IAEA FEC2020 : Tuesday 11 May 2021, TECH/1 ITER Technology (17:20-17:40)
[TECH/1-787] Wednesday 12 May 2021, P3 Posters 3 (08:30-12:30)
[P3-1406]

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

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[P3-1410]

New Developments in Russia of Gyrotrons for Plasma Fusion Installations

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Outline

Topic.1

Progress on manufacturing of ITER-gyrotrons and the performance tests in Japan and Russia

Topic.2

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

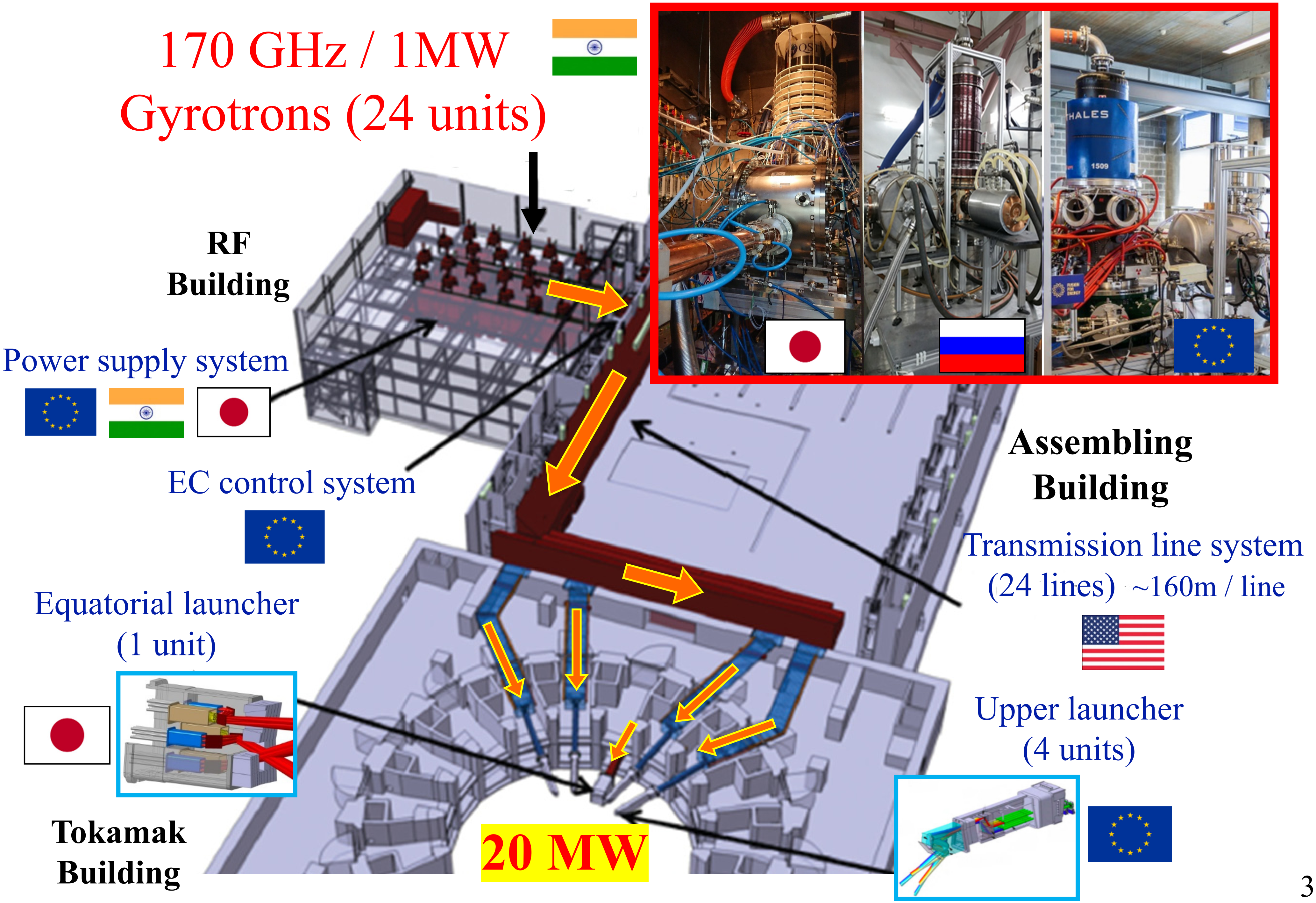
Topic.3

Gycom/IAP deliveries of MW gyrotrons in last years

and

New approaches in development of MW gyrotrons

ITER EC H/CD system

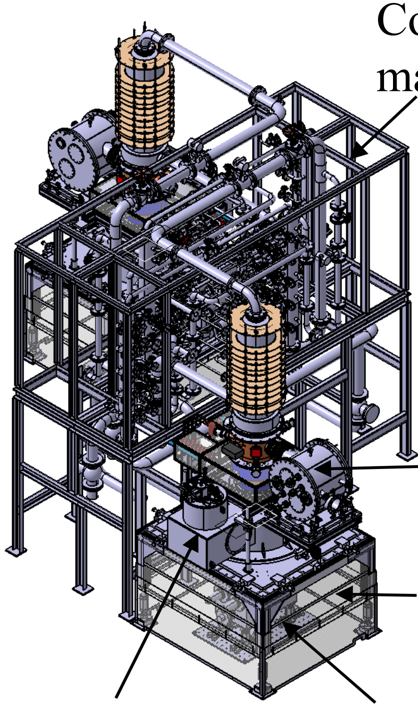


Status of ITER gyrotrons in Japan

QST procures 8 sets of gyrotron systems

- Gyrotron tubes
- Auxiliaries to assemble gyrotron complex
- Power supplies and control systems to derive JA-gyrotron

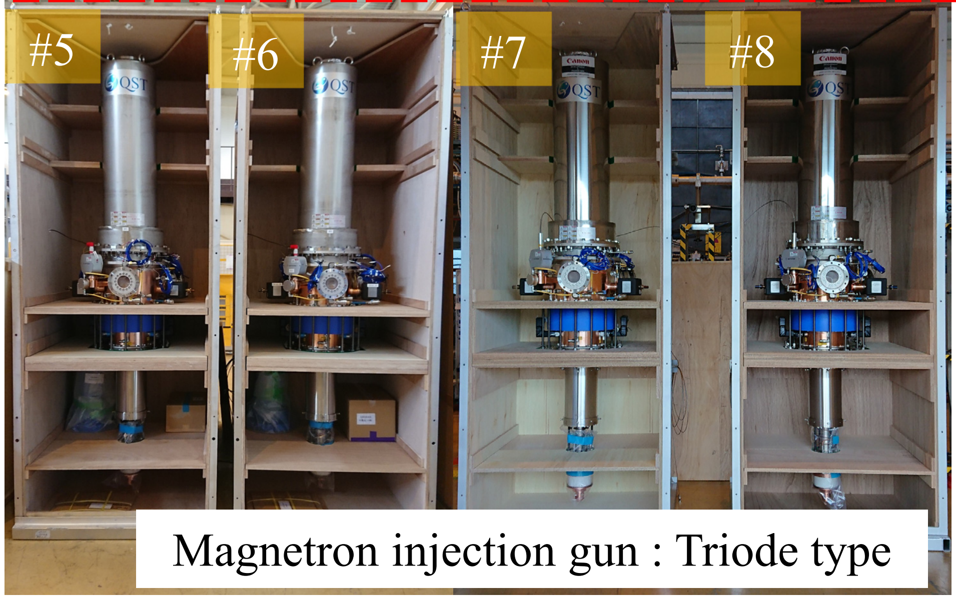
Gyrotron complex



Power supply system

Control system

Performance tests

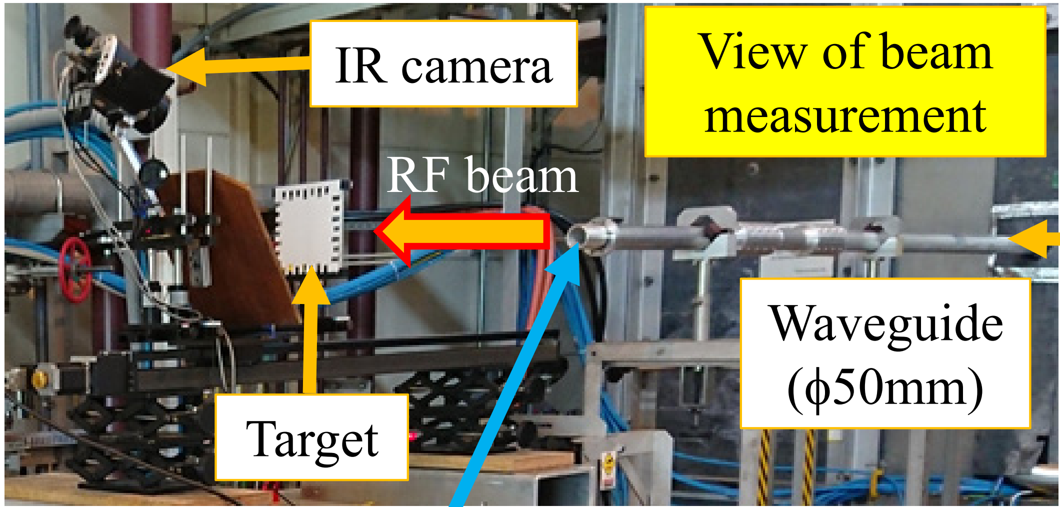


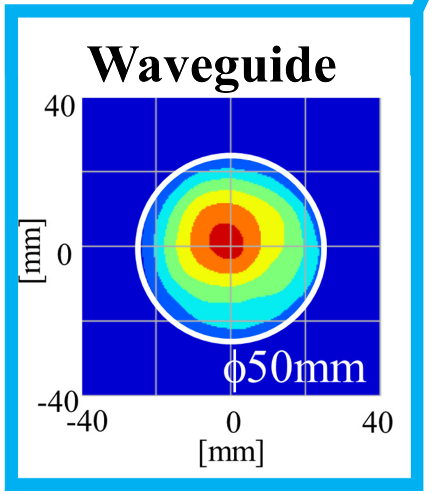
Manufacturing of all components is completed.
Performance tests of four gyrotron has been competed.

Beam coupling to waveguide in the performance tests

Integration of actual components (Gyrotron, Matching Optics Unit and Superconducting magnet) and ITER-relevant transmission-line with 50 mm Dia.

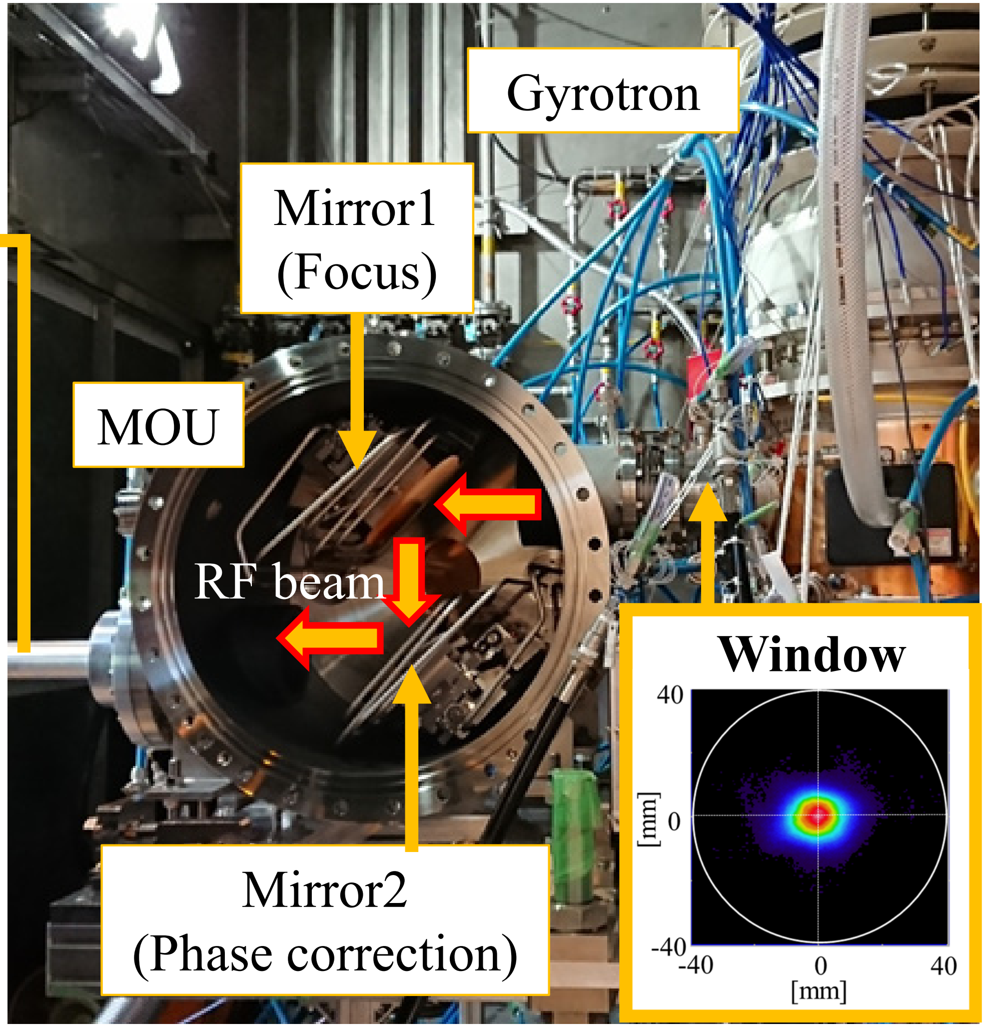
ITER requirement : LP_{01} mode of 95 % at waveguide inlet





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 %)

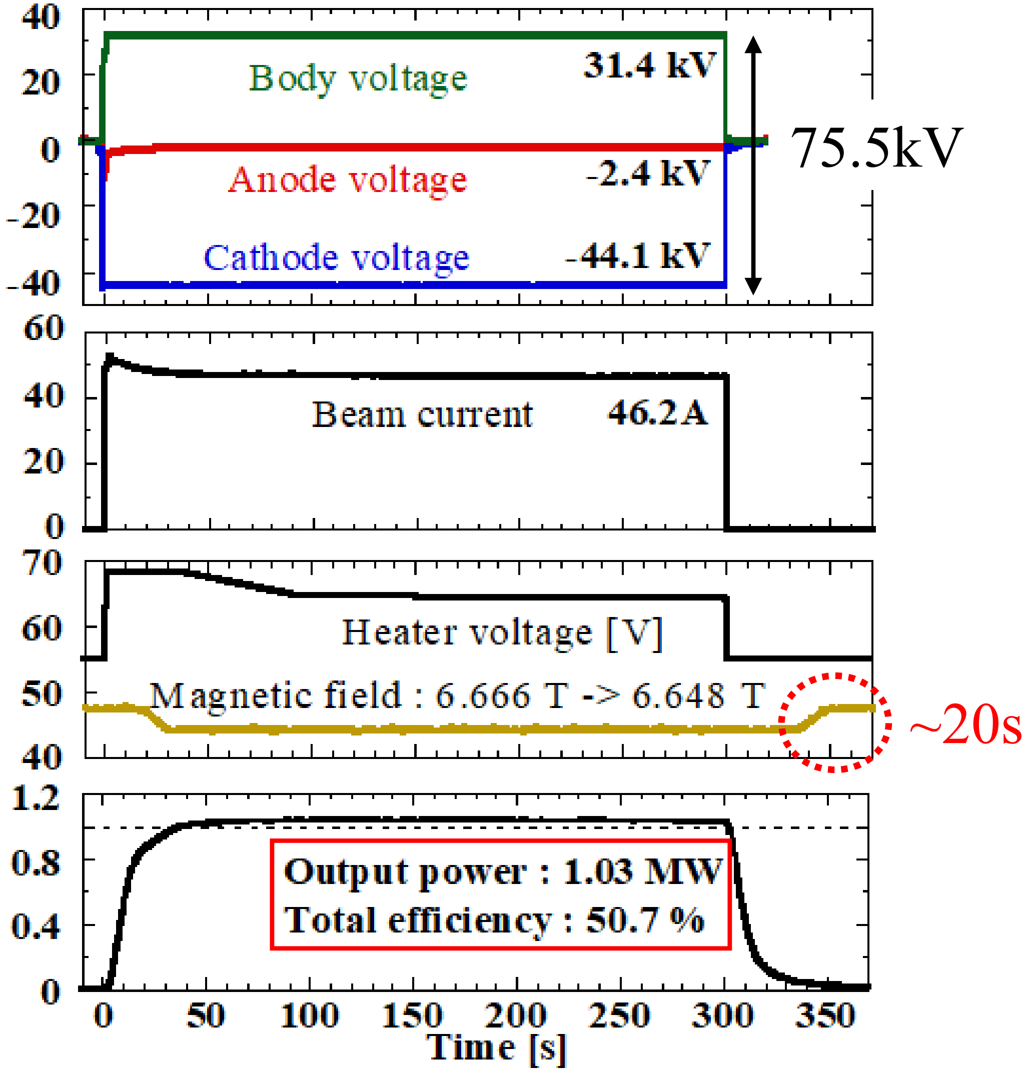


LP_{01} mode of ≥ 95 % was achieved by combining the actual components.

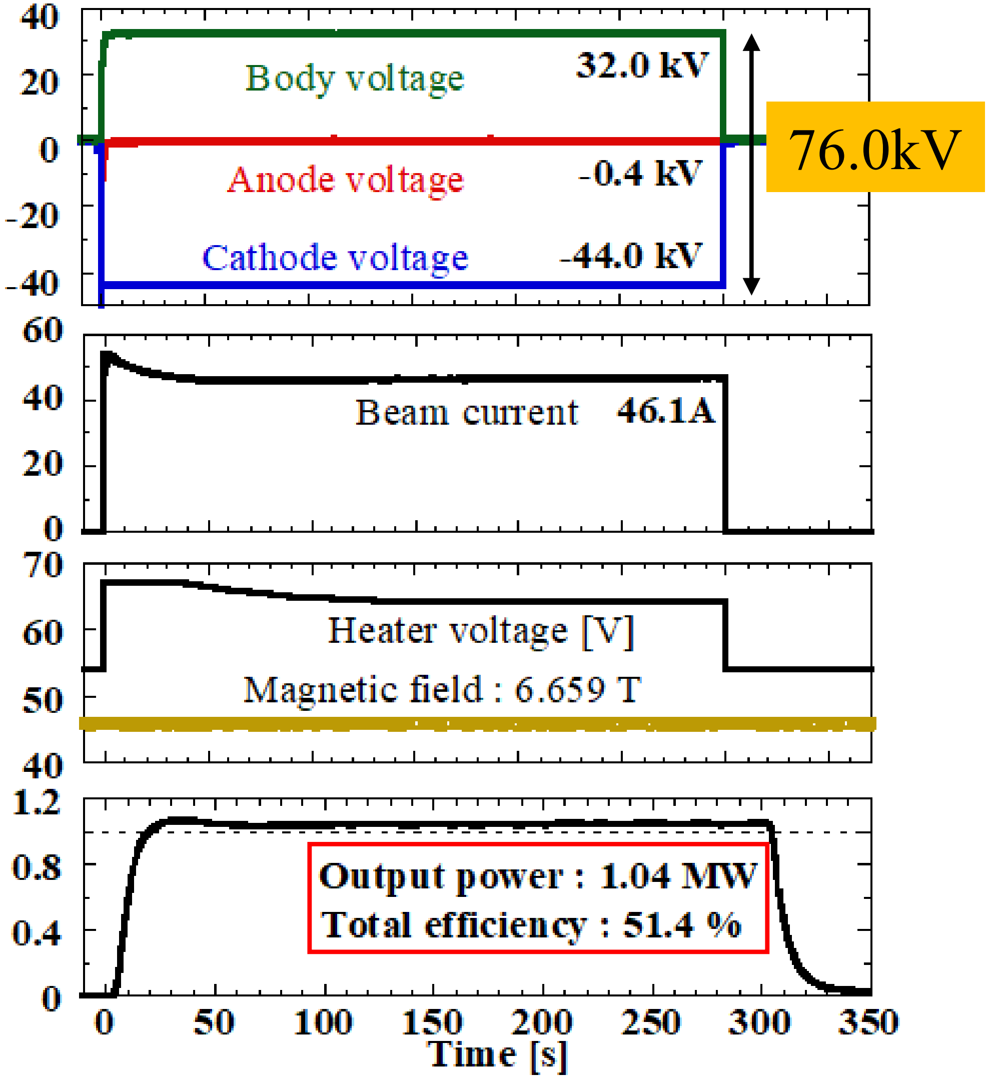
Optimization for CW operation of 1 MW power

ITER requirement : output power of 1 MW and efficiency of 50 %

Optimized by decreasing magnetic field

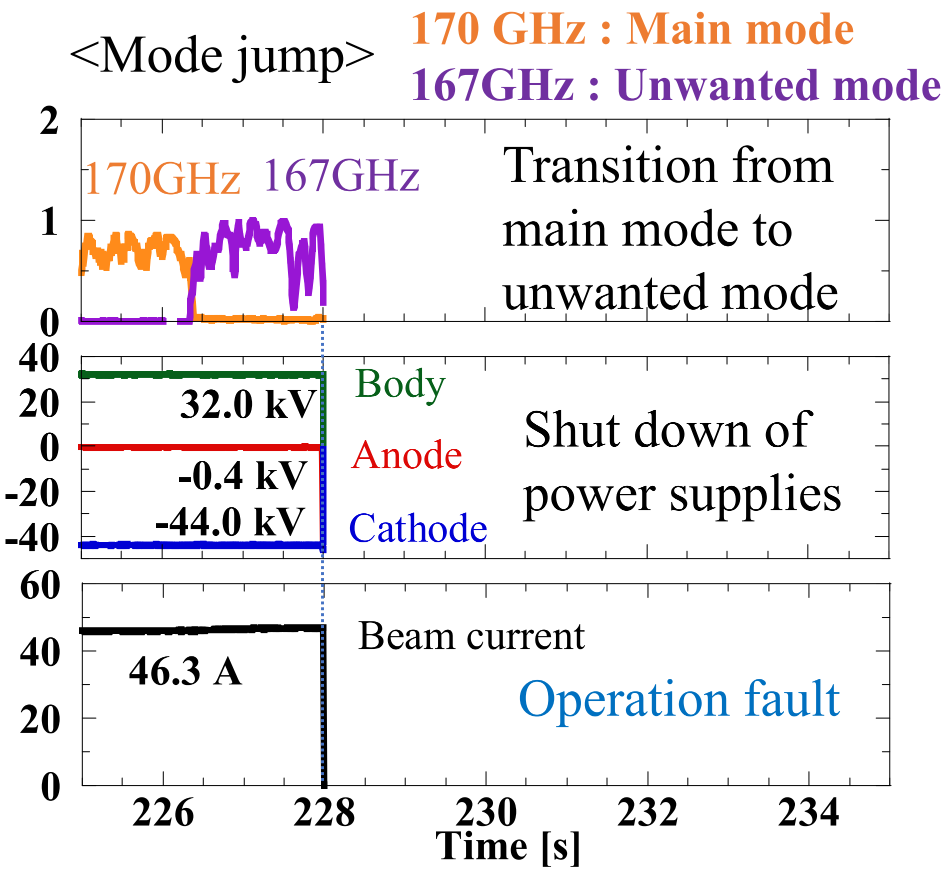


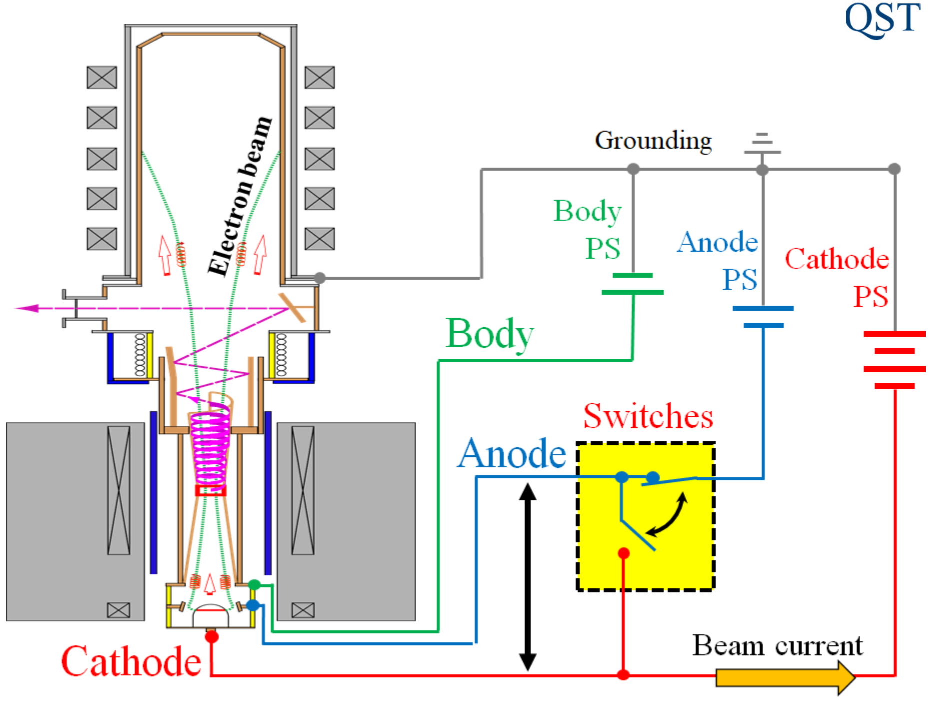
Optimized by increasing beam voltage



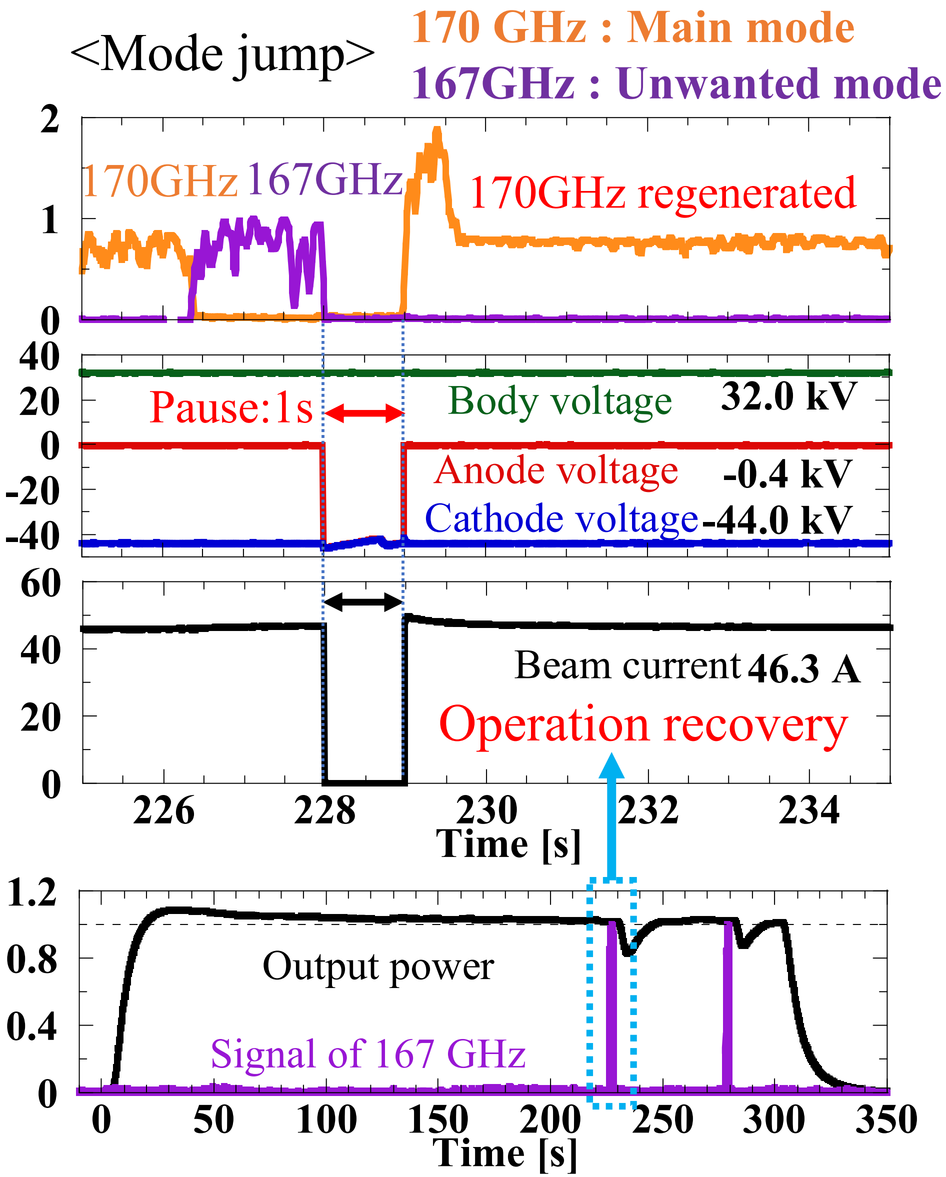
Achievement of operation optimization for 1 MW power and 50 % efficiency without the use of slow response magnetic field strength control.

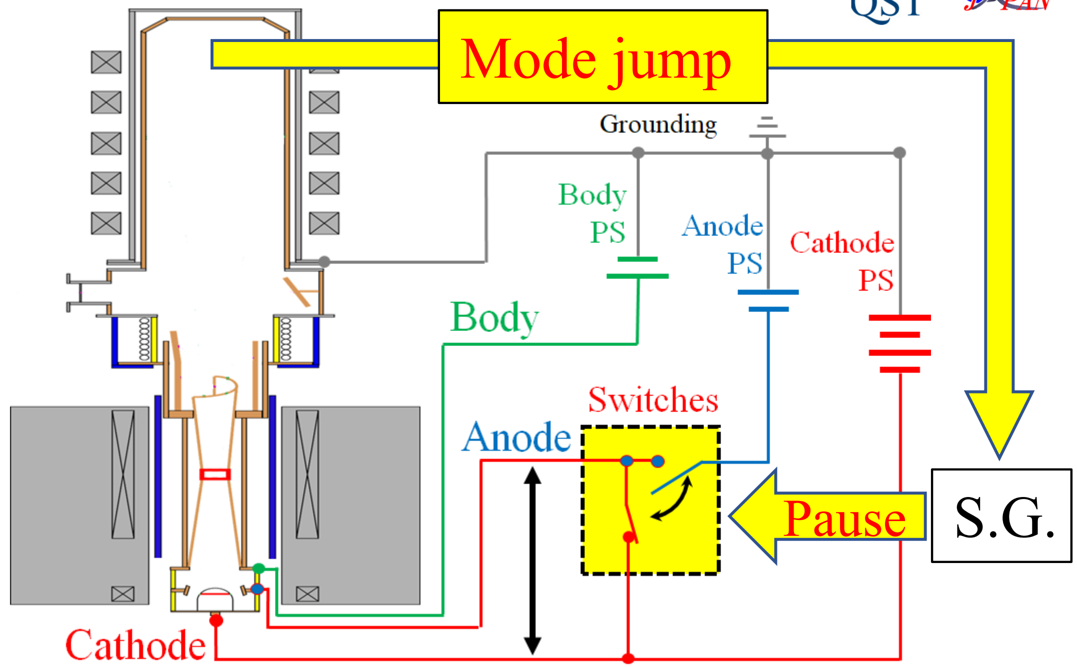
Enhancement of reliability by using pause function



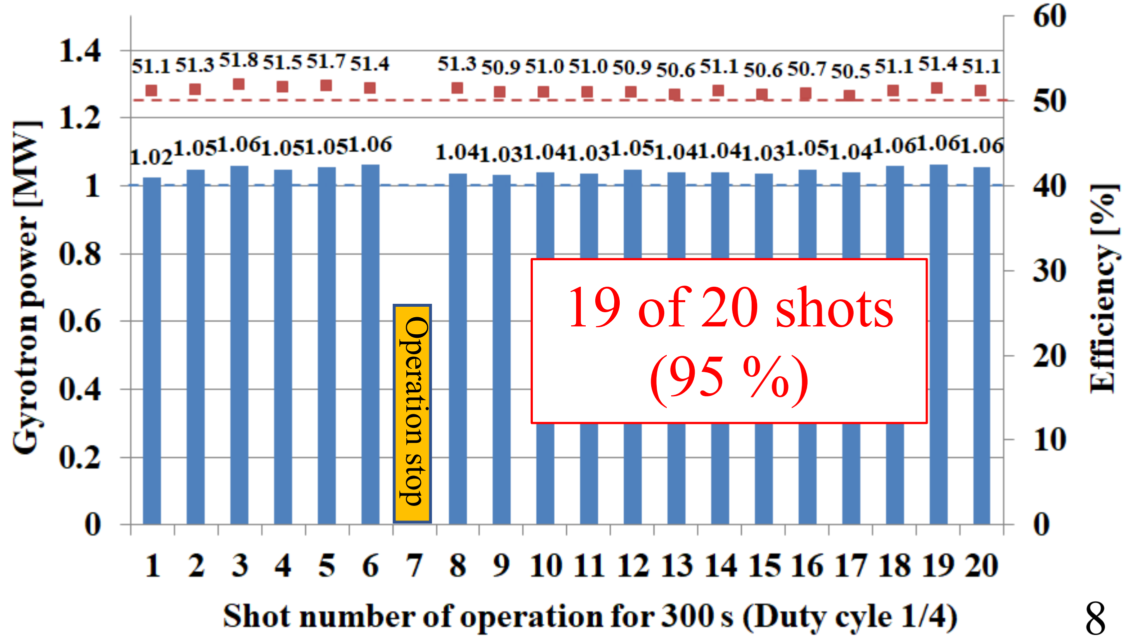


Enhancement of reliability by using pause function





ITER requirement : Reliability of 90 %

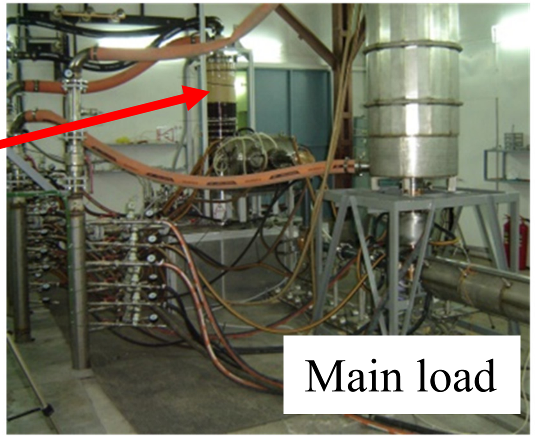


Pause function : Without stopping the operation sequence, temporary stop for failures and resumption of operation.

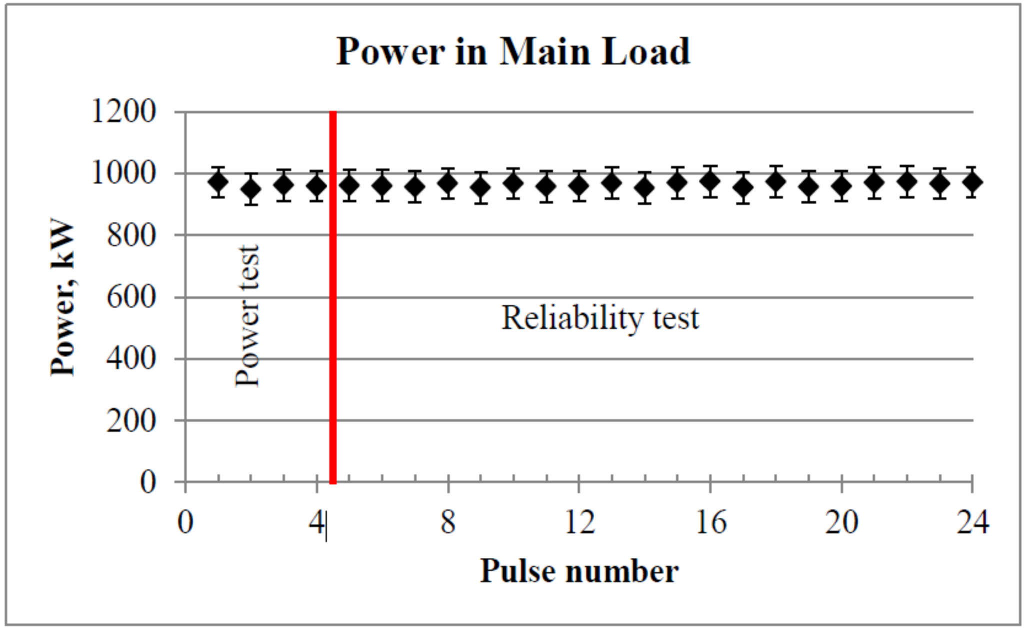
Status of ITER gyrotrons in Russia

- In May 2015, a Russian prototype of the ITER gyrotron system was completed and its operation was demonstrated. From 2016 to 2020, four serial gyrotron systems were fabricated. Two more systems are in manufacturing.
- All four of these ITER gyrotron systems showed reliable operation in 1000-s pulses at megawatt power and efficiency higher than 50%. The gyrotron output wave beam was fed with low losses to the corrugated HE_{11} waveguide of 50 mm diameter. The measured X-ray radiation and stray microwave radiation do not exceed safety levels.


Gyrotron complex


Main load


Controller system



20 pulses of 1 MW power / 500 s with duty cycle 1/4 were repeated, and the operation reliability achieved 100 %.

Test summary of eight gyrotrons

No.	Date	Frequency (170 ± 0.3 GHz)	Power at HE_{11} waveguide inlet (≥ 0.96 MW)	Cathode voltage / Beam current Total efficiency (≥ 50%)	Full-power modulation (≥ 0.8 MW, ≥ 60s)	Safety for X-rays and Stray RF
#1 (Japan)	10.10.2018	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	OK
#2 (Japan)	12.07.2019	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	OK
#3 (Japan)	01.07.2020	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	OK
#4 (Japan)	29.01.2021	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	OK
#1 (Russia)	13.10.2017	169.9 GHz	0.96 MW	42.5 kV / 42 A 55%	0.1 kHz / 0.81 MW / 200 s 0.5 kHz / 0.81 MW / 200 s 1 kHz / 0.81 MW / 200 s	OK
#2 (Russia)	22.08.2018	169.9 GHz	0.96 MW	44 kV / 42.4 A 53%	0.1 kHz / 1 MW / 200 s 0.5 kHz / 1 MW / 200 s 1 kHz / 1 MW / 200 s	OK
#3 (Russia)	04.10.2019	169.9 GHz	0.97 MW	43.7 kV / 40 A 57%	0.1 kHz / 1 MW / 200 s 0.5 kHz / 1 MW / 200 s 1 kHz / 1 MW / 200 s	OK
#4 (Russia)	12.06.2020	169.84 GHz	0.97 MW	42.5 kV / 42.8 A 55%	0.1 kHz / 1 MW / 200 s 0.5 kHz / 1 MW / 200 s 1 kHz / 1 MW / 200 s	OK

Japan & Russia gyrotrons have passed the performance tests and are ready for ITER First Plasma.

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Necessary of 104 GHz ECH for ITER

Pre-Fusion Power Operation 1 (PFPO-1, next stage after First Plasma in ITER) :

Generation of H-mode plasma at very low field of 1.8 T

(Benefit : Validity of L-H scaling, ELM control, Estimation of divertor heat loads)

At 1.8 T operation:

104 GHz beam is necessary for plasma start-up by 2nd harmonics X-mode.

(170 GHz beam is not feasible for plasma start-up by 3rd 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.

Dual-frequency gyrotron is necessary to guarantee maximum EC-power injection.

Demonstration of multi-frequency oscillation (104/137/170/203 GHz) was performed using a prototype ITER gyrotron (same design as ITER gyrotron) [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 output window

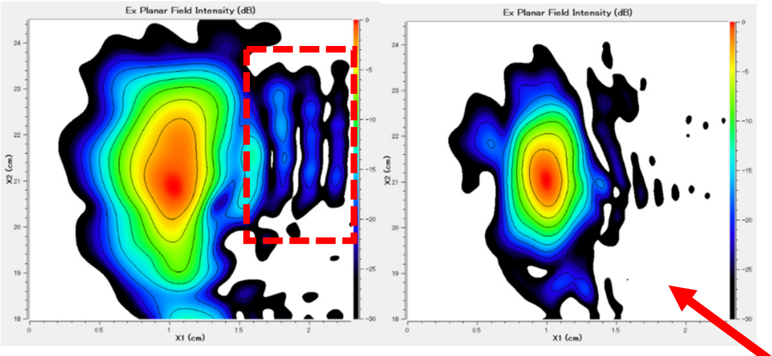
The internal components have to be improved for CW dual frequency operation.

Design optimization of internal components

Improvement of wall surface structure of a mode converter

(ITER gyrotron design)

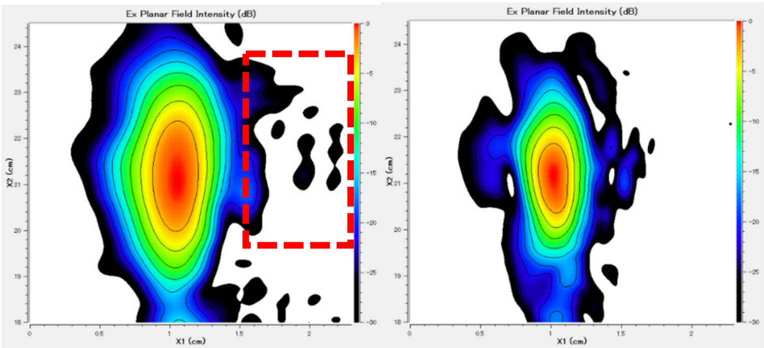
104 GHz 170 GHz

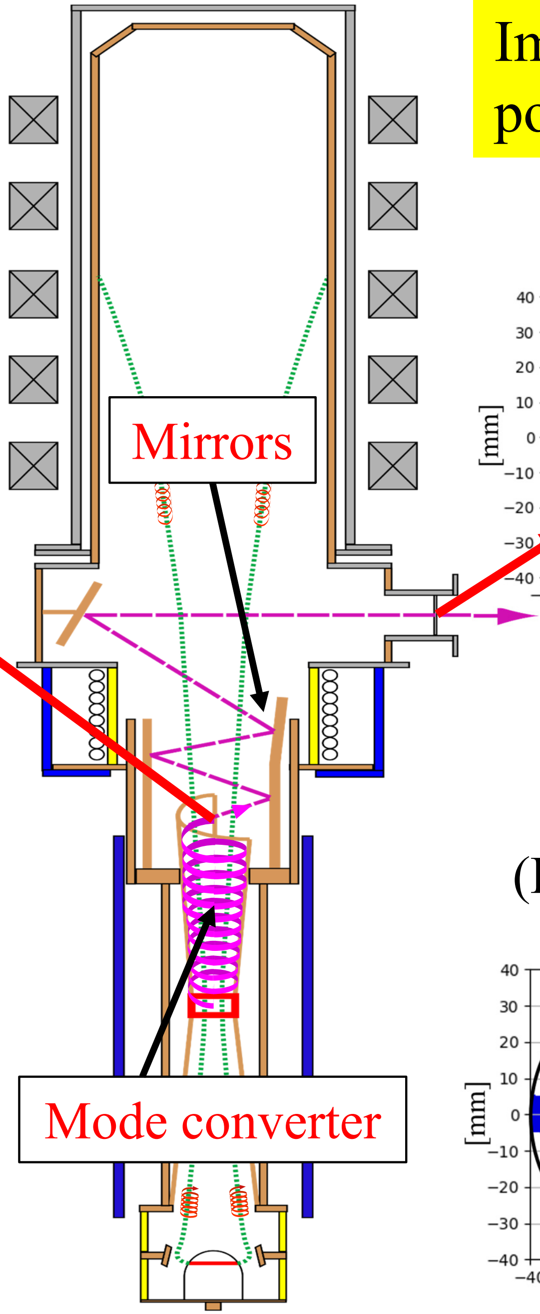


Reduction of side-lobes of RF-beam at outlet of the mode converter

(Dual-frequency gyrotron design)

104 GHz 170 GHz

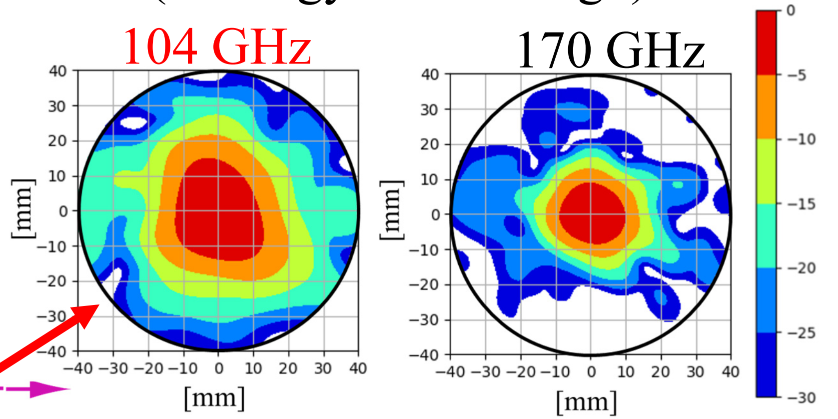




Improvement of curvature and position of internal four mirrors

(ITER gyrotron design)

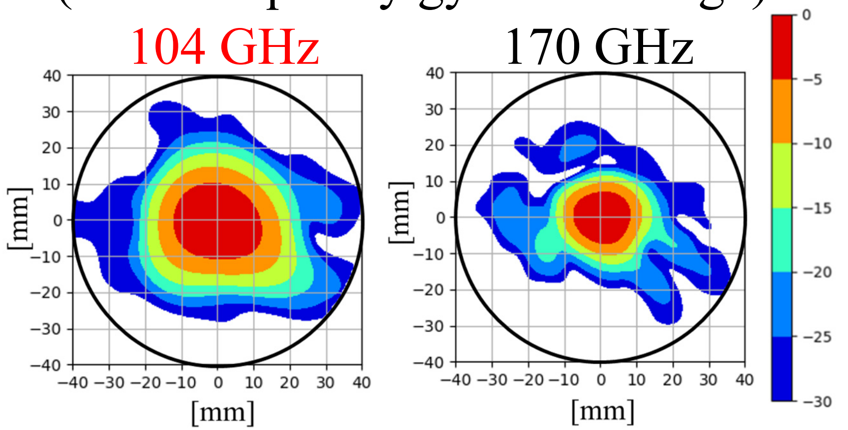
104 GHz 170 GHz



Optimization of RF-beam size at the output window

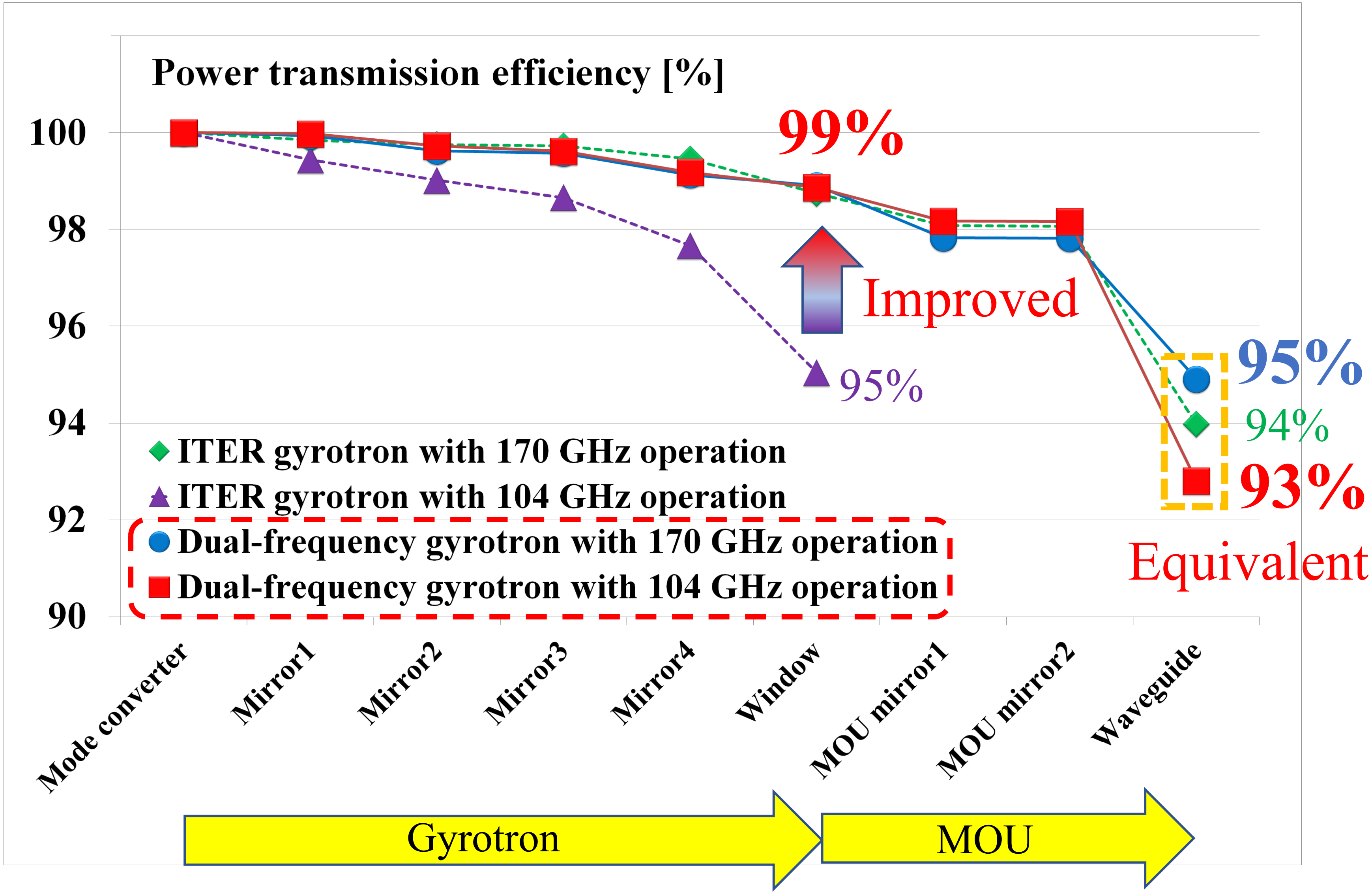
(Dual-frequency gyrotron design)

104 GHz 170 GHz



Design improvements of internal mode converter and mirrors were completed.

Improvement of power transmission efficiency for 104 GHz operation



Power transmission efficiency equivalent to that of the ITER gyrotron was achieved.
Fabrication of prototype dual-frequency gyrotrons has started.

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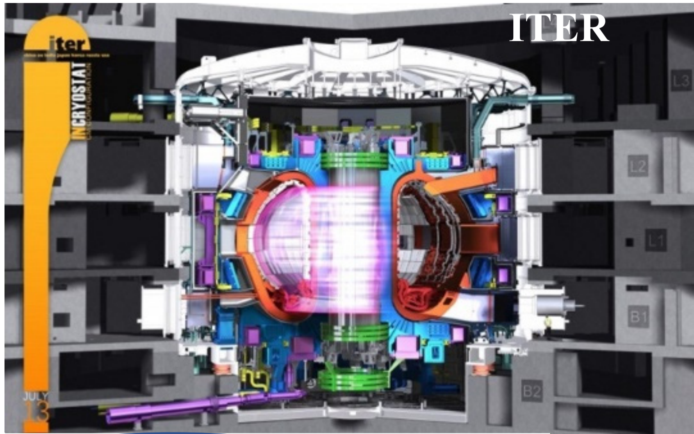
Gycom/IAP deliveries in last years

GYCOM

140/105 GHz
8 gyrotrons

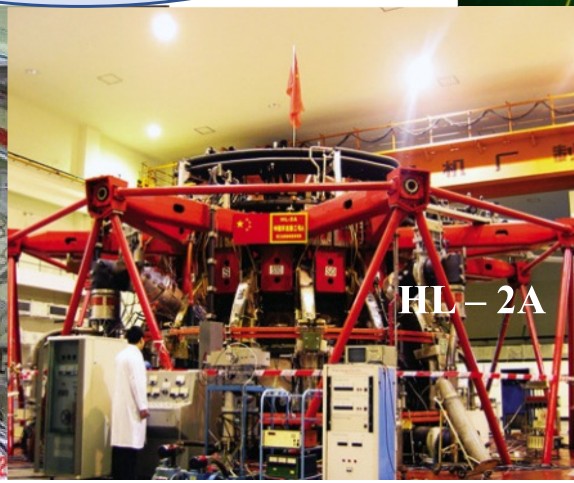
170 GHz
8 gyrotrons are to be delivered to ITER
+1 for F4E
+ 1 for ITER-India



140/105 GHz/300 sec
4 gyrotrons
+ 1 tube
170 GHz / 300 sec

1MW / 3-1000sec
gyrotrons for EC systems

140 GHz/1000 sec
3 gyrotrons



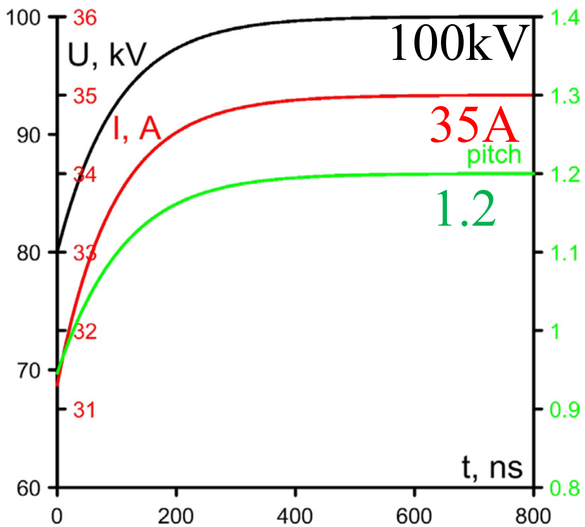
140 GHz
2 gyrotrons
105 GHz
5 gytrotrons

+
- T-15MD (82.6 GHz/ 30 sec)
- Tokamak Energy 140/105 GHz

More than thirty MW gyrotrons in last 10 years

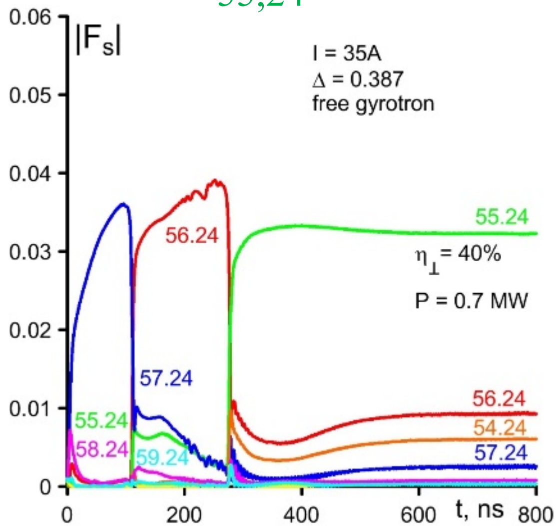
New approaches in development of MW gyrotrons

Simulations show that using gyrotron frequency stabilization and oscillator phase locking helps in providing stable gyrotron operation at very high $TE_{56.24}$ mode, at very high frequencies 345 GHz with megawatt power. High frequencies are required for future plasma machines having high magnetic fields.



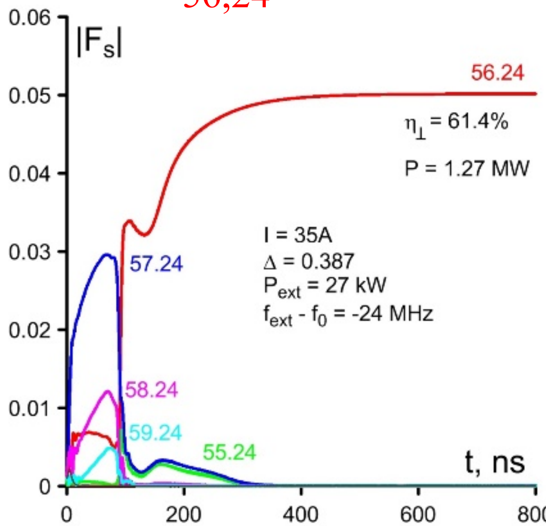
Electron beam parameters (Voltage, Current , Pitch factor)

$TE_{55,24}$: 0.7 MW



Free running gyrotron (no input signal)

$TE_{56,24}$: 1.27 MW



New approach (27 kW external signal)

External signal provides the single mode gyrotron operation with significantly higher power and oscillation efficiency.

Principal enhancement of THz-range gyrotron parameters using injection locking
V.Bakunin, G. Denisov, Yu.V Novozhilova, 2020/3/11, IEEE Electron Device Letters, V. 41, Issue 5, pp 777-780.

Summary

1 : QST iTER JAPAN iter ИПФ РАН GYCOM

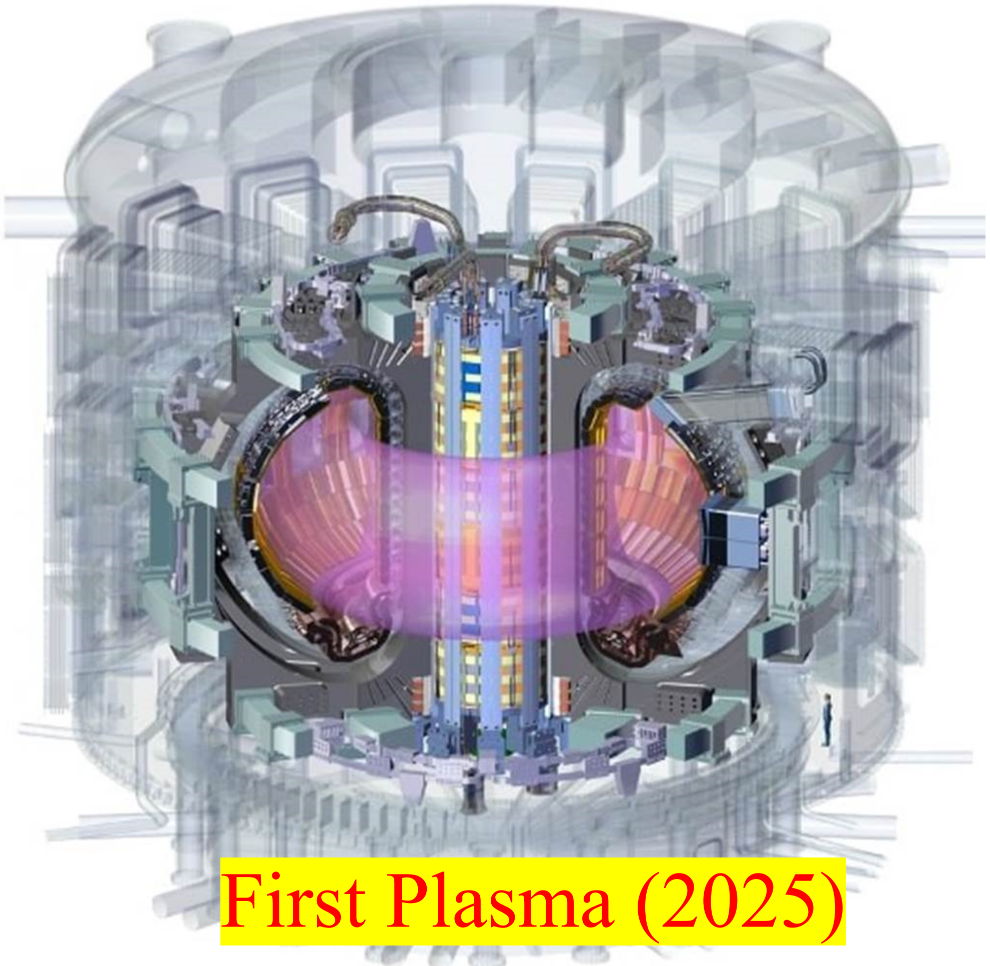
- Fabrication for 8 Japan-Gyrotrons was completed and fabrication of 6 Russia-Gyrotrons is ongoing as planned.
- 8 gyrotrons (Japan : 4, Russia : 4) have completed their performance tests and are being prepared for delivery to ITER for First Plasma.

2 : QST iTER JAPAN iter

- Design of 104 GHz/170 GHz dual-frequency gyrotron for ITER is successfully completed and the proto-type gyrotron is fabricating.

3 : ИПФ РАН GYCOM

- Delivered More than thirty MW gyrotrons are contributing to the advancement of plasma and fusion physics. Stable 1 MW power operation at 345 GHz was simulated by introducing new approach.



Thank you for attention