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Prospects of X-band Klystron Based on Experience of High Power Klystron Development in TETD

Toshiba Electron Tubes & Devices Co., Ltd.

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   - E37202: C-band, 50 MW
   - E3768: X-band, 50 MW
3. Promising or expected output power for X-band
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   - Performance of E3712, E37202, E3768 and XL-4
4. Summary

TETD: Profile

“To Be the Best Electron Tube & Divices Company”

Electron Tube & Devices Works having
Function from development to production

■Name：
Toshiba Electron Tubes & Devices Co.,Ltd.

◇Established：October,1,2003

◇Headquarters：
1385 Shimoishigami Otawara-shi,Tochigi,Japan

◇Tokyo office：
Level 17A ,1-1Shibaura 1Chome,Minato-ku,Tokyo,Japan

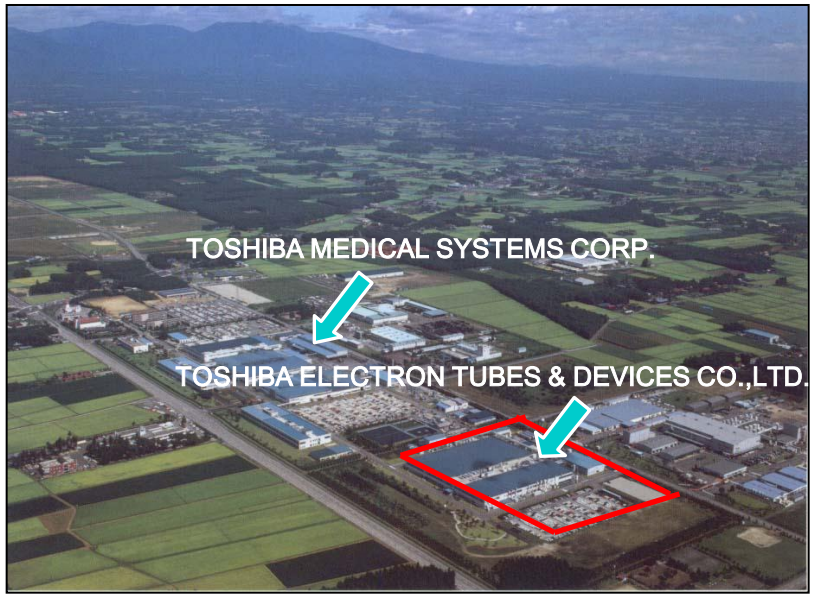
◇Capital：480 million yen（Toshiba Medical Systems 100%）

◇President and CEO：Takashi Yanagawa

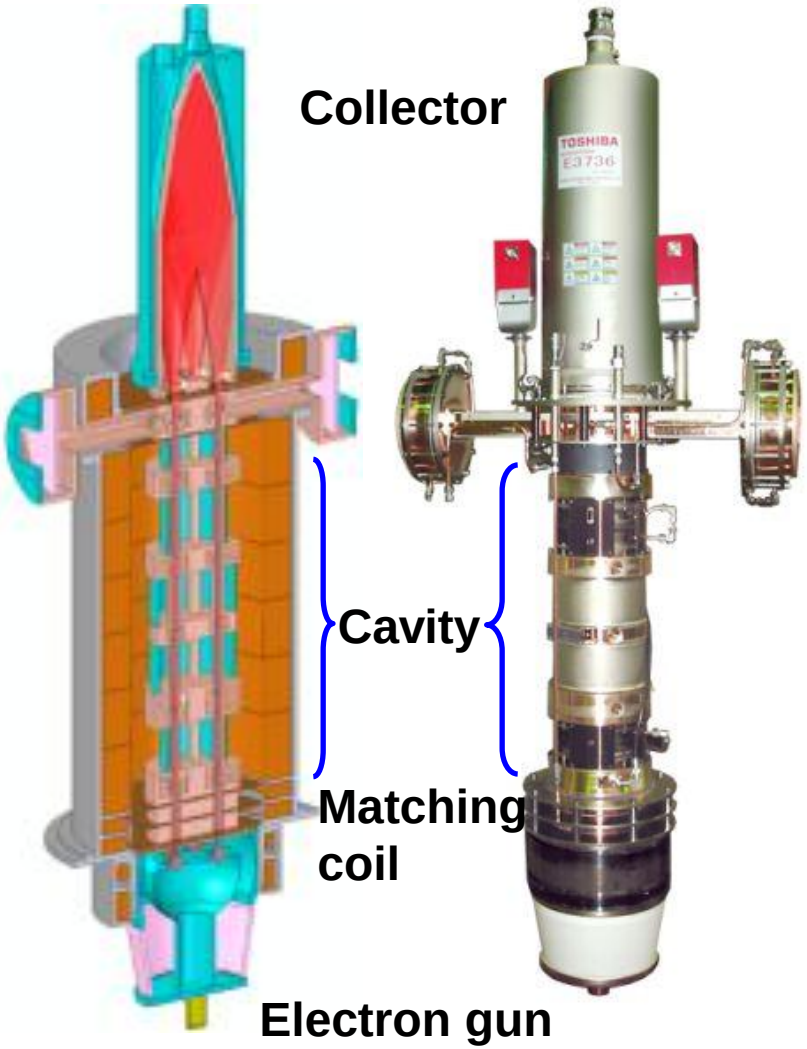
◇Employees：411 persons

◇Operations：
Development of an electron tube and an application product, manufacture, and sales

◇Products：
X-ray tubes, X-ray Image Intensifier, Klystron, Gyrotron, Grid tube, Magnetron, Monitor tube



E3736H: MBK (Multi Beam Klystron)



Typical Operations

Frequency	1.300 GHz
Peak Power	10.3 MW
Pulse Length	1.5 ms
Repetition Rate	10 pps
Beam Voltage	117 kV
Beam Current	131 A
Efficiency	67%
Gain	50 dB

S-band pulsed klystron

E3712

1.9 m

Typical Operations

Frequency	**2.856 GHz**
Peak Power	**80, 100 MW**
Pulse Length	**4, 1 μs**
Repetition Rate	**50 pps**
Beam Voltage	**400, 422 kV**
Efficiency	**42, 46%**

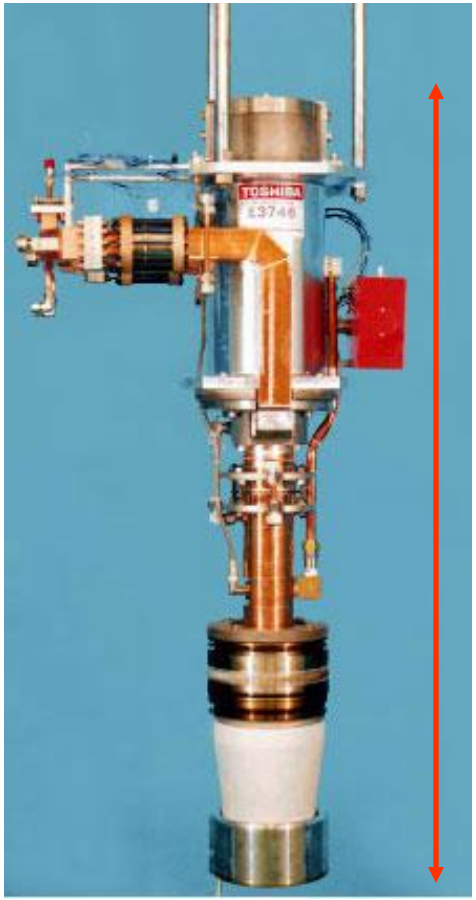
Accelerator Facilities

KEK-ATF, SP-8, Osaka Univ., SAGA-LS,
Tokyo Univ. of Science, AIST,
PLS(KOREA), NSRL(China), etc.

Total number of installed unit : 82 units

C-band pulsed klystron

E37202



Typical Operations

Frequency	**5.712 GHz**
Peak Power	**50 MW**
Pulse Length	**2.5 μs**
Repetition Rate	**60 pps**
Beam Voltage	**350 kV**
Efficiency	**47%**

Accelerator Facilities

SACLA, PSI, INFN, etc.

★ 3-Cell Traveling-wave Output Cavity

Total number of installed unit : 71 units

X-band pulsed PPM klystron

E3768

2 m

Typical Operations

Frequency	**11.424 GHz**
Peak Power	**50 MW**
Pulse Length	**0.5 μs**
Repetition Rate	**50 pps**
Beam Voltage	**460 kV**
Efficiency	**46%**

Accelerator Facilities

KEK-NEXTF, Tokyo Univ., etc.

Total number of installed unit : 9 units

We found unstable phenomena that the after-part of RF pulse dropped out.

RF break down in the output cavity or oscillation ?

Prospects of X-band klystron performance by using scaling law

Issues for higher frequency and higher power klystron developments

- **Output window: puncture by higher electric field**
- **Output cavity: RF breakdown by higher electric field**
- **Instability of klystron operation**

Front end klystron parameters for stable operation

	Unit	S-band E3712	C-band E37202	X-band XL-4	X-band E3768
Frequency	MHz	2856	5712	11424	11424
Output power	MW	80	50	50	50
Pulse duration	μs	4	2.5	1.5	0.4
Beam perveance	μP	2.0	1.5	1.2	0.85
Window type	—	Double-Standard Pill Box	Double-Long Pill Box	Double-TE01 mode	Double-Mixed mode
Output cavity type	—	single	3-cell	4-cell	4-cell

Scaling of power capability

A. Window electric field strength

Break down limit $\propto f^{0}$? (Ceramics)

$$P \propto f^{-2} \cdot \tau^{-\frac{2}{3}}$$

P : output power
τ : pulse duration

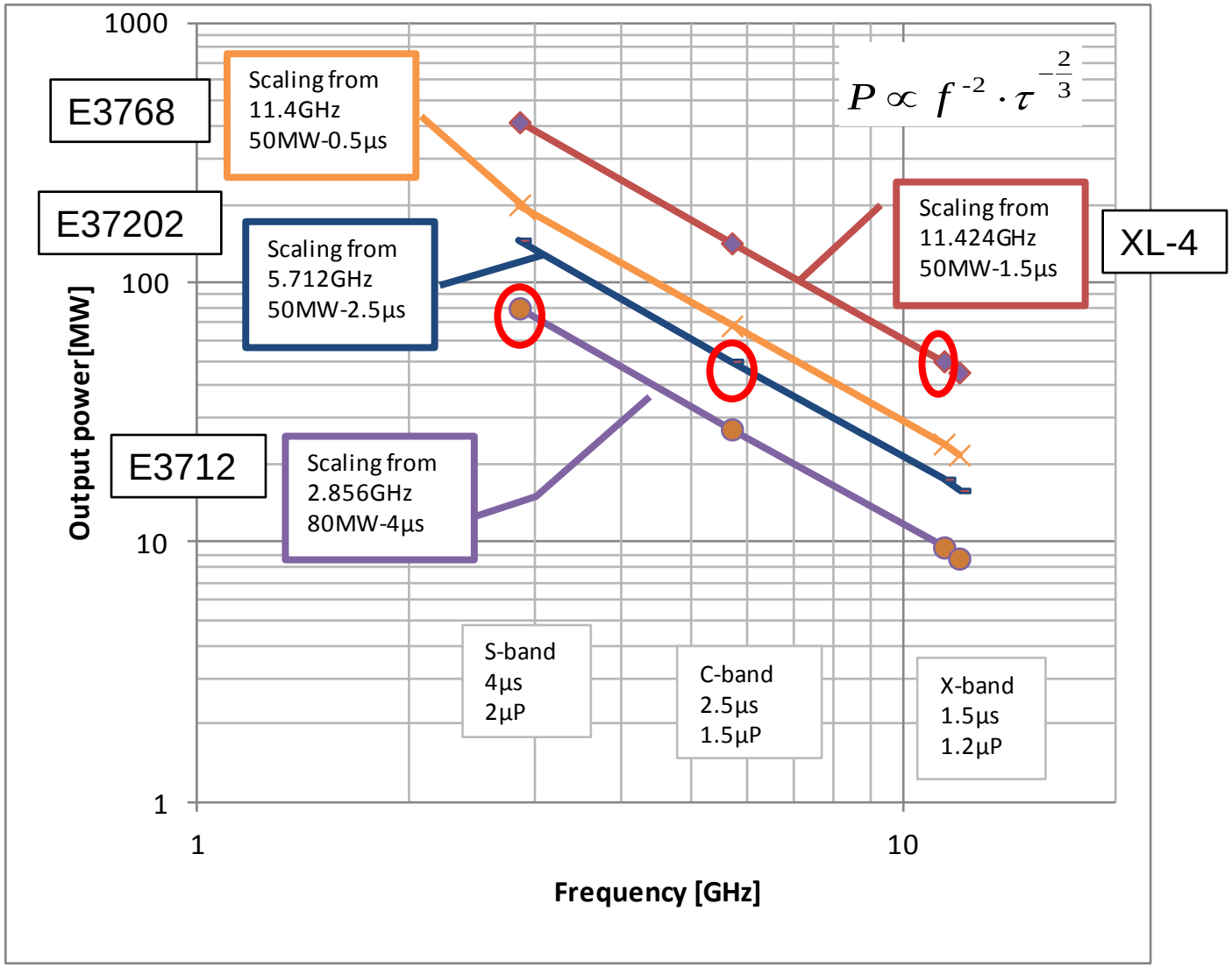
B. Output cavity electric field strength

Break down limit $\propto f^{0.3}$ from SLAC (Wang & Loew curve)

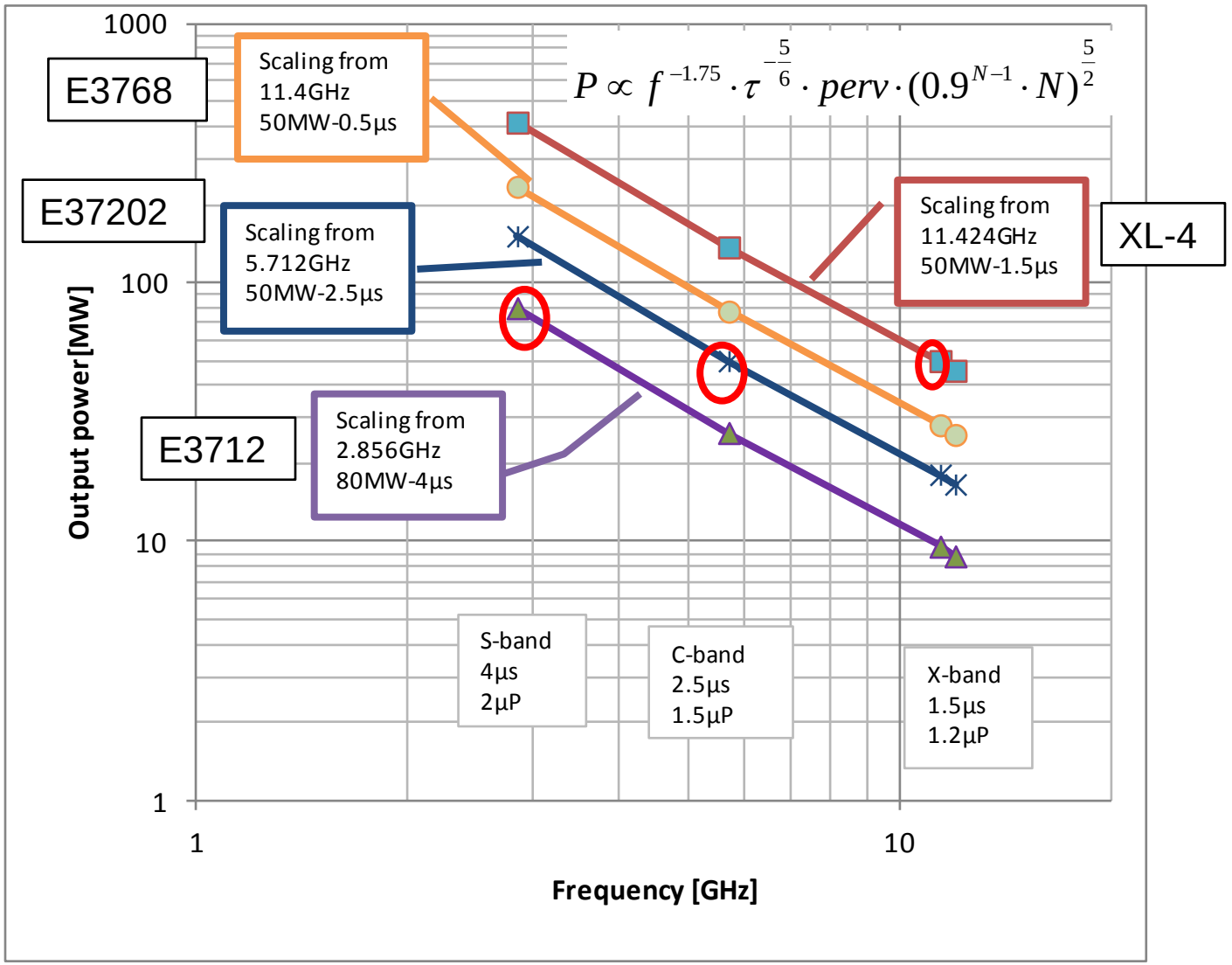
$$P \propto f^{-1.75} \cdot \tau^{-\frac{5}{6}} \cdot perv \cdot (0.9^{N-1} \cdot N)^{\frac{5}{2}}$$

P : Output power
τ : pulse duration
$perv$: beam perveance
N : number of cavity cells

Results of scaling for output window



Results of scaling for output cavity



Conclusions

	Scaled output power [MW] from Window performance (A)	Scaled output power [MW] from Output cavity performance (B)	Remarks
	12GHz-1.5μs 1.2μP	12GHz-1.5μs 1.2μP	
S-band 80MW base	9	9	Normal output cavity Double standard Pill Box Windows
C-band 50MW base	16	17	Multi-cell output cavity Double long Pill Box Windows
X-band 50MW 1.5μs base	45	46	Multi-cell output cavity Double TE01 Windows
X-band 50MW 0.5μs base	22	26	Multi-cell output cavity Double mixed mode Windows

Summary

1. According to the scaling from E3712 (S band) and E37202 (C band),
   We are confident that we will provide X-band klystrons with output powers up to 17 MW.

2. Regarding 50-MW and 1.5-μs tube,
   Even though we know success operation of XL-4, taking account of our experience,
   we need a couple of years to develop it perfectly.

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Thank you for your attention