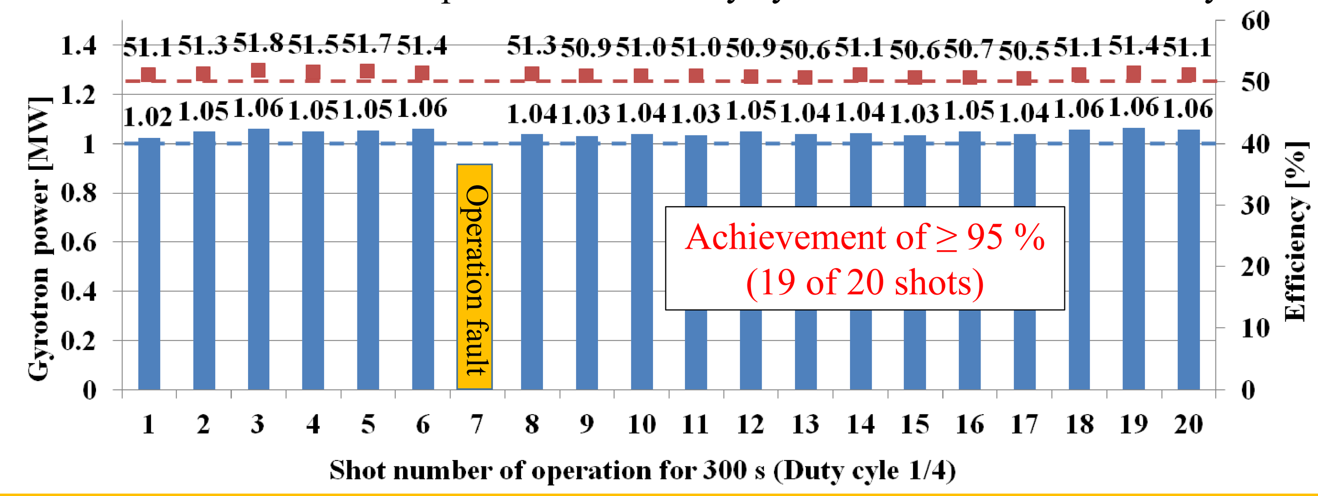
Optimization for CW operation of 1 MW power

ITER requests quick restart of the system within a couple seconds after the operation, especially if the operation is accidentally stopped.
Operation optimization for 1 MW power and 50 % efficiency was demonstrated by increasing the beam voltage from 75.5 to 76kV in the start-up phase without applying slow response magnetic-field control.



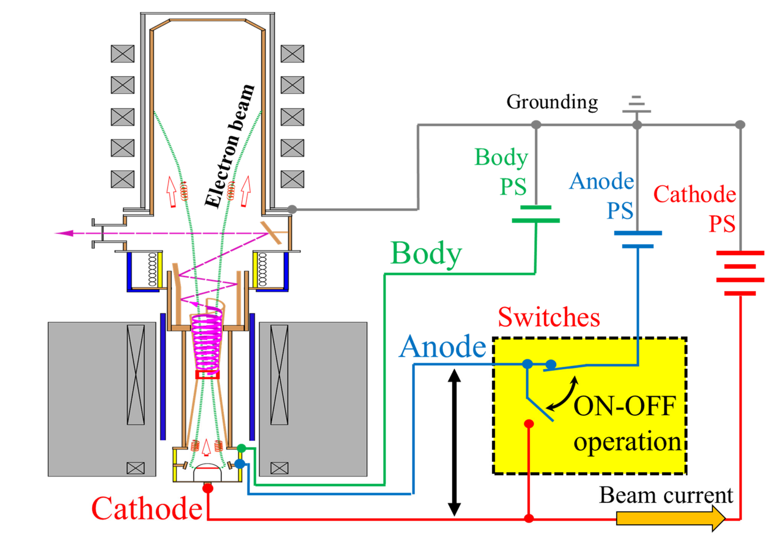
Operation reliability with duty cycle ¼ (Requirement : ≥ 90 %)

When a mode jump occurred, power supplies shut down because the oscillation of the unwanted mode was continued. But, by introducing a pause function, a reliability of 95% in 20 shots of 300 s operation with a duty cycle of ¼ was achieved easily.

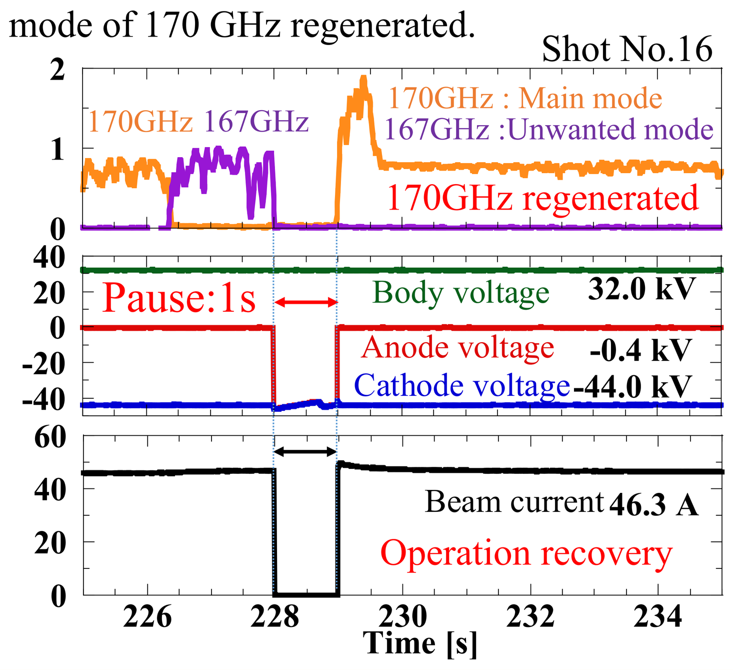


Enhancement of operation reliability

The electron beam can be controlled by anode-cathode voltage due to the advantage of triode MIG. By sending a modulation operation command or a pause command to semiconductor switches, it is possible to feed power to the anode electrode or to shorten to the cathode electrode.

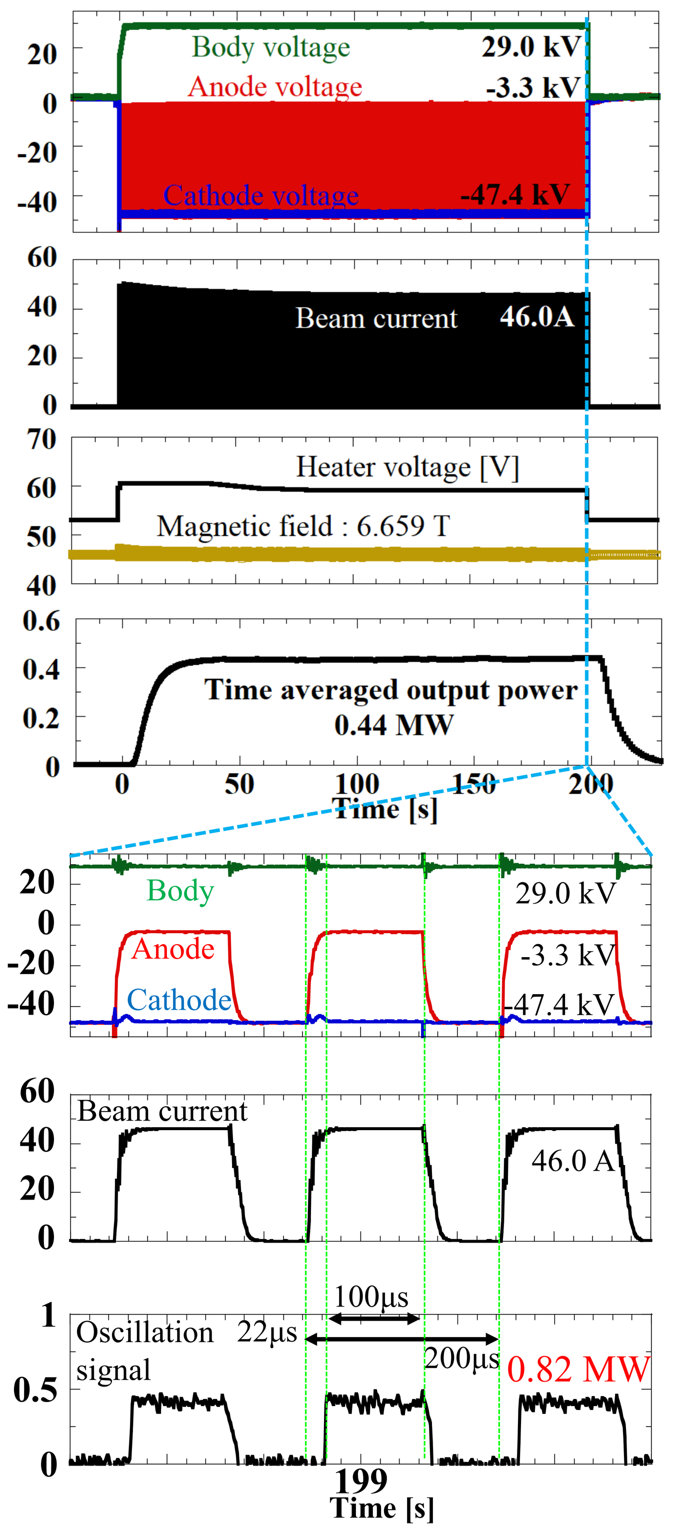


[Recovery from mode jump by a pause function]
By stopping the electron beam temporarily and reapplying a voltage between the cathode and anode electrodes by opening the switches, the unwanted mode disappeared and the main mode of 170 GHz regenerated.



5 kHz full-power modulation

0.8 MW power for 200 s was achieved under the same magnetic field and beam current as in CW operation. Operation reliability of power modulation was 100%.



Design study of dual-frequency gyrotron of 170 GHz and 104 GHz for ITER

For generation of H-mode plasma at very low field of 1.8 T in Pre-Fusion Power Operation 1 in ITER.

At 1.8 T operation:	104 GHz beam is necessary for plasma start-up by 2nd harmonics X-mode. 170 GHz and104 GHz beams are available for ECH and ECCD.
At nominal operation : (2.65 T / 5.3 T)	170 GHz RF beam is necessary for plasma start-up, ECH and ECCD.

Demonstration of multi-frequency oscillations (104 / 137 / 170 / 203 GHz) were performed using a prototype ITER gyrotron (same design as ITER gyrotron). [IAEA FEC2016]

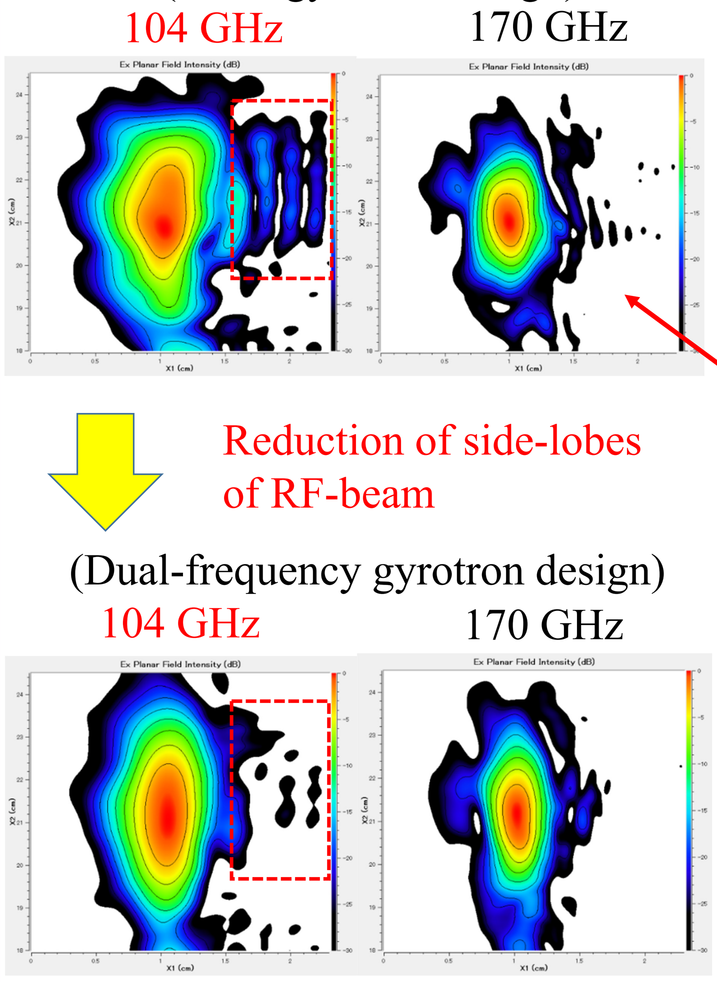
- ◆170 GHz : 1 MW 300 s (CW)
- ◆104 GHz : 1 MW up to 2 s (Non-CW)

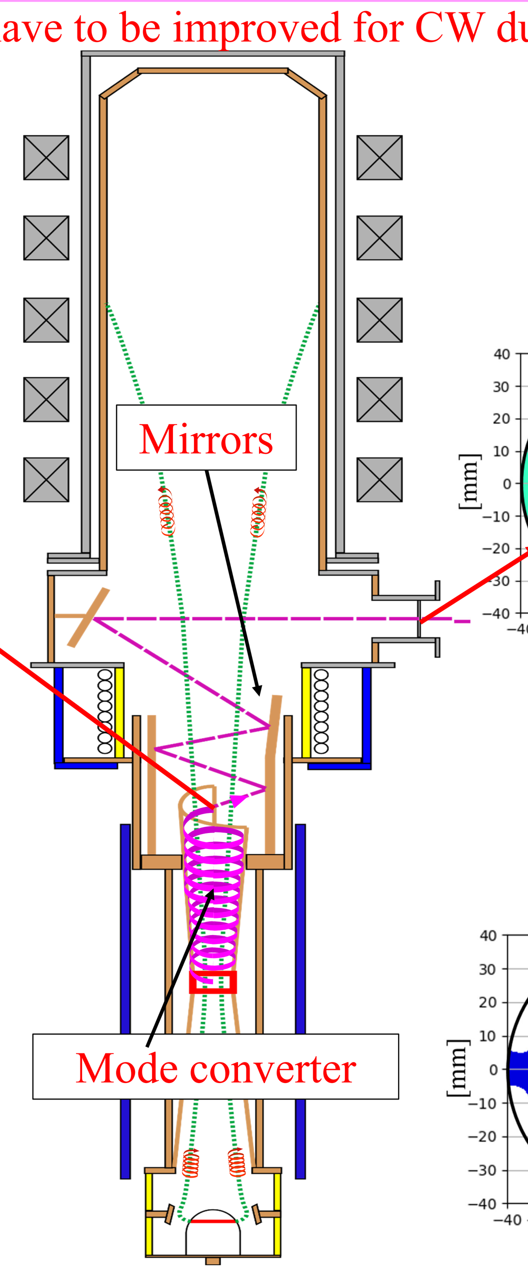
Issues for CW operation at 104 GHz
- Large power loss in the gyrotron
- Large beam size at the window

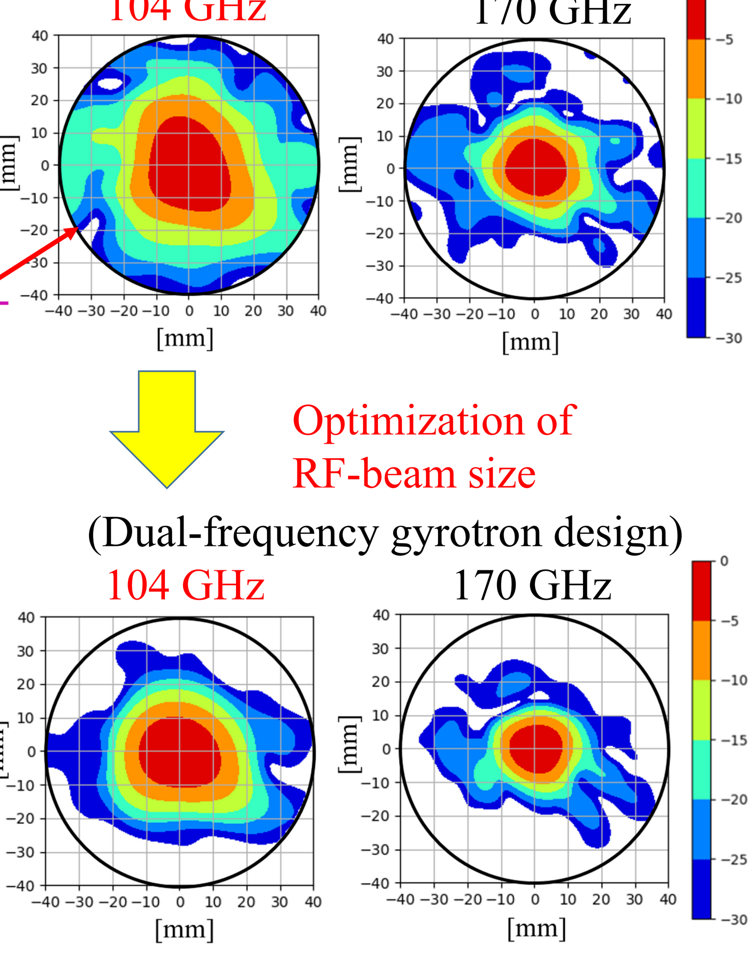
The internal components have to be improved for CW dual frequency operation.

1. Internal wall surface structure of internal mode converter

2. Curvature and position of internal four mirrors



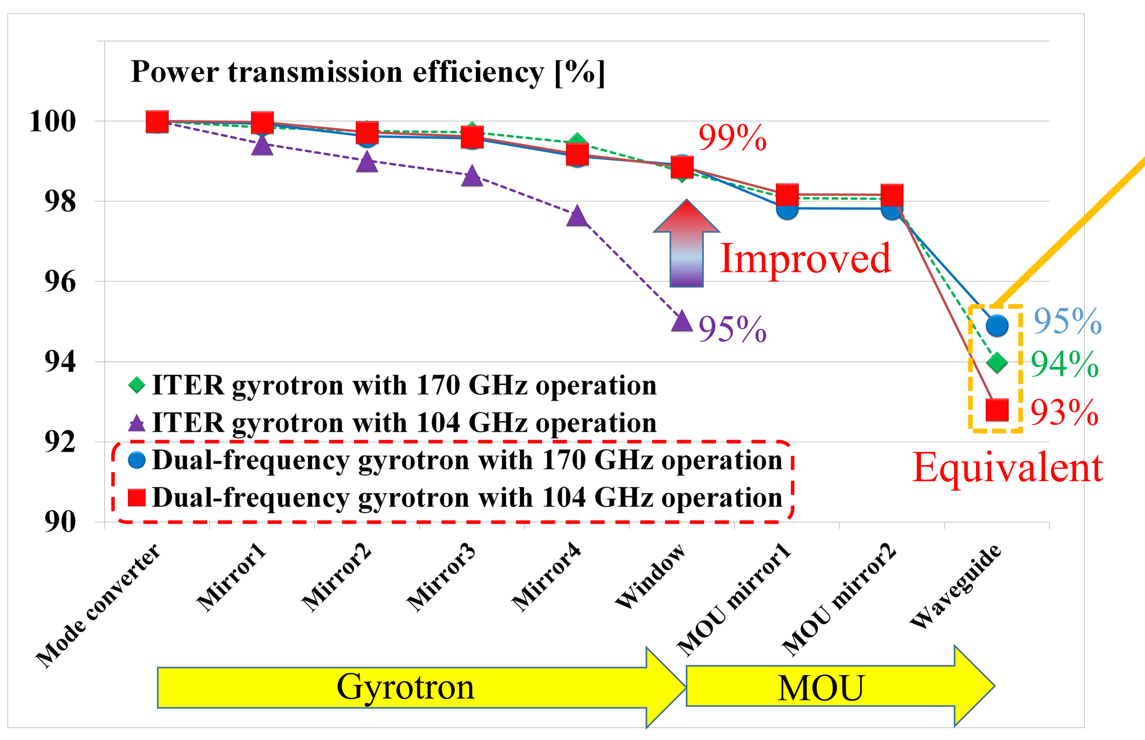


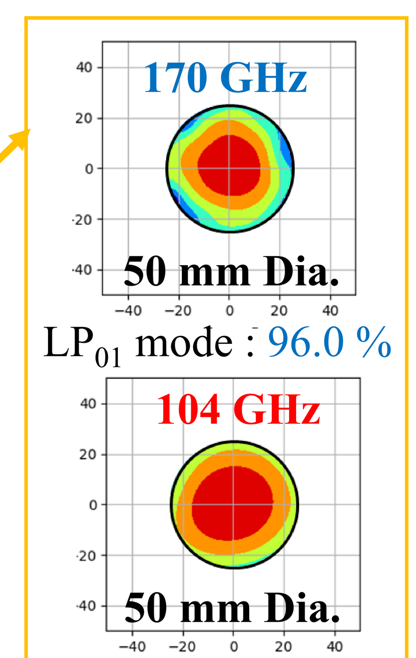


The side lobes of 104-GHz operation at the outlet of the mode convertor were successfully eliminated without affecting the beam pattern at 170-GHz operation. Moreover, the beam pattern for 104 GHz operation at the output window became smaller with minimal changes to the beam pattern at 170 GHz operation.

Design of ITER gyrotron	At aperture of mode convertor		At output window	
	Gaussian	Discrepancy angle	Gaussian	Discrepancy angle
170 GHz	94.5%	0.60 degree	95.8%	0.23 degree
104 GHz	90.7%		96.6%	

Design of DF-gyrotron	At aperture of mode convertor		At diamond window	
	Gaussian	Discrepancy angle	Gaussian	Discrepancy angle
170 GHz	95.4%	0.18 degree	96.4%	0.08 degree
104 GHz	97.5%		98.0%	





LP_{01} mode : 96.0 %

LP_{01} mode : 95.8 %

The newly designed dual-frequency gyrotron largely improves the power transmission efficiency of 104 GHz operation from 95% to 99% at the output window.
Power transmission efficiency equivalent to that of the ITER gyrotron was achieved.