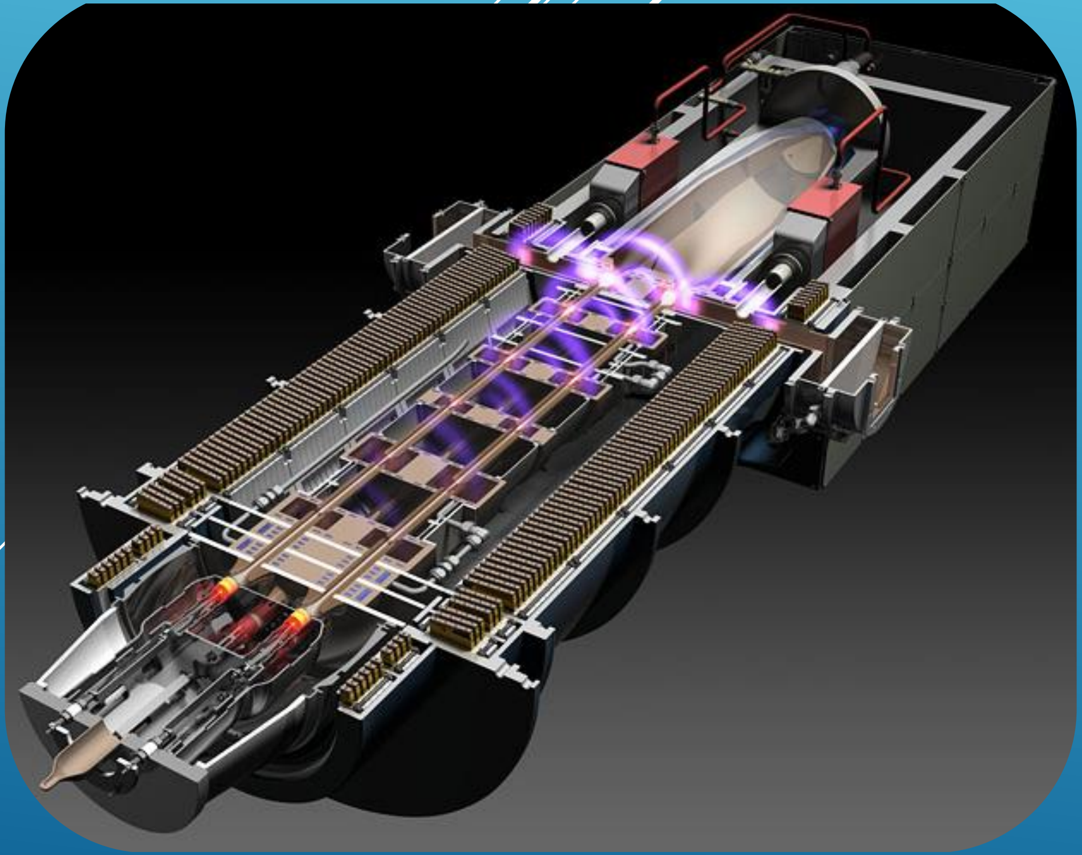
به نام خدا

SECOND SESSION HPMA GROUP

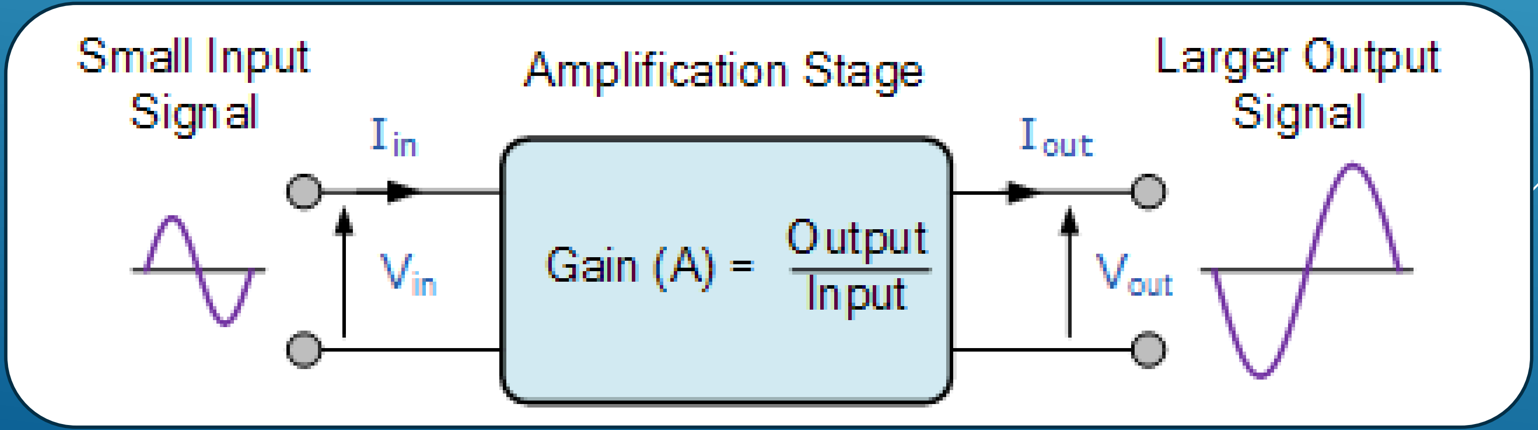


Mohammad Ostovar

RF group, Iranian Light Source Facility (ILSF)

November 2021

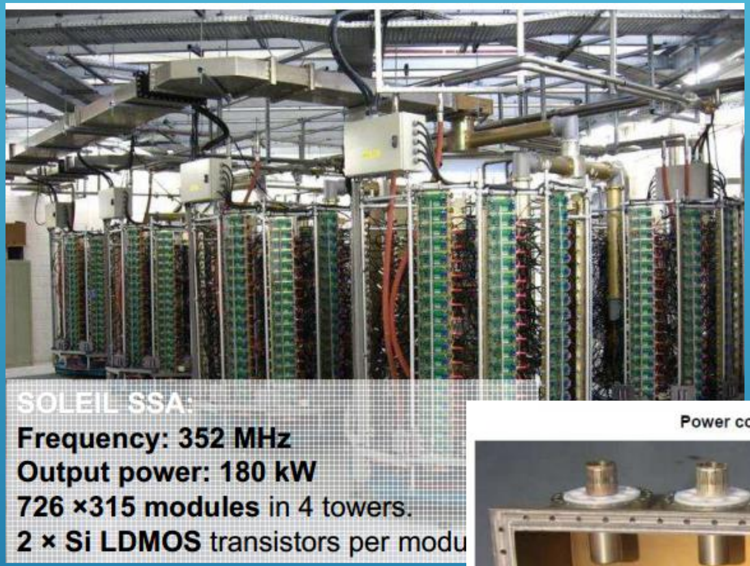
INTRODUCTION (WHAT IS AMPLIFIER?)



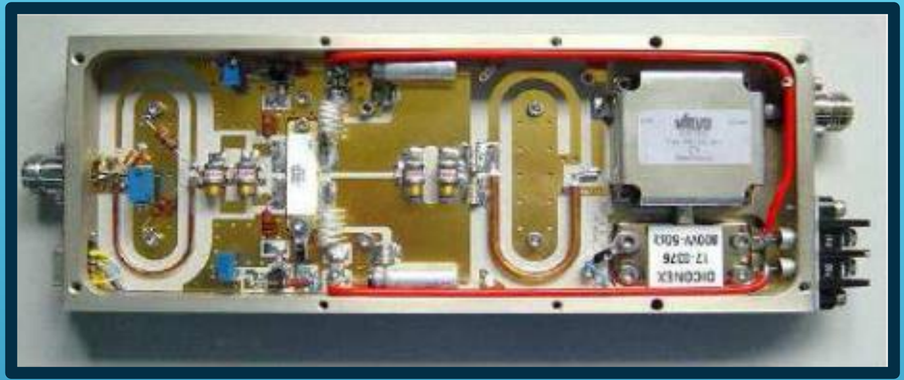
INTRODUCTION (CLASSIFICATION OF AMPLIFIERS)

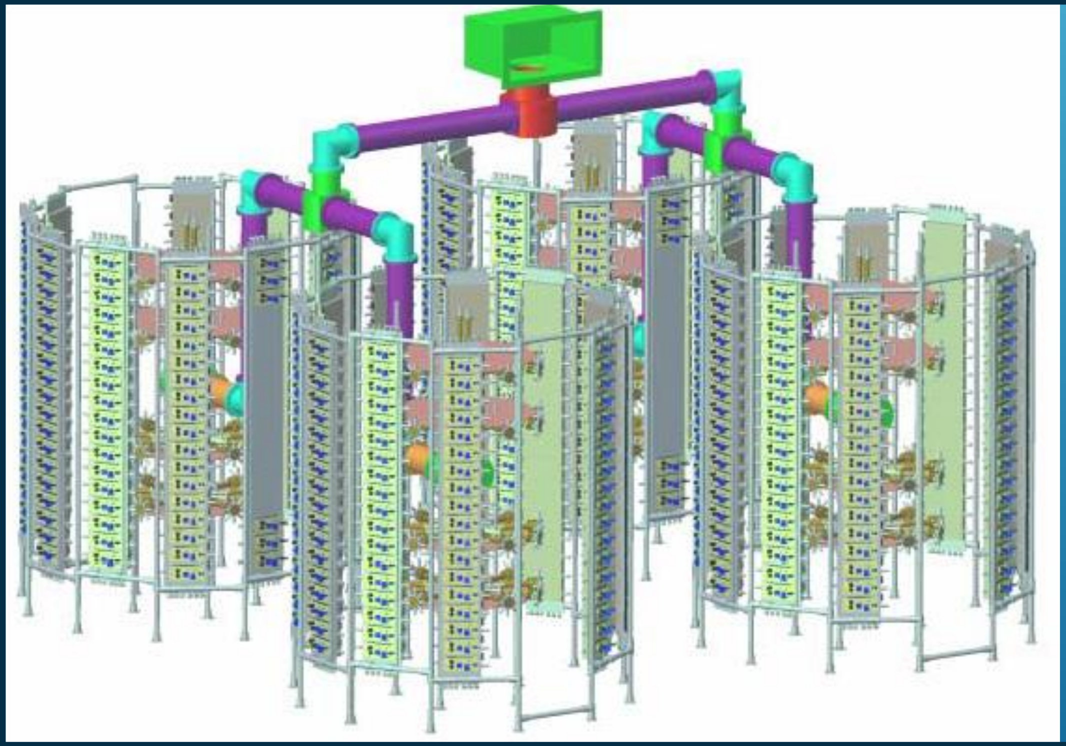
Solid-state amplifier

Vacuum tube

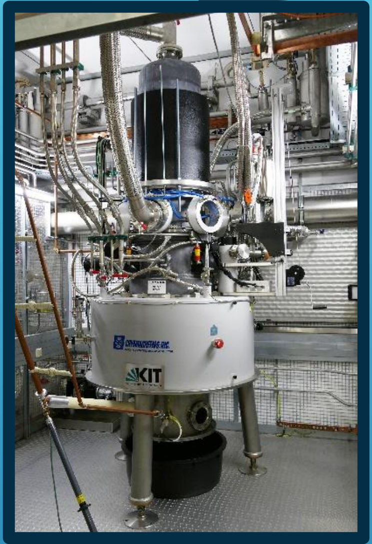


INTRODUCTION (CLASSIFICATION OF AMPLIFIERS)

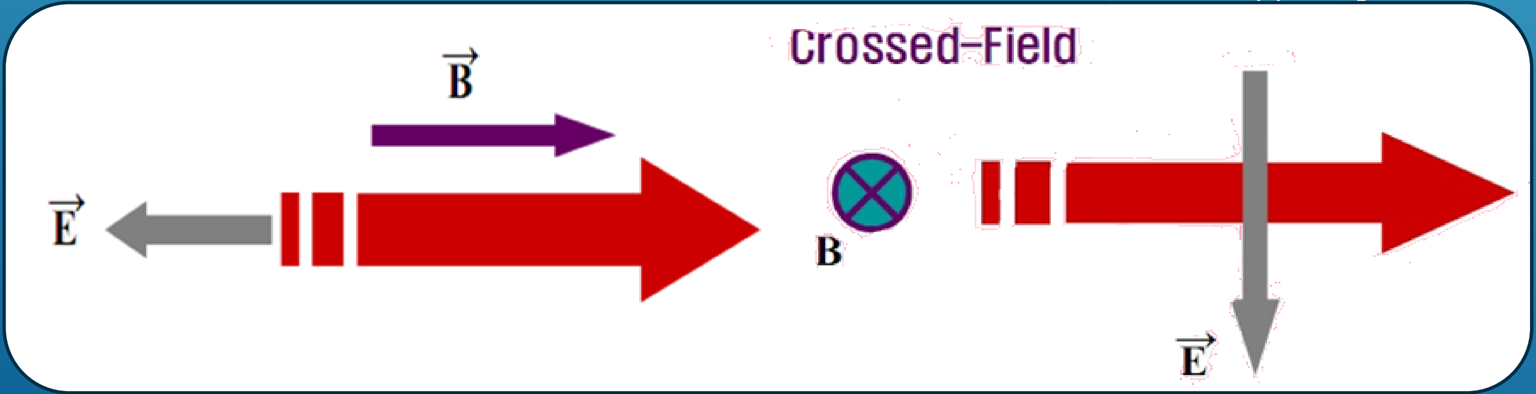




INTRODUCTION (MICROWAVE VACUUM TUBE)



	O-type (ordinary type) device	M-type (magnetic type) devices	Gyrotrons
Travelling wave devices	TWT (Travelling wave tubes)	TWT-M (Travelling wave tubes - magnetic), Amplitrons	Gyro-TWT
Resonant devices	Klystrons, IOT (Inductive output tubes)	Magnetrons	Gyroklystrons



INTRODUCTION (MICROWAVE VACUUM TUBE)

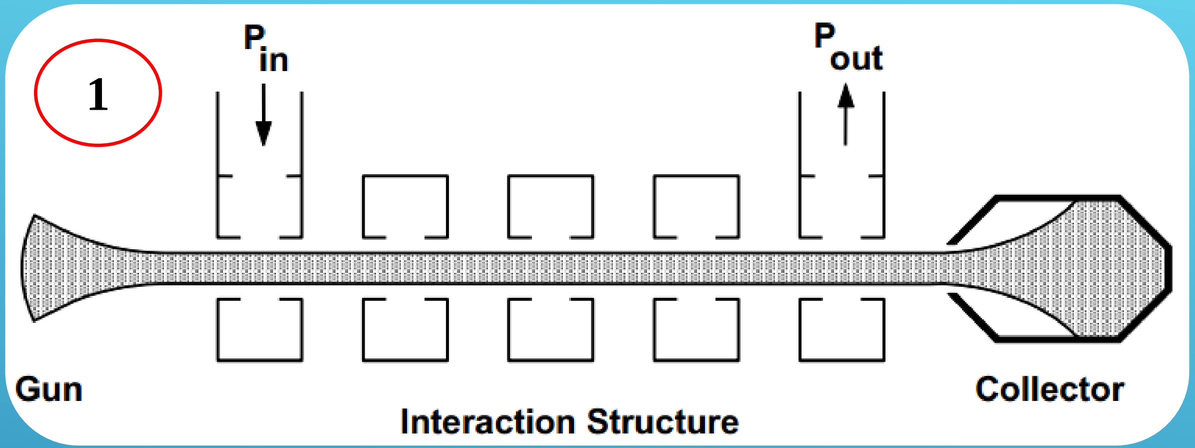
		Magnetron	Klystron	TWT	Gyrotron
Frequency range (GHz)	CW	1.5-2.5	0.5-40	3-40	30-300
	Pulse	15-25	0.5-50	3--40	30-300
Power level (MW@GHz)	CW	0.005 @ 3	1 @ 3	0.006 @ 3	0.2 @ 30
	Pulse	4 @ 3	80 @ 3	0.5 @3	1 @ 30
Phase Stability	CW	Good	Excellent	Good	Poor
	Pulse	Poor	Excellent	Good	Poor
Amplitude Stability	CW	Good	Excellent	Good	Fair
	Pulse	Poor	Excellent	Good	Fair
Noise level	CW	Good	Excellent	Good	Poor
	Pulse	Poor	Excellent	Good	Poor
Major Application	CW	Industrial App	Space Tele Communication		Plasma Heating
	Pulse (Short)	Radar	Particle Accelerator	Radar	Radar
	Pulse (Long)	Plasma Heating	Plasma Heating	Radar	Plasma Heating
Tube Structure		Simple	Complex	Medium	Complex

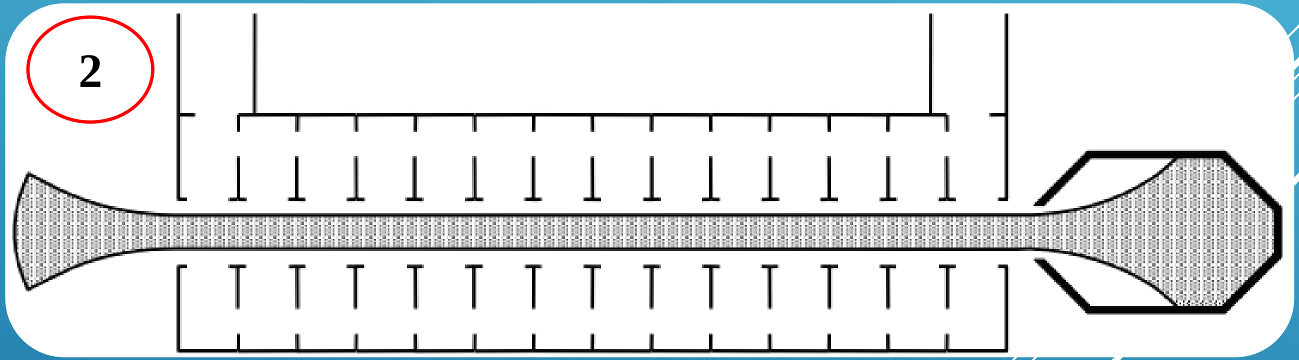
Features of klystrons

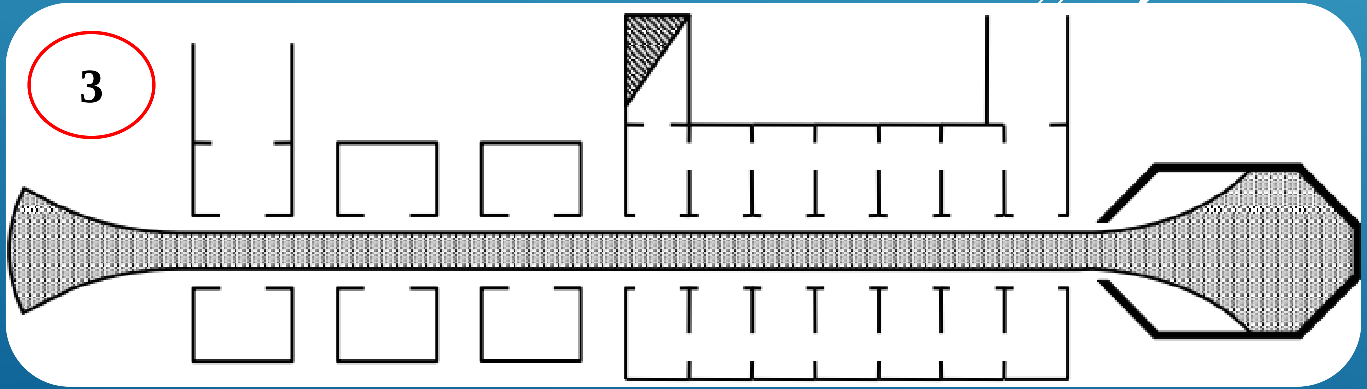
- High peak power
- High amplitude stability
- High phase stability
- Medium efficiency

INTRODUCTION (MICROWAVE VACUUM TUBE)

- **Linear beam tubes:**
  1) Klystrons
     1) High power
     2) Narrow band
  2) TWTs
     1) Low and medium power
     2) Wide band
  3) Hybrid tubes (Twystrons)
     1) TWTs <Power< Klystrons
     2) Klystrons <Bandwidth< TWTs

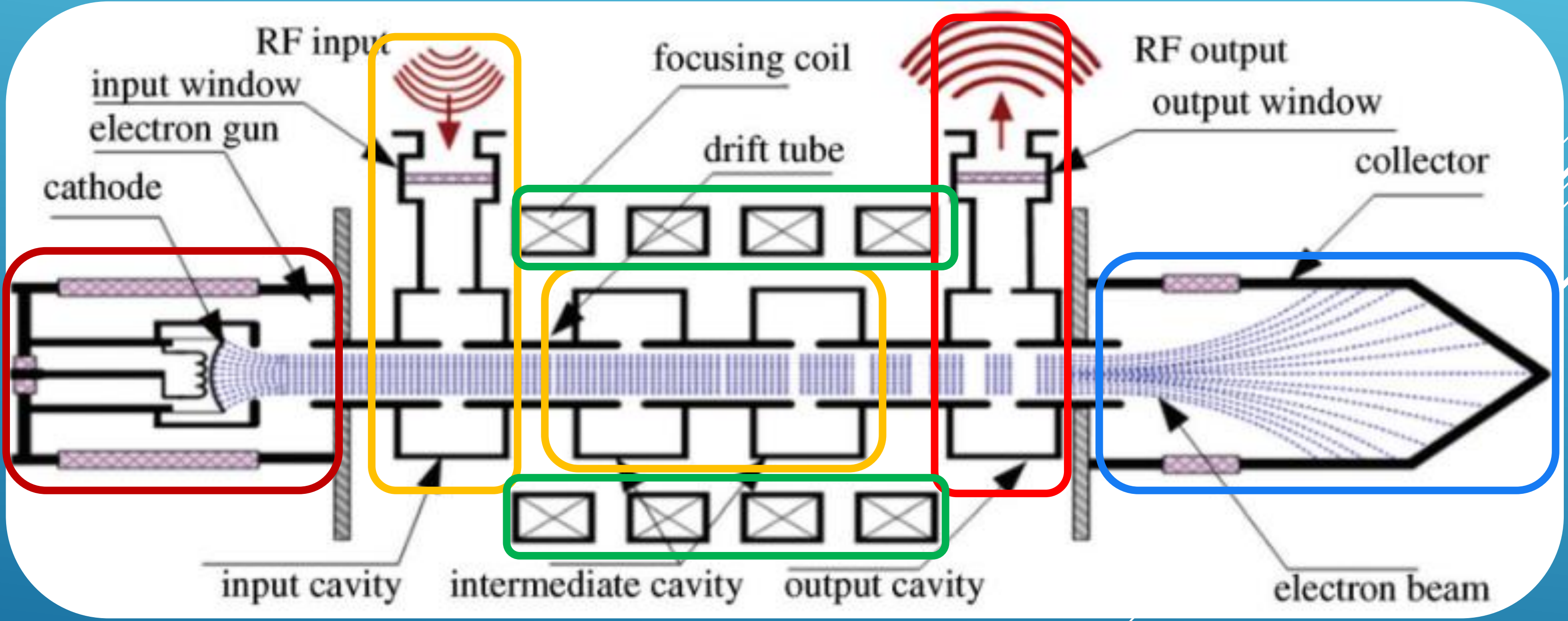






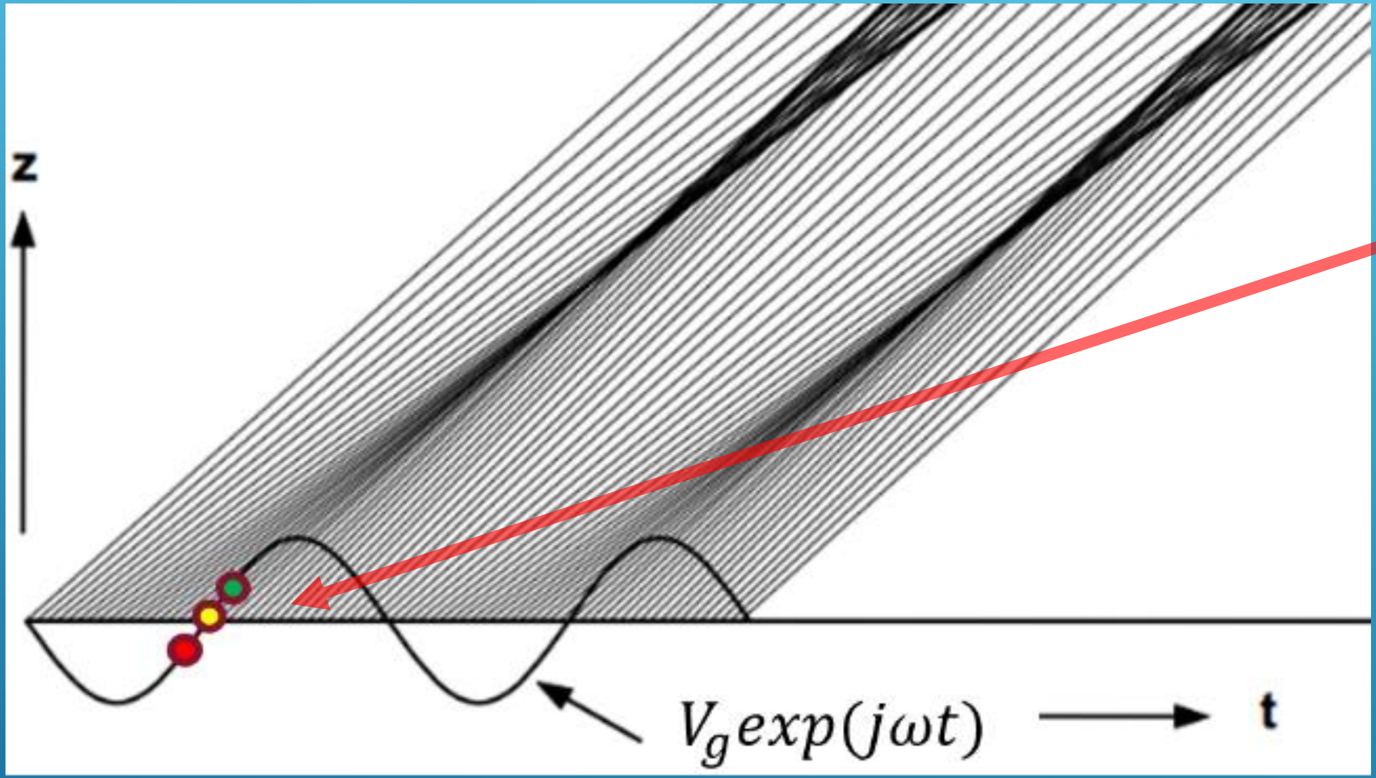
INTRODUCTION (KLYSTRON)

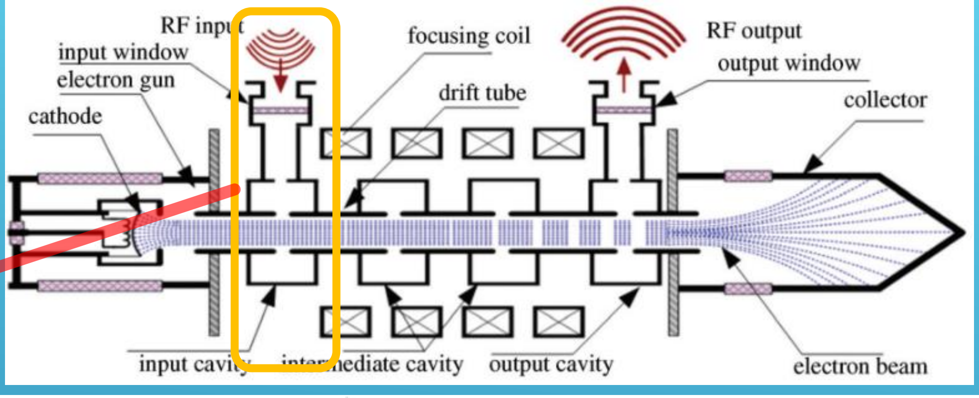
- **<u>Components of Klystron:</u>**
  1) Electron gun
  2) Input cavity
  3) Intermediate cavities
  4) Focusing magnets
  5) Output cavity
  6) Collector
  7) Windows

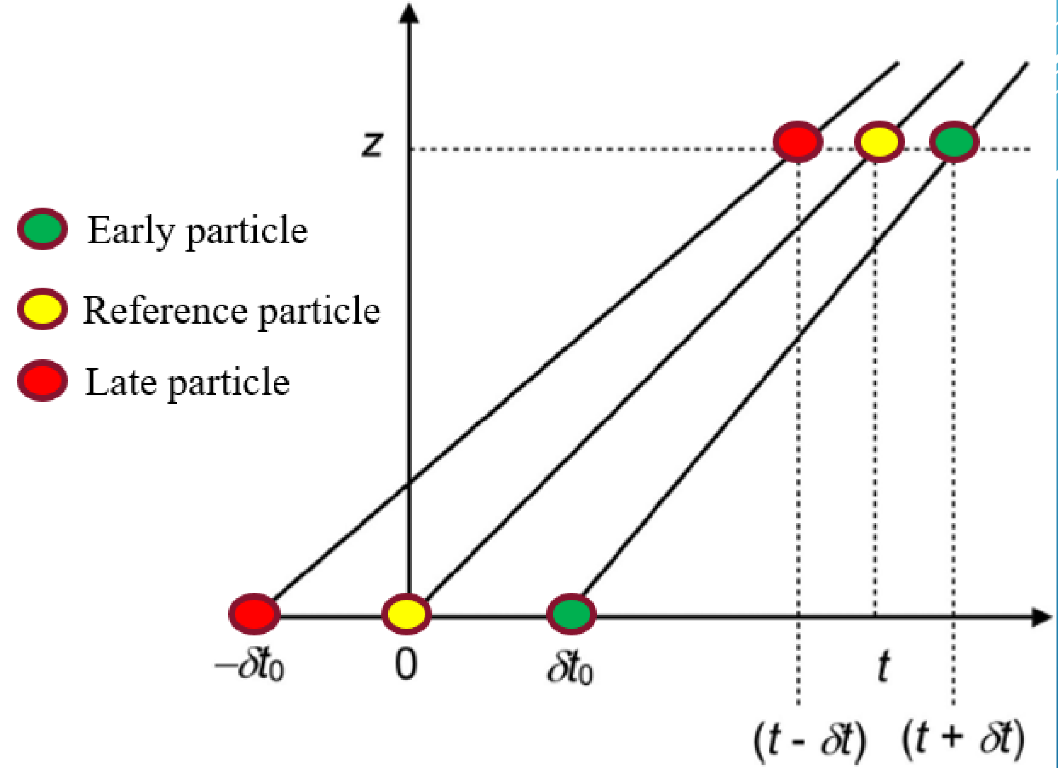


KLYSTRON

- **How dose klystron work?**







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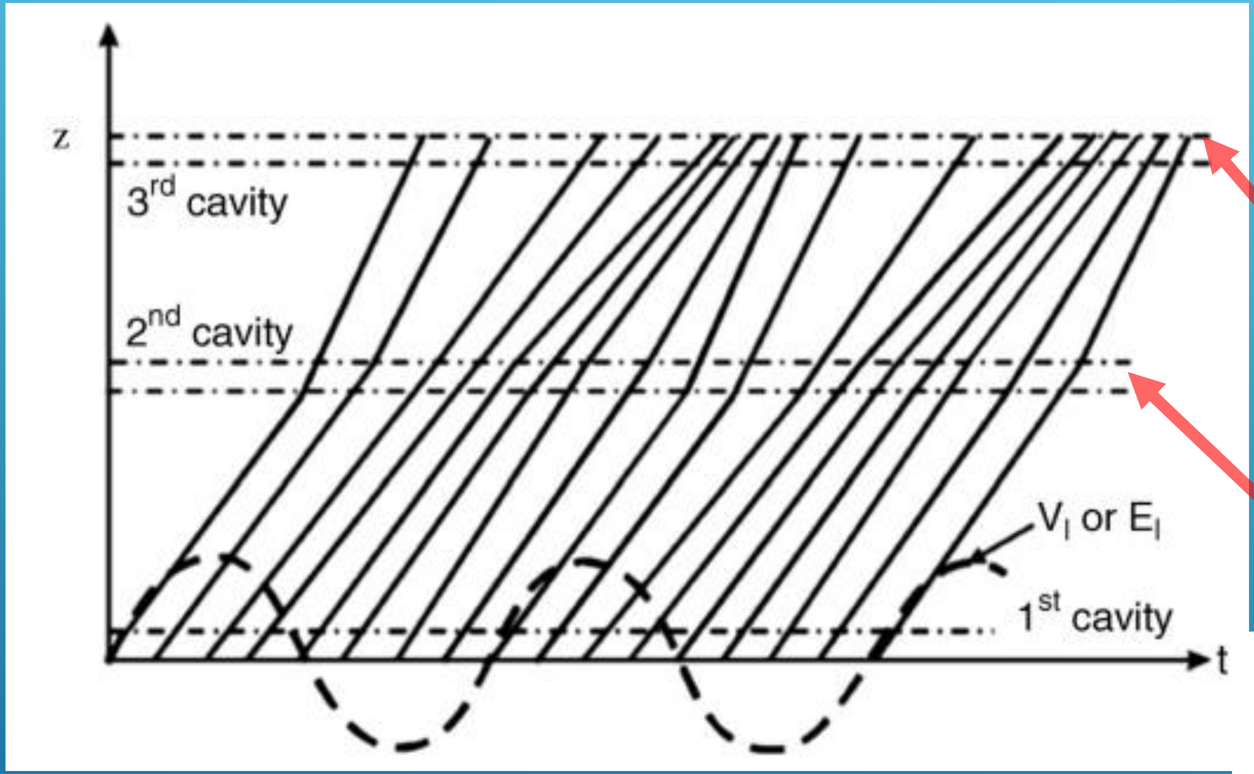

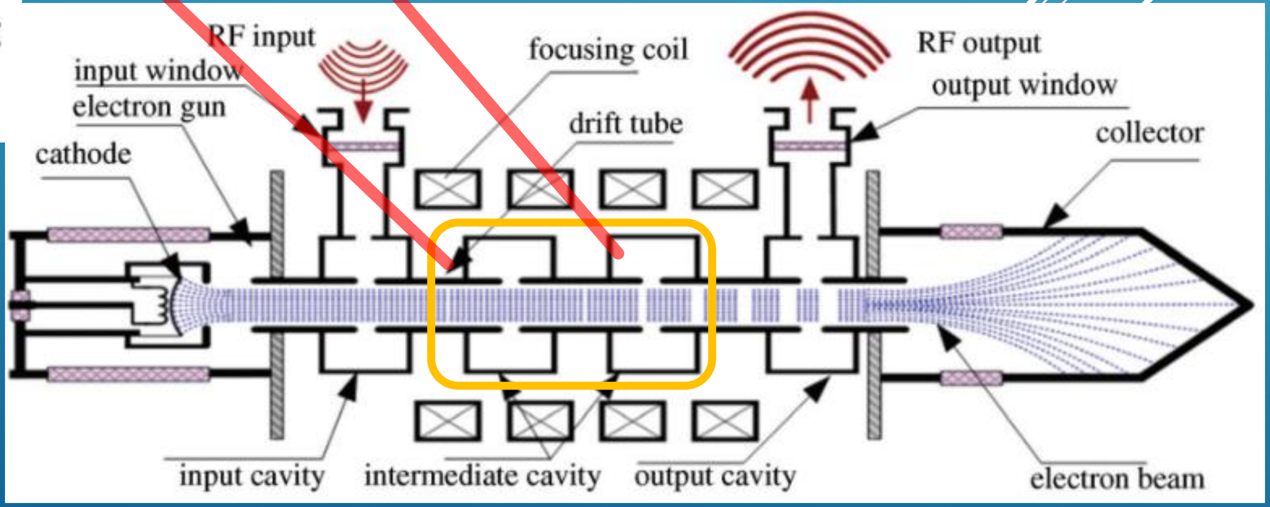

KLYSTRON

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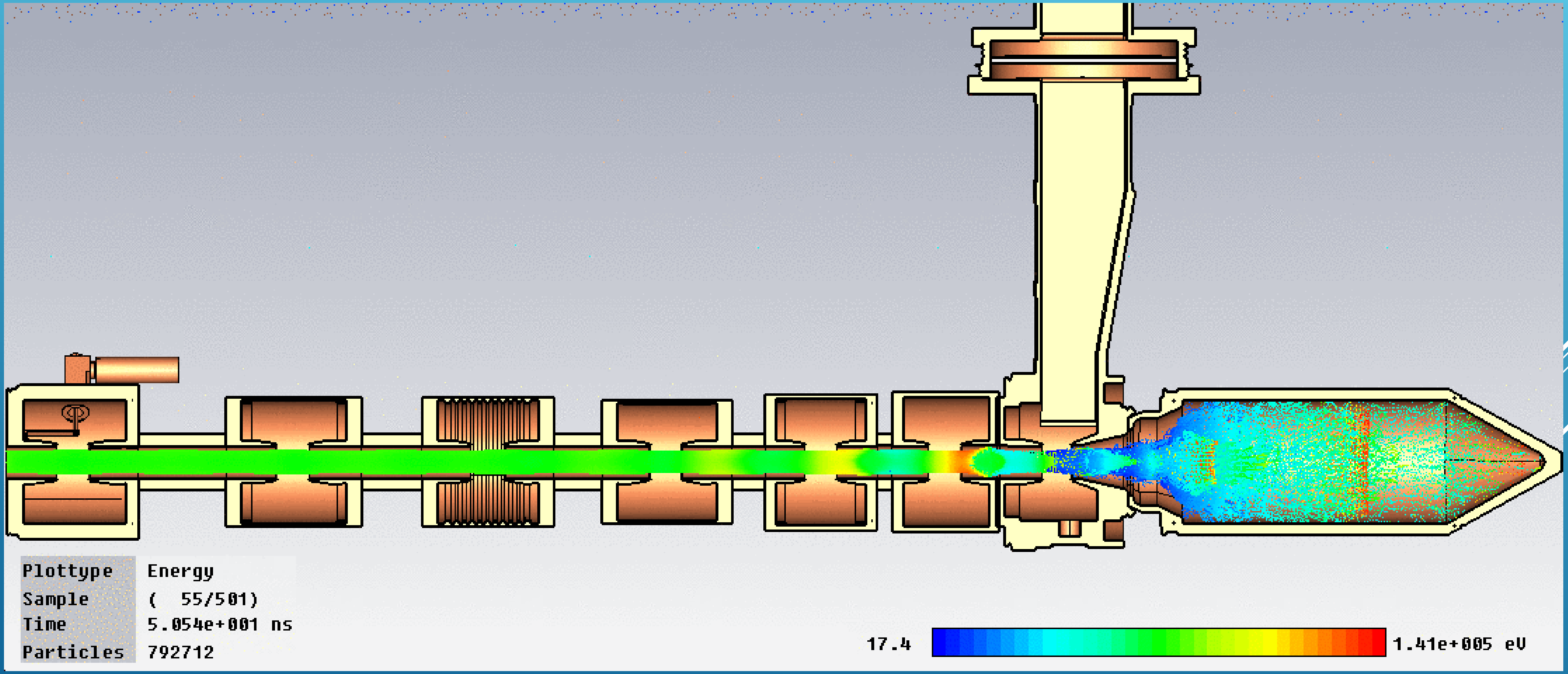

KLYSTRON

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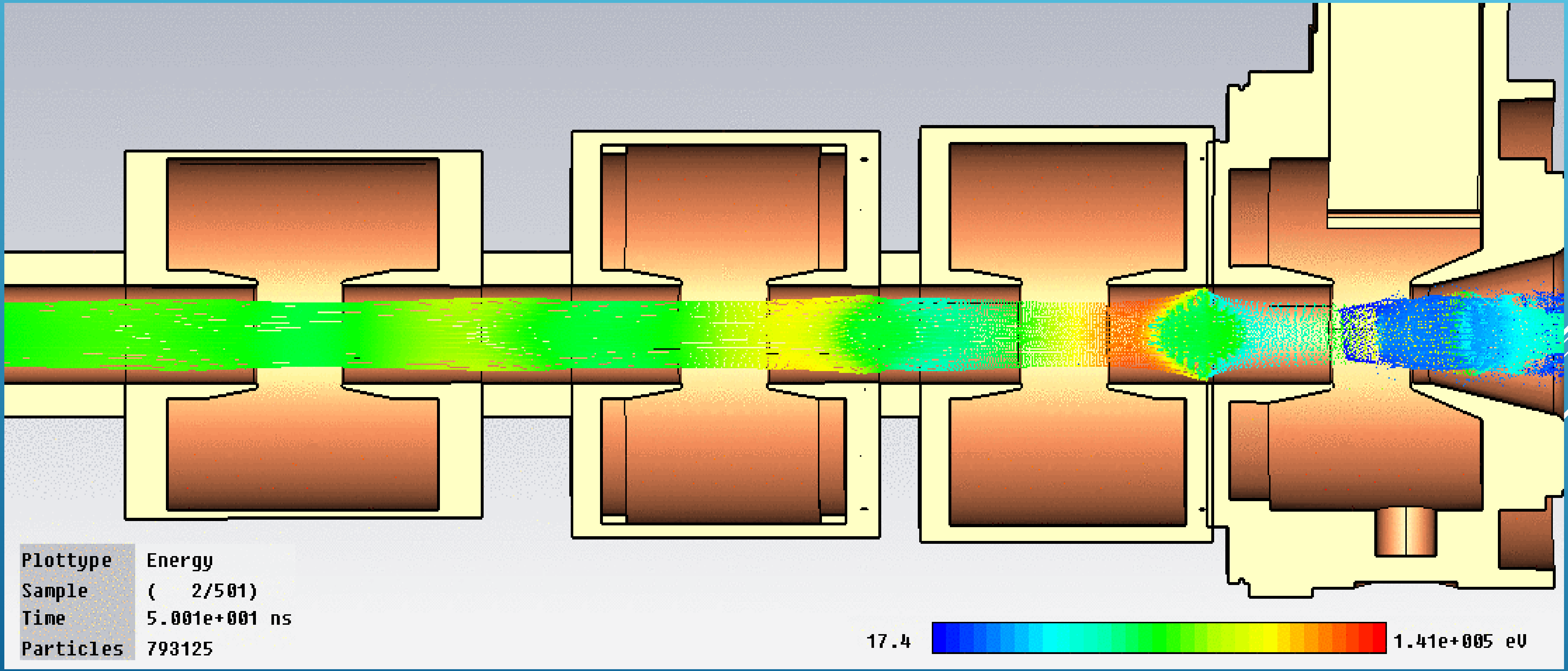

KLYSTRON

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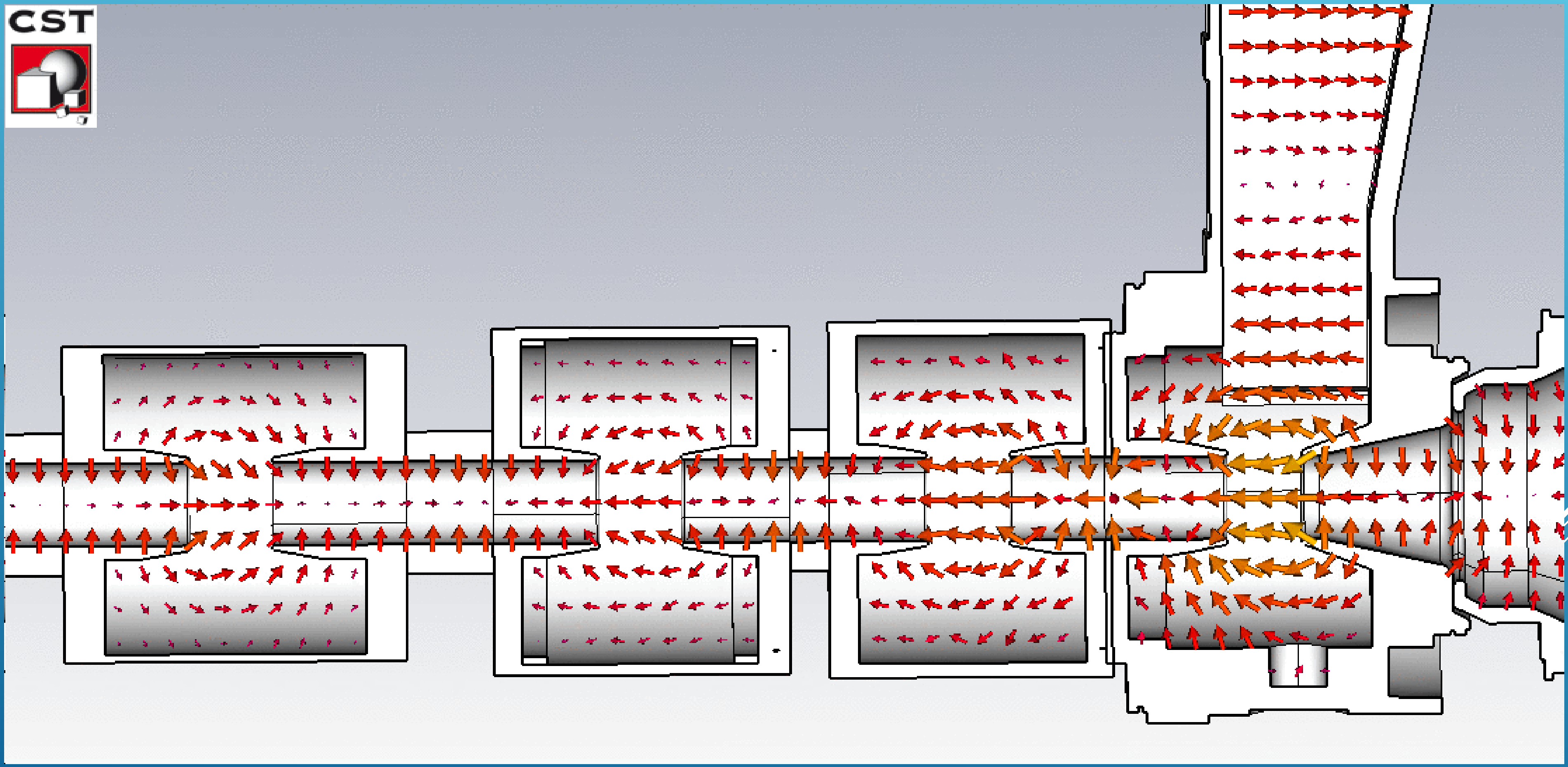
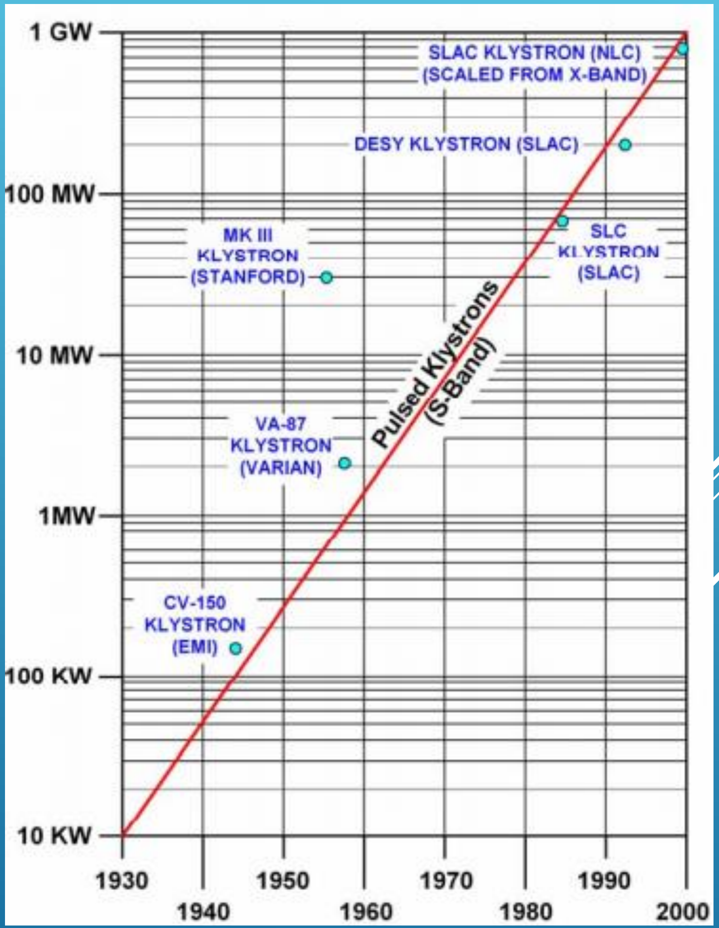
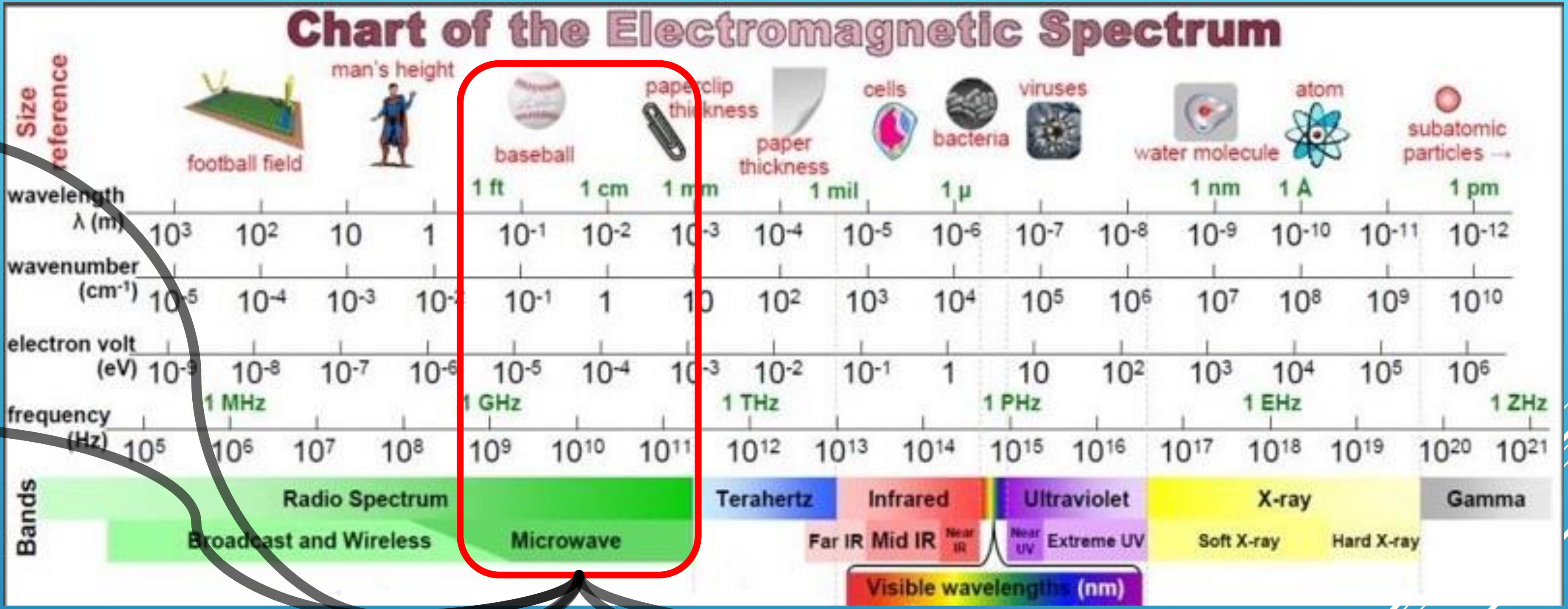
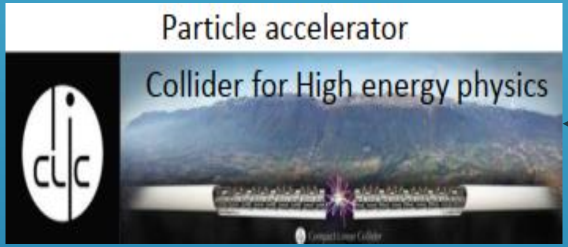


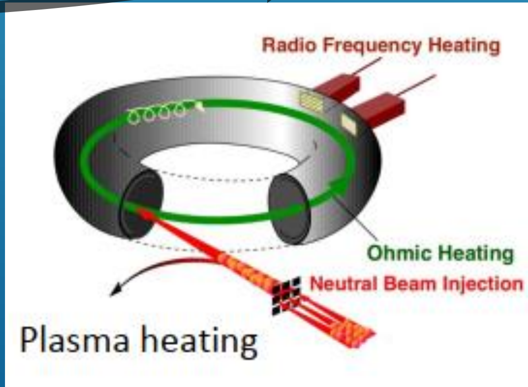
- **History of Klystron:**

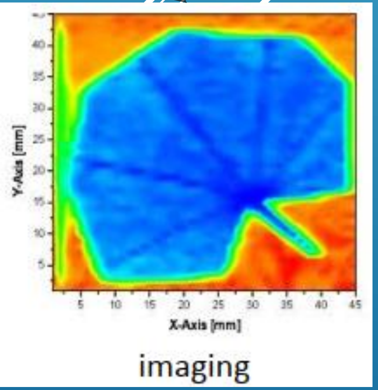


KLYSTRON (AREAS OF KLYSTRON'S APPLICATION)



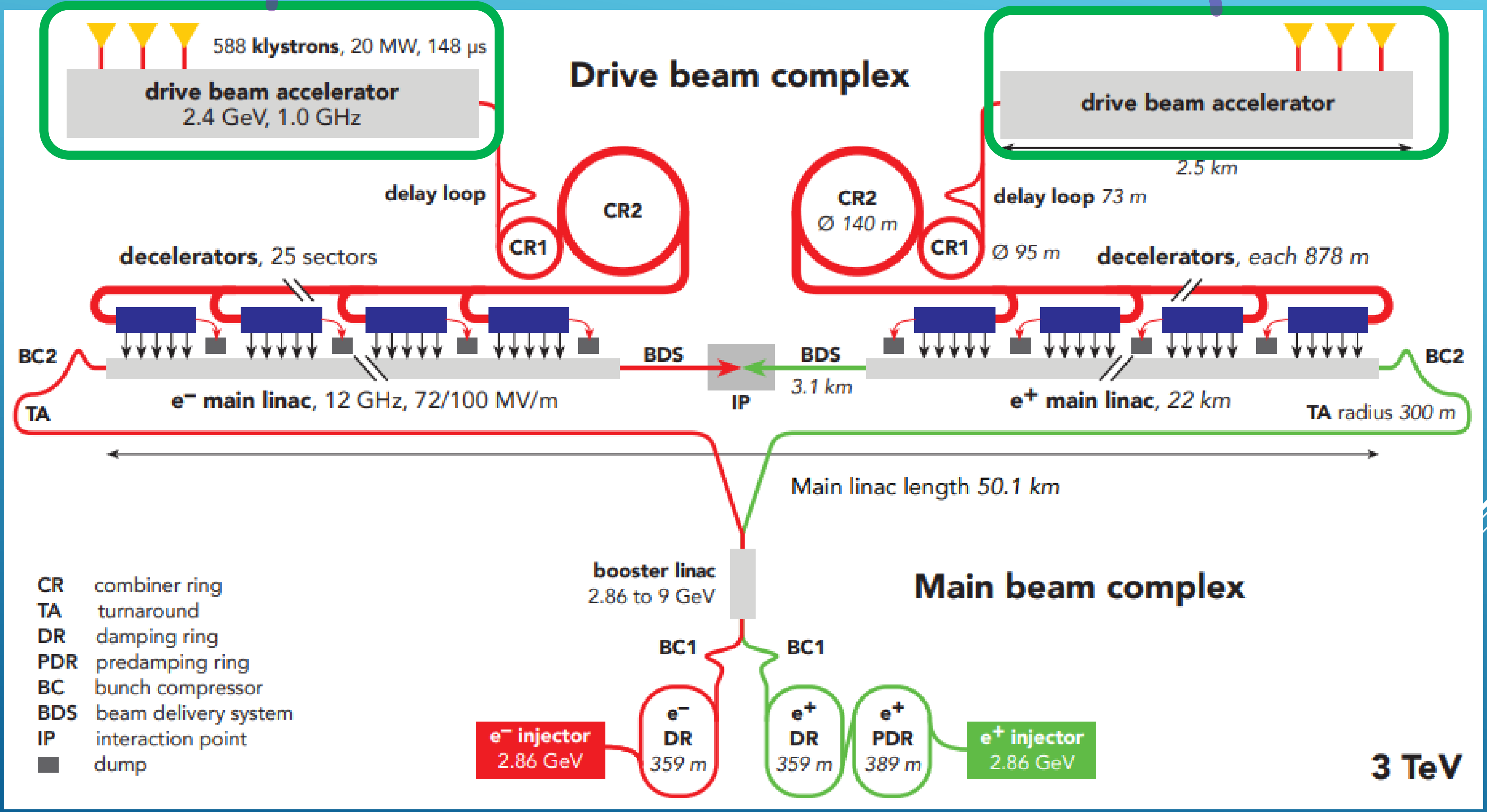






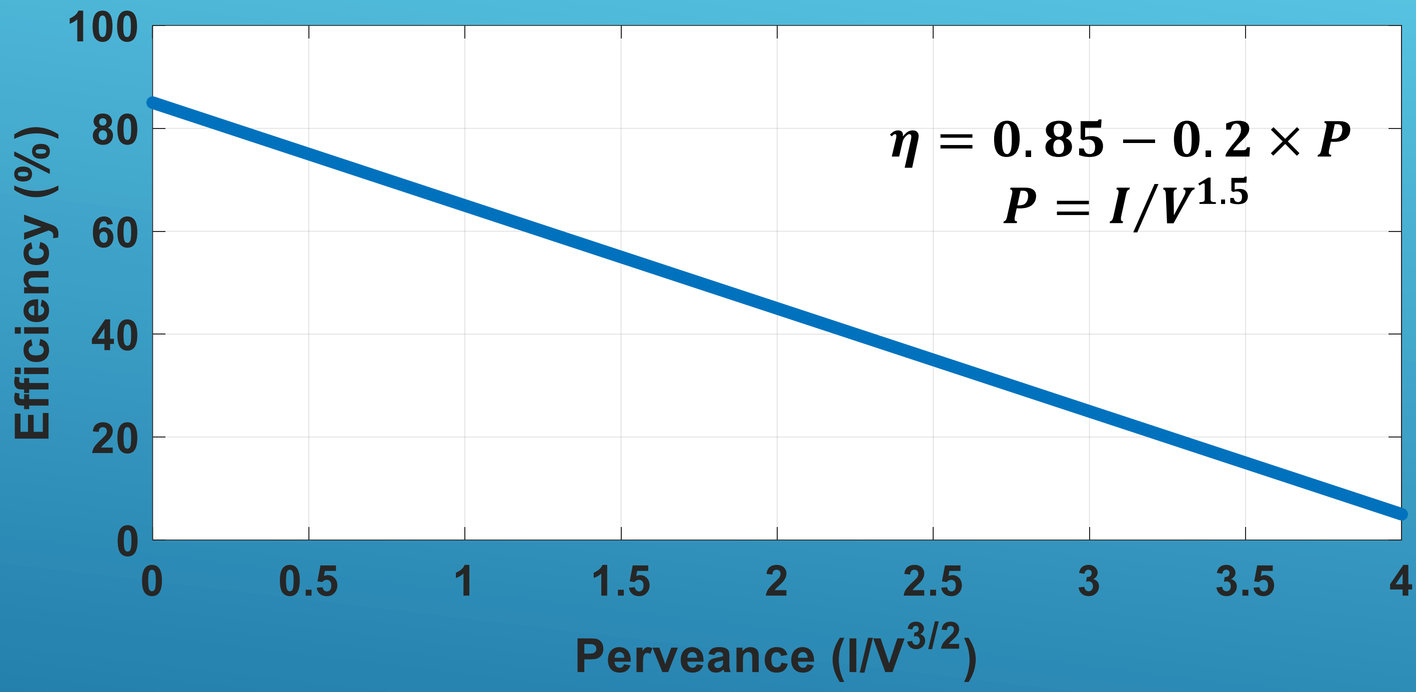
KLYSTRON (AREAS OF KLYSTRON'S APPLICATION)

Klystrons required: 1176



MULTI-BEAM KLYSTRON

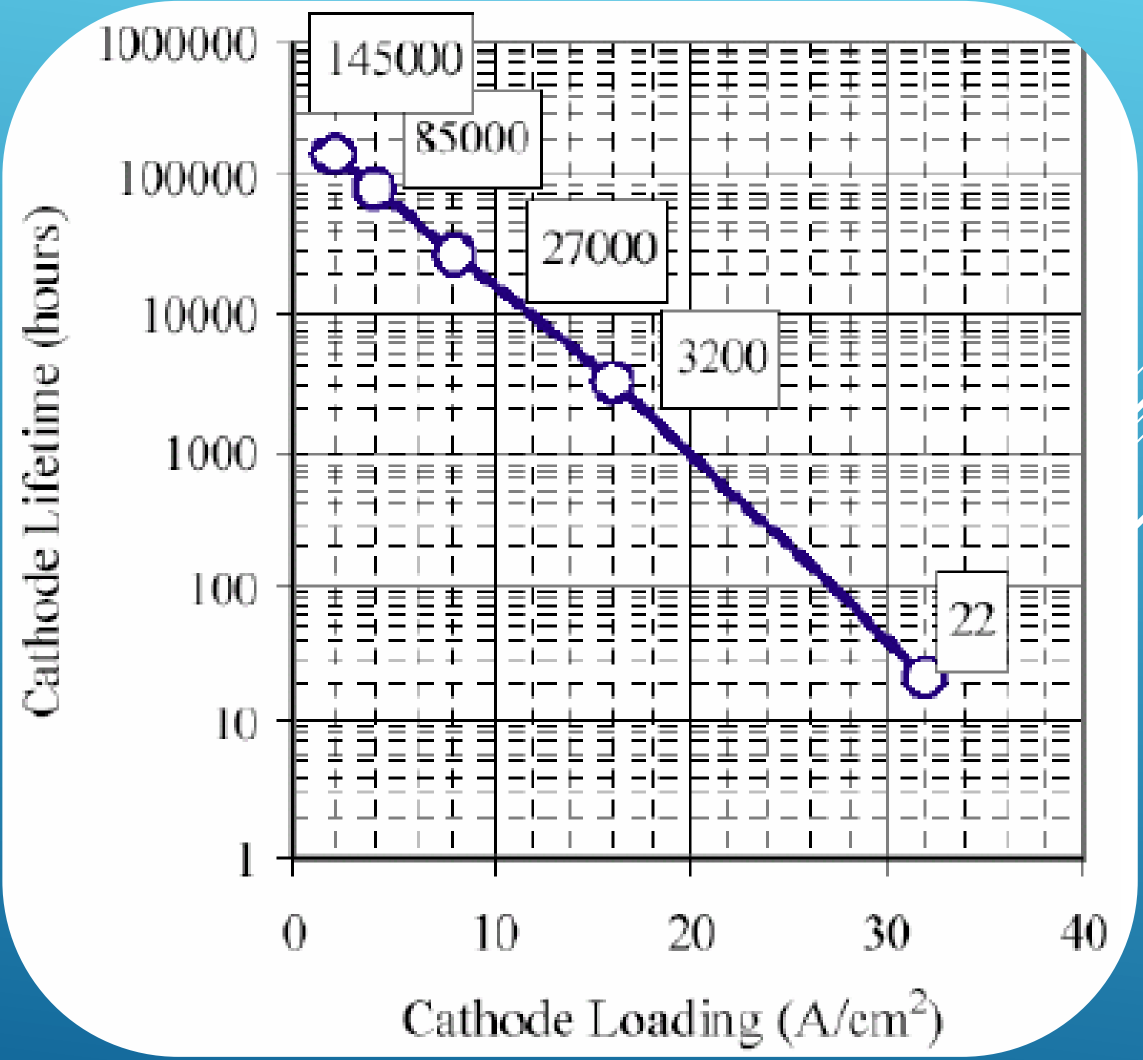
- **High power and efficiency Klystron:**



High power and efficiency → Low perveance → Low Current or/and High voltage → Multi-beam klystron

- **Features of Multi-Beam Klystrons (MBKs)**

  1) Higher power and efficiency
  2) Life time increasing



MULTI-BEAM KLYSTRON

- **<u>Features of Multi-Beam Klystrons (MBKs)</u>**

1) Higher power and efficiency
2) Life time increasing
3) Reduction of focusing magnet's volume and weight

$$\boxed{B_b = \sqrt{\frac{I_0\sqrt{2}}{\epsilon_0 \pi b^2 \eta_e^{3/2}\sqrt{V_0}}}}$$

$$\Downarrow$$

$$\boxed{B_b \propto \sqrt{I_0}}$$

MULTI-BEAM KLYSTRON

- **Features of Multi-Beam Klystrons (MBKs)**

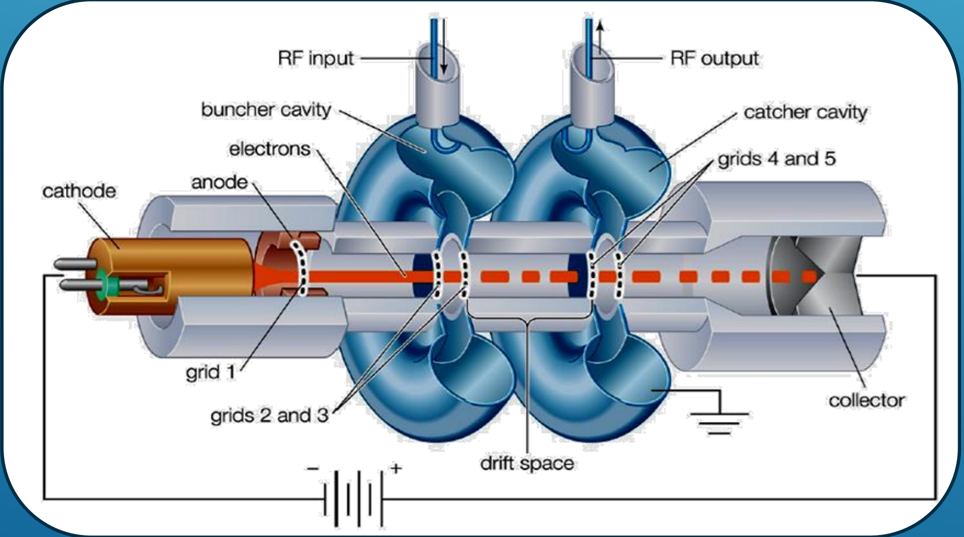
1) Higher power and efficiency
2) Life time increasing
3) Reduction of focusing magnet’s volume and weight
4) Higher stability

$$P = \mathrm{VI} = V^{2.5}\frac{I}{V^{1.5}} = V^{2.5}K \longrightarrow \Delta P = 2.5\mathrm{K}V^{1.5}\Delta V \longrightarrow \boxed{\frac{\Delta P}{P} = 2.5\frac{\Delta V}{V}}$$

$$\varphi = \omega t + \varphi_0 = \frac{\omega L}{v} + \varphi_0 \longrightarrow$$

$$\Delta\,\varphi = \frac{-\omega L}{c}\,\frac{1}{(\gamma_R + 1)(\gamma_R{}^2 - 1)^{1/2}}\,\frac{\Delta V}{V}$$

$$\boxed{\Delta\varphi \propto \frac{\Delta V}{V} = \frac{\Delta E}{E}}$$



MULTI-BEAM KLYSTRON

- **<u>Comparison between single and multiple beam Klystron:</u>**

Parameters	Single beam klystron	Multi-beam klystron
Efficiency	**Lower**	**Higher**
Peak power	**Lower**	**Higher**
Stability	**Lower**	**Higher**
Bandwidth	**Lower**	**Higher**
Lifetime	**Lower**	**Higher**
Size	**Bigger**	**Smaller**
Cooling	**Higher**	**Lower**
Structure complex	**Lower**	**Higher**
High voltage	**Higher**	**Lower**

SMALL SIGNAL

KLYSTRON EQUIVALENT CIRCUIT

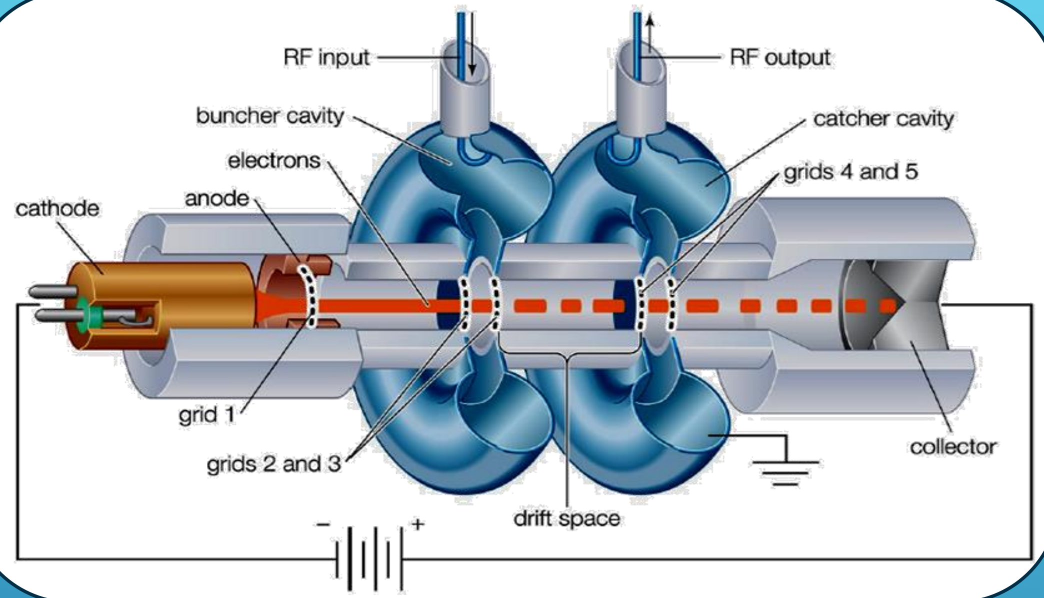
- **Assumptions:**
  - No intermediate cavities
  - No Space charge
  - No beam impedance

$$G_s = 1/R_s$$

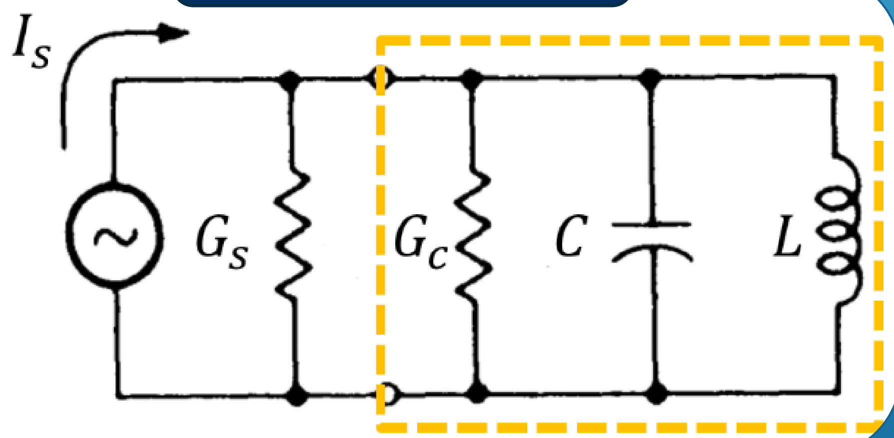
$$Y_c = G_c\left(1 + jQ\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right)$$

$$V_{in} = \frac{I_s}{G_s + G_c\left(1 + jQ\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right)}$$

$$\boxed{P_{in} = \frac{G_c V_{in}^2}{2} = \frac{G_c I_s^2}{2(G_s + G_c)^2}}$$



Buncher Cavity



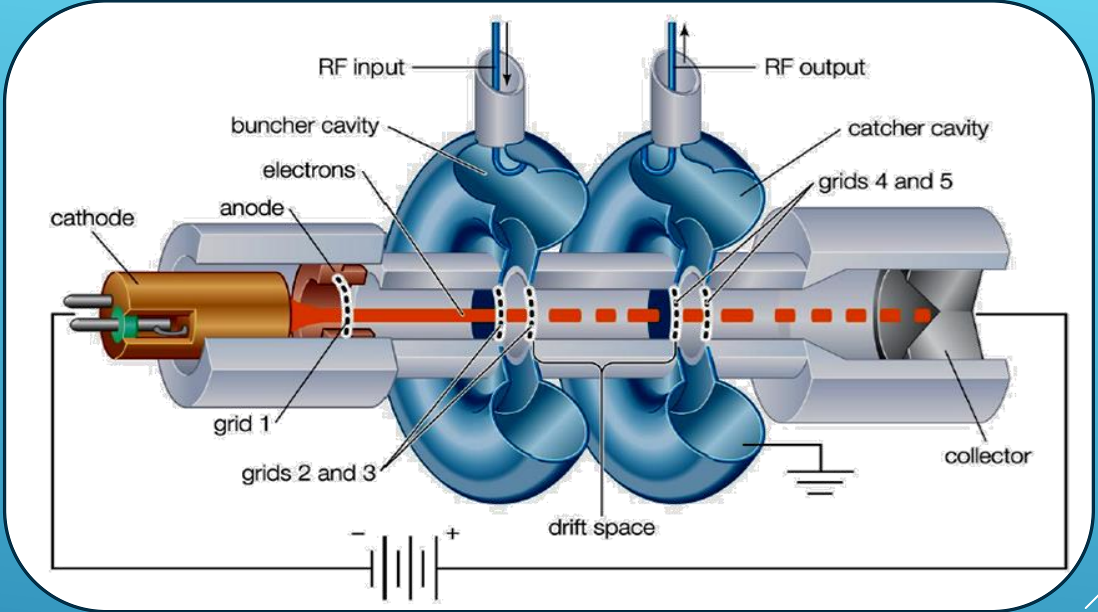
KLYSTRON EQUIVALENT CIRCUIT

- **Assumptions:**
  - No intermediate cavities
  - No Space charge
  - No beam impedance

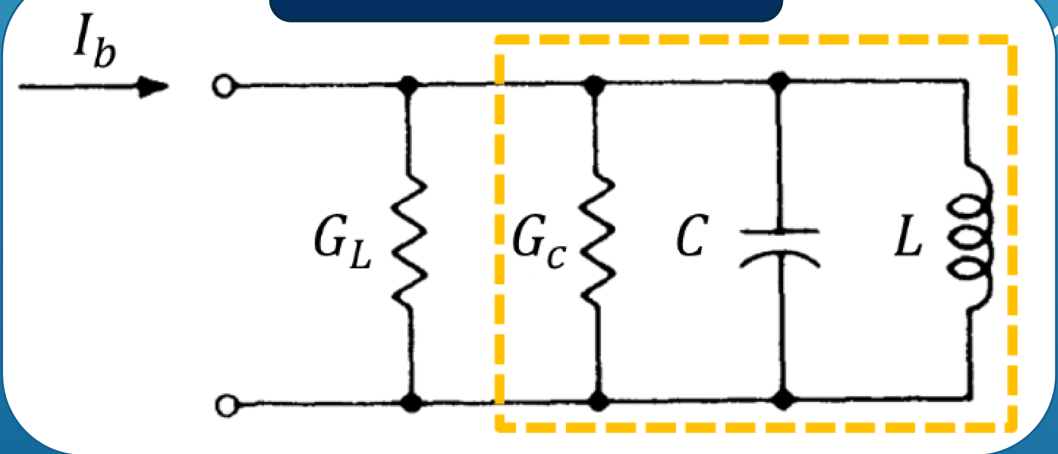
$$V_{out} = \frac{I_b}{G_L + G_c\left(1 + jQ\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right)}$$

$$\boxed{P_{out} = \frac{G_L V_{out}^2}{2} = \frac{G_L I_b^2}{2(G_L + G_c)^2}}$$

$$\boxed{P_{in} = \frac{G_c V_{in}^2}{2} = \frac{G_c I_s^2}{2(G_s + G_c)^2}}$$



Extraction Cavity

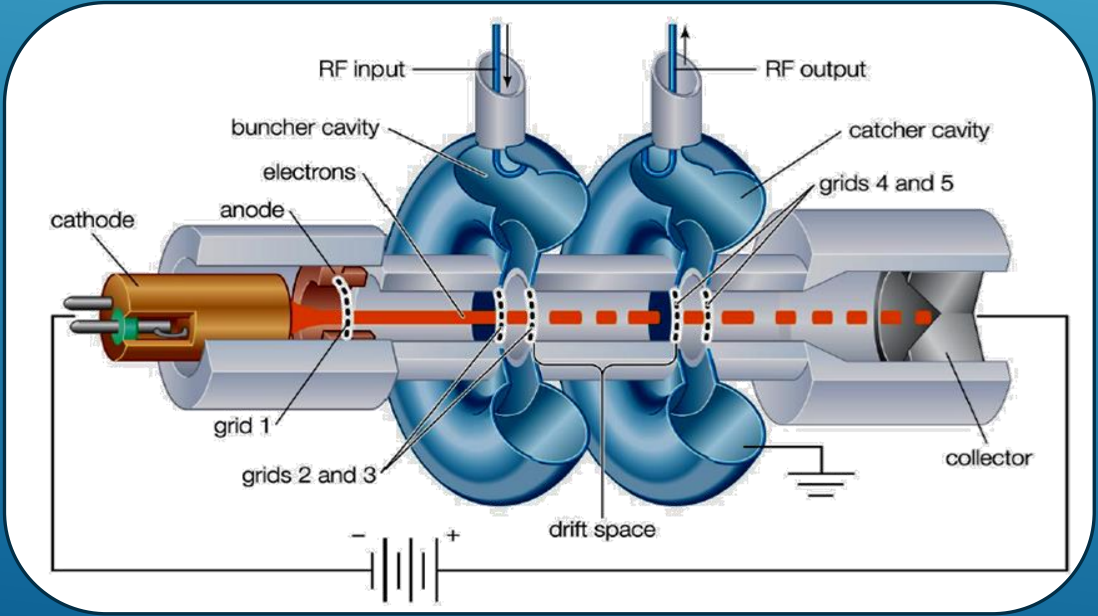


KLYSTRON EQUIVALENT CIRCUIT

$$P_{out} = \frac{G_L V_{out}^2}{2} = \frac{G_L I_b^2}{2(G_L + G_c)^2}$$

$$P_{in} = \frac{G_c V_{in}^2}{2} = \frac{G_c I_s^2}{2(G_s + G_c)^2}$$

$$Gain_{dB} = 10\log(\frac{P_{out}}{P_{in}}) = 10\log(\frac{\frac{G_L I_b^2}{2(G_L + G_c)^2}}{\frac{G_c I_s^2}{2(G_s + G_c)^2}}) = 10\log(\left(\frac{G_L}{G_c}\right)\left(\frac{G_s + G_c}{G_L + G_c}\right)^2\left(\frac{I_b}{I_s}\right)^2)$$



Thanks for your attention