國家同步輻射研究中心
National Synchrotron Radiation Research Center

Introduction of High Power Microwave Source

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2026 FEL Winter School

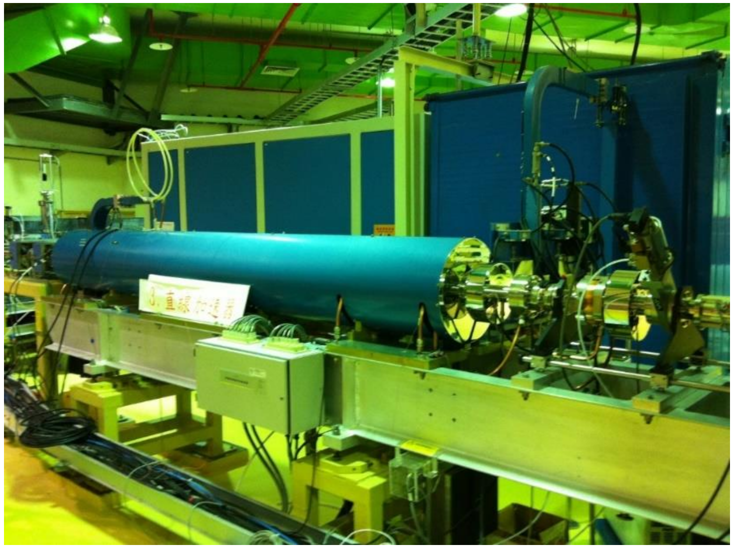
Outline

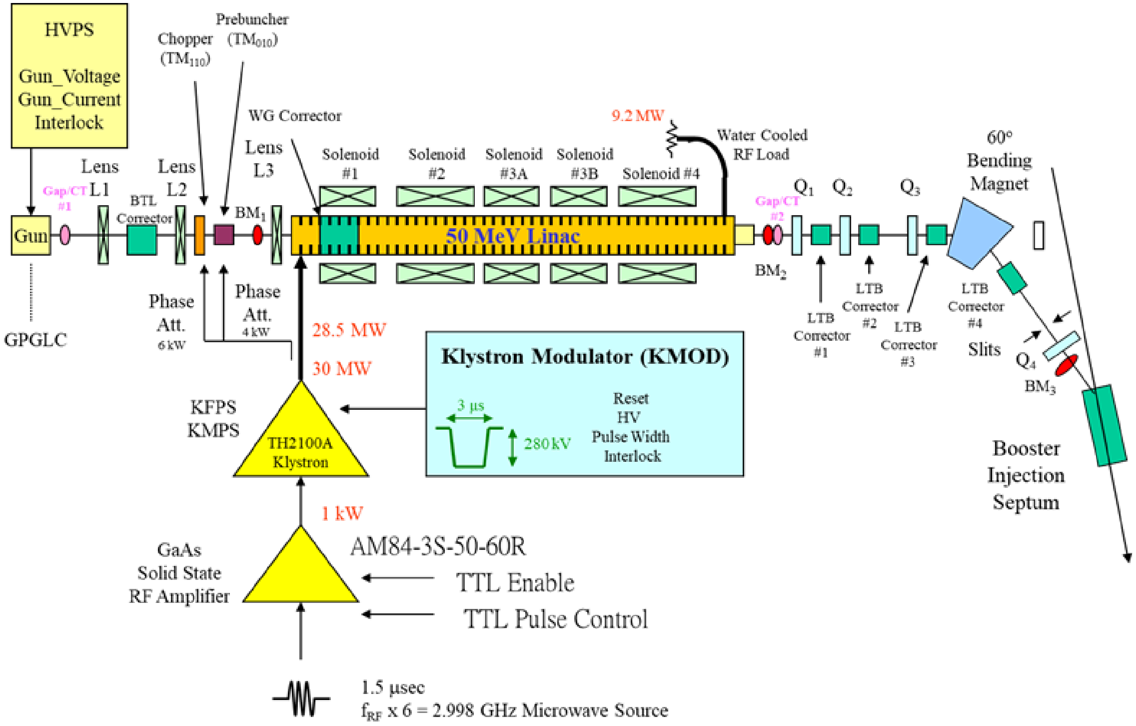
- The NSRRC LINAC
- Introduction of Microwave Tubes
- Microwave Tube R&D
- Klystrons
- SLED (RF Pulse Compressor)
- Application of High-Power Microwave Source

LINAC - TLS Pre-Injector Systems

TLS pre-injector : 3 GHz, 10Hz, 50MeV (Scanditronix turn-key system)

- 140 keV DC electron gun (Thermionic Cathodes)
- Chopper (3 GHz)
- Prebuncher (3 GHz)
- LINAC (3 GHz, 3m, SLAC type)
- Klystron (3 GHz, Canon E37310A)

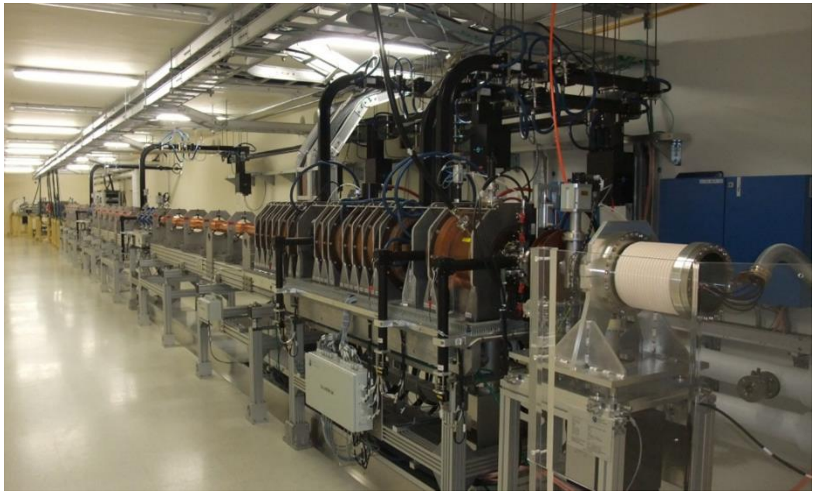


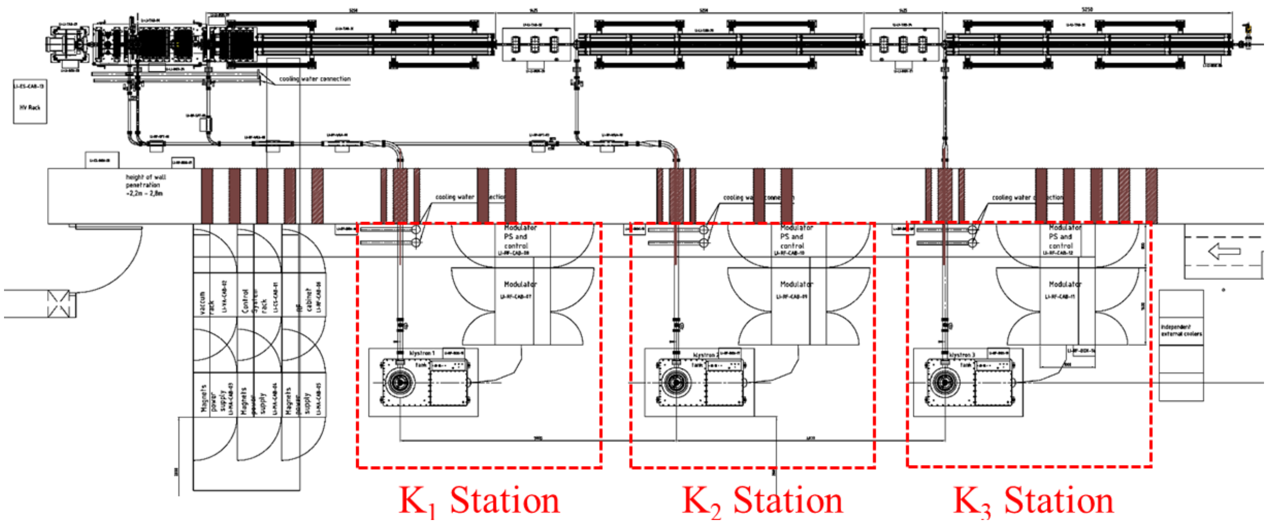


LINAC - TPS Pre-Injector RF Distribution

TPS pre-injector : 3 GHz, 3Hz, 150MeV (RI turn-key system)

- 90 keV DC electron gun (Thermionic Cathodes)
- Sub harmonic pre-buncher SPB (500 MHz)
- Primary buncher PBU (3 GHz)
- Final buncher FBU (3 GHz)
- Three 5.2 m linacs (3 GHz)
- Three klystrons stations(TH2100A)



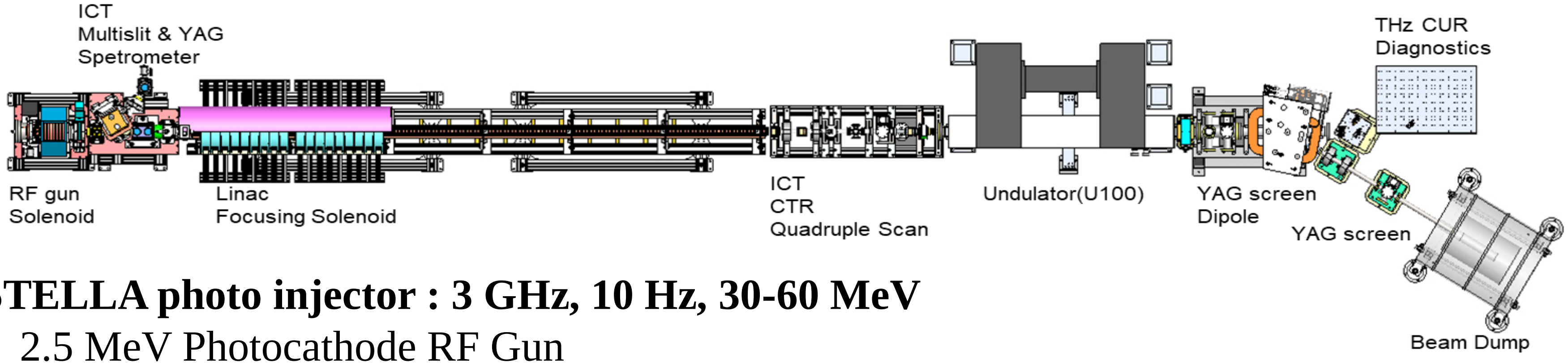


LINAC - Superradiant Terahertz Light based on LINAC

LINAC-based Coherent THz sources :

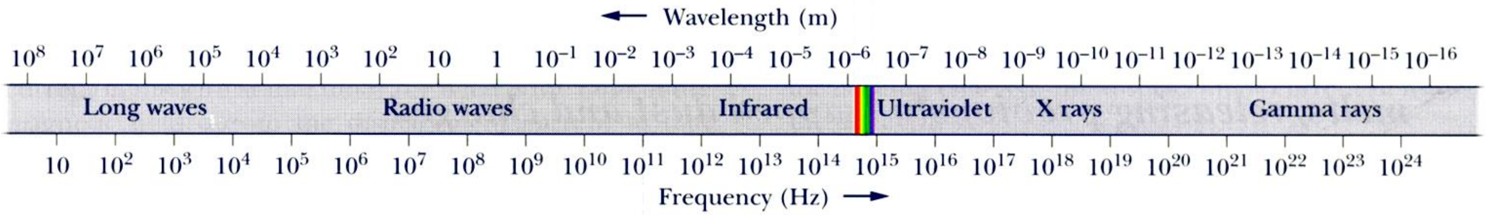
•Coherent undulator radiation (CUR) : Radiation produced by passing through an undulator

•Coherent transition radiation (CTR) : Radiation produced by hitting a metal foil



STELLA photo injector : 3 GHz, 10 Hz, 30-60 MeV

- 2.5 MeV Photocathode RF Gun
- One 5.2 m LINAC (3 GHz)
- One klystrons station(Canon E37310A, Homemade modulator)



Frequency Bands for Household Electronics

AM broadcast band: 535-1605 kHz

Shortwave radio: 3-30 MHz

FM broadcast band: 88-108 MHz

VHF TV (channel 2-4): 54-72 MHz

VHF TV (channel 5-6): 76-88 MHz

UHF TV (channel 7-13): 174-216 MHz

UHF TV (channel 14-83): 470-890 MHz

Microwave Bands

L-band: 1 - 2 GHz

S-band: 2 - 4 GHz

C-band: 4 - 8 GHz

X-band: 8 - 12 GHz

Ku-band: 12 - 18 GHz

K-band: 18 - 26.5 GHz

Ka-band: 26.5 - 40 GHz

U-band: 40 - 60 GHz

V-band: 60 - 80 GHz

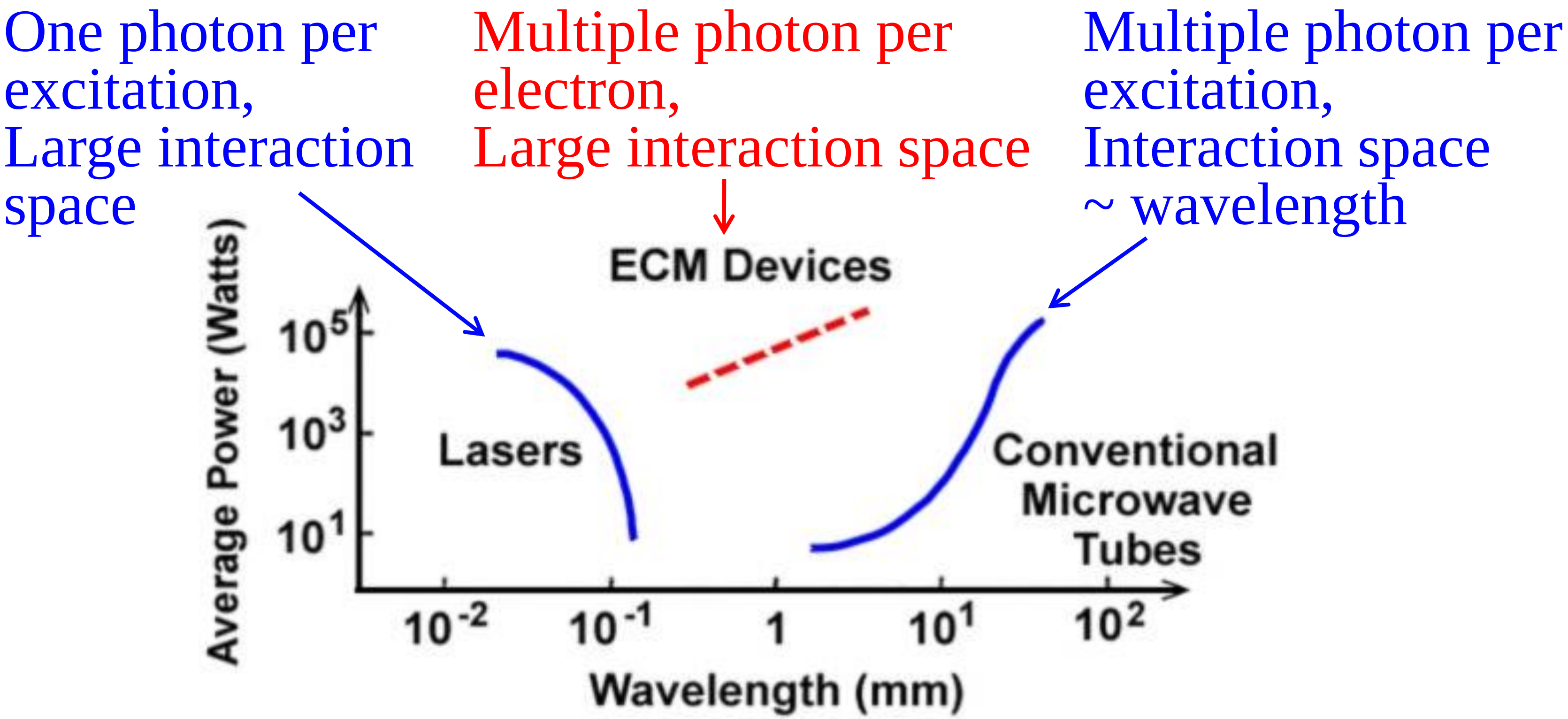
W-band (IEEE): 80 - 100 GHz

Vacuum Electronics

Vacuum electronics addresses electron-wave interactions in a vacuum, usually for radiation generation. It involves a much broader frequency range than the microwave band (e.g. X-ray free electron laser, FEL). This chapter covers only the microwave regime.

	Conventional Microwave Electronics	Relativistic Electronics
Examples ,	TWT, Klystron, Magnetron	ECM, FEL
Frequency	$< 10^{11}$ Hz	10^{10} Hz – X-ray
Power	$< 10^{6}$ W	10^{4} W – 10^{10} W
Electron Energy	$< 10^{5}$ V	10^{3} V – 10^{10} V
Beam Current	$< 10^{2}$ A	1 A – 10^{6} A
Basic Equations	Circuit equations + Fluid equations	Maxwell equations + Relativistic particle eqs.

Power Capabilities of Laser and Microwave Tubes



The figure above compares the power capabilities of lasers and microwave tubes. Lasers are quantum mechanical devices, while the conventional microwave tubes and ECM (a new type of microwave tubes) are vacuum electronic devices. The term "microwave tube" refers to microwave generators requirng a vacuum environment for the electron-wave interaction

An Overview of Microwave Tubes

Microwave tubes (or simply "tubes") are the main subject of this chapter. They have a long histroy of research and are still being enriched by new physical insights and the discovery of novel types of tubes. Microwave tubes are widely used in our daily life.

Tubes are bulkier than solid state microwave devices, but they generate much higher power. The basic types of microwave tubes are listed below (and will be discussed later).

Conventional Microwave Tubes: matured in the 1960s

Cornerstones:
1. Traveling Wave Tube (TWT)
2. Klystron
3. Magnetron

Relativistic Microwave Tubes: 1970s-present

Cornerstone: Gyrotron [a device based on a relativistic effect called the electron cyclotron maser (ECM)]

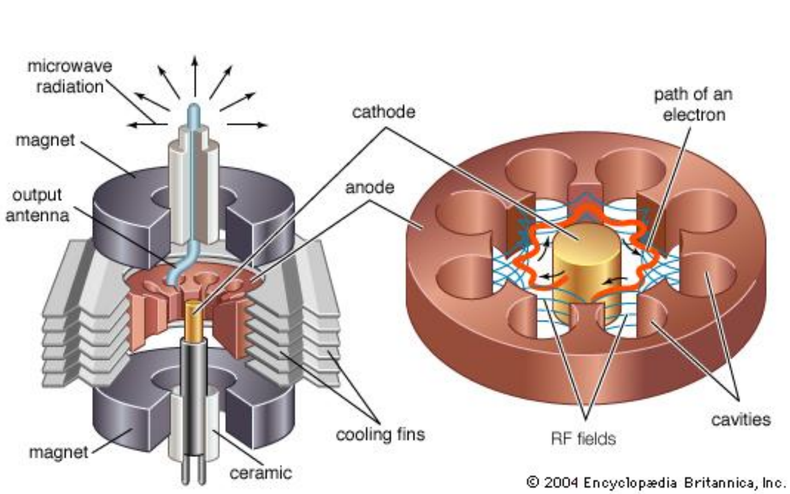
An Overview of Microwave Tubes

Amplifier	Oscillator	Interaction Process
Gridded Tube	Gridded Tube	Grid control of the beam current
Klystron	1.Two Cavity Oscillator 2.Extended Interaction Oscillator 3.Reflex Klystron	Velocity Modulation with resonant cavities
1.Helix TWT 2.Coupled Cavity TWT	Backward wave Oscillator	Velocity Modulation with traveling wave structure
Crossed Field Amplifier	1.Carcinotron(M-type BWO) 2.Fixed Frequency Magnetron 3.Coaxial Magnetron 4.Voltage Tuned Magnetron	Crossed Field
Gyrotron	Gyrotron	Spiraling beam

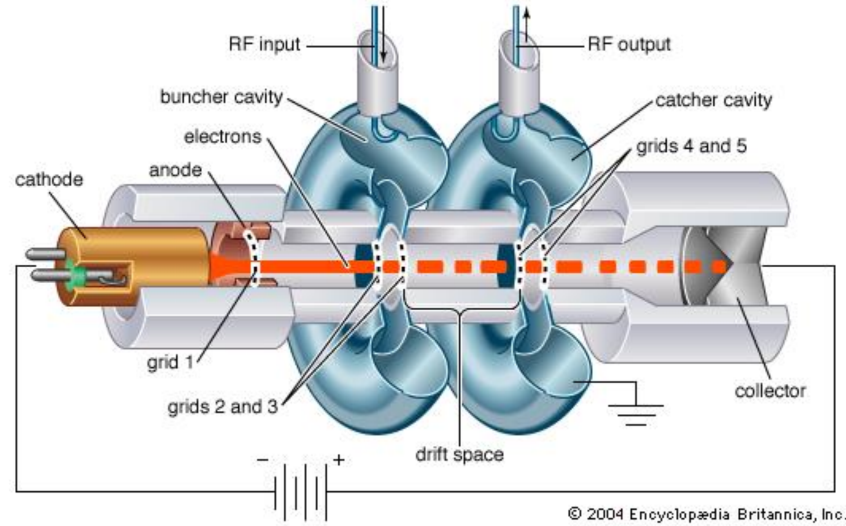
※Linear beam tubes are called O-type devices.

※Crossed-field tubes are called M-type devices.

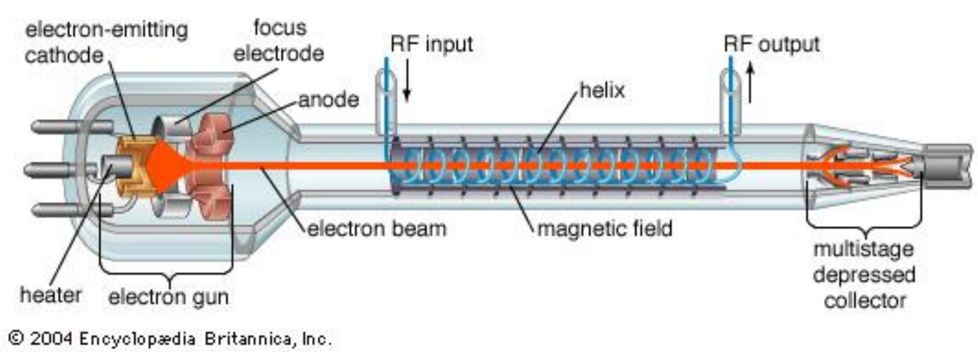
Conventional Microwave Electronics



Magnetron



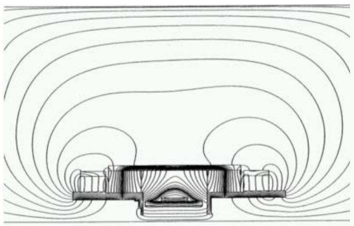
Klystron

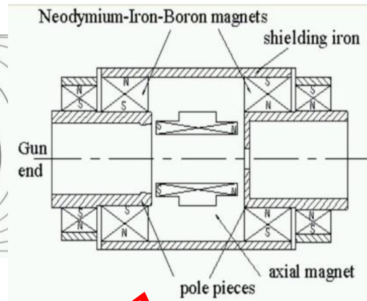


Helix TWT

https://www.britannica.com/technology/electron-tube/Common-tubes-and-their-applications

Microwave Source R&D





CAD

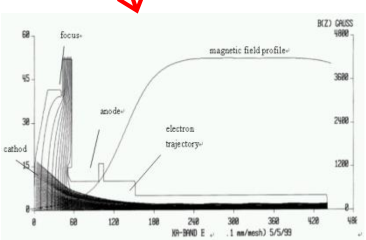
Engineering Drawing

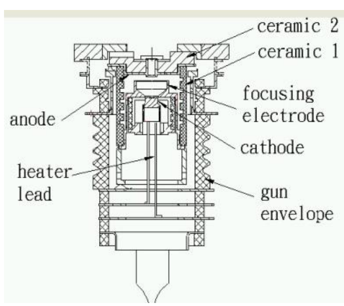
Precision Machining

Brazing

EIKA Assembly

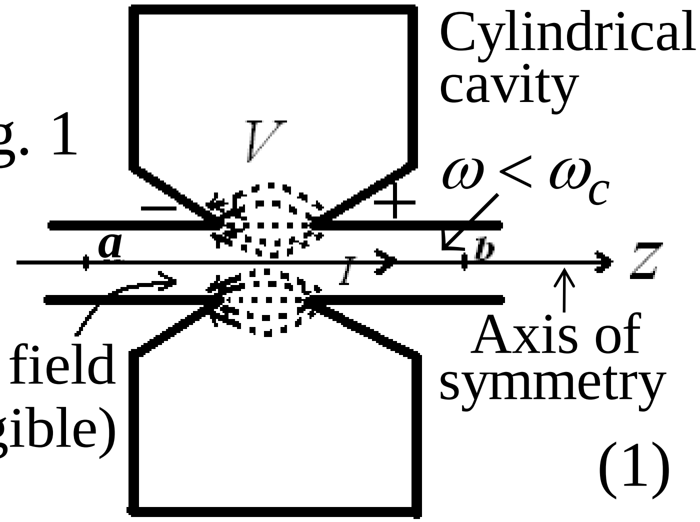
Hot Test





Gap Voltage and Shunt Impedance:

Assume a mode is present in the cavity in Fig. 1, the voltage difference across the gap is a parameter of interest. Define the gap voltage V as



$$V \equiv -\int_a^b E_z(z)dz \quad \text{[Gap voltage]}, \qquad (1)$$

where the integration is along the z-axis.

Question: Can there be a voltage difference on the same conductor?

In (1), V and E_z are phasors (ω-space complex quantities), i.e. in t-space, we have $V(t) = \mathrm{Re}[Ve^{j\omega t}]$ and $E_z(z,t) = \mathrm{Re}[E_z(z)e^{j\omega t}]$.

When V is defined as in (1), the reference polarity [direction of positive $V(t)$] is shown in Fig. 1. Let P_{loss} be the total power loss in the cavity (e.g. Ohmic loss). In terms of V and P_{loss}, we define a shunt impedance as

$$R \equiv \frac{|V|^2}{2P_{loss}} \quad \text{[Shunt impedance]} \qquad (2)$$

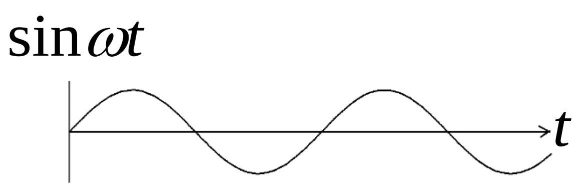
Conditions Required for the Generation of Coherent Radiation - Common to All Types of Microwave Tubes

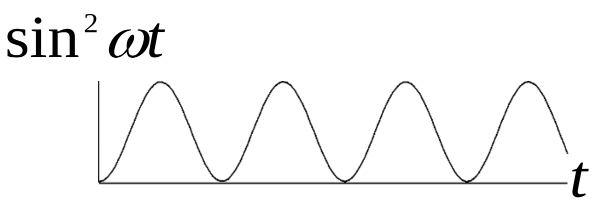
1. A mechanism for the RF fields to *bunch* a DC electron beam into an AC electron beam (Microwave tubes are distinguished by their bunching mechanisms).
2. *Synchronism* between the bunched electrons and the RF fields.

$$\text{Let} \begin{cases} J \ \text{(electron current)} = \begin{cases} J_0 & \text{[DC]} \\ J_0 \sin \omega t & \text{[AC]} \end{cases} \\ E \ \text{(wave electric field)} = E_0 \sin \omega t \end{cases}$$

$$\text{Then, } P \ \text{(power)} = JE = \begin{cases} J_0 E_0 \sin \omega t & \text{[DC]} \\ J_0 E_0 \sin^2 \omega t & \text{[AC]} \end{cases}$$

$$\Rightarrow \quad \langle P \rangle_t \begin{cases} = 0 & \text{[DC], no energy exchange} \\ \neq 0 & \text{[AC], energy exchange} \end{cases}$$

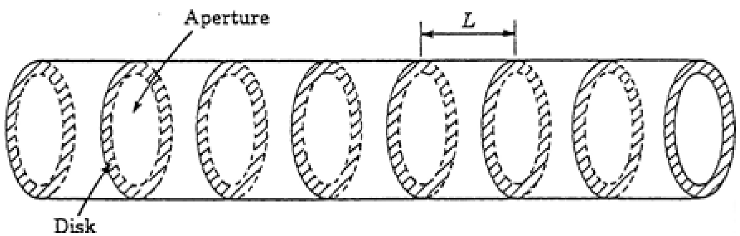


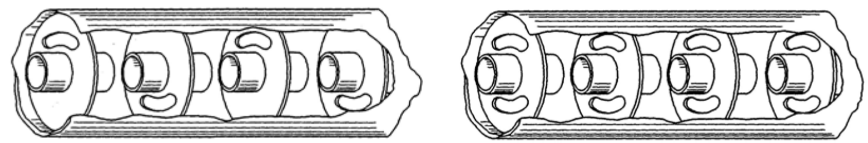


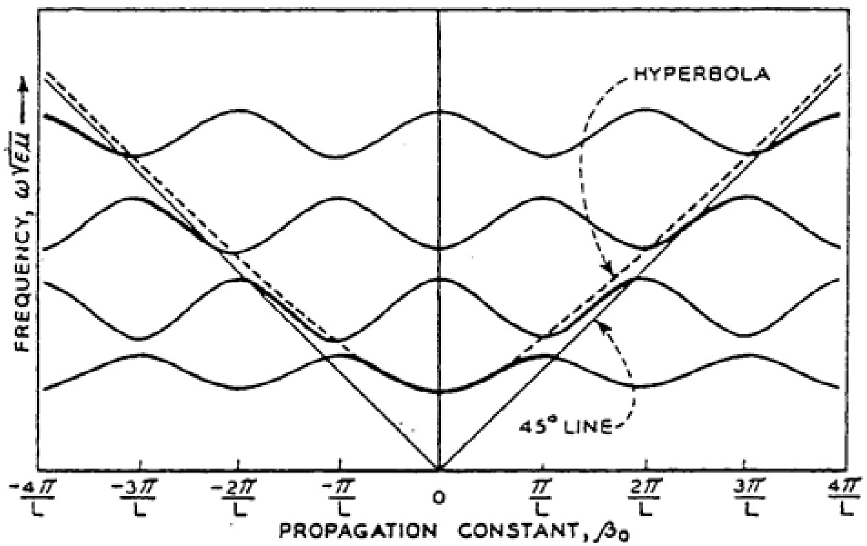
Waves in Periodic Structures

weak periodic loading

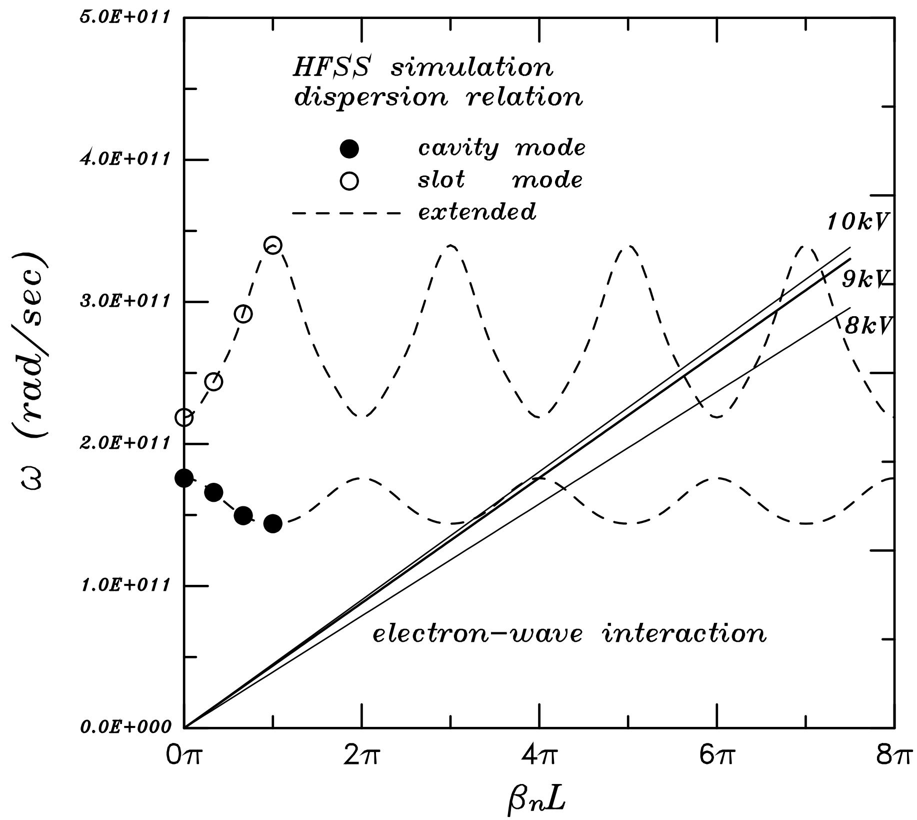
strong periodic loading





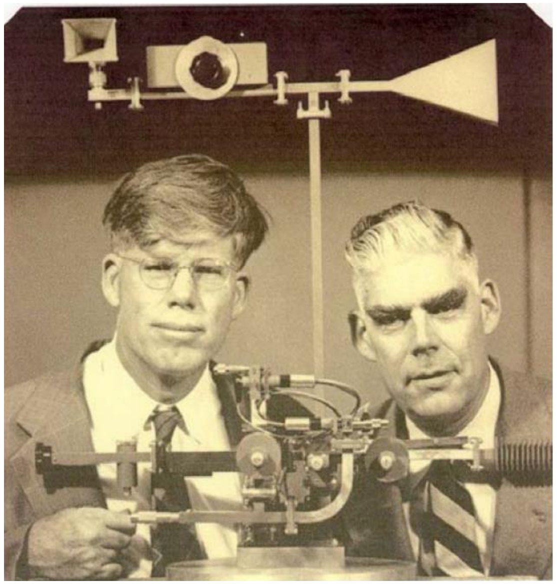


ω-β Diagram of slow wave structure

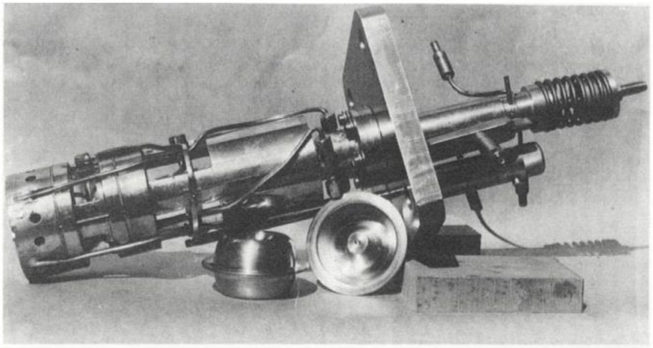


ω-β Diagram of slow wave structure

Klystrons



The first klystron invented by the Varian brothers at Stanford



The Stanford "Model A" klystron

Table 1: Typical 5045 Operating Parameters

Operating Parameter	Value
Frequency	2.856 GHz
Beam Voltage	350 kV
Perveance	2.0 $\mu A/V^{1.5}$
Peak Output Power	65 MW
Average Output Power	41 kW
RF Pulse Width	3.5 μs
Pulse Rep. Rate	180 Hz
Gain	50 dB
3 dB Bandwidth	20 MHz
Saturated Efficiency	45%
Cathode Current Density	8 A/cm^2

The SLAC S-band klystron

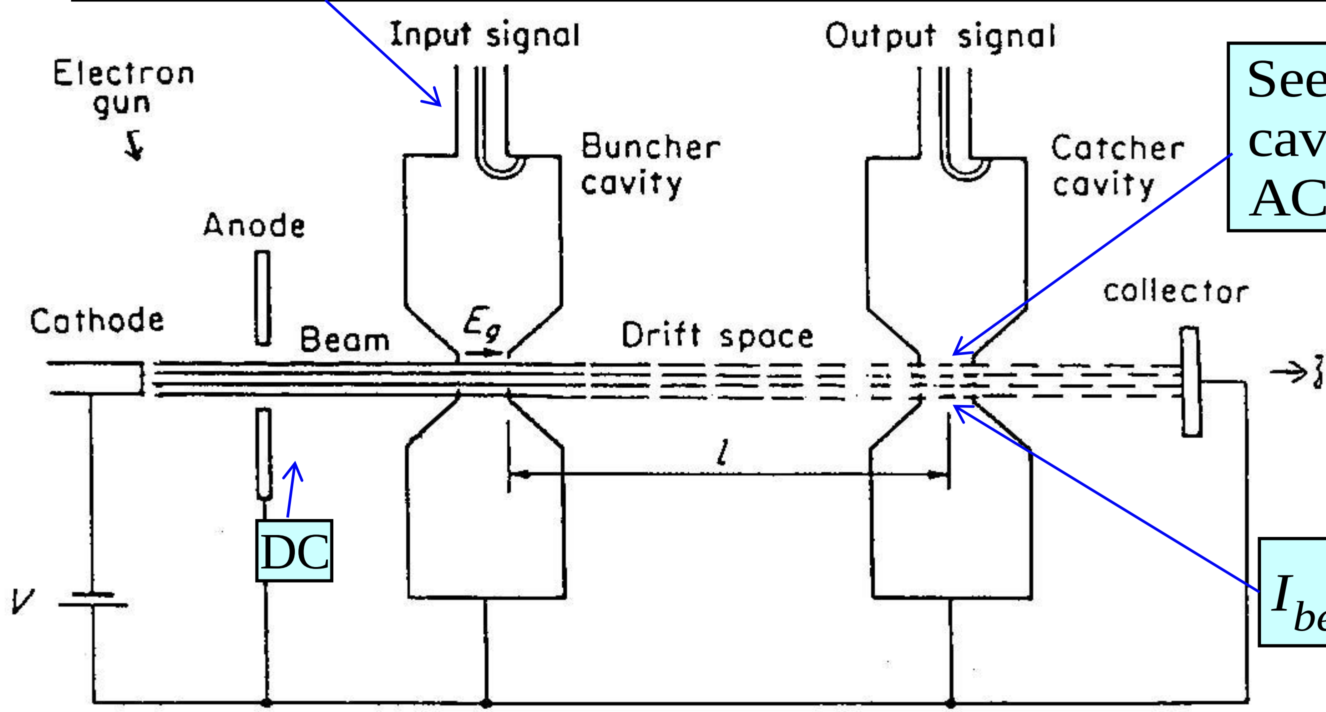
The design principle of the klystron

Principle of the klystron amplifier:

{velocity modulation in buncher cavity} ⇒ {electron bunching in the drift space} ⇒ {density modulation}

See Ch. 7, Sec. 5 for cavity excitation by external coupling.

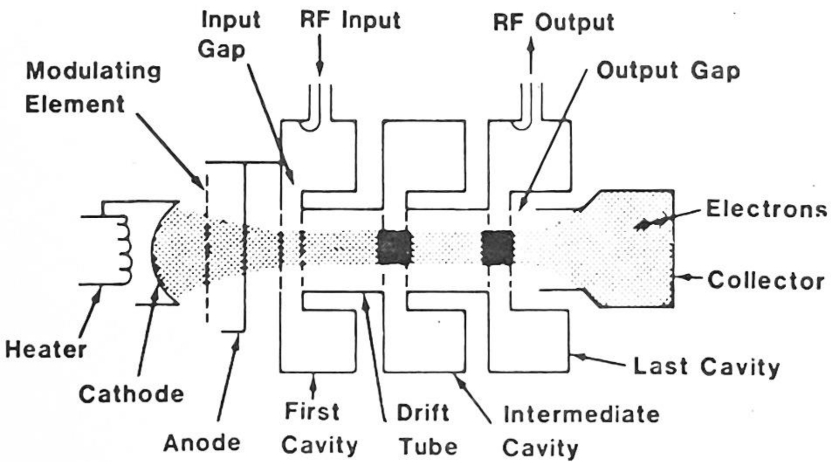
See Ch. 7, Sec. 3 for cavity excitation by AC beam current.



$$I_{beam} = I_{dc} + I_{ac}e^{j\omega t}$$

A two-cavity klystron amplifier.

The design principle of the klystron



Elements of a Three-Cavity Klystron Amplifier

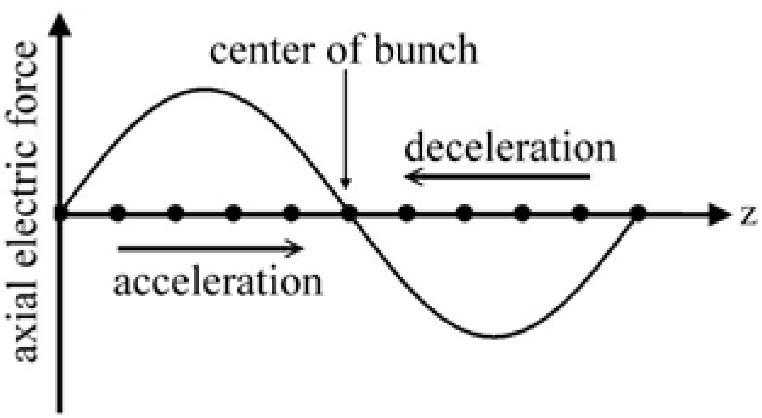
Plasma Frequency

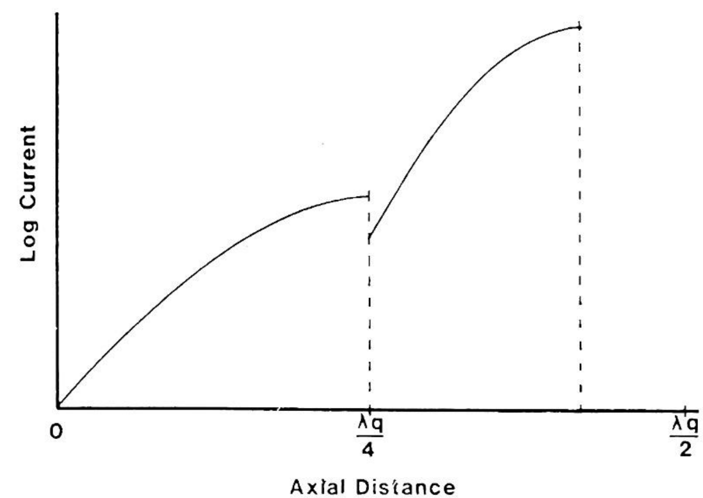
$$\begin{cases}\omega_{pe}\equiv\sqrt{\dfrac{4\pi n_0 e^2}{m_e}}\ \left[=5.64\times10^4\sqrt{n_0(\mathrm{cm}^{-3})}\ \dfrac{\mathrm{rad}}{\mathrm{sec}}\right] \\ \omega_{pi}\equiv\sqrt{\dfrac{4\pi n_0 e^2}{m_i}}\ \left[=\sqrt{\dfrac{m_e}{m_i}}\omega_{pe}\ll\omega_{pe}\right]\end{cases}$$

For (18) to have a non-trivial solution ($E_{1k}\neq 0$), ω can only have a single frequency given by $\omega^2=\omega_{pe}^2+\omega_{pi}^2=\omega_p^2$ (19)

where $\omega_p^2\equiv\omega_{pe}^2+\omega_{pi}^2$ (20)

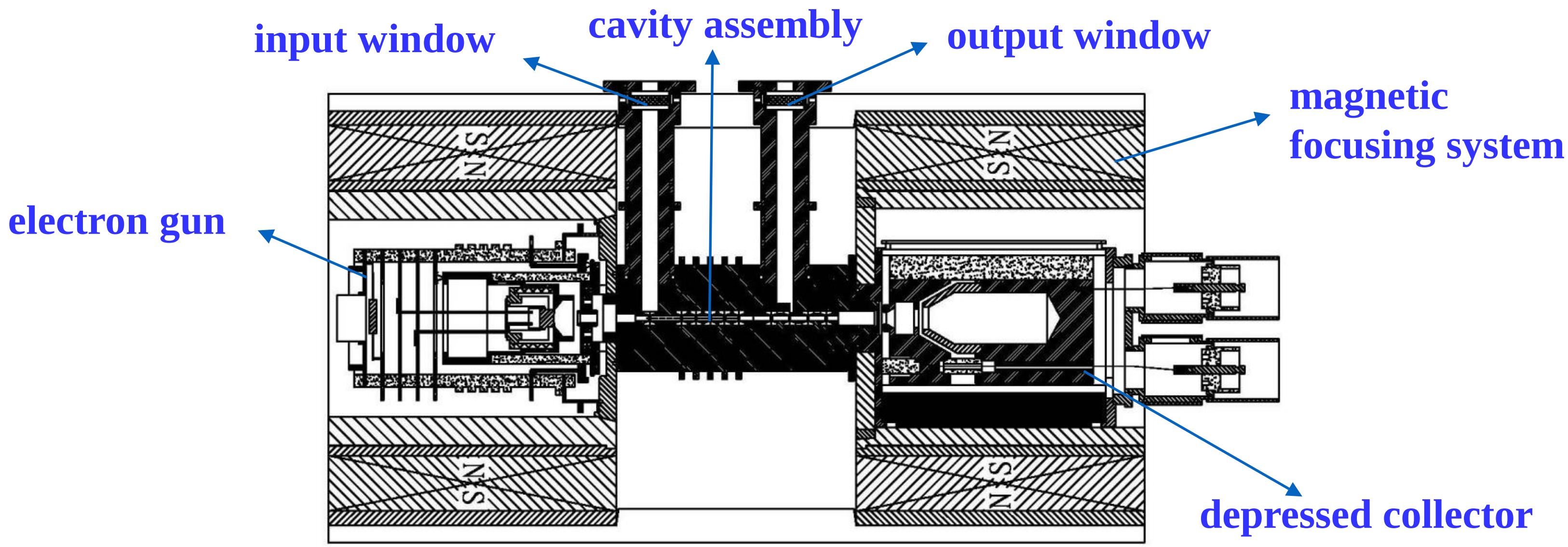
ω_p is called the plasma frequency. It is a characteristic frequency of the plasma most frequently encountered in plasma studies.



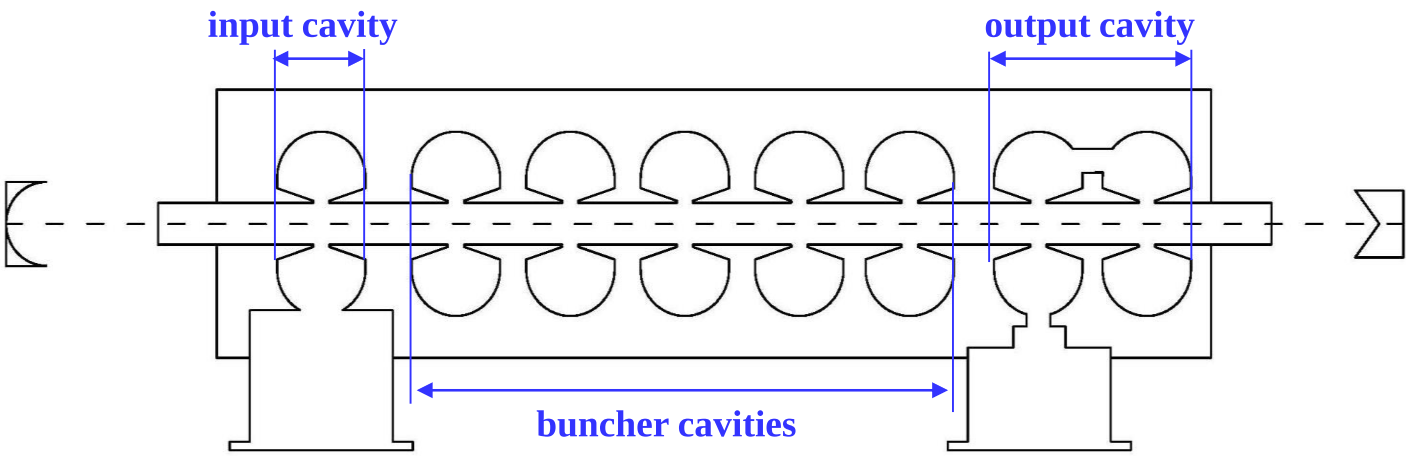


RF Current Growth in Beam in a Three-Cavity Klystron Amplifier

Klystron Assembly



Interaction Circuit



Tuning of the multi-cavity klystron

(1) Synchronously tuning (for maximum gain)

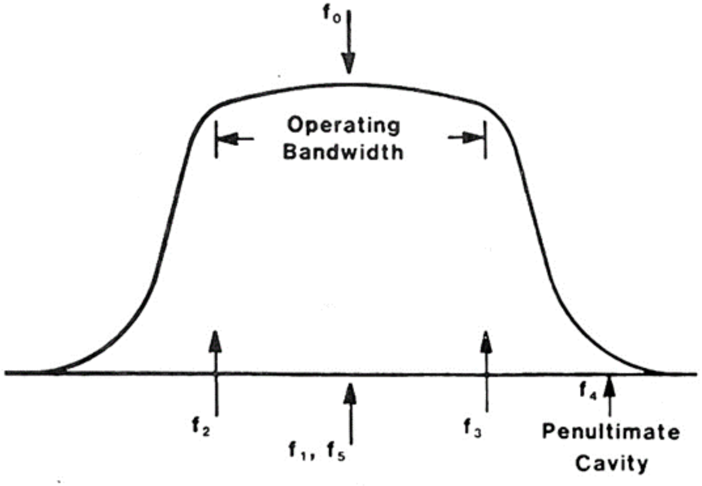
All cavities are tuned to the same frequency, which is also referred to as gain tuning. Generally, each cavity provides a gain of about 15-20 dB, so a klystron amplifier with four resonant cavities is expected to offer a total gain of over 50 dB.

(2) Efficiency tuning (for maximum efficiency)

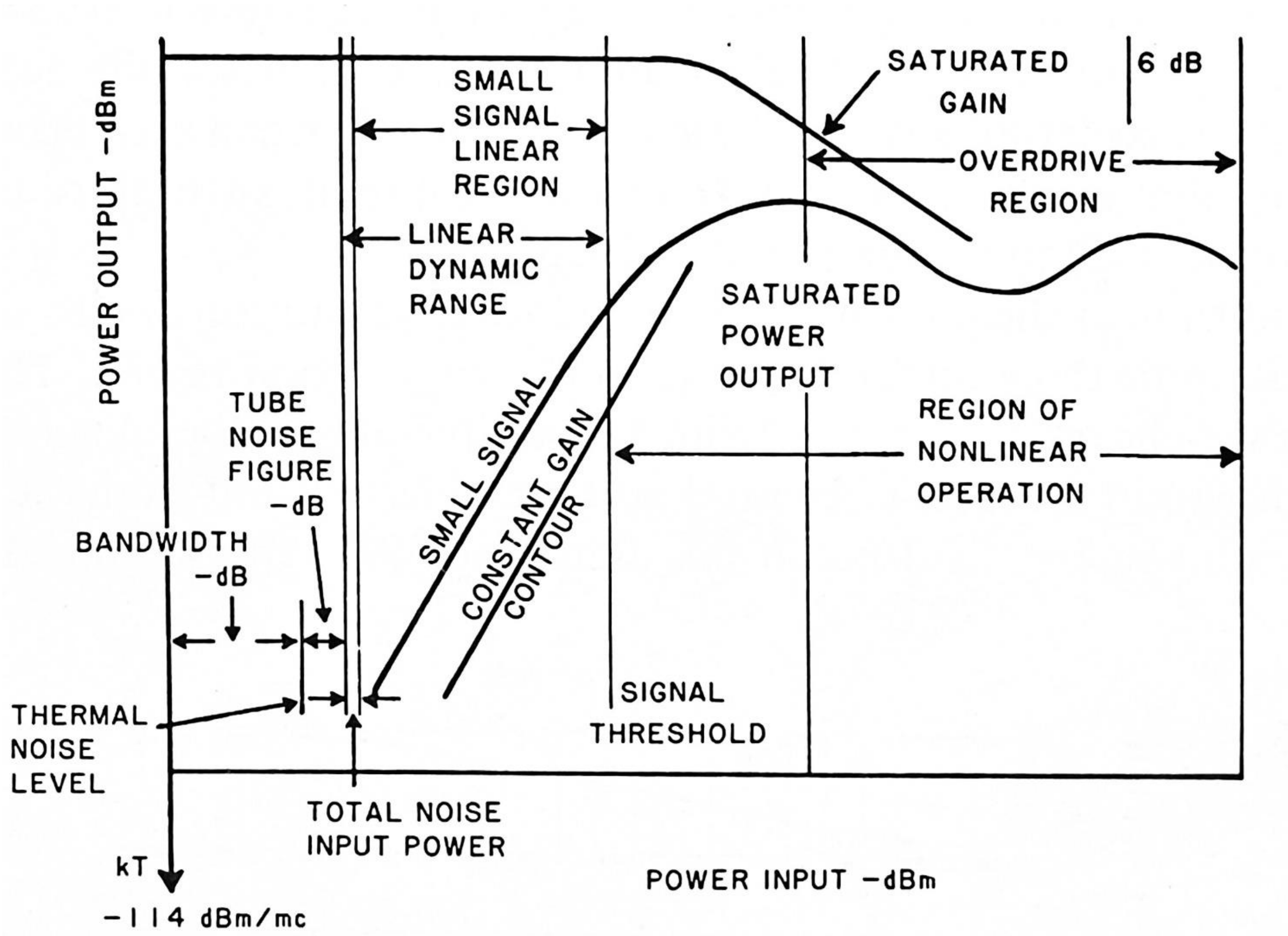
The penultimate cavity (i.e. next-to-the last cavity) is tuned upward in frequency (making it inductive at the operating frequency) ◦ If the resonant frequency of the penultimate cavity is increased, the bandwidth will be widened. Although the gain will decrease by about 10 dB, efficiency tuning will enhance the bunching efficiency of the electron beam, resulting in a 15-20% increase in power output.

(3) Broadband tuning (for wide bandwidth)

A klystron is typically a narrow-bandwidth microwave source. Usually, stagger tuning is employed, sacrificing high gain to achieve a wider bunching bandwidth. Stagger tuning involves adjusting the resonant frequencies of different cavities above or below the center frequency to increase the overall bandwidth.



The design principle of the Klystron



Transfer Curve of rf amplifier

Small-Signal Analysis

Big-Signal Analysis

Ka-Band Klystron

P3 := PPmax − 3   P1 := PPmax − 1

Vo ≡ 14000	Beam Voltage (V)	Number of Data Points	npoints ≡ 256
Io ≡ 0.5	Beam Current (A)	Calculation Bandwidth (GHz)	BW ≡ 0.30
f0 ≡ 35	Center Freqency (GHz)	Plot Markers	fl = 34.886 fh = 35.088 PPmax = 52.633 dB
a ≡ 0.000375	Tunnel Radius (m)	Gain at center frequency	PPf0 = 52.002 dB
b ≡ 0.000225	Beam Radius (m)	1dB Bandwidth (GHz)	Bndwthdb = 0.179 % BW(1dB) fbw1 = 0.512
		3dB Bandwidth (GHz)	Bndwth = 0.202 % BW(3dB) fbw3 = 0.576

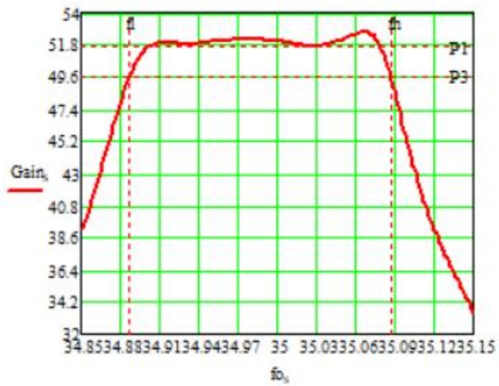
Remember to update the shape factor d2 if the fill-factor changes.

$\beta e = 3.212 \times 10^{3}$ $\beta q = 169.200$ $\gamma \cdot a = 1.173$

Empirical expression for Qe of the output cavity - not used in the gain calculation: Irf ≡ 1.5

$$Qe_N := \frac{\frac{Vo}{Io}}{RQ_N \left[\frac{2}{\sigma \cdot (\sigma + 1)} \cdot (M_N)^2 \cdot Irf\right]} \quad (11)$$

$Qe_N = 176.205$



Number of Klystron Cavities: N ≡ 6

Gun Microperveance (uA/V^1.5)   K = 0.302

Brillouin Field (gauss) $Bbr = 2.397 \times 10^{3}$

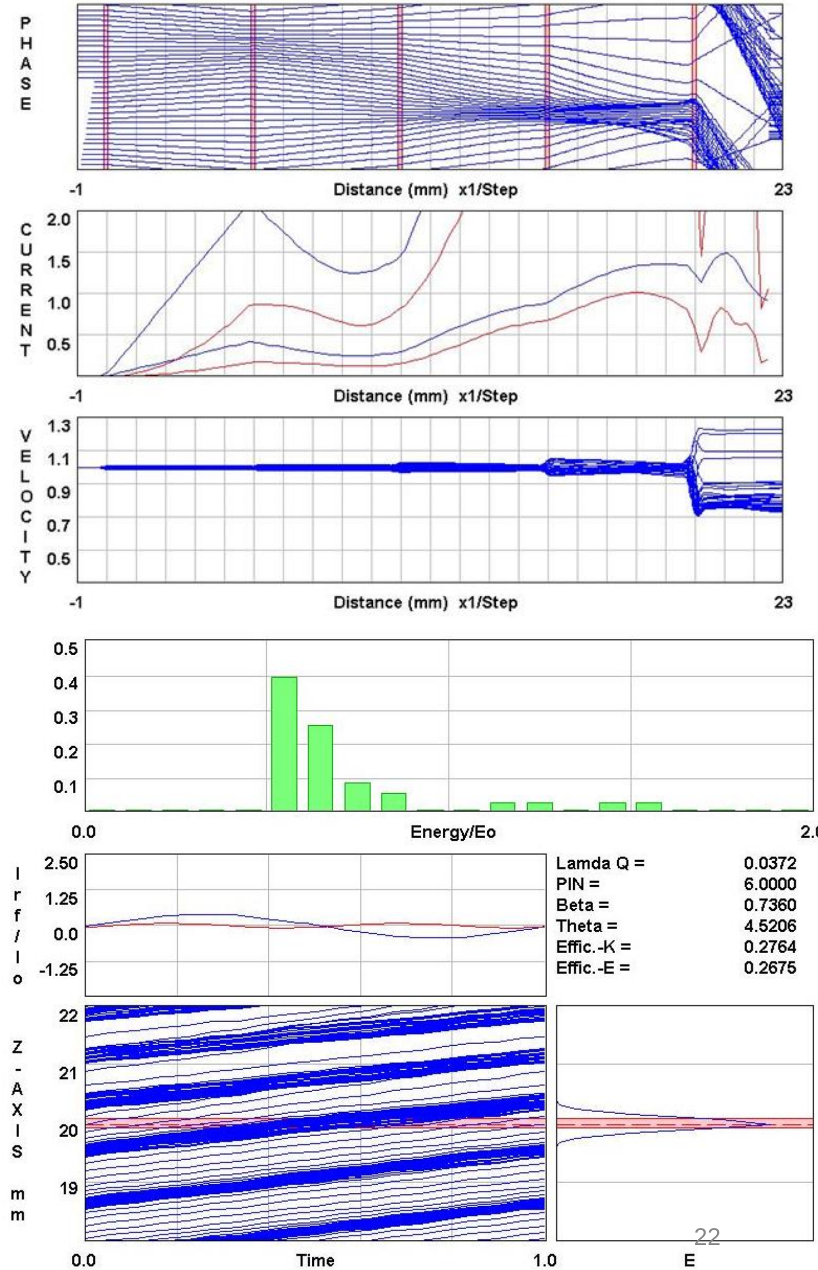
Beam current density (A/cm²)   Jbeam = 314.380   Cathode current density (A/cm²)   Jcathode := 5

Gun convergence $\frac{Jbeam}{Jcathode} = 63$

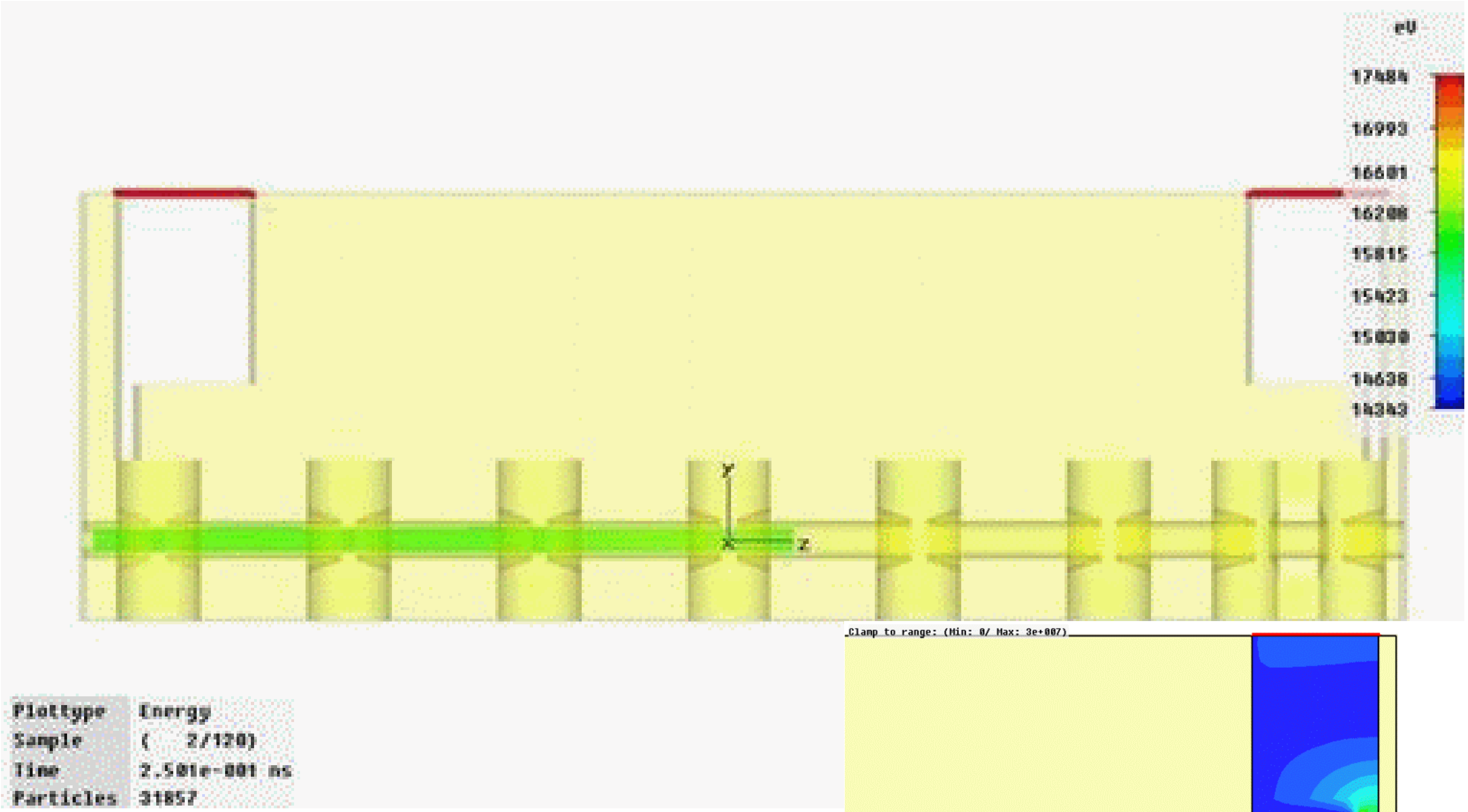
Cavity Rs/Q (Ohms)	External Q and Qo		Cavity Frequency (GHz)	Gap-Gap L (m)	Gap Length (m)	Coupling coefficient at r=a
$RQ_1 \equiv 128$	$Qe_1 \equiv 350$	$Qo_1 \equiv 2000$	$f_1 \equiv 34.98$	$L_1 \equiv 0$	$d_1 \equiv 0.0004$	$Ma_1 \equiv 0.919$
$RQ_2 \equiv 128$	$Qe_2 \equiv \infty$	$Qo_2 \equiv 2000$	$f_2 \equiv 34.9$	$L_2 \equiv 0.005$	$d_2 \equiv 0.0004$	$Ma_2 \equiv 0.919$
$RQ_3 \equiv 128$	$Qe_3 \equiv \infty$	$Qo_3 \equiv 2000$	$f_3 \equiv 35.09$	$L_3 \equiv 0.005$	$d_3 \equiv 0.0004$	$Ma_3 \equiv 0.919$
$RQ_4 \equiv 128$	$Qe_4 \equiv \infty$	$Qo_4 \equiv 2000$	$f_4 \equiv 35.09$	$L_4 \equiv 0.005$	$d_4 \equiv 0.0004$	$Ma_4 \equiv 0.919$
$RQ_5 \equiv 128$	$Qe_5 \equiv \infty$	$Qo_5 \equiv 2000$	$f_5 \equiv 35.17$	$L_5 \equiv 0.005$	$d_5 \equiv 0.0004$	$Ma_5 \equiv 0.919$
$RQ_6 \equiv 218$	$Qe_6 \equiv 350$	$Qo_6 \equiv 2000$	$f_6 \equiv 35.00$	$L_6 \equiv 0.0047$	$d_6 \equiv 0.0004$	$Ma_6 \equiv 0.919$

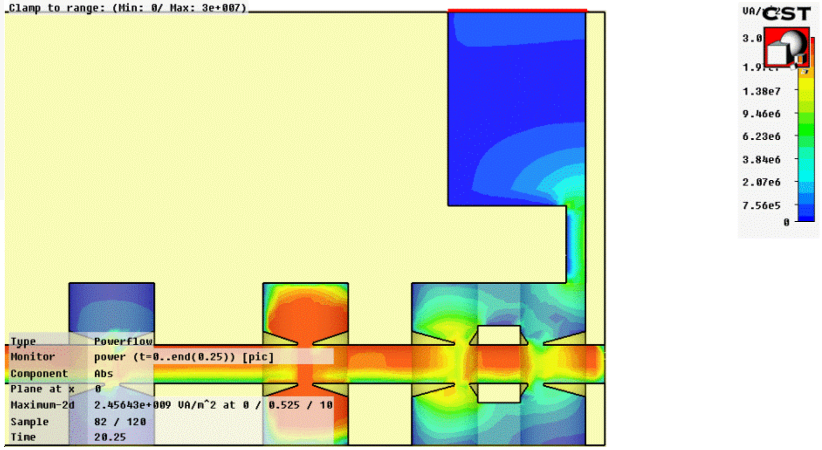
Total coupling coefficient

$$M = \begin{pmatrix} 0.711 \\ 0.711 \\ 0.711 \\ 0.711 \\ 0.711 \\ 0.711 \end{pmatrix}$$

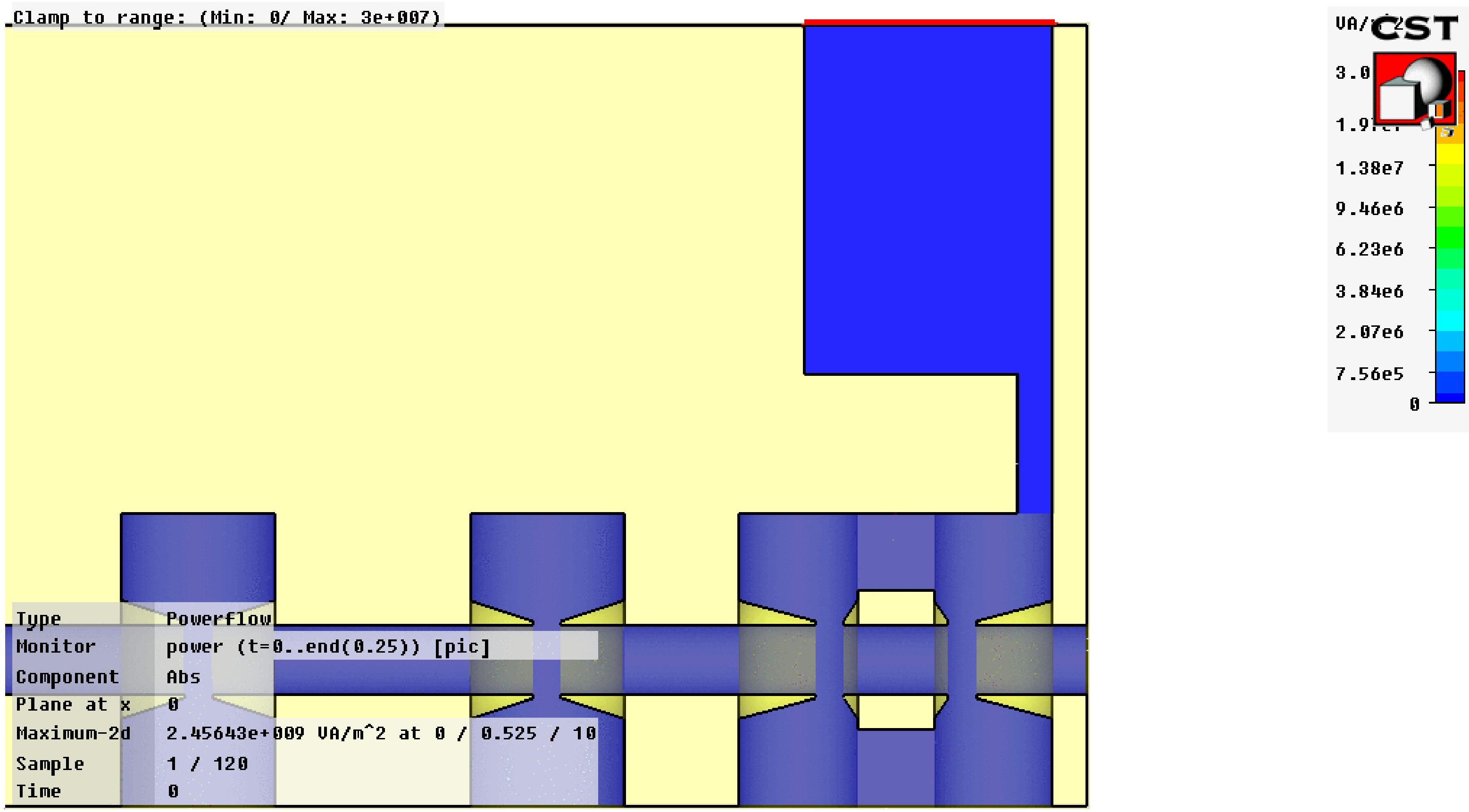


Principle of beam-wave interaction

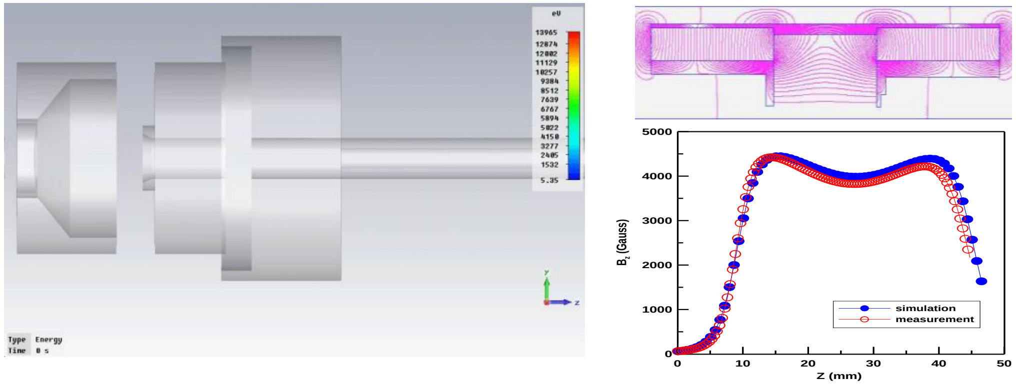




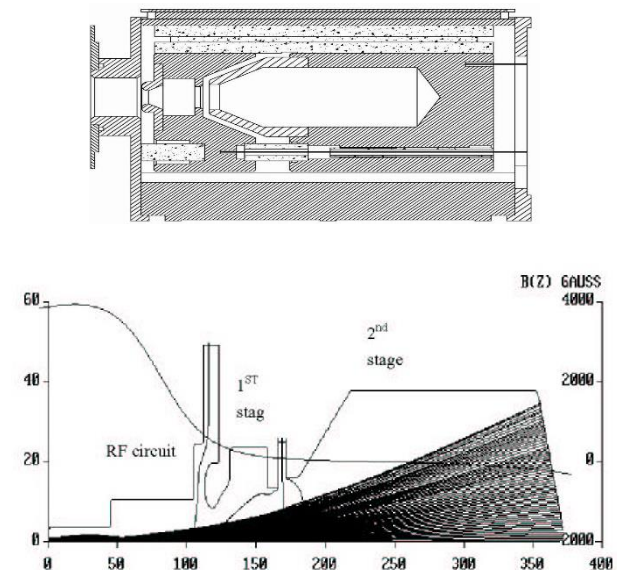
Principle of beam-wave interaction



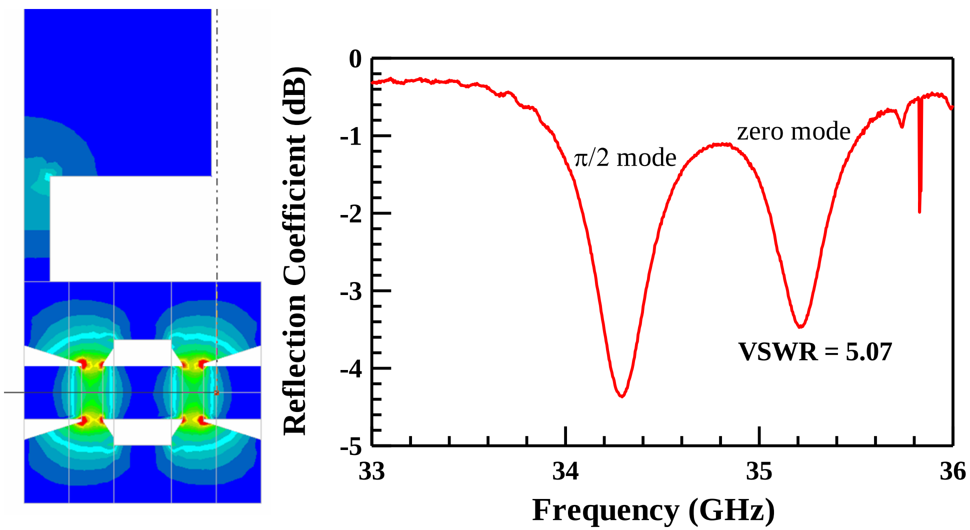
Simulation of the Klystron



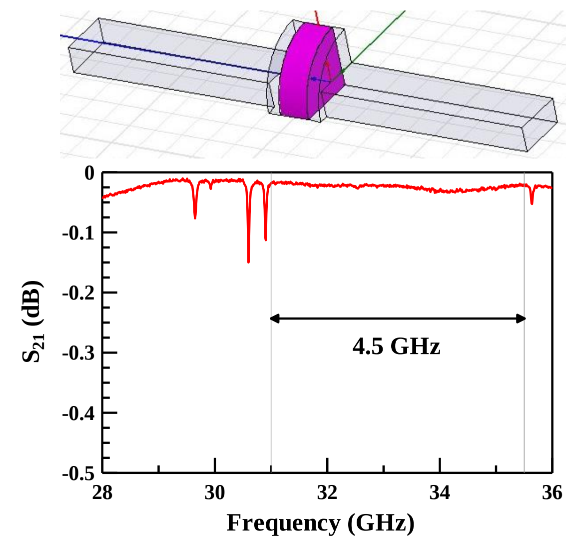
E-Gun and Magnetic Focusing System



Collector Simulation



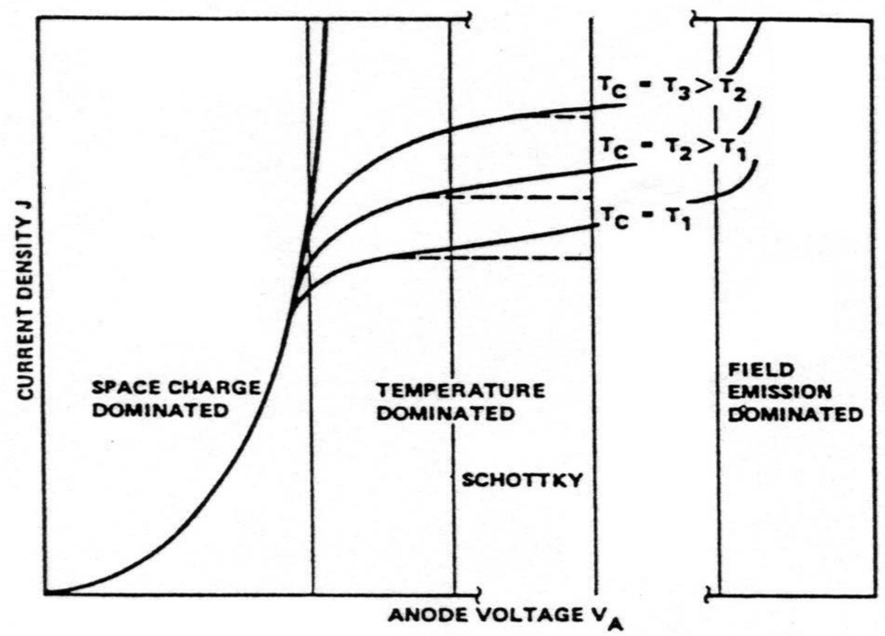
Interaction Structure



Pillbox Window

Summary of Mechanisms Dominating Current Flow Through a Thermionic Diode

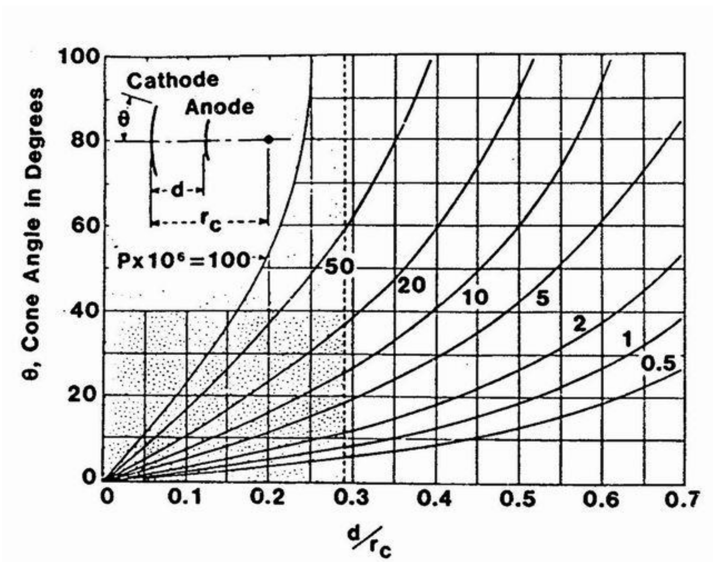
- Space Charge Dominated
- Temperature Dominated
- Field Emission Dominated



Perveance 導流係數

$P = I/V^{3/2} \rightarrow 29.33\times10^{-6}/\alpha^2$ (in spherical diode)

$$P = 14.67\times10^{-6}\frac{1-\cos\theta}{\alpha^2}$$



Perveance 的物理意義

1. 電流供應之能力
2. 空間電荷作用的程度
3. 電子槍之結構特點與尺寸大小

導流係數-僅與結構有關(under space-charge-limited flow)

Thales TH2100 klystron

RF performance

Frequency	2 998.5	2 998.5	MHz	
RF output power				
• peak	37	45.1	MW	
• average	17	20	kW	
Peak RF drive power	200	200	W	max.
- 1 dB bandwidth	10	10	MHz	min.
RF pulse duration	4.5	4.5	µs	max.
Saturated gain	53.5	55	dB	typ.
Efficiency	45	43	%	typ.

Electrical characteristics

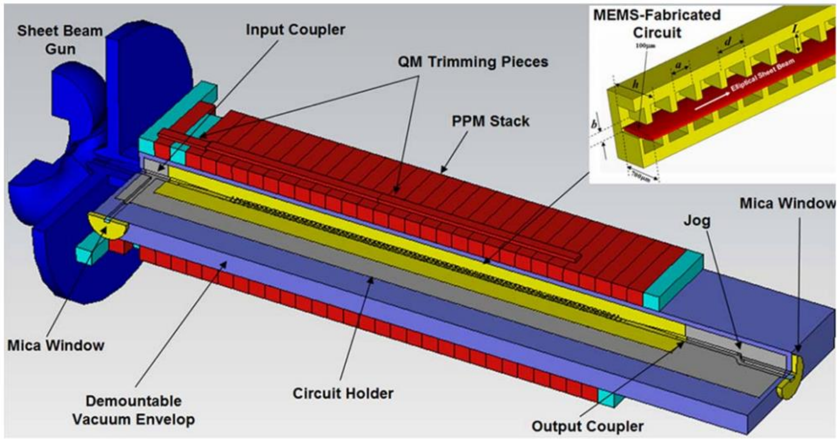
Anode voltage	279	307	kV	typ.
Beam current	295	340	A	typ.
Heater voltage	30	30	V	max.
Heater current	28	28	A	max.

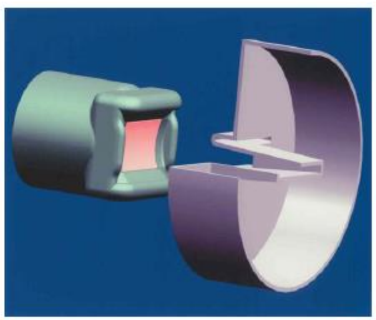
Canon E37310A pulsed klystron

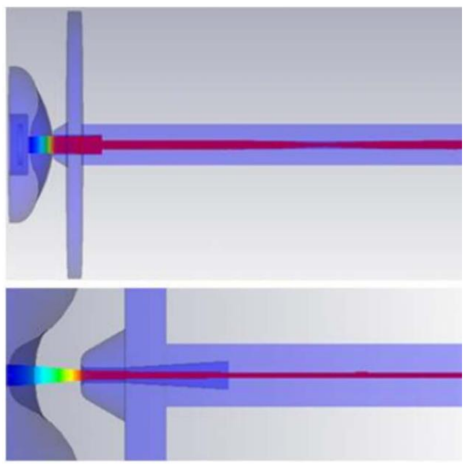
Typical Operation

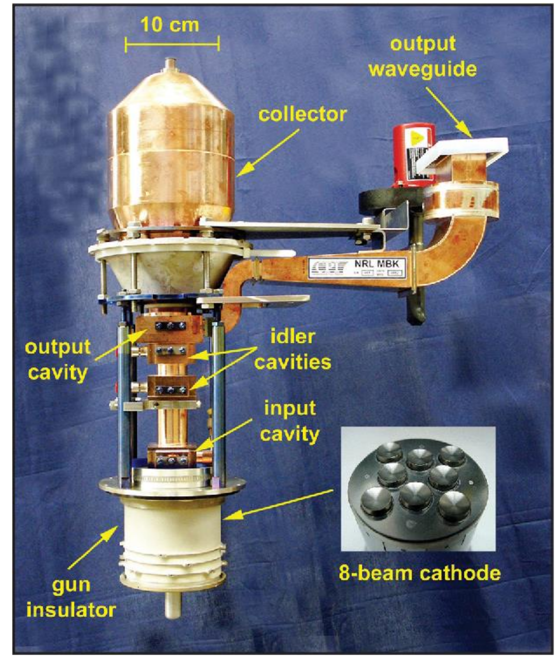
Frequency	2998 MHz
Peak beam voltage	293 kV
Peak beam current	320 A
Beam pulse width	6.2 μs
RF pulse duration	4.0 μs
Drive power	374W
Peak output power	35.5MW
Efficiency	38.8%
Gain	49.7dB
Filament voltage	18.3Vac
Filament current	18.4Aac

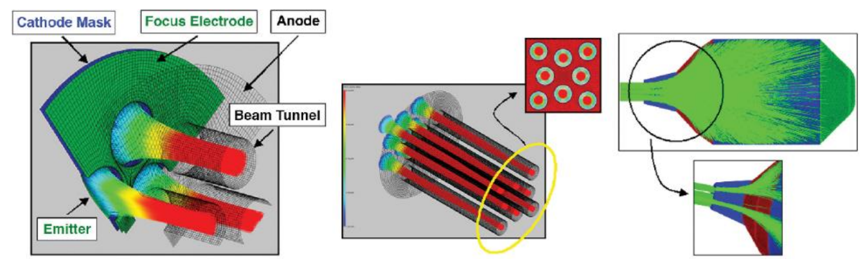
Advanced Klystron Configurations











Sheet-Beam Klystrons (SBKs)

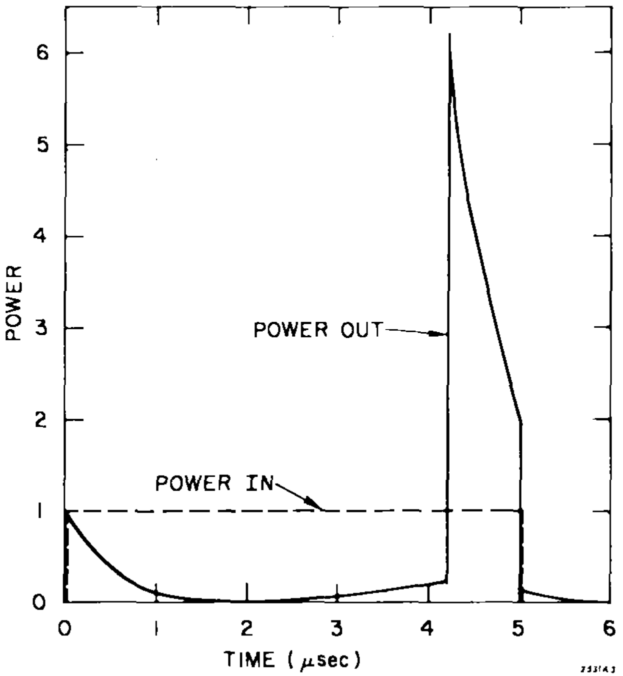
Multiple Beam Klystrons (MBKs)

SLED Cavity

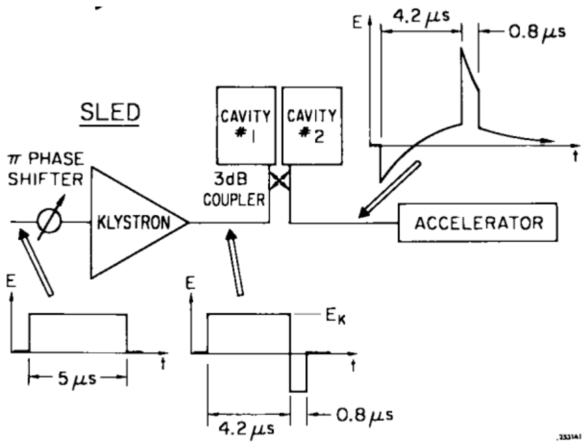
SLED = SLAC Energy Doubler

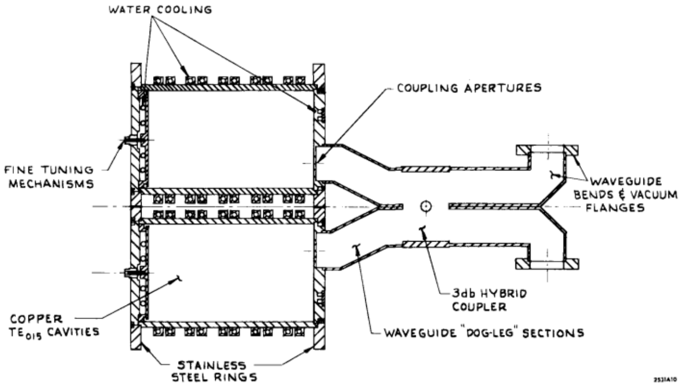
•A method of achieving RF pulse-compression through the use of high-Q resonant cavities.

•The cavities store klystron energy during a large fraction of each pulse and then discharge this energy rapidly into the accelerator during the remainder of the pulse.

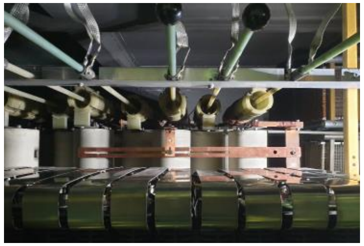


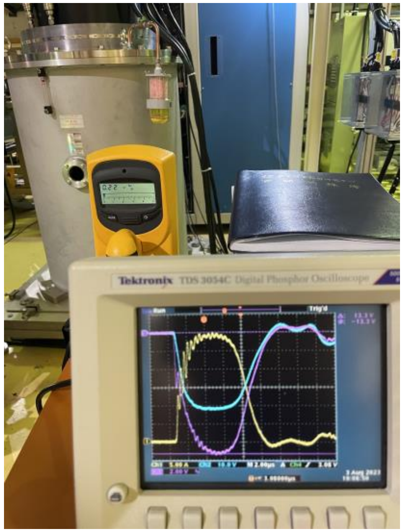
SLED output power waveform

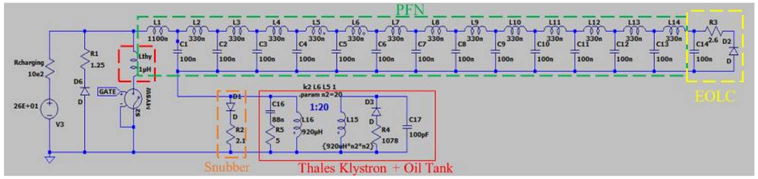




TLS - Canon RF System Introduction

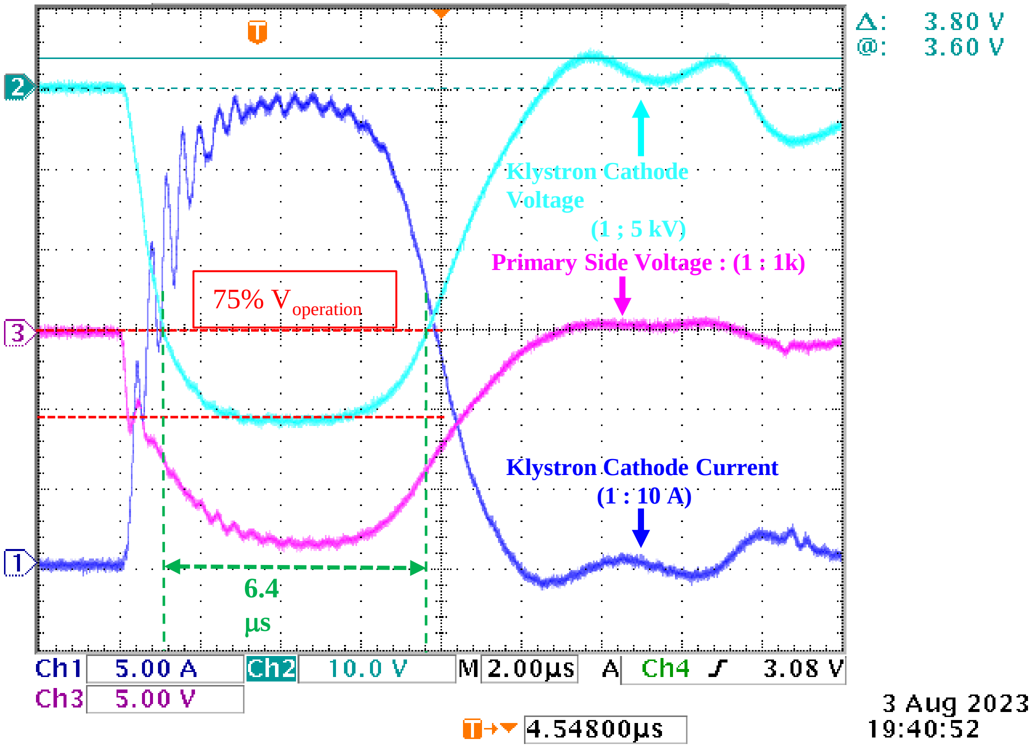


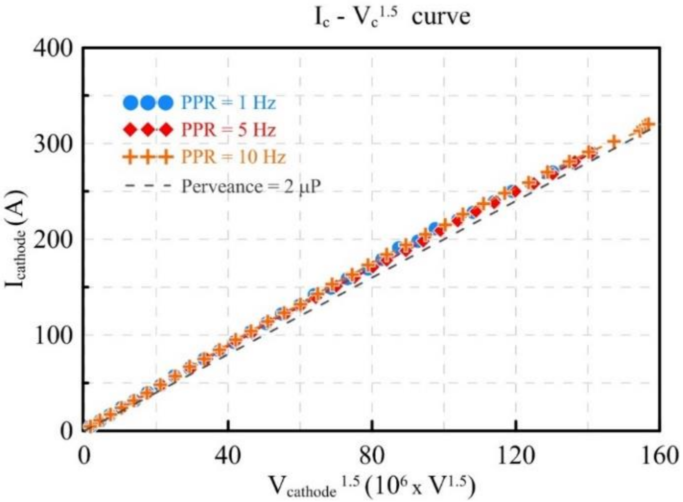


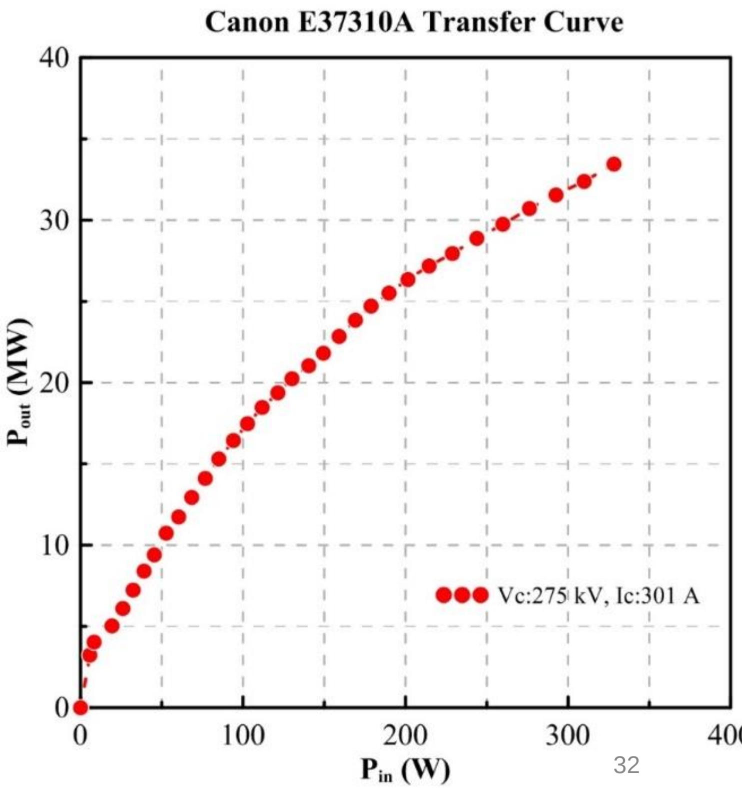


TLS - Canon RF System Properties

10 sections







SLAC Energy Doubler (SLED, RF Pulse Compressor)

Research Instruments SLED

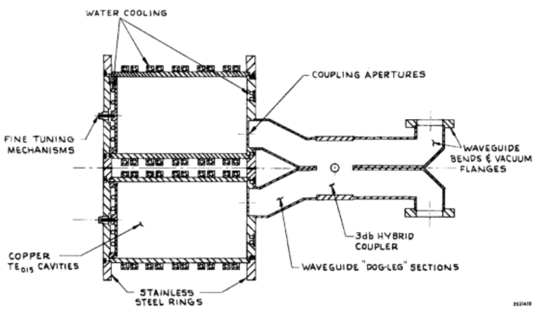
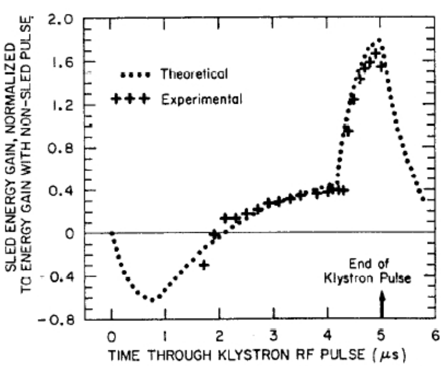
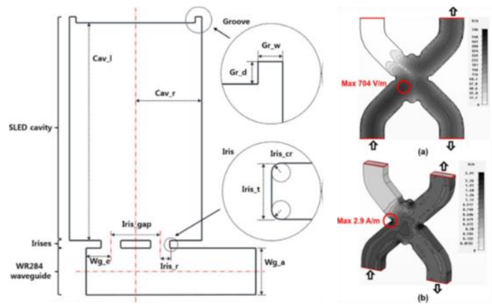
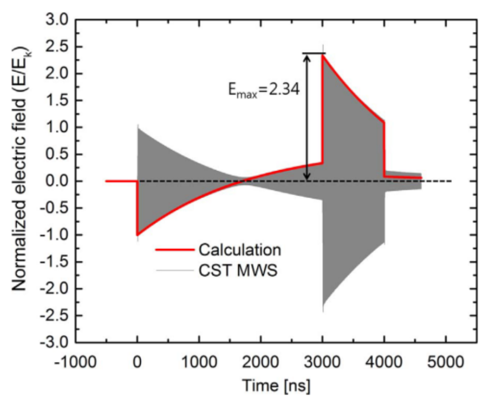


FIG. 9--Assembly drawing of the prototype microwave network for SLED.

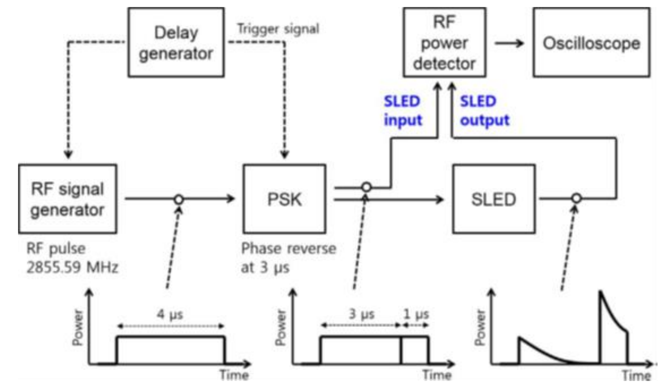


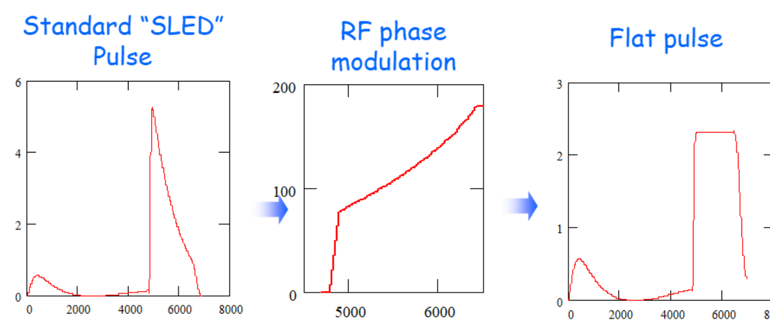
DAWON(KOREA) SLED





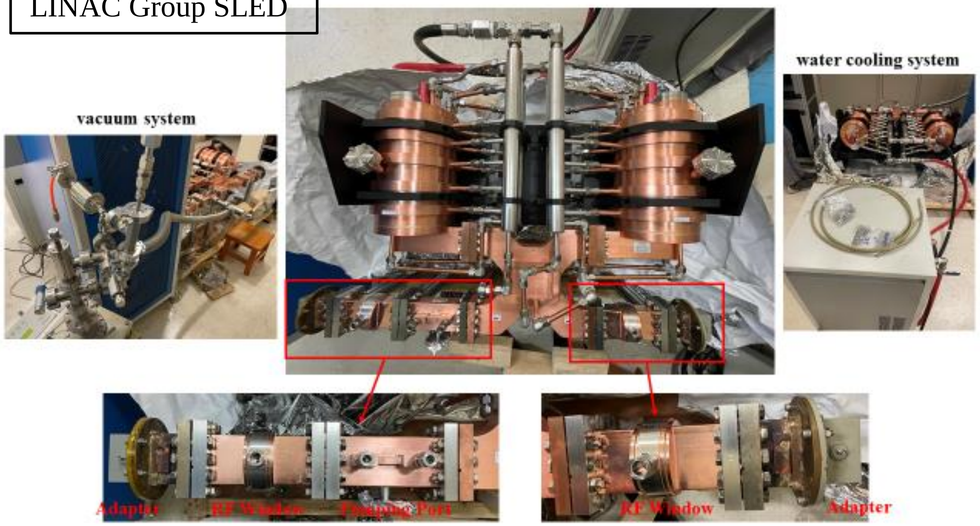
SLED Test Circuit



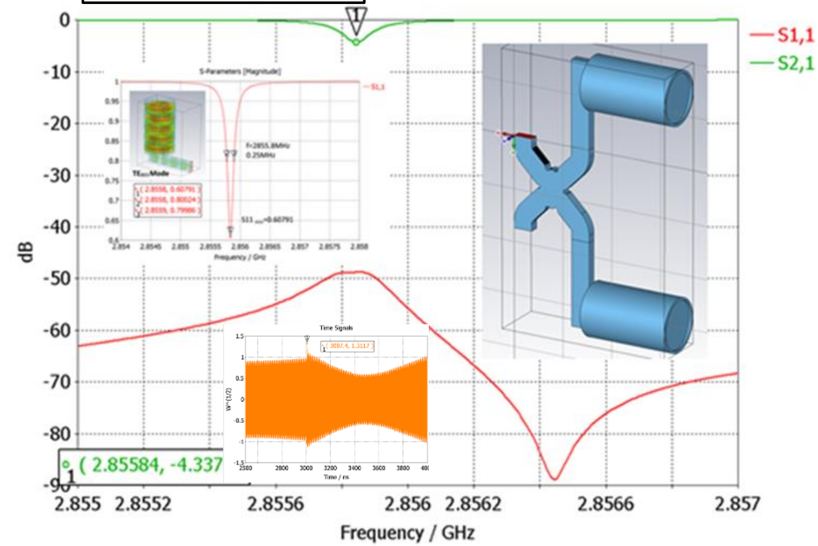


SLAC Energy Doubler (SLED, RF Pulse Compressor)

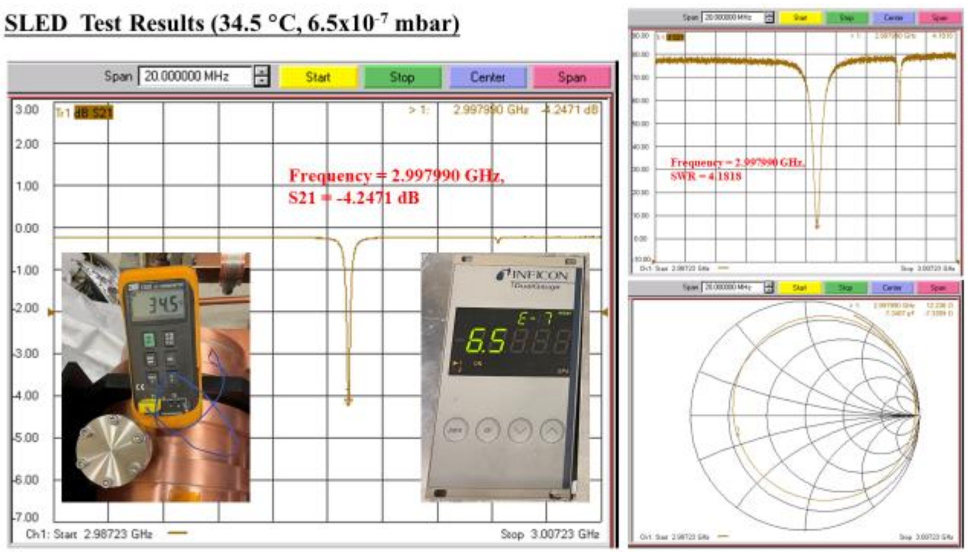
LINAC Group SLED

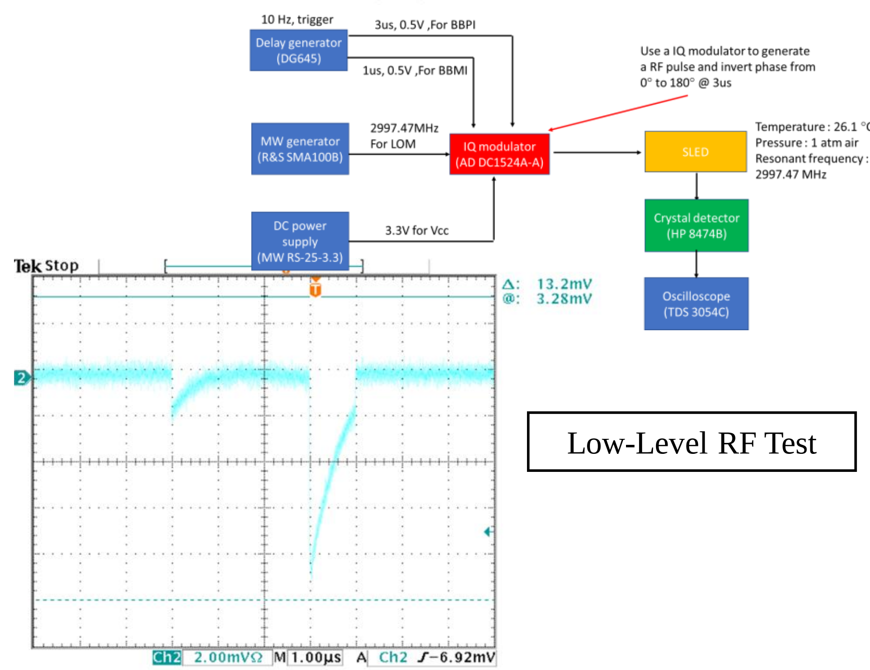


SLED Simulation



SLED Test Results (34.5 °C, 6.5x10^{-7} mbar)

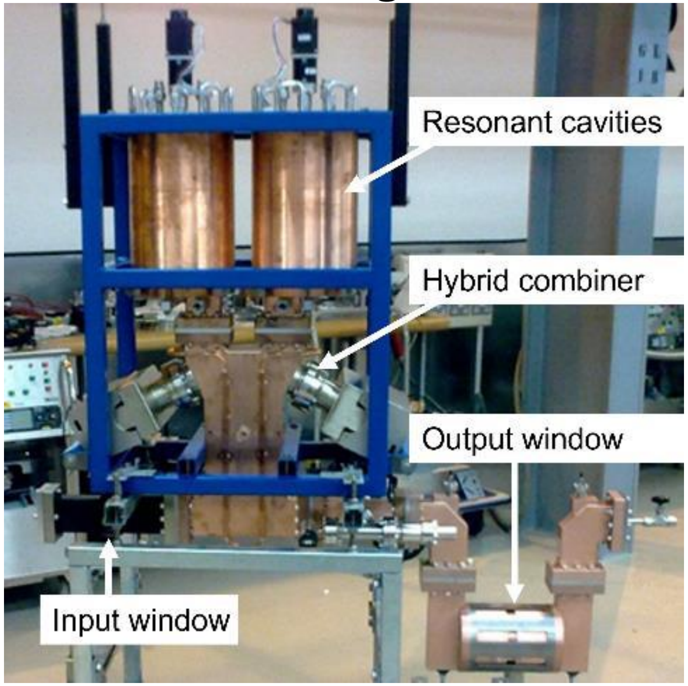


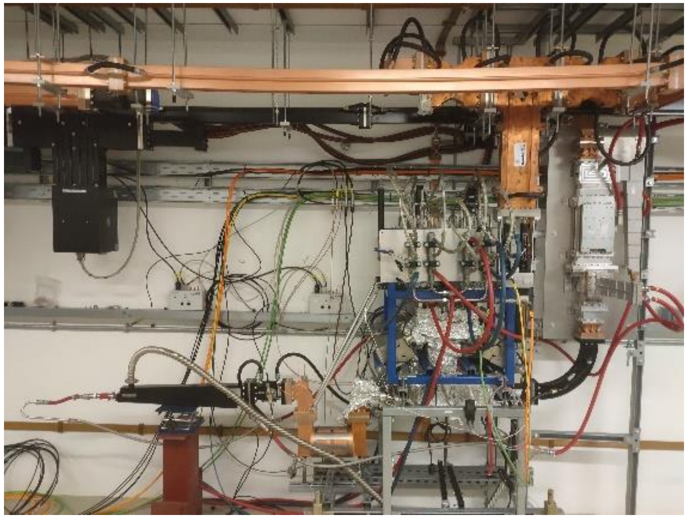


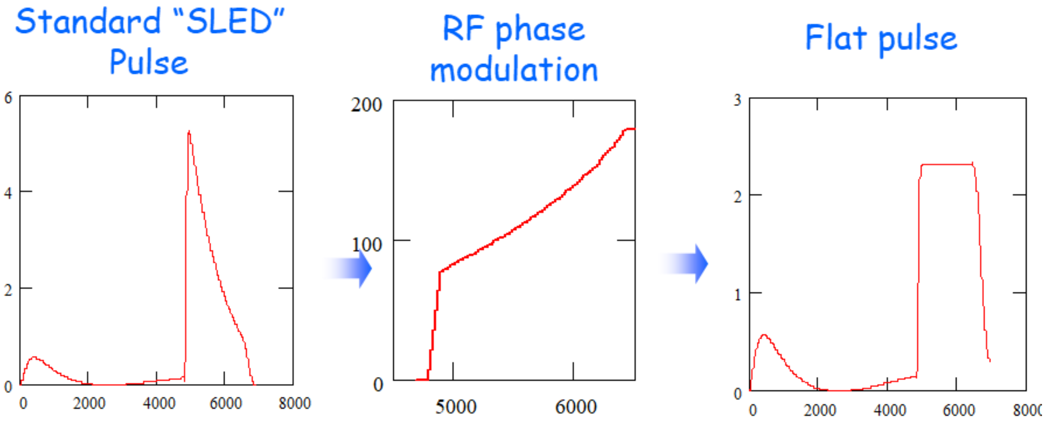
Low-Level RF Test

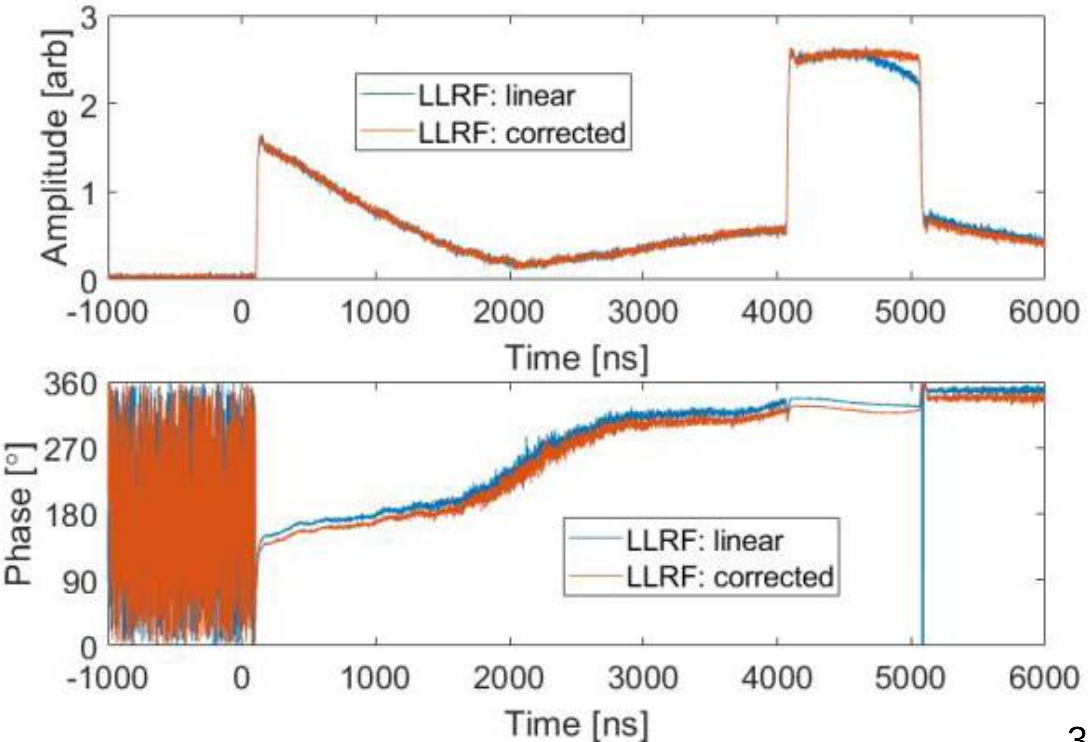
Cavity application – SLED Flat Pulse Operation

Diamond Light Source



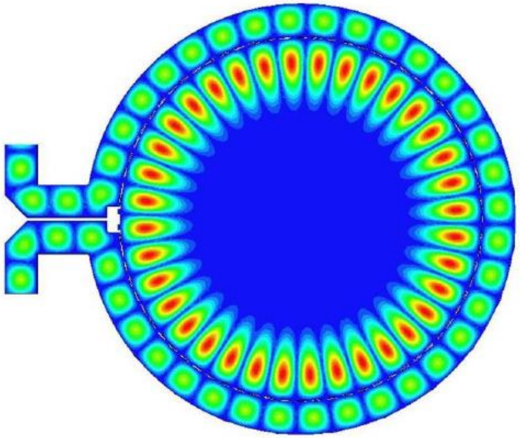




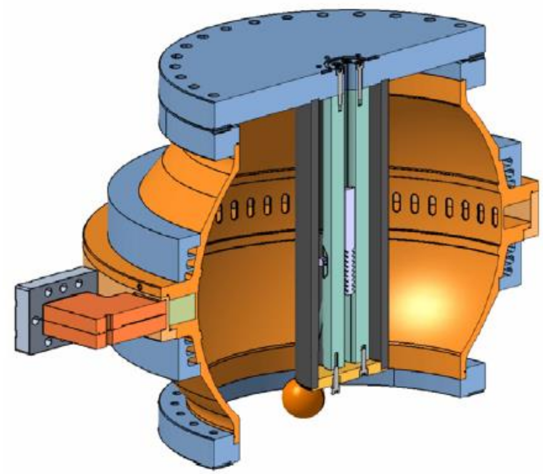


doi:10.18429/JACoW-LINAC2022-MOPOJO19

Cavity application – SLED-II BOC (Barrel Open Cavity)



C-band BOC of Swiss FEL



rid

Table 1: Main Parameters of BOC

Pulse compressor	**Design parameter**
Type	Barrel Open cavity
Frequency	5.712 GHz
Resonant mode	$TM_{18,1,1}$
Diameter	492 mm
Number of coupling slots	70
Q	216000
Coupling factor (β)	10
Max. input power	50 MW
RF input pulse length	3 μs
RF compressed pulse length	330 ns
Energy multiplication factor (M)	2.13
Repetition rate	100 Hz

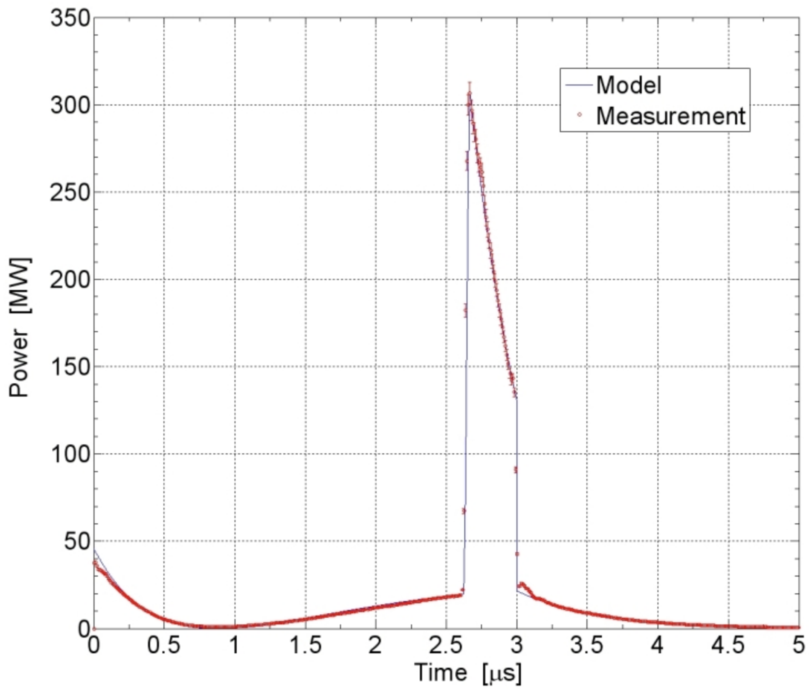
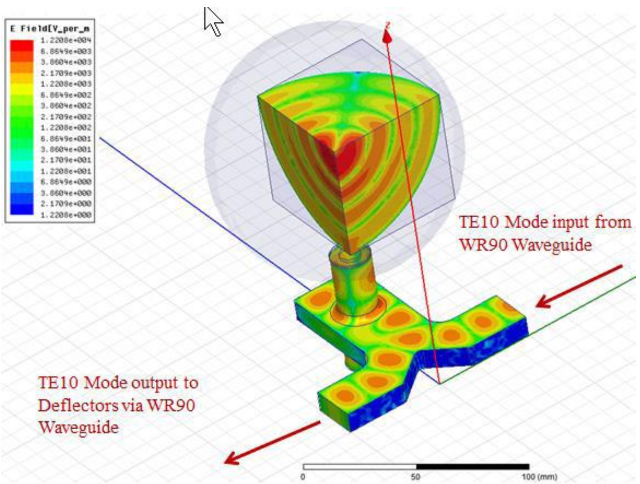
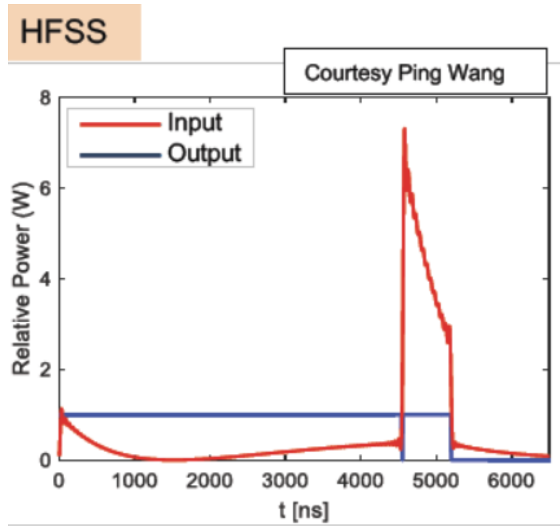


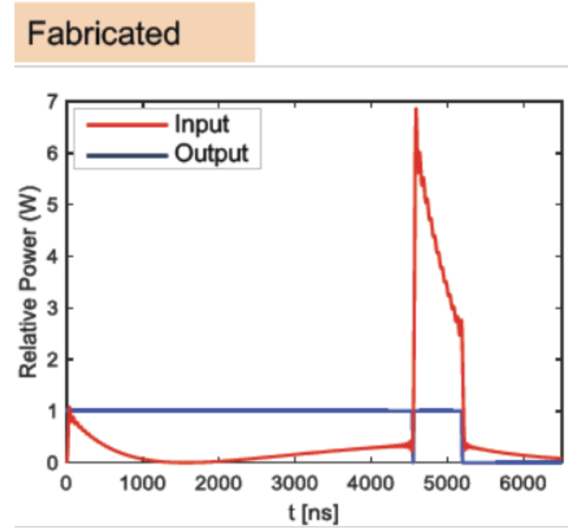
Figure 8: Compression of a 50 MW, 3 μs rectangular pulse.

R. Zennaro, et al. IPAC 2013, WEPFI059 .

Cavity application – SLED-III SCPC (spherical pulse compressor)







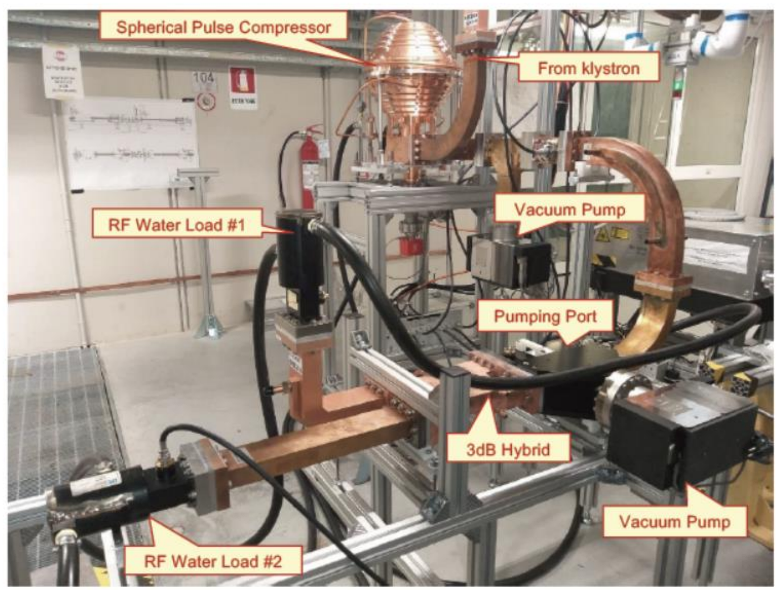
Elettra SCPS Test Results

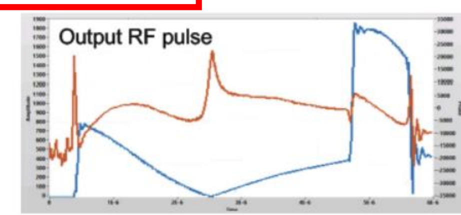
Phase I (90 MW)

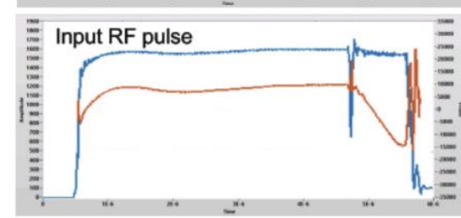
- ❑ Rep. Rate: 50 Hz
- ❑ Start Date: 06-12-2022
- ❑ End Date: 21-12-2022
- ❑ Output power: 90MW, 700 ns
- ❑ Input power: 26 MW, 4000 ns
- ❑ Operating temperature: 32.25 °C

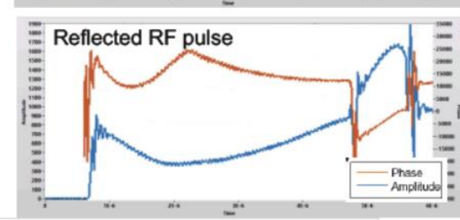
Phase II (100 MW)

- ❑ Rep. Rate: 50 Hz
- ❑ Start Date: 23-03-2023
- ❑ End Date: 31-03-2023
- ❑ Output power: 100 MW, 700 ns
- ❑ Input power: 29 MW, 4000 ns
- ❑ Operating temperature: 31.47 °C



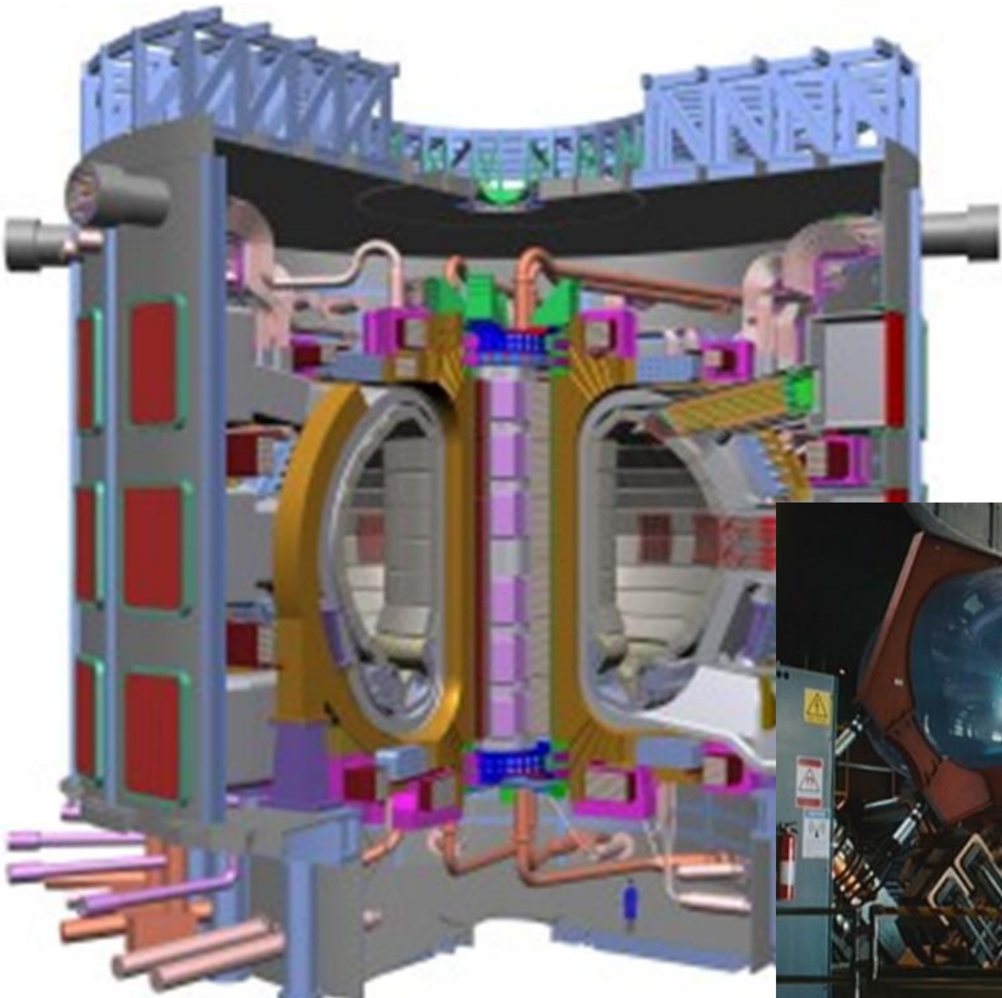






J.W.Wang, et al. PRAB 20, 110401, 2017.

Application of the Gyromonotron:Fusion plasma heating



ITER Tokamak

Participants: EU, USA, Russia, Japan, China, Korea

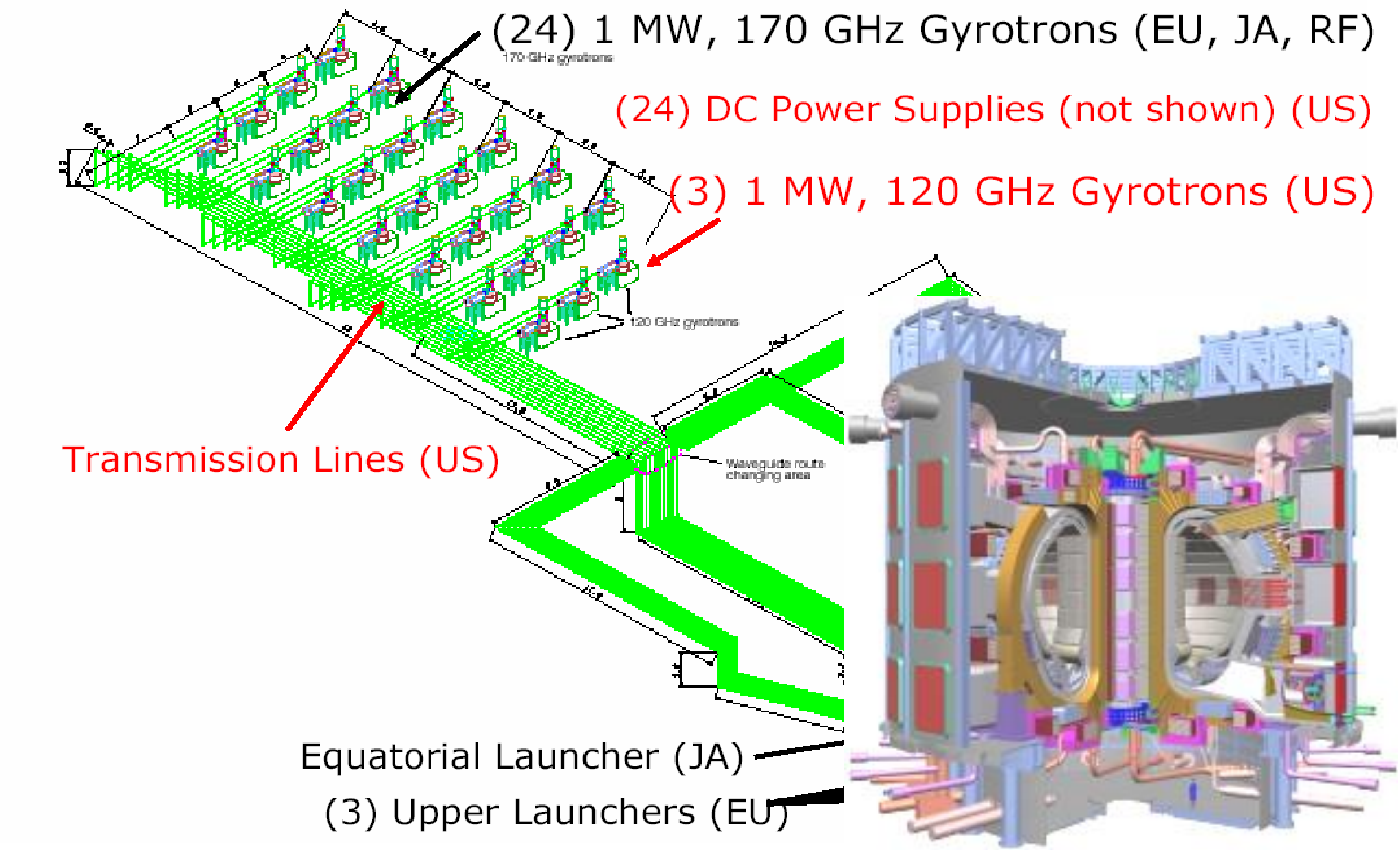
Cost: > US$22 Billion

Completion date: > 2025

Plasma temp: 10^8 K

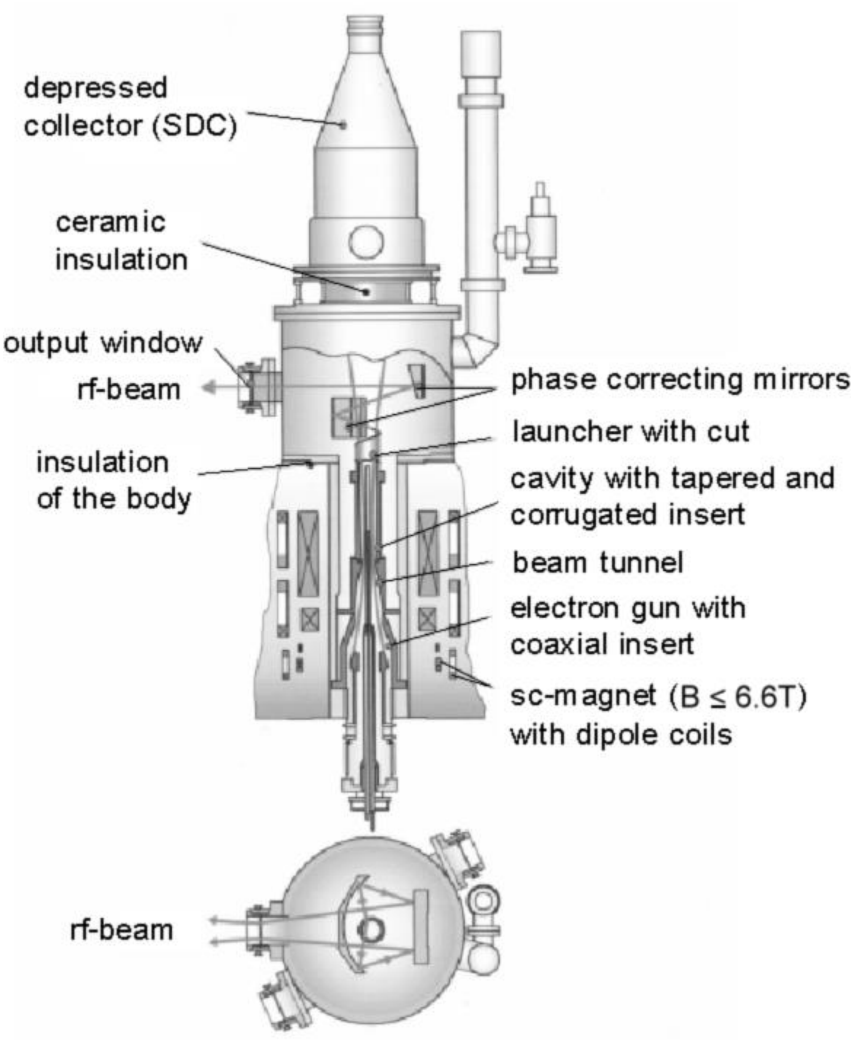
Output power: 500 MW

ITER Plasma Heating System



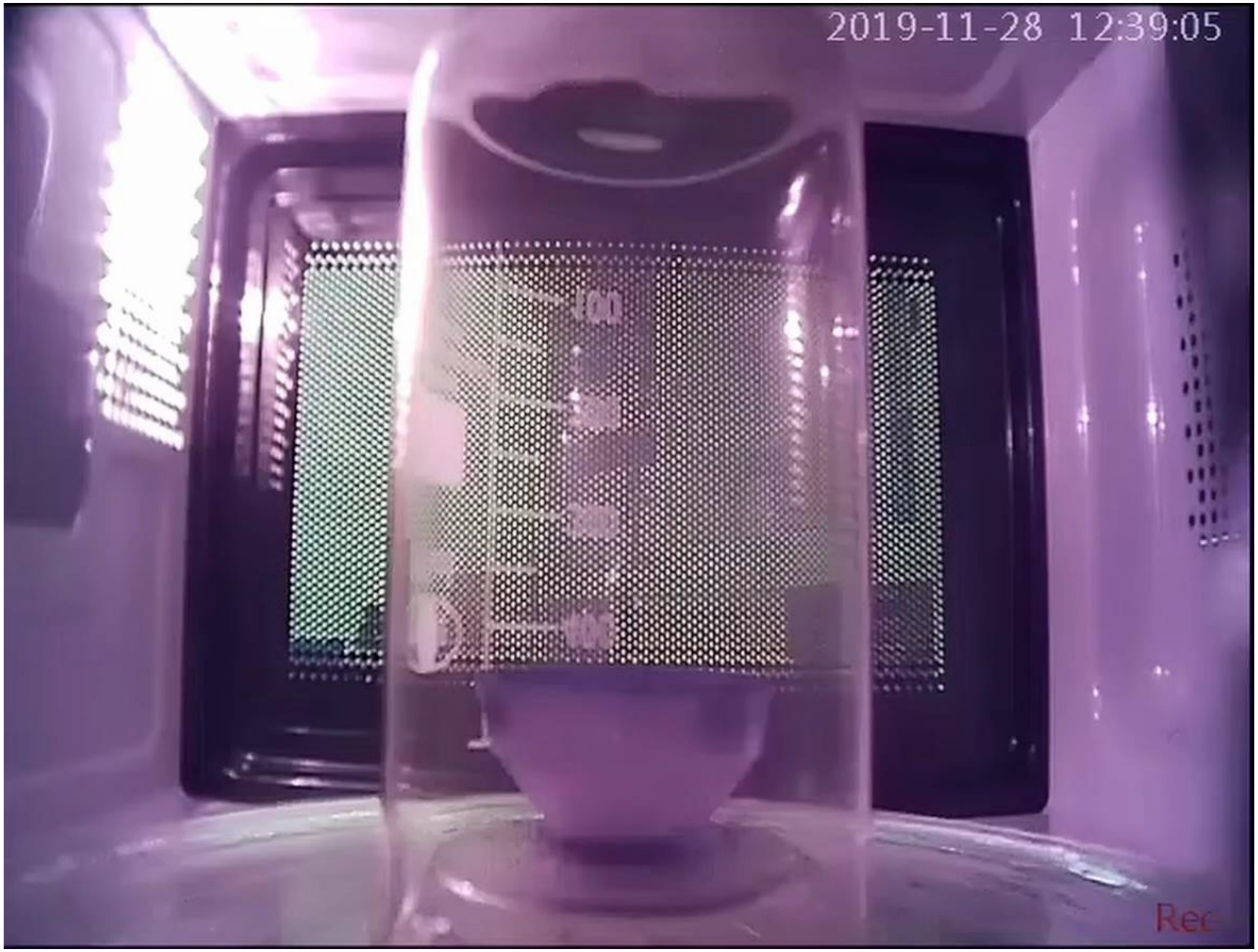
R. Vernon *et al.*, in the 16th ANS Meeting on the Technology of Fusion Energy, Madison, Wisconsin, 2004

The Gyromonotron Oscillator

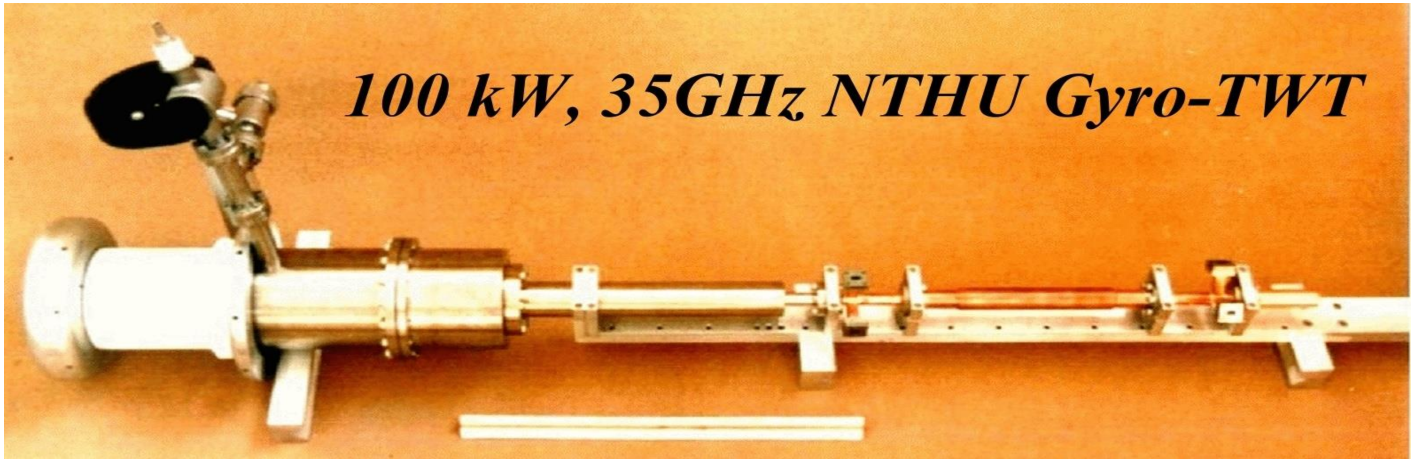


165 GHz, $TE_{31,17}$ mode, 2.2 MW coaxial gyromonotron for fusion plasma heating *(Piosczyk et al.,2002)*

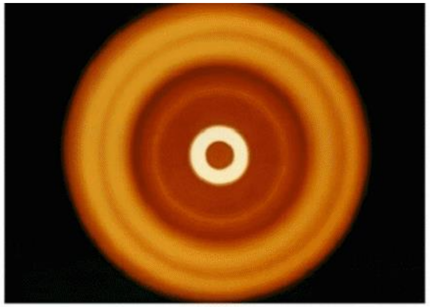
Using incense sticks and microwave ovens to generate plasma



Gyro - TWT



Magnetron injection GUN



	Peak Power	Efficiency	Gain	Bandwidth
Gyro-TWT	93 kW	26.5 %	70 dB	8.6 %
Conventional-TWT	50 kW	16 %	40 dB	6 %

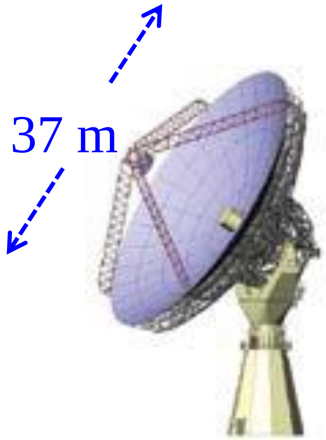
Upgraded Haystack Radar (Operational since 2014)

(Higher frequency → higher directivity and resolution)

Goals: Imaging and tracking of space objects

Radio astronomy

Largest radome-enclosed antenna in the world

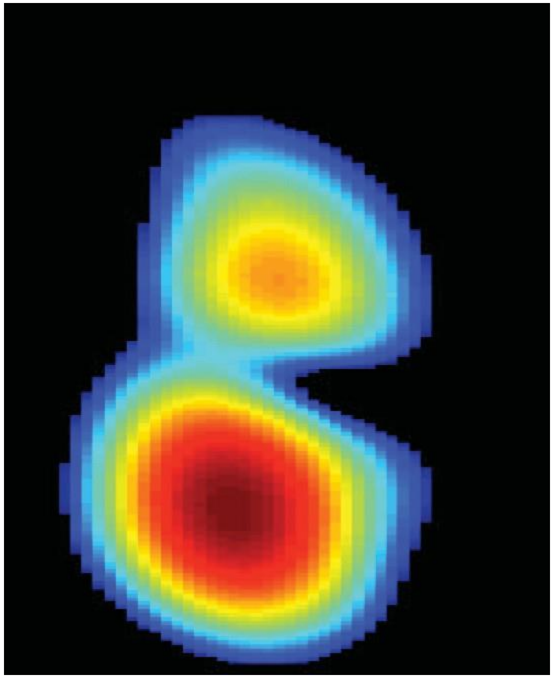


37-m diameter antenna

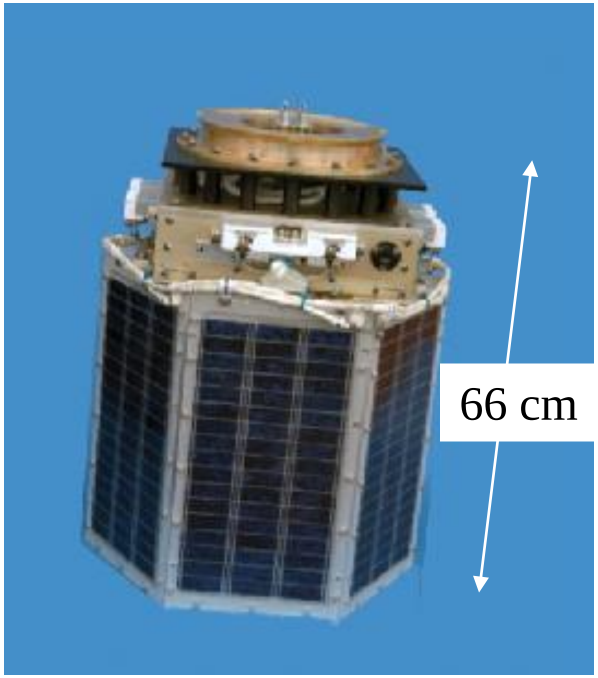
0.1-mm rms tolerance, 90 dB gain at W-band

W. M. Brown and A. F. Pensa, Lincoln Lab Journal **21**, 4 (2014).
J. M. Usoff, M. T. Clarke, C. Liu, and M. J. Silver, *ibid*, p. 83.

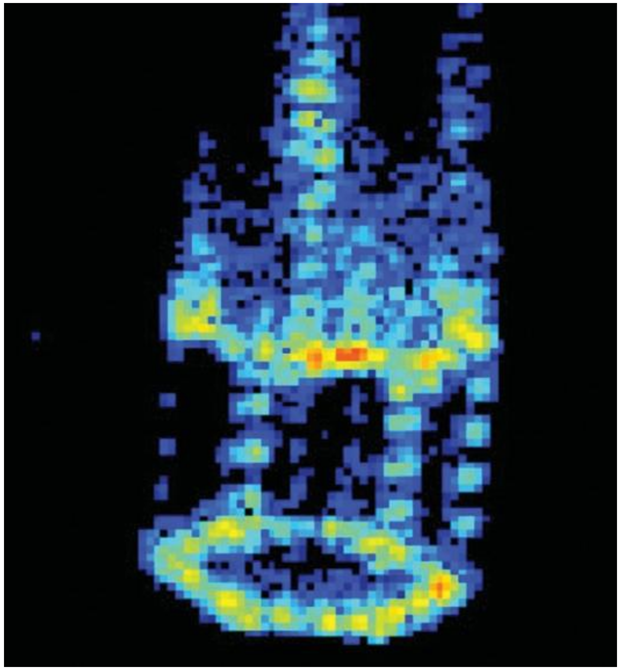
Haystack Satellite Imaging : X-band vs W-band



9.5 – 10.5 GHz
25-cm resolution



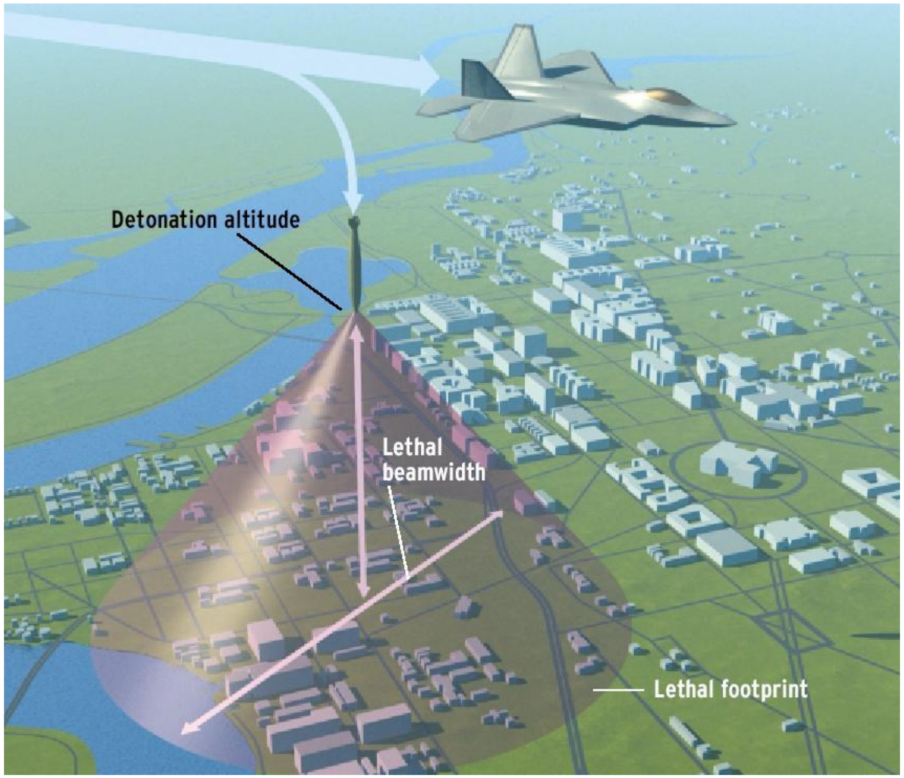
Model of
NASA satellite

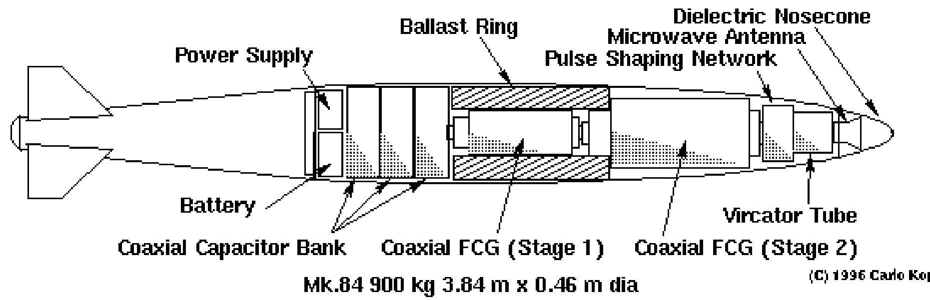


92 – 100 GHz
3-cm resolution

M. G. Czerwinski and J. M. Usoff, Lincoln Lab Journal **21**, 28 (2014).

Non-lethal weapons : Vircator of E-Bomb





HIGH POWER MICROWAVE E-BOMB – GENERAL ARRANGMENT MK.84 PACKAGING
WARHEAD USING VIRCATOR AND 2 STAGE FLUX COMPRESSION GENERATOR

FIG.6 HPM E-BOMB WARHEAD (Mk.84 FORM FACTOR)

Low Frequency E-bomb

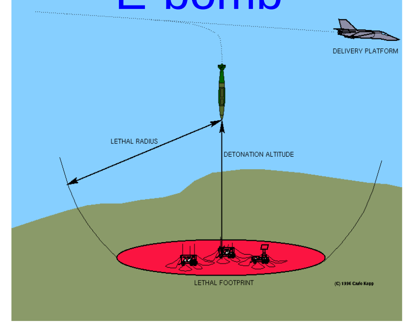


FIG.7 LETHAL FOOTPRINT OF LOW FREQUENCY E- BOMB IN RELATION TO ALTITUDE

High Frequency E-bomb

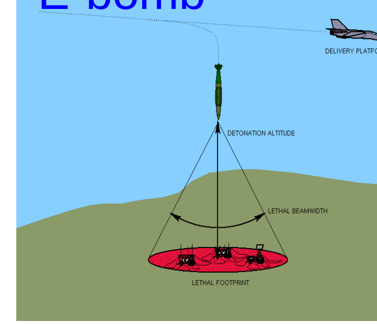
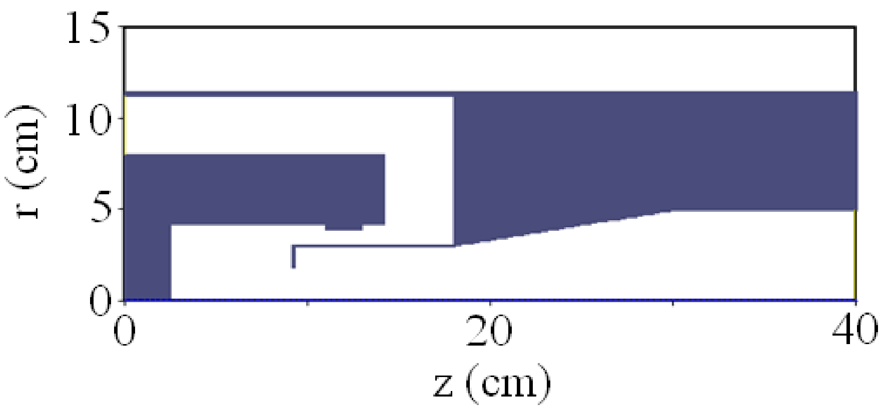
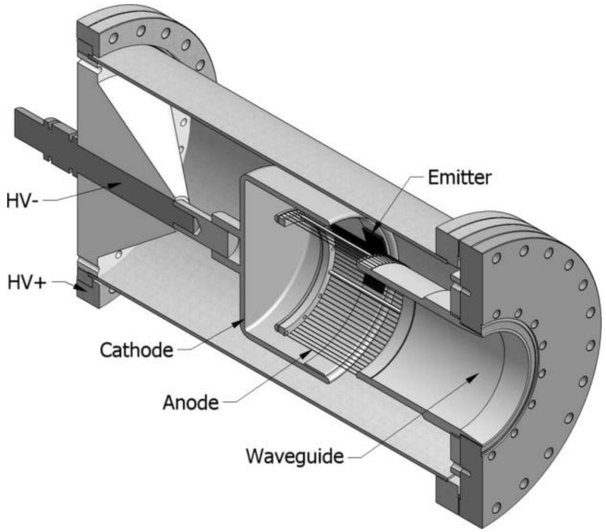
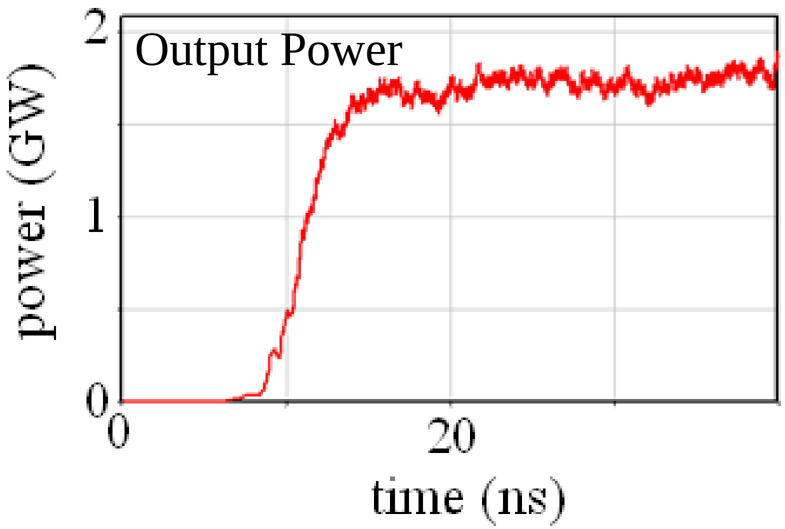


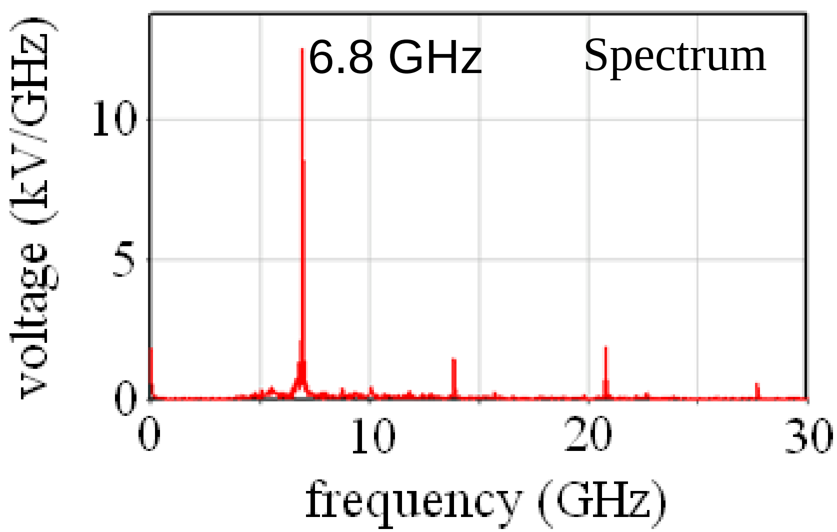
FIG.8 LETHAL FOOTPRINT OF A HPM E-BOMB IN RELATION TO ALTITUDE

Non-lethal weapons : Vircator of E-Bomb



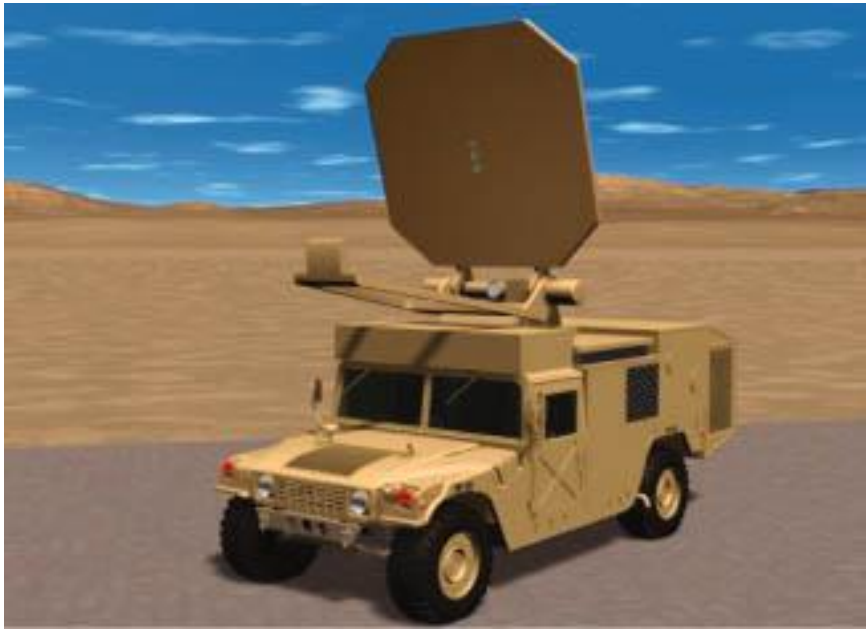






Non-lethal weapons : Active Denial System

Infrared image of silhouette targets



Vehicle-mounted ADT concept

Active Denial System –“the Pain Ray”

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非致命電磁波武器 讓人一心想逃

▲美軍展示最新型非致命武器「主動拒止系統」，以強力電磁波束讓接觸到的人只想逃之夭夭。一位記者親身體會它的威力。（法新社）

中國時報【尹德瀚／綜合報導】2012.3.13

美國軍方日前對媒體展示了一種最新的非致命武器「主動拒止系統」(Active Denial System，ADS），它可放出強力電磁波束，讓接觸到的人在瞬間產生難以忍受的灼熱感，只想儘快逃離。這種武器可用於驅散暴動群眾、周邊維安、區域拒止（area denial）、檢查哨維安及保護基礎設施等多種用途。

美軍聯合非致命武器管理局局長塔福拉上校，在陸戰隊關地哥基地主持這項展示，她解釋說，ADS看不到、聽不到、聞不到，卻可以感覺到。在場記者親身體驗時，立即產生快逃的本能反應。 塔福拉表示，ADS威力雖然強大，且射程達一千公尺，卻是軍方最「安全」的非致命武器，開發歷時十五年，尚未用於實戰，二○一○年短暫部署於阿富汗，但不曾實際使用。

這項科技引起安全顧慮，可能是其波束容易與加熱食物的微波混淆。負責測量生物效應的軍方研究人員米勒說，ADS的頻率為 95 GHz，只能穿透○．四公釐，安全上沒有問題。相較之下，微波頻率約一吉赫，但波速更快，穿透更深。

米勒說，軍方對一萬一千多人做過實驗，只有兩人受傷，需要接受治療，後來完全復原，沒有併發症。另一位研究員說，ADS放出的電磁波束，即使強度為微波的一百倍，也無法讓玉米粒變成爆米花。

塔福拉說，主動拒止系統可安裝於卡車上執行任務，其發射鈕有自動閉鎖裝置，超過三秒就會停止發射。國防部尚未訂購ADS，但塔福拉表示，只要五角大廈開口，廠商立刻可以交貨。

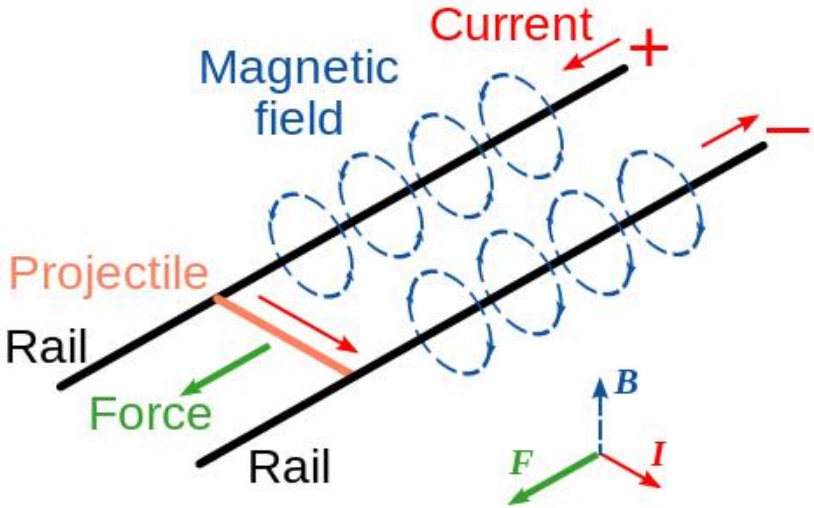
Active Denial System–Russian Versions

魔鬼毀滅者（*Eraser*）

Российские испытания проводят сотрудники 12-го Центрального НИИ военного ведомства, расположенного в Сергиевом Посаде Московской области. В качестве поражающего фактора используется крайне высокочастотное (КВЧ) электромагнитное излучение, рассказал "Интерфакс" замначальника отдела ЦНИИ подполковник Дмитрий Сосков.

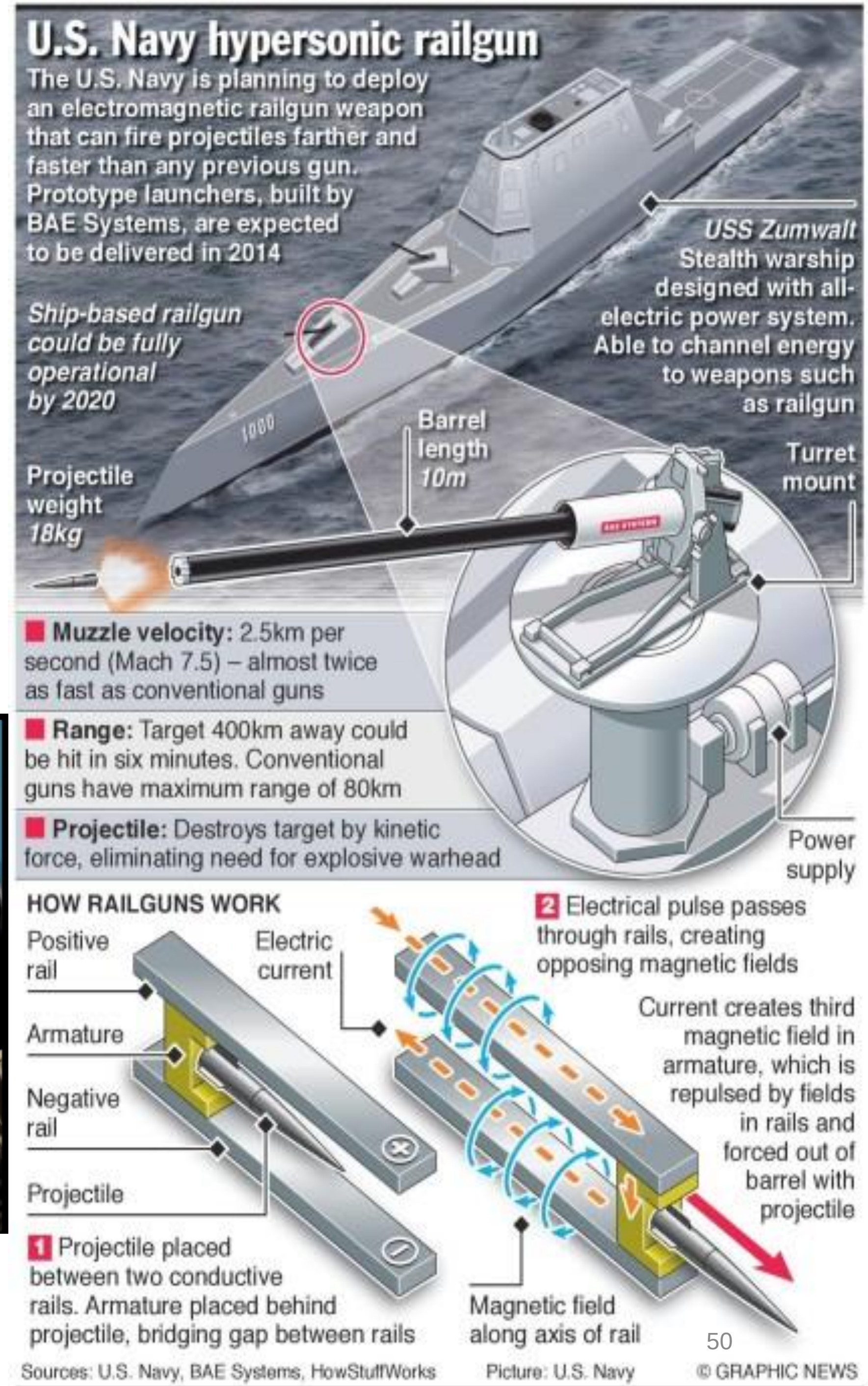
По его словам, сгенерированный установкой мощный направленный луч взаимодействует с влагой, находящейся в верхних слоях кожи человека и проникает внутрь всего на десятые доли миллиметра. При этом человек испытывает ощущения как при сильном ожоге и рефлекторно пытается скрыться от поражающего невидимого луча.

Railgun

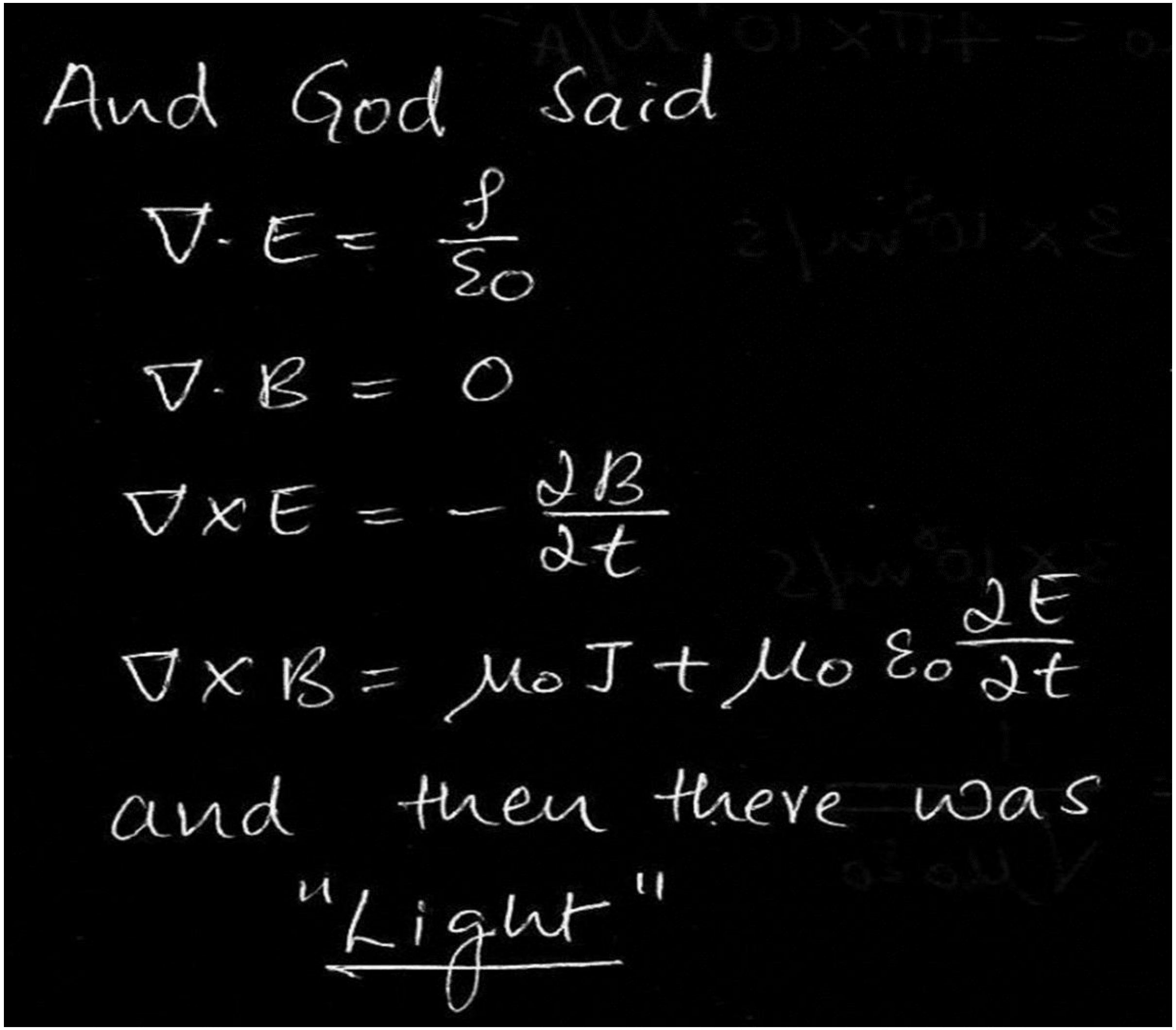


變形金剛（Transformers)

https://www.youtube.com/watch?v=58MmOpSm4LY



Thank You !


And God Said
$\nabla \cdot E = \frac{\rho}{\varepsilon_0}$
$\nabla \cdot B = 0$
$\nabla \times E = -\frac{\partial B}{\partial t}$
$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t}$
and then there was
"Light"


祝大家新的一年
馬剋四威方成事
$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$
$\nabla \cdot \mathbf{B} = 0$
$\nabla \times \mathbf{B} = \varepsilon_0 \mu_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \mathbf{j}$