Basic Linac Microwave

In 2.7 x 10^9 μsec

Part I

Lecture presented to OPS Group

May 17, 2000

A. Nassiri, RF Group

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Outline

Part I:

- Linac Layout
- Power system
- Klystron Operation
- RF Breakdown and RF Conditioning

Part II:

- RF Components
  - SLED
  - Waveguide
- Measurement Techniques
- Some Examples

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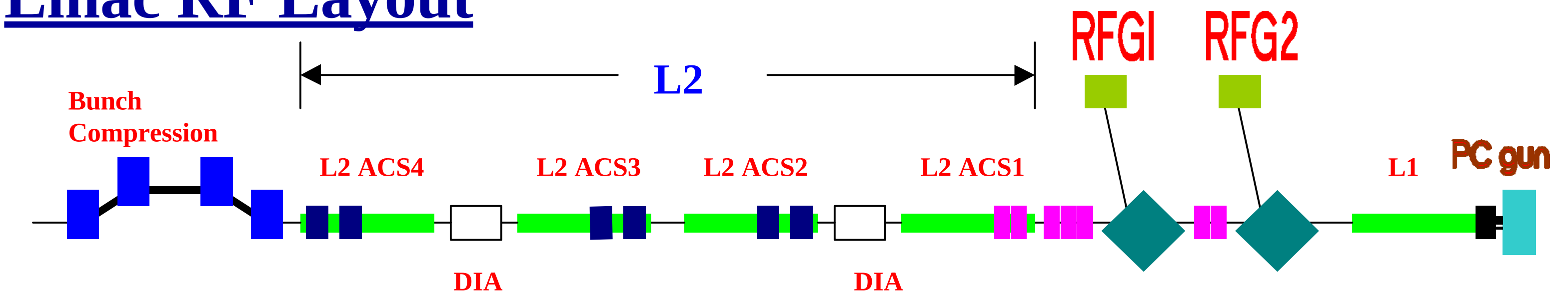
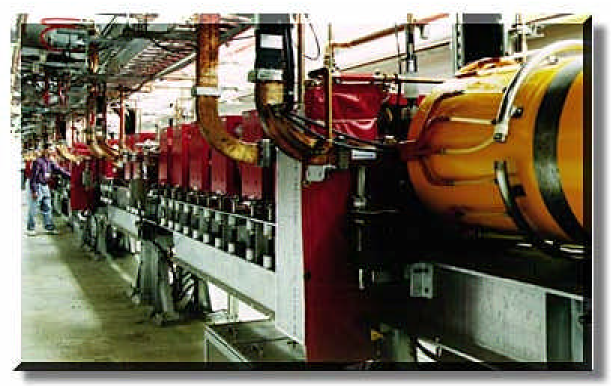
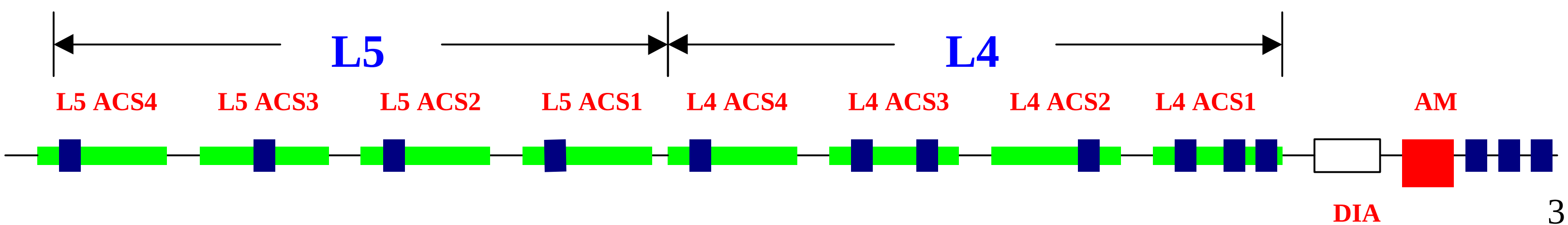
Linac RF Layout







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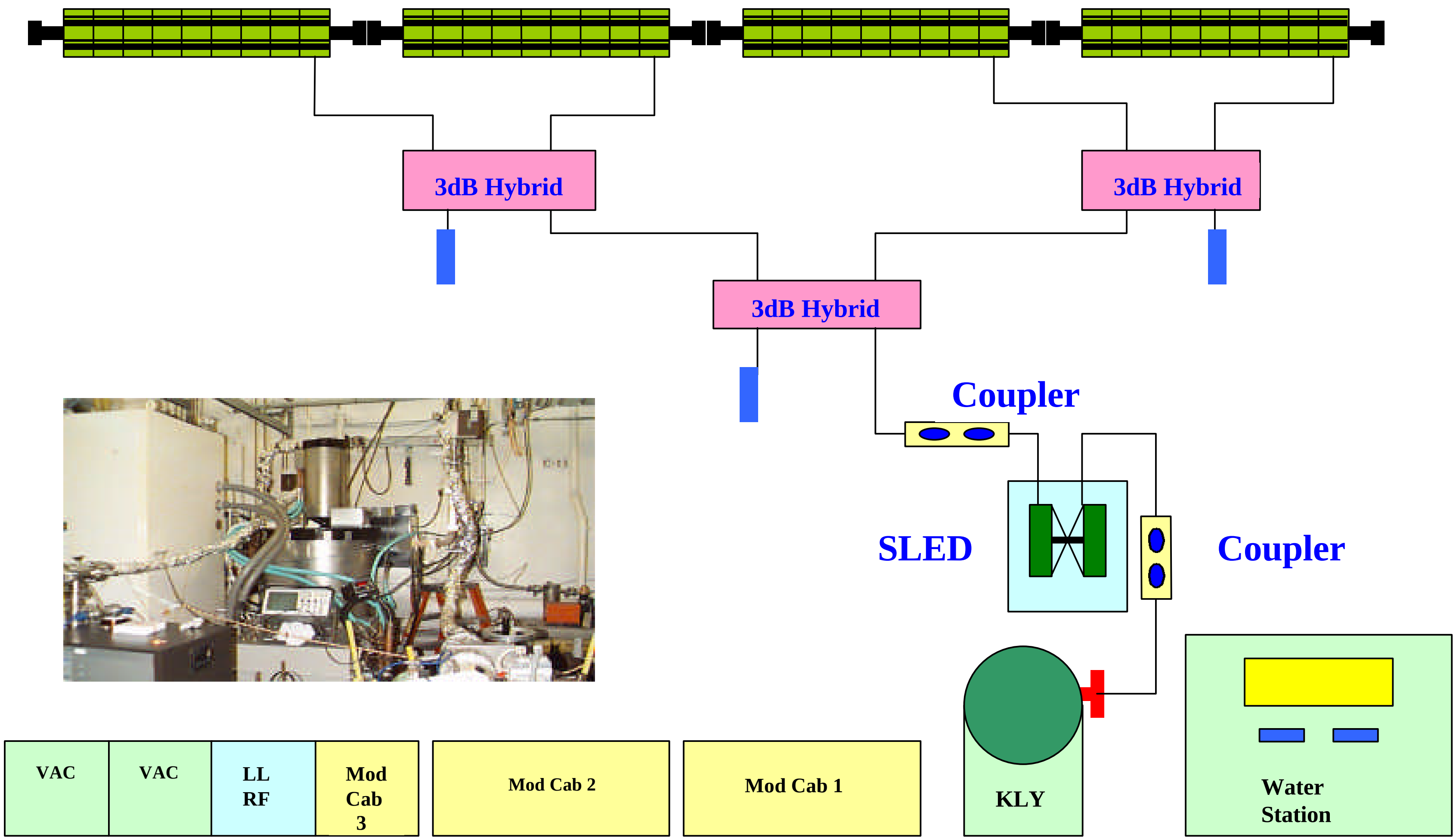

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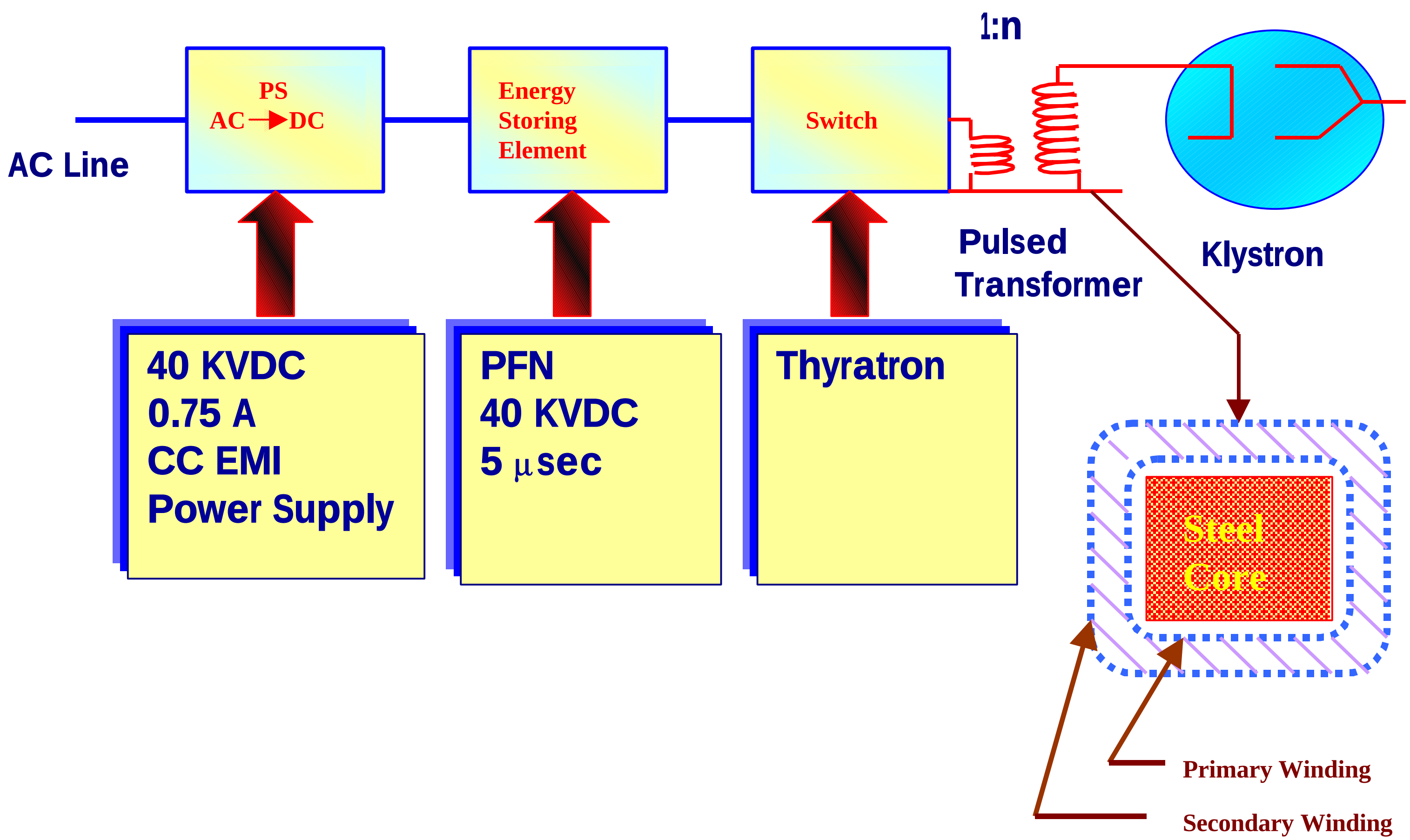
Linac Modulator System



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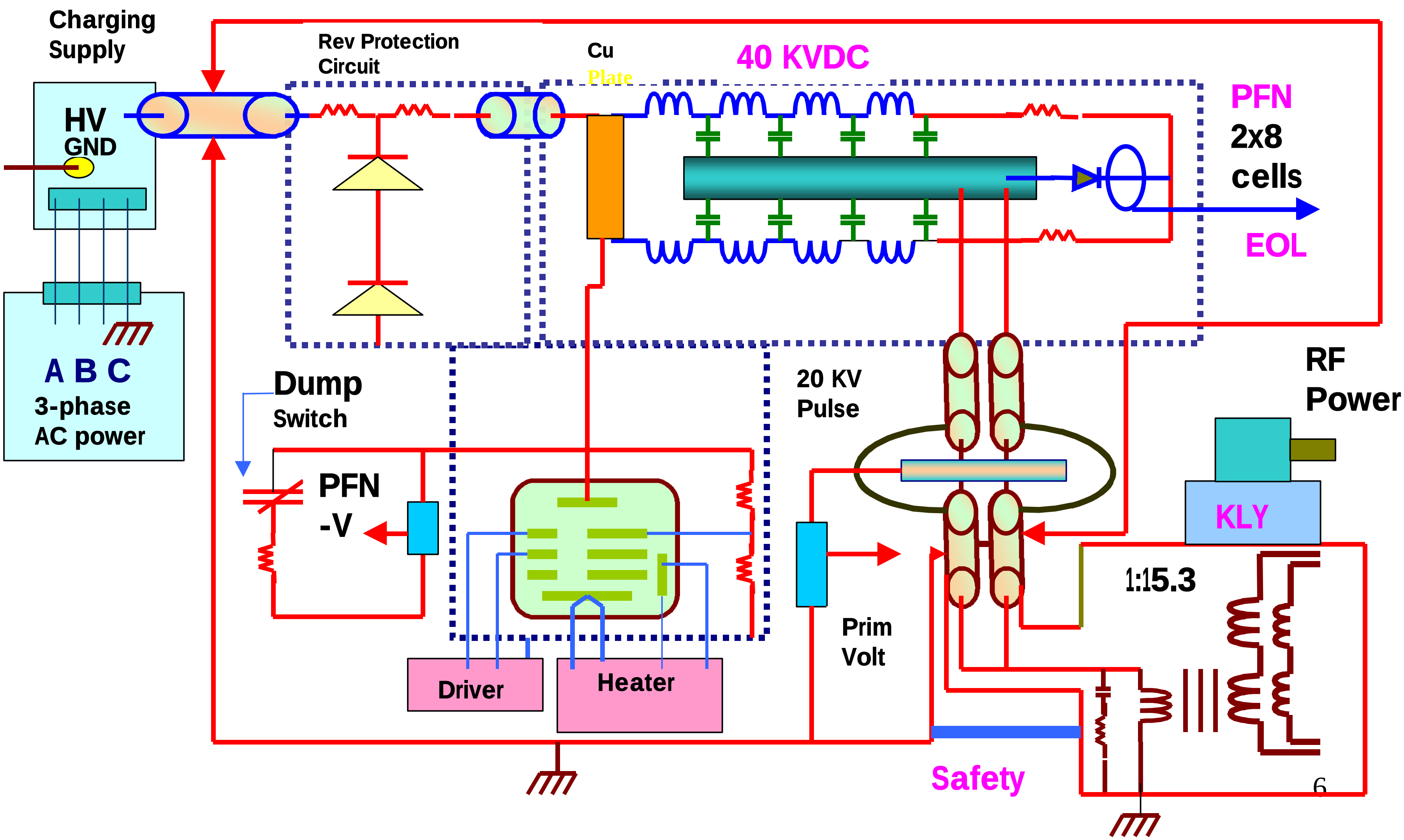
APS Linac Modulator 300 kV/300 A



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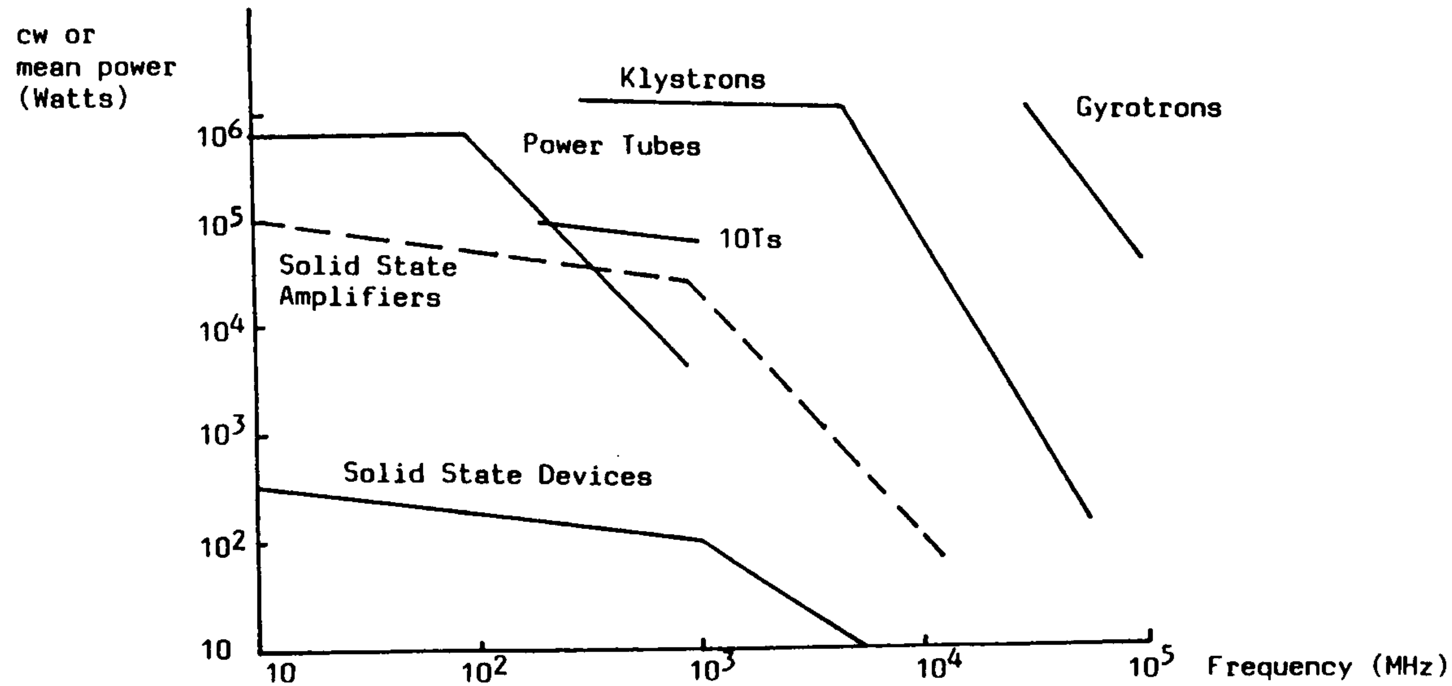

State of the art of RF power sources

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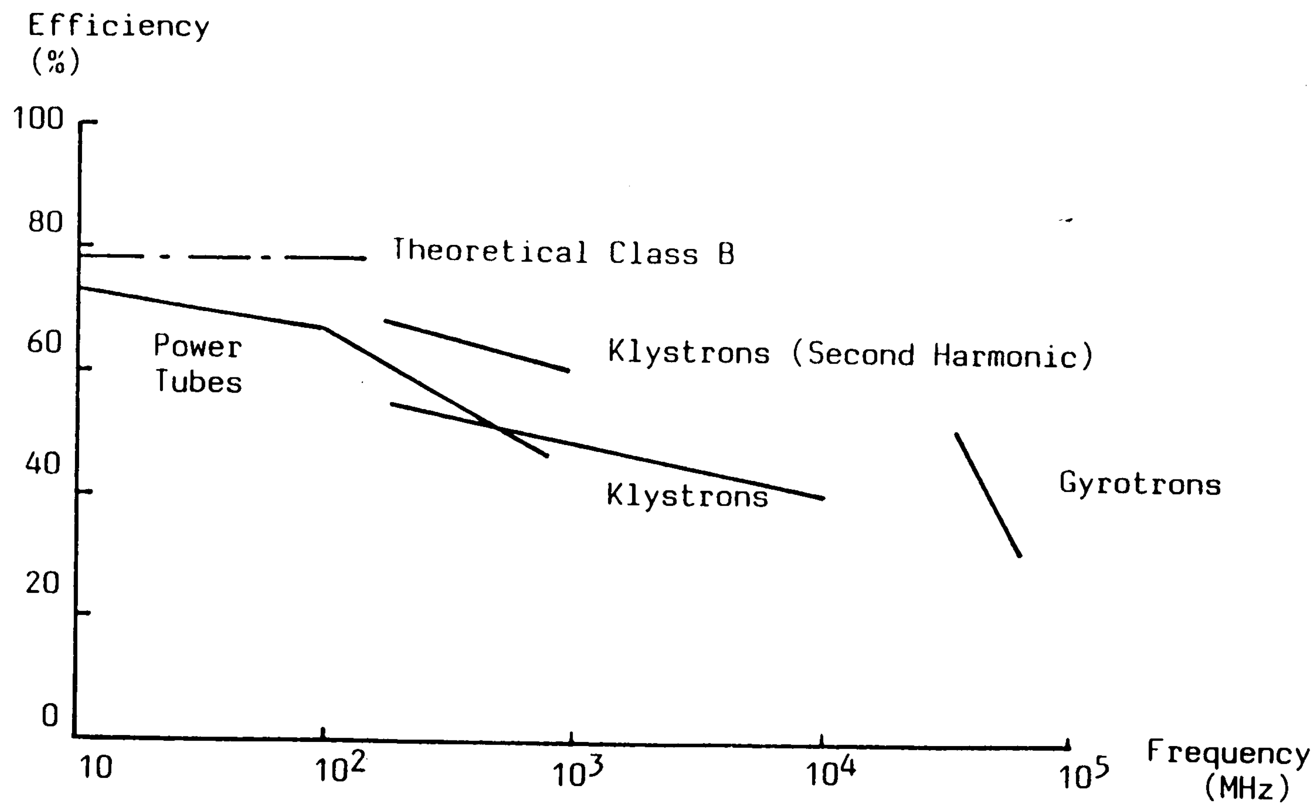

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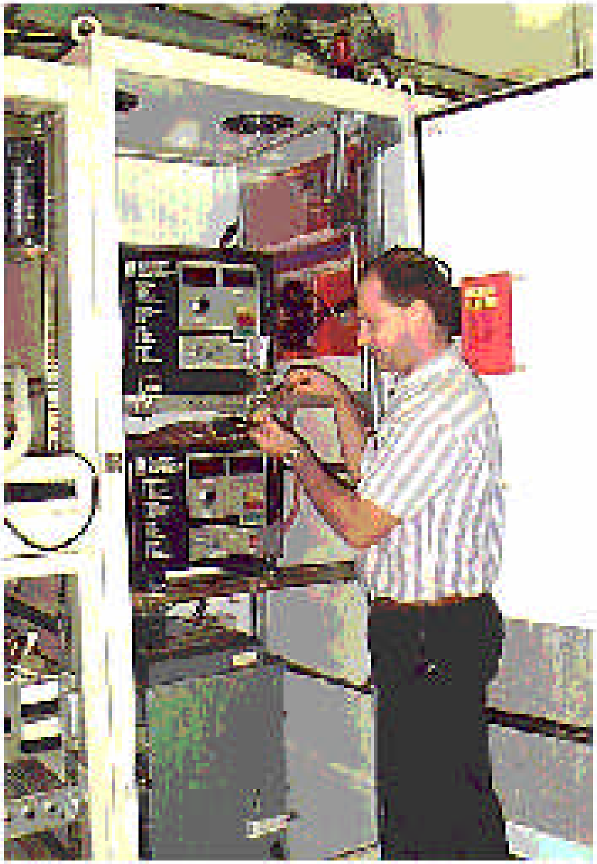
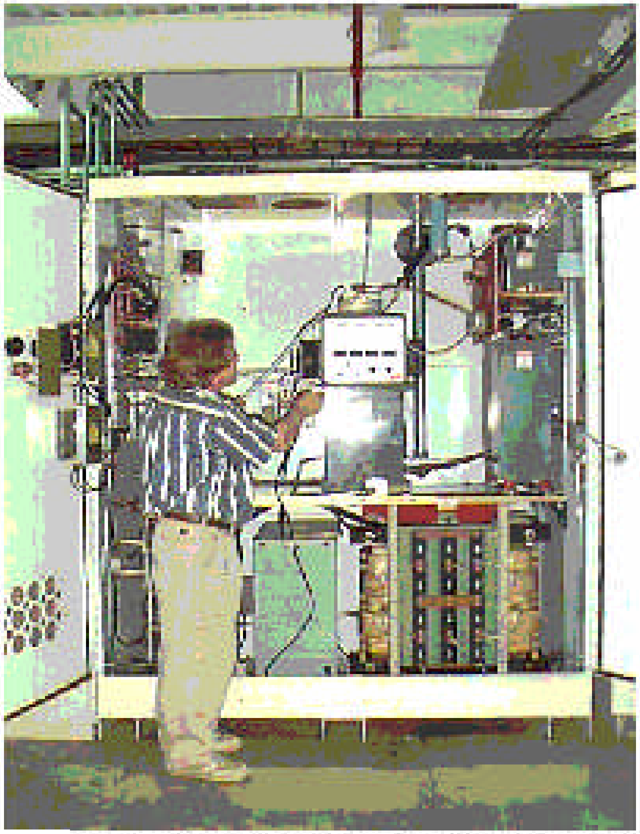


One single-width cabinet contains two constant-current power supplies.



A double-width high voltage power supply cabinet contains most of the resonant-charging system.

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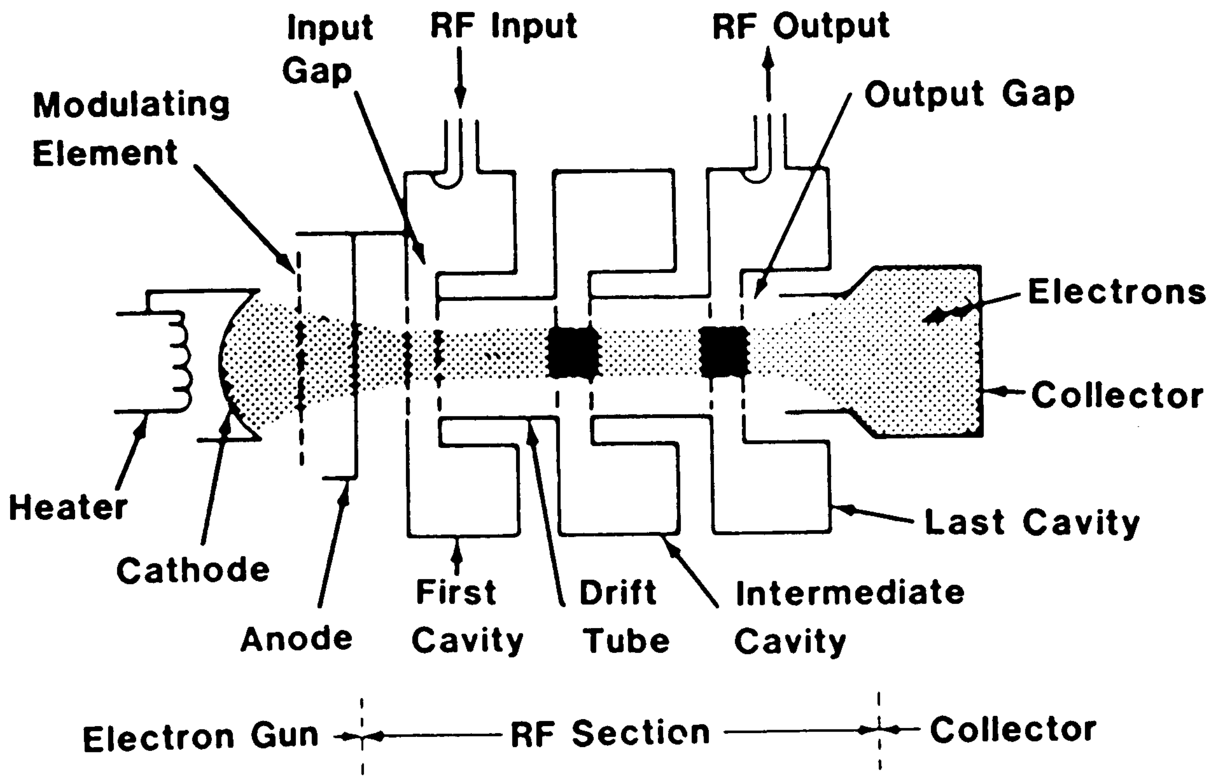

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S-Band 35 MW Klystron (TH2128)

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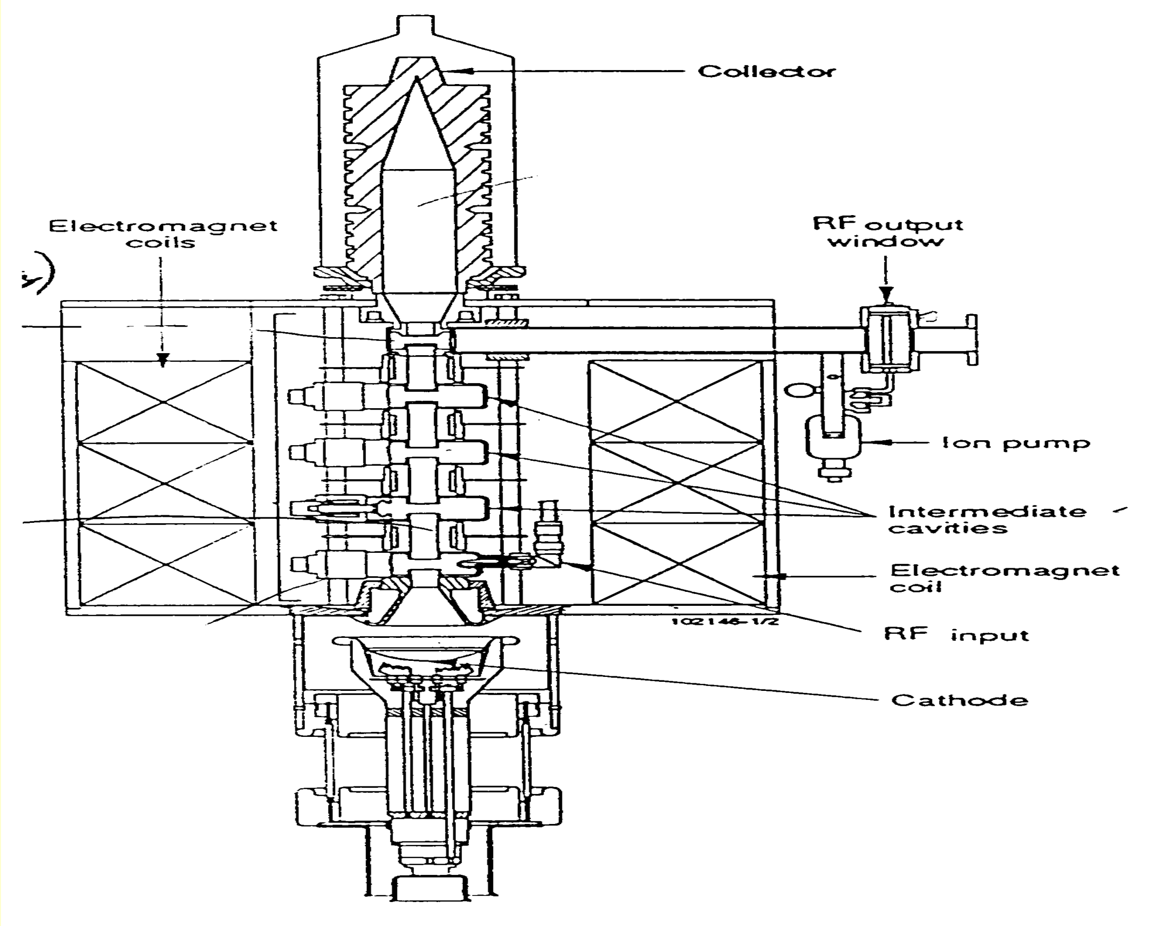
General Description of Thomson Klystron TH2128:



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Main Parameters of TH2128 Klystron:

Frequency	2856 MHz
Peak Output Power	35 MW
Average Power	11kW
RF Pulse Duration	5μsec
Peak Beam Voltage,Max	300 kV
Peak beam Current,Max	300 A
Peak RF Drive Power, Max	200 W
Efficiency	42%
Perveance	1.9 to 2.15 $\mu A \cdot V^{-3/2}$
Filament Voltage	20 to 30 V
Hot Filament Resistance	1.1 Ω
Cold Filament Resistance	0.1 Ω

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Typical Operation:

Frequency	2856 MHz
VSWR, Max.	1.1:1
Peak Beam Voltage	280 kV
Peak Beam Current	297 A
Peak RF Power	35 MW
Average Output Power	10.5 KW
RF Pulse (at -3 dB)	5 μsec
Power Dissipated on the Body	800 W

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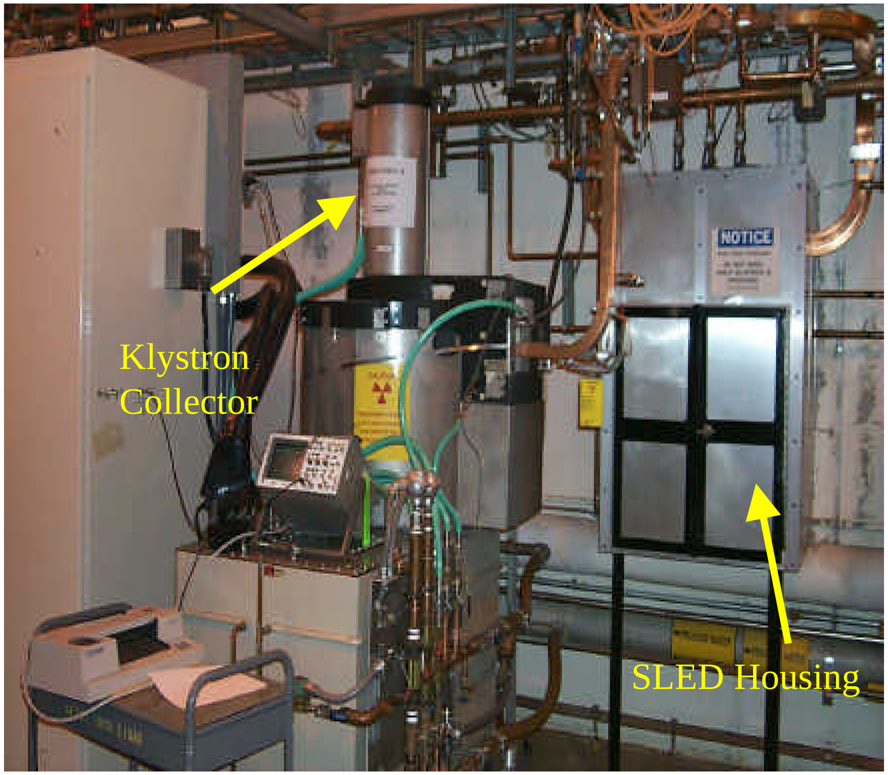

Klystron/SLED Unit

WG Coupler at the output of the klystron

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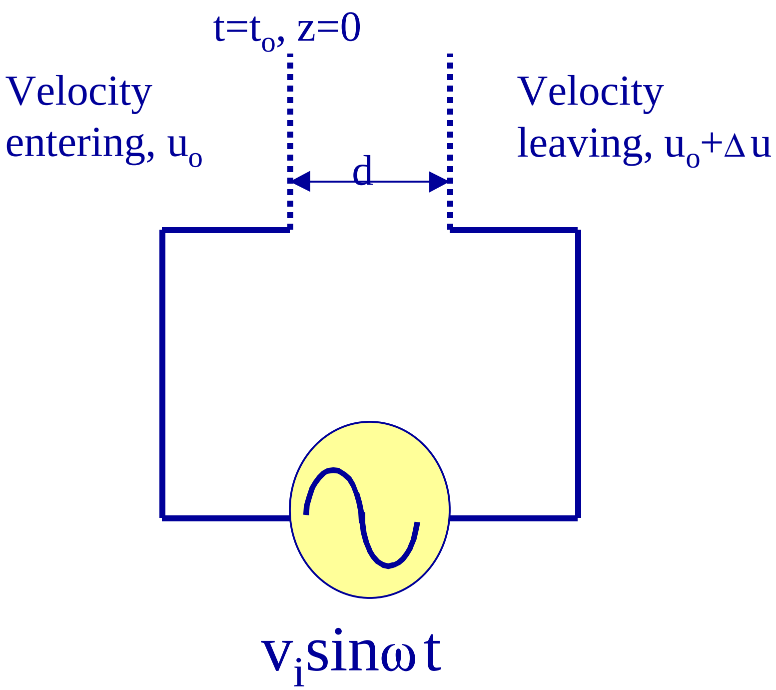
Velocity Modulation



When electrons are passed through the modulating field, some electrons have their velocities increased and some will have their velocities decreases when the voltage is reversed.

As the electrons leave the gap, those with increased velocities overtake the slower electrons, as a result electron bunching (density modulation) occurs.

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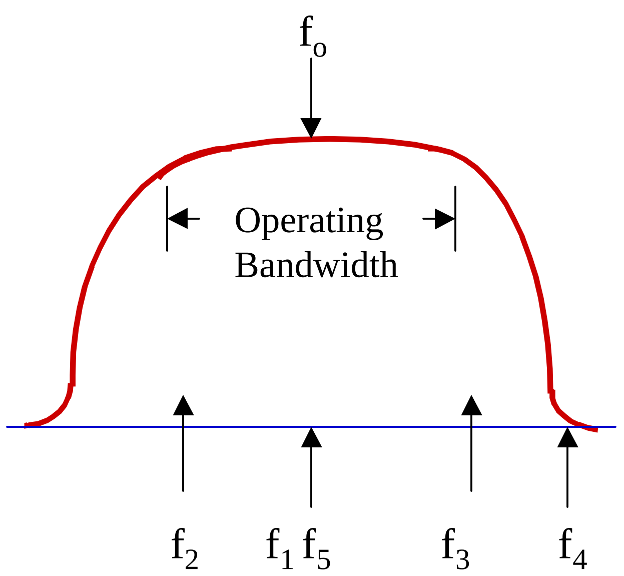
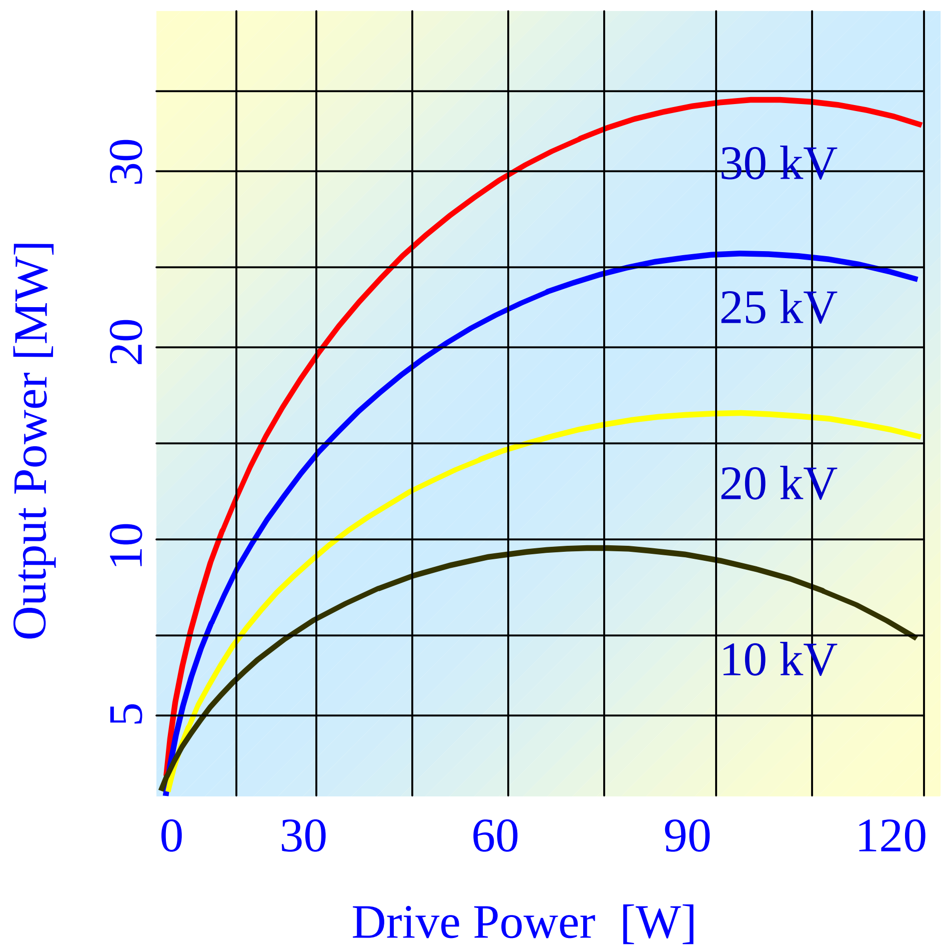
Cavity Bandwidth



Typical Klystron Saturation Curves



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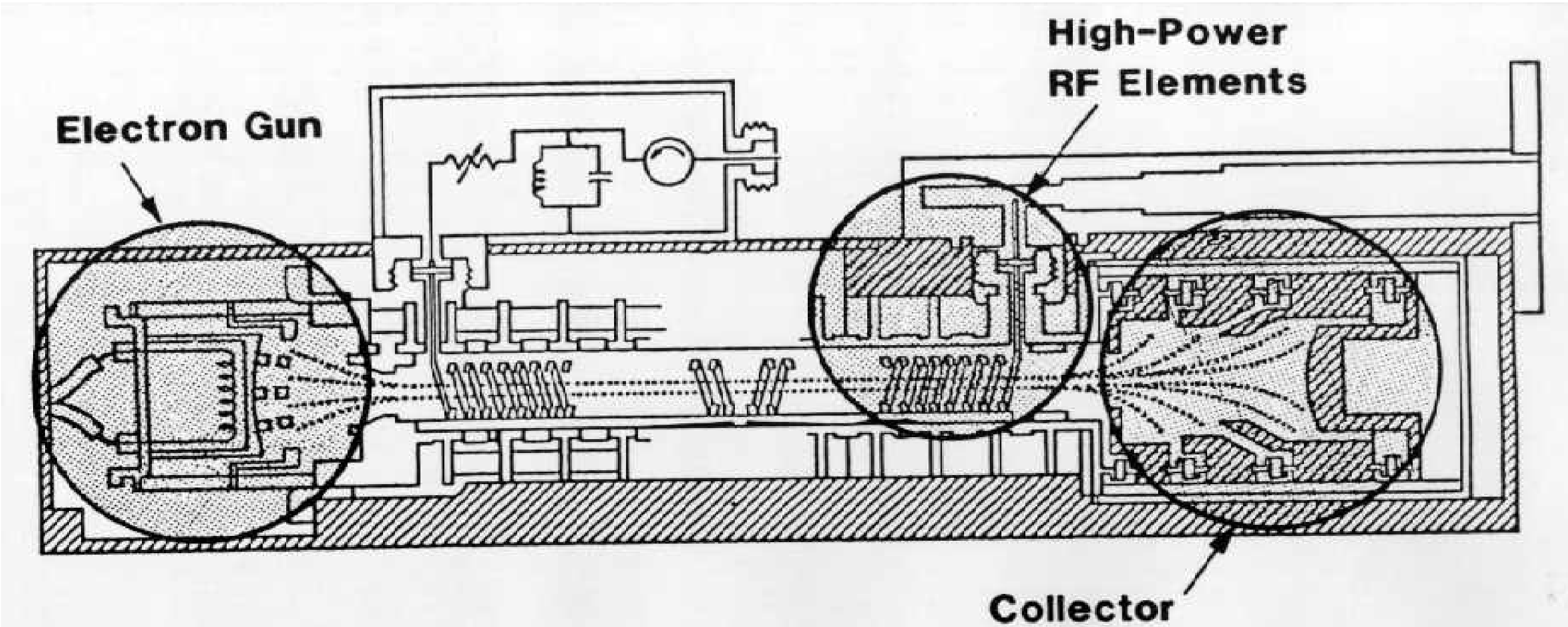
Breakdown and Protection



- In the gun (between electrodes,between leads or from electrodes or leads to ground)
- In the collector
- In high-power portion of the RF structure

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RF Components:

- Driver amplifier to power klystron
- Klystron is used to generate high peak power (A small accelerator)
- Need to transport power to the accelerating structure
- Waveguide is used (under vacuum) to propagate and guide electromagnetic fields
- Windows (dielectric material, low loss ceramic) are used to isolate sections of the waveguide
- Termination loads (water loads) are used to provide proper rf match and to absorb wasted power
- Power splitters are used to divide power in different branches of the waveguide run

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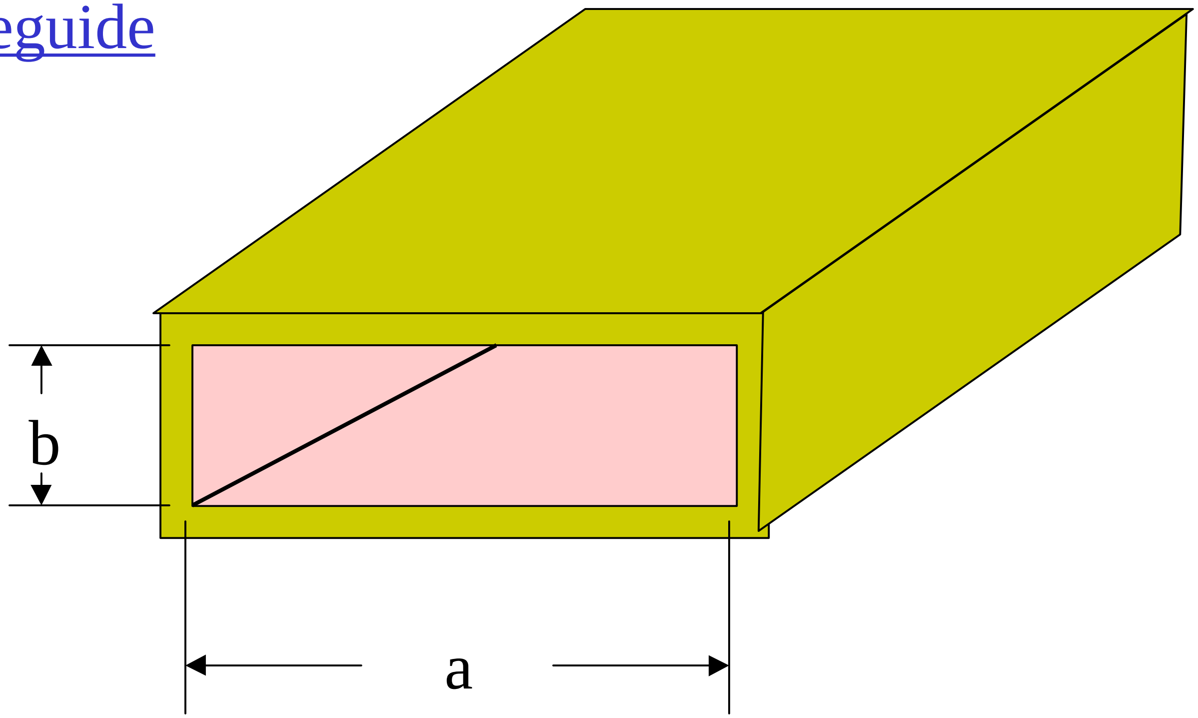
Rectangular Waveguide

Cut-off frequency:

$$f_c = \frac{c}{2a}$$



For S-band:

$$a = 8\ cm$$

$$f_c = \frac{3\times 10^{10}\ cm/\sec}{16\,cm} = 1.875\ GHz$$

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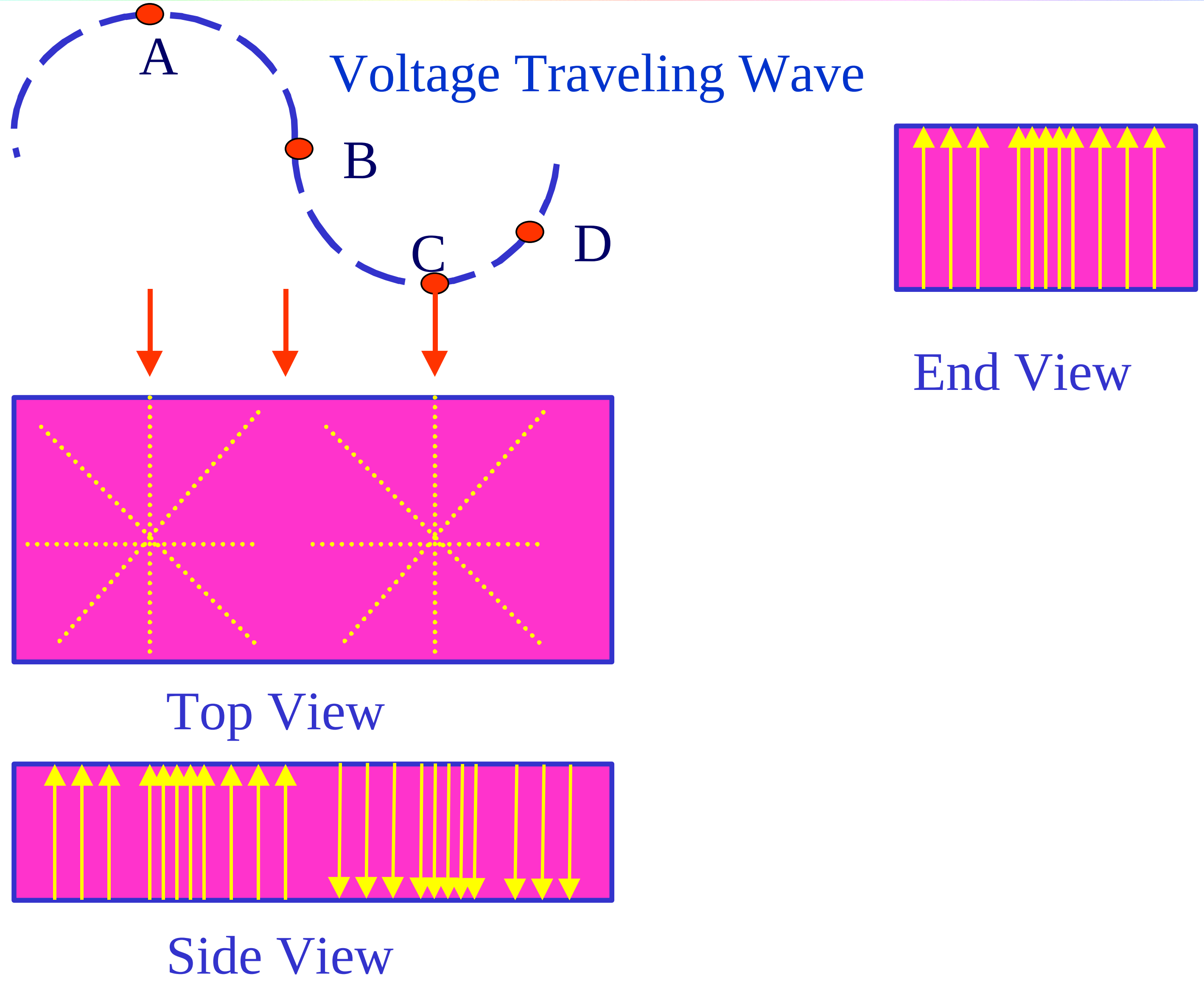

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Guide Wavelength:

$$l_g = \frac{l}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

Using $f_c = 1.875\,GHz$,

$$l_g = \frac{10.5\,cm}{\sqrt{1-\left(\frac{1.875\,GHz}{2.856\,GHz}\right)^2}} = 18.5\,cm$$

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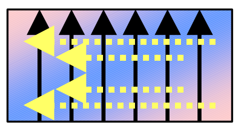
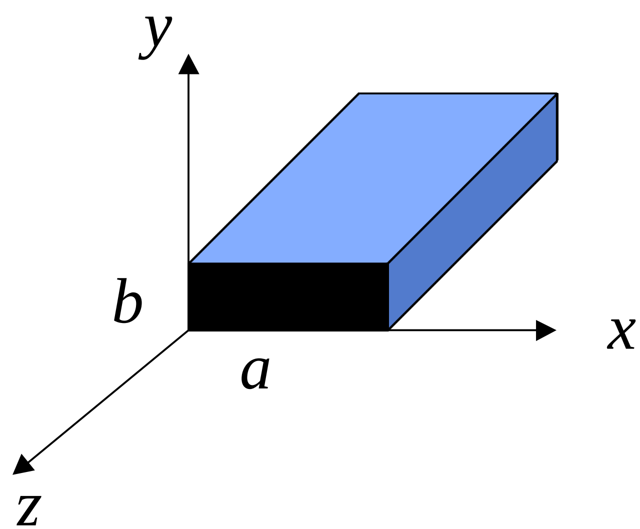
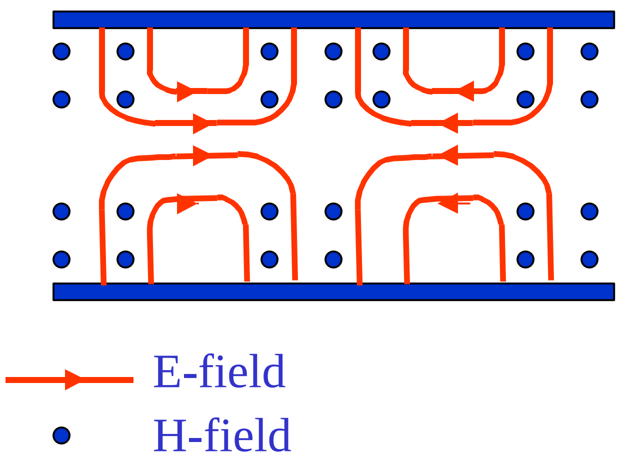
Waveguide Propagation Modes

TE - Transverse Electric Field





TM - Transverse Magnetic Field



$$k = \frac{\omega}{v} = 2\pi \frac{f}{v} = \frac{2\pi}{\lambda}$$

$$k_0 = \frac{2\pi}{\lambda_0}, \quad k_c = \frac{2\pi}{\lambda_c}$$

$$\beta = \left(k_0^2 - k_c^2\right)^{1/2}$$

$\beta \equiv real \Rightarrow$ *propagating* mode

$\beta \equiv imaginary \Rightarrow$ *evanescent* mode

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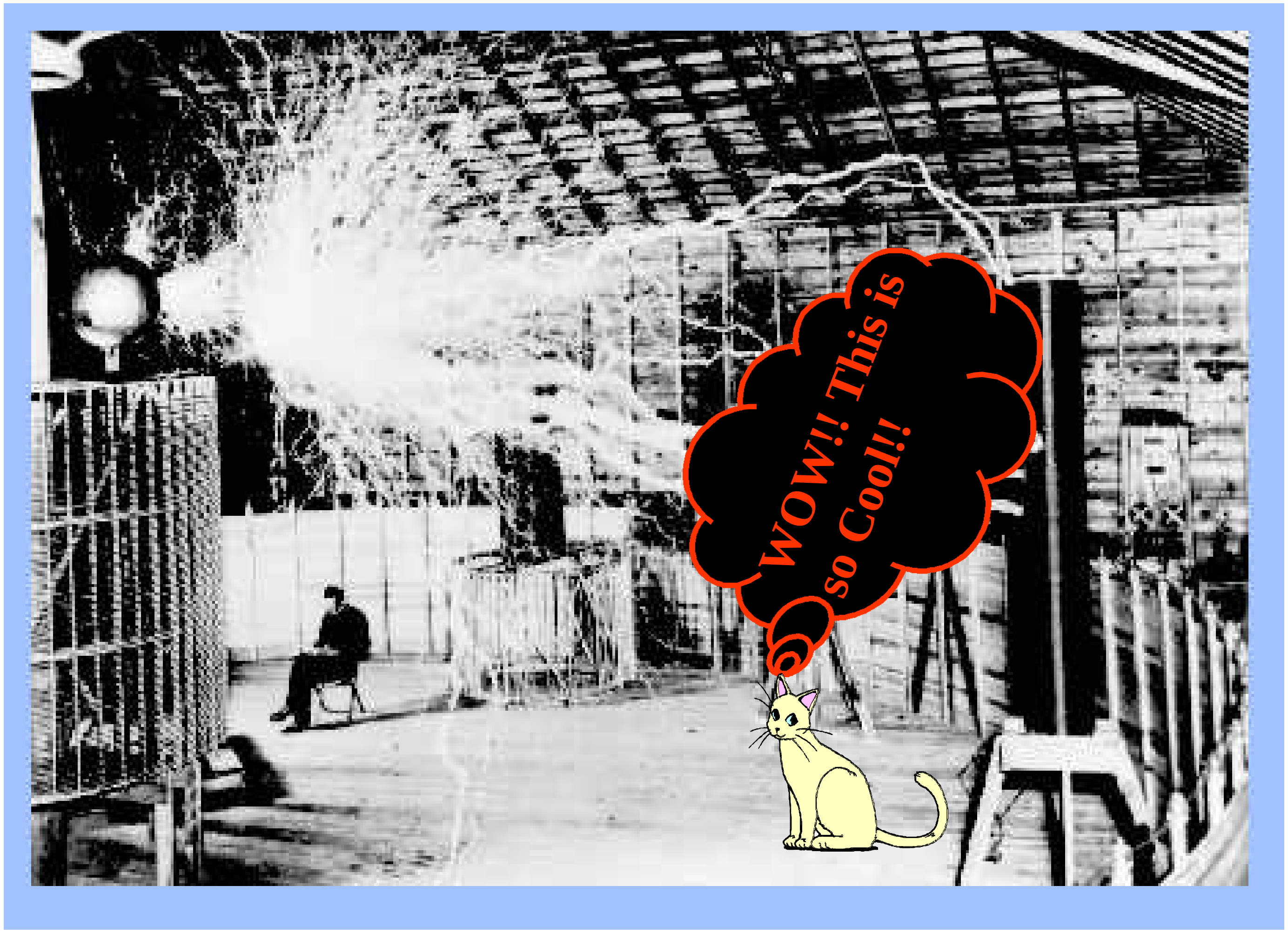

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Breakdown depends on:

- The applied field level and local field enhancement
- The breakdown field of the medium (gas,Vacuum,solid)

Gas	~10's V/cm - 10 kV/cm (depends on pressure and type)
Vacuum	~ 0.5 - 1MV/cm

Types:

- DC Breakdown in Gas
- DC Breakdown in Vacuum
- RF Breakdown in Gas
- RF Breakdown in Vacuum

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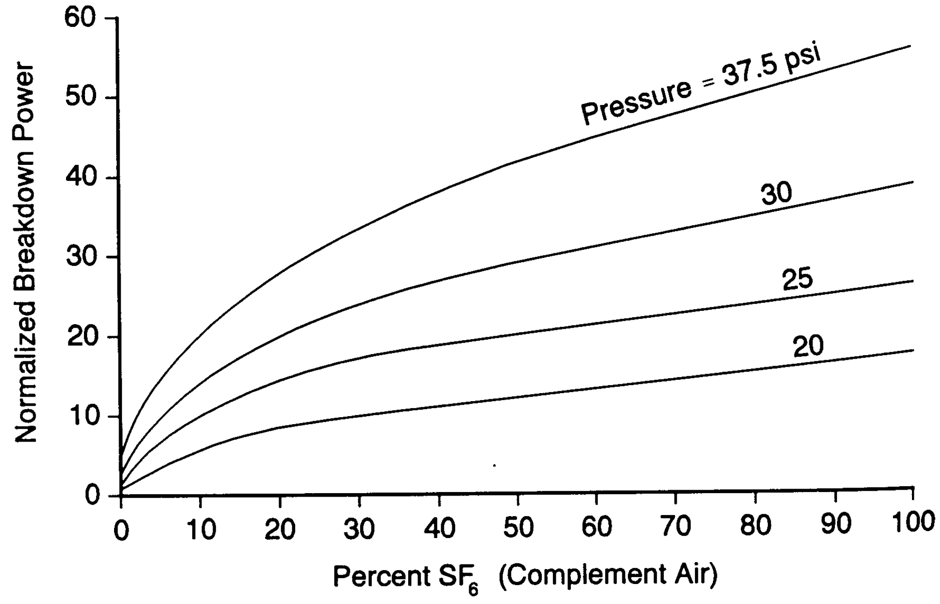
RF Breakdown in Gas:

- DC breakdown field for air at atmospheric pressure is about 30 kV/m
- RF breakdown field depends on the frequency, spacing and pressure



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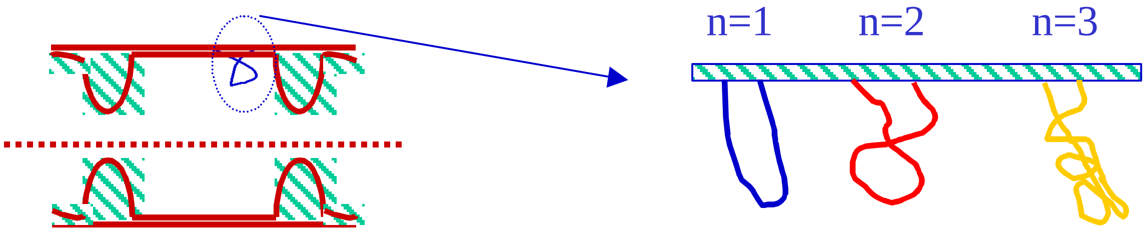
RF Breakdown in Vacuum:

1. Kilpatrick's criterion: Relates max. field E_k[MV/m] at any frequency f[Hz];

$$f = 1.64 \times 10^6 E_k^2 \exp(-8.5 / E_k)$$

Very often, however, another king of discharge develops at voltage levels well below the Kilpatrick level. This discharge is called ***Multipactor Discharge***.

Multipacting occurs when electrons move back and forth across a gap in synchronism with an rf field. If the secondary emission ratio of the gap surface is greater than unity, then the number of electrons involved in the process build up with time and electron avalanche will be initiated and sparking might result.



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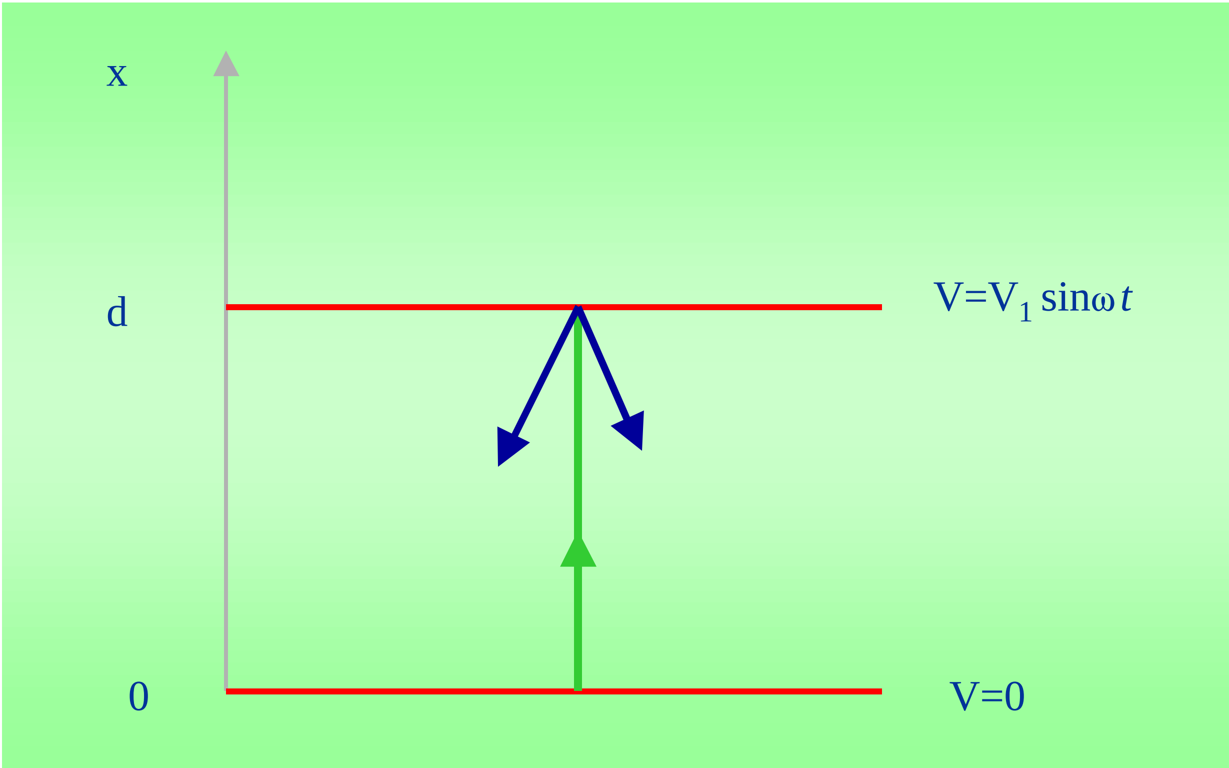
Principle of the Multipactor Discharge:



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Secondary electron emission coefficient of materials used in vacuum tubes:

Matetial	δ_m	E_{pm}(Volts)
Copper	1.3	600
Platinum	1.8	800
Carbon	0.45	500
Alumina	2.35	500

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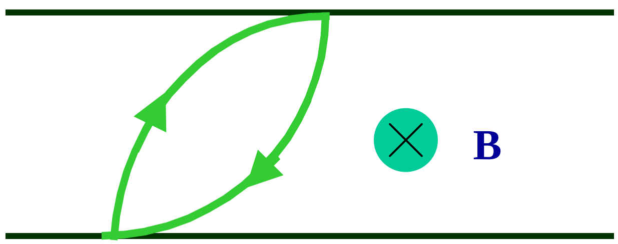
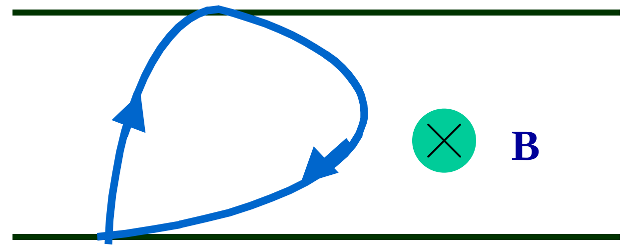
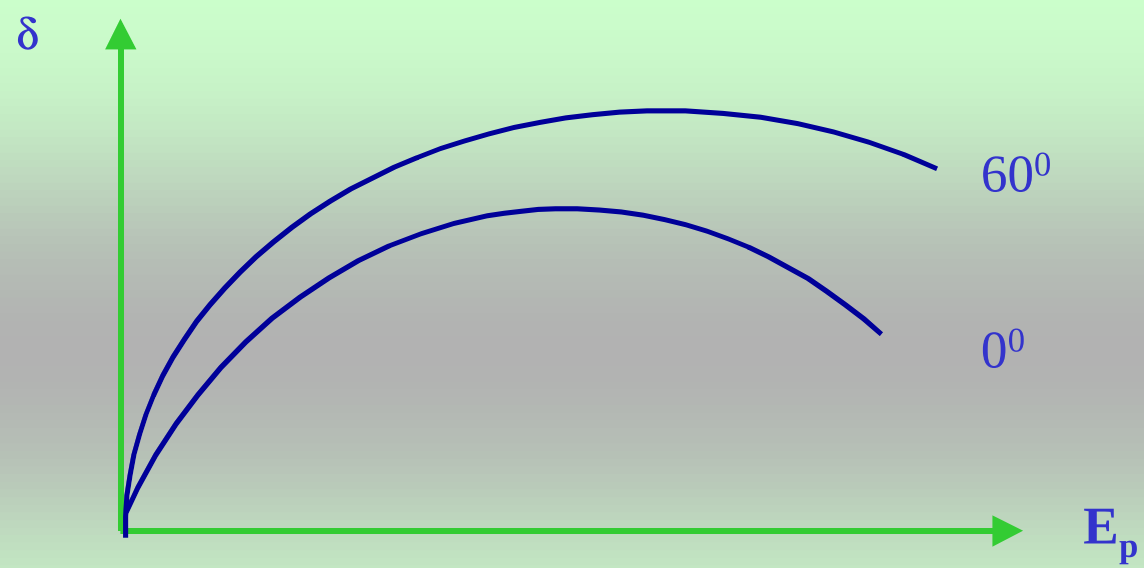




Cross-field multipactor discharges



Effect of the angle of incident on secondary electron emission coefficient

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RF Conditioning with short Pulse: