High Power Microwave Sources EEC746

Topic 1

Introduction

Course Contents

- Introduction: Overview, Static Fields Produced by Electrons
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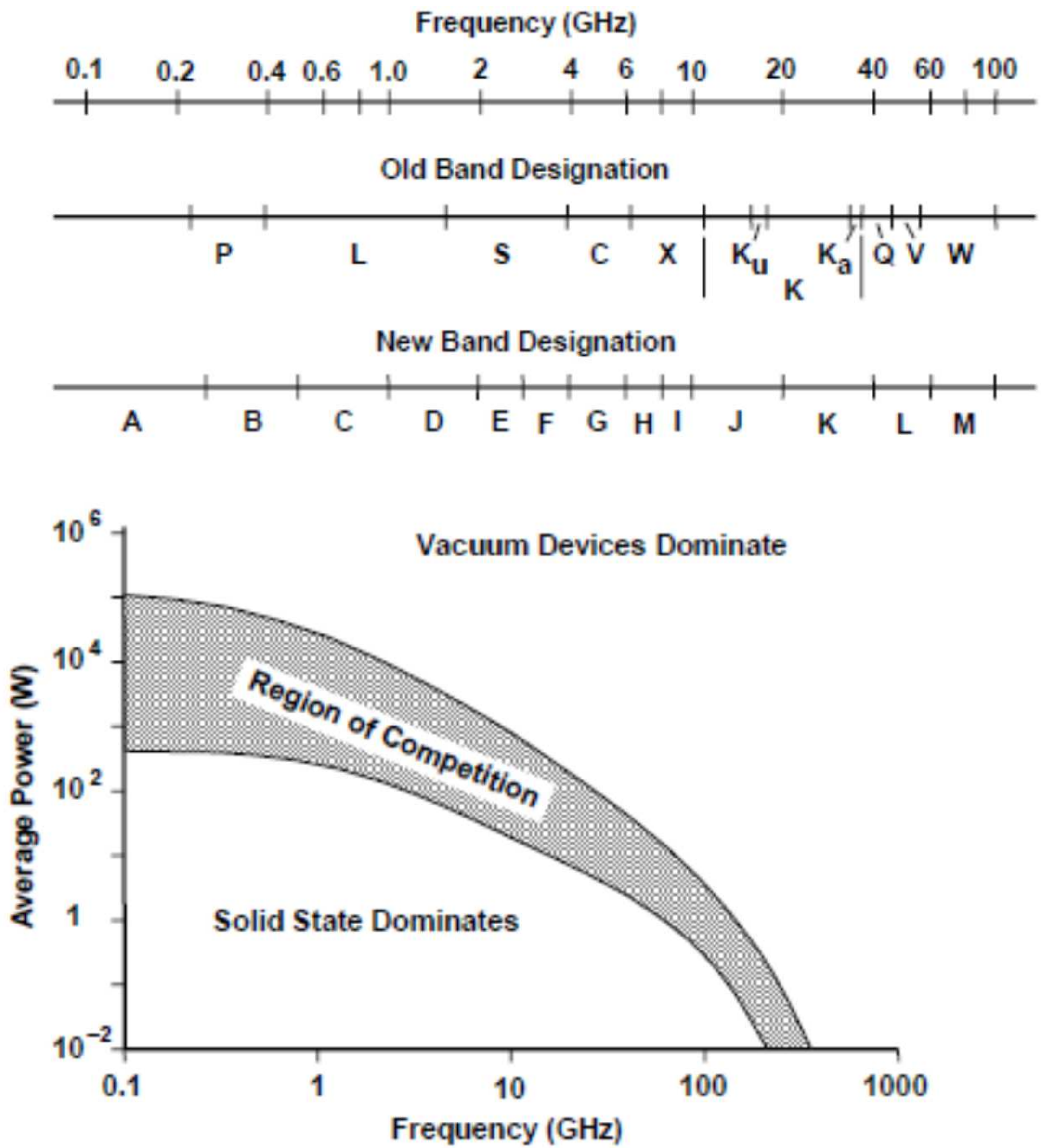
- Traveling Wave Tubes TWT
- Crossed Field Devices (Magnetron)
- Gyrotron
- References:

  - (Main Reference) A. S. Gilmour Jr., Klystrons, Traveling Wave Tubes, Magnetrons, Cross-Field Amplifiers, and Gyrotrons, 1st ed. Artech House, 2011.
  - J. Benford, J. A. Swegle, and E. Schamiloglu, High power microwaves, Taylor & Francis, 2007.

The Domain of Microwave Tubes



The Domain of Microwave Tubes

- In general, microwave tubes are far more efficient than solid-state devices. With the use of the appropriate collector technology, tube, efficiencies can approach or, in some cases, exceed 70%.
- Microwave tubes can operate at much higher temperatures than solid state devices. This, coupled with higher efficiency, means that tubes can be smaller and lighter than solid-state devices and still eliminate waste heat.
- Because of their extremely high reliability, traveling wave tubes are the ampliffiers of choice for many satellite applications.
- A factor of great importance in many applications is the large bandwidth for some microwave tubes. This can be over 2 octaves for some helix type traveling wave tubes (TWTs).

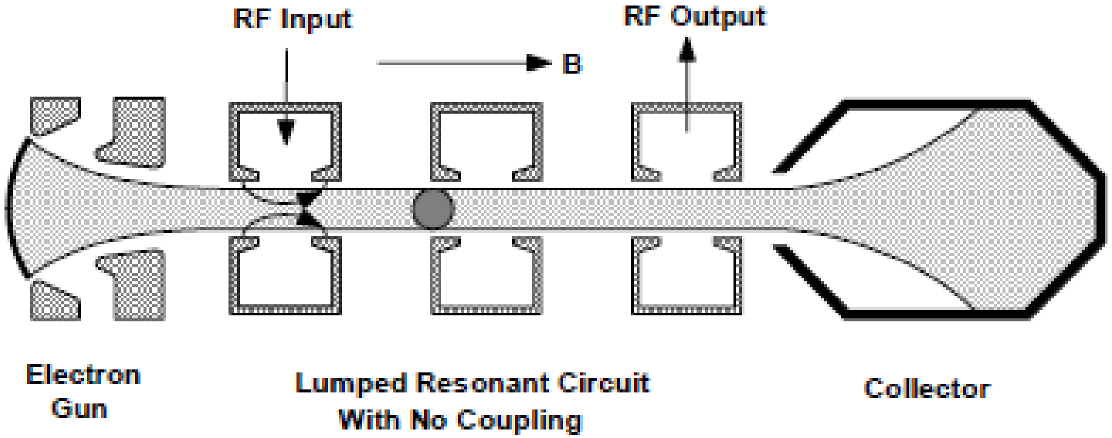
Classifications of Microwave Tubes

Linear-Beam Tubes	Crossed-Field Tubes	Fast-Wave Tubes
Klystrons	Magnetrons	Gyro-Monotrons
Traveling Wave Tubes	Crossed-Field Amplifiers	Gyro-Amplifiers

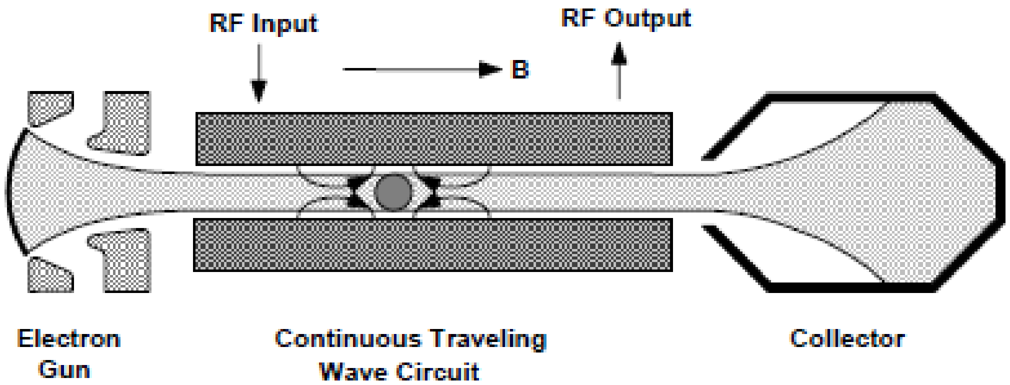
- Linear-Beam Tubes: electron beam is moving linearly along the tube axis.
- Crossed Field Tubes: crossed static electric and magnetic are used to guide the electron beam.
- Fast-Wave Tubes: Interaction is between a rotating annular electron beam and a fast wave.

Classifications of Microwave Tubes

Linear Beam Tubes



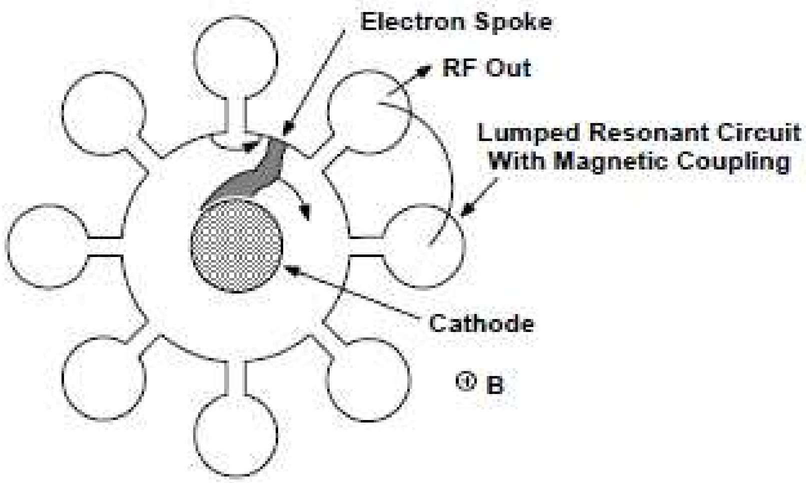
Klystron



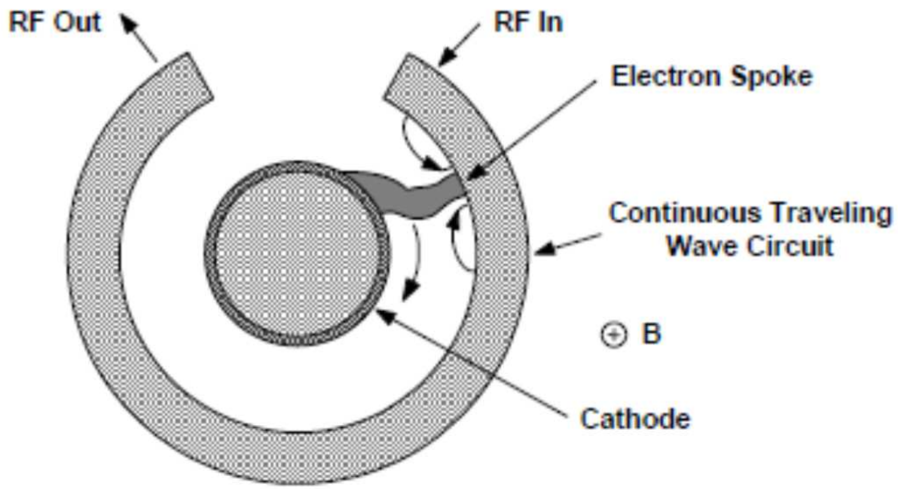
TWT

Classifications of Microwave Tubes

Linear Beam Tubes



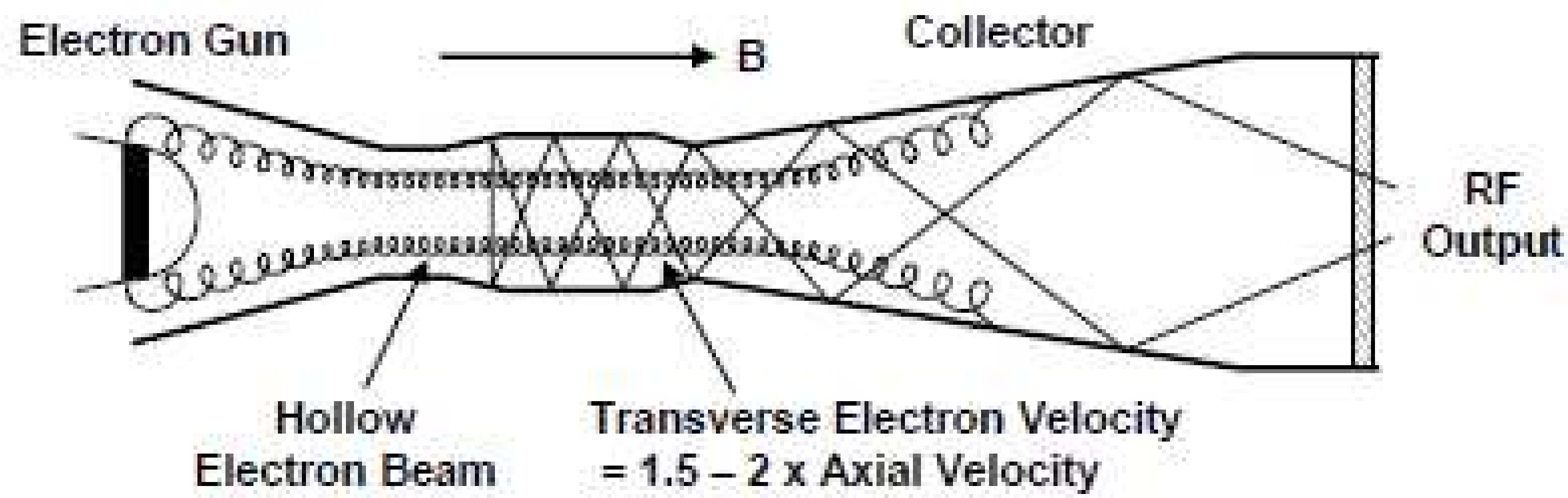
Magnetron



Crossed Field Amplifier

Classifications of Microwave Tubes

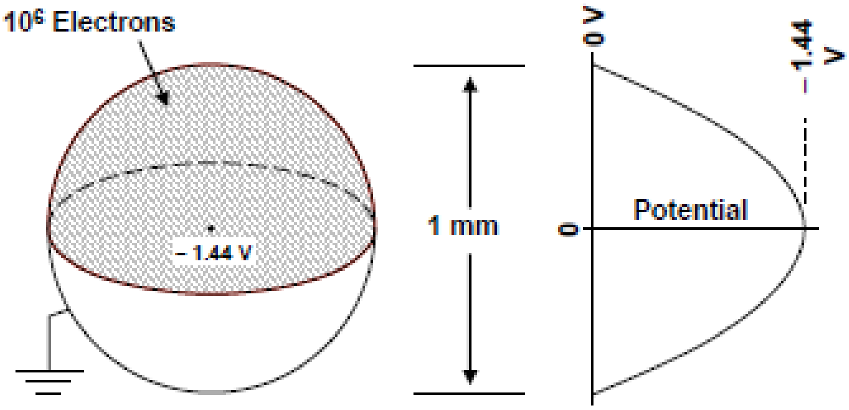
Fast-Wave Tubes



Gyrotron Oscillator

Static Fields Produced by Electrons

Potential depression due to electrons



$$\text{Charge density } \rho = \frac{eN}{4\pi a^3/3}$$

$$\text{Electron charge } e = 1.6022 \times 10^{-16}\ \text{C}$$

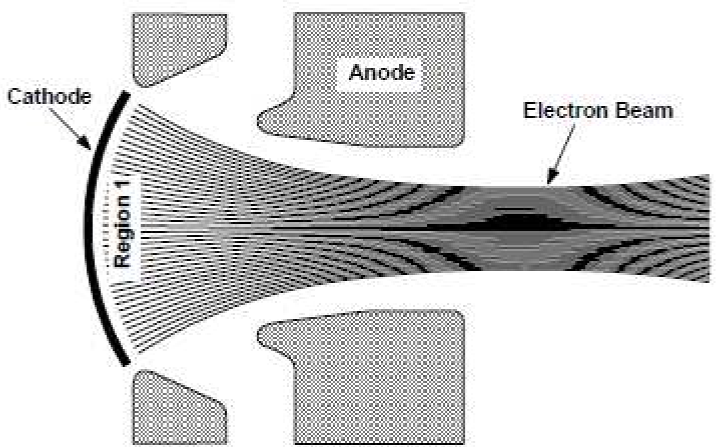
$$\text{Number of charges } N = 10^6$$

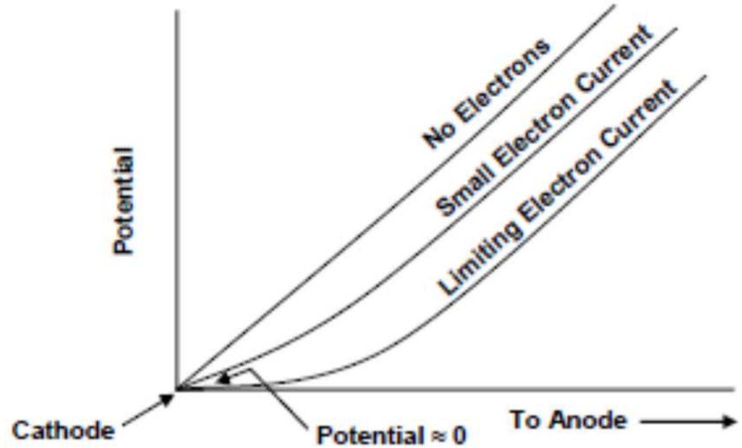
- Potential variation in a sphere containing electrons. The potential depression in the center of a sphere with a 1-mm diameter containing 10^6 electrons is 1.44V.

$$\nabla^2 \Phi = -\left(-\rho\right)/\epsilon_0 \qquad \Longrightarrow \qquad \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial \Phi}{\partial r}\right) = \frac{\rho}{\epsilon_0}$$

$$\Phi = \frac{-\rho}{6\epsilon_0}\left(a^2 - r^2\right), \qquad \Phi\left(r=0\right) = \frac{-\rho a^2}{6\epsilon_0} = \frac{-eNa^2/6\epsilon_0}{4\pi a^3/3} = \frac{-eN}{8\pi\epsilon_0 a}$$

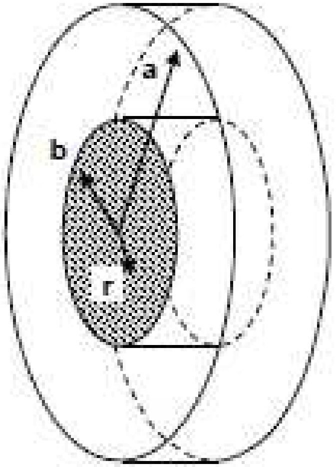
Potential Near the Cathode

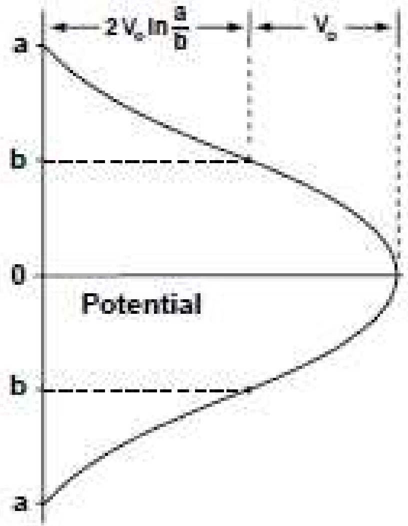




- Each electron extracted from the cathode, depresses (reduces) the nearby potential.
- When cathode temperature is high enough the potential near the cathode is nearly zero, and the current is saturated to a limiting value called (charge limiting current).
- Space Charge limiting current is not dependent on the cathode temperature.

Potential Depression inside the beam





$$\rho = \frac{I}{\pi b^2 v_0}, \qquad v_0 = \sqrt{2\eta V_b}$$

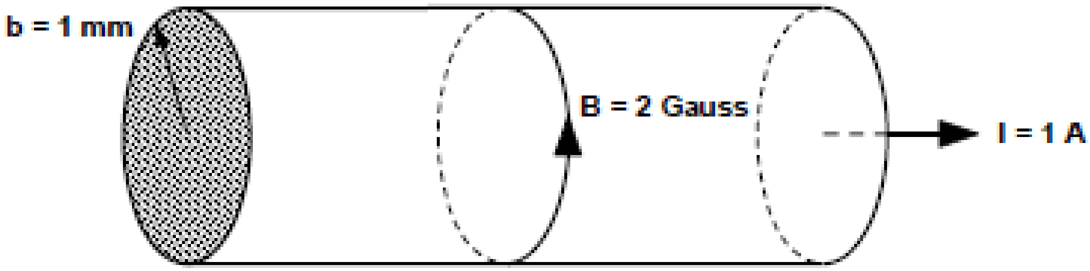
$$\rho = \frac{I}{\pi b^2 \sqrt{2\eta}\sqrt{V_b}}$$

where $\eta = e/m = 1.7588 \times 10^{11}$ C Kg^{-1}

- No external electric field exists.
- Electrons have acquired energy by the applied cathode potential V_b.
- Voltage depression between the beam axis and the outer beam radius b is, $V_0 = \frac{\rho b^2}{(4\epsilon_0)} = \frac{1}{4\pi\epsilon_0\sqrt{\epsilon_0}} \frac{I}{\sqrt{V_b}}$.
- The voltage depression to the outer conductor is,

$$V = 2V_0 \ln\left(\frac{a}{b}\right) + V_0$$

Magnetic Field Induced by the Beam



Current is opposite to the electron flow direction

- Magnetic field induced by current *I*,

$$B = \mu_0 H = \frac{\mu_0 I}{2\pi b}$$

- TWT contains a 1-A electron beam with radius, *b*=1 mm as shown in the figure. The magnetic flux density is

$B = 2 \times 10^{-4}$ T = 2G   (1 Gauss=10^{-4} T)