Chapter 7

Microwave Tubes

Microwave Tubes

- Microwave tubes are **a type of vacuum tube that can generate and amplify high frequency microwave signals from 300 MHz to 300 GHz**.
- They can generate high output power levels from a few hundred watts to more than 10 MW.
- Examples of microwave tubes are: Klystron oscillator, Klystron amplifier, Magnetron, Travelling wave tubes. Backward wave oscillator.

Limitations of Conventional Tubes in Microwave Frequencies

- Conventional low-frequency tubes like Triodes, Tetrodes, and Pentodes fail to operate at microwave frequencies (MF) because:

As frequency increases, the size of these devices reduces, increasing noise levels, and hence power handling capability reduces.

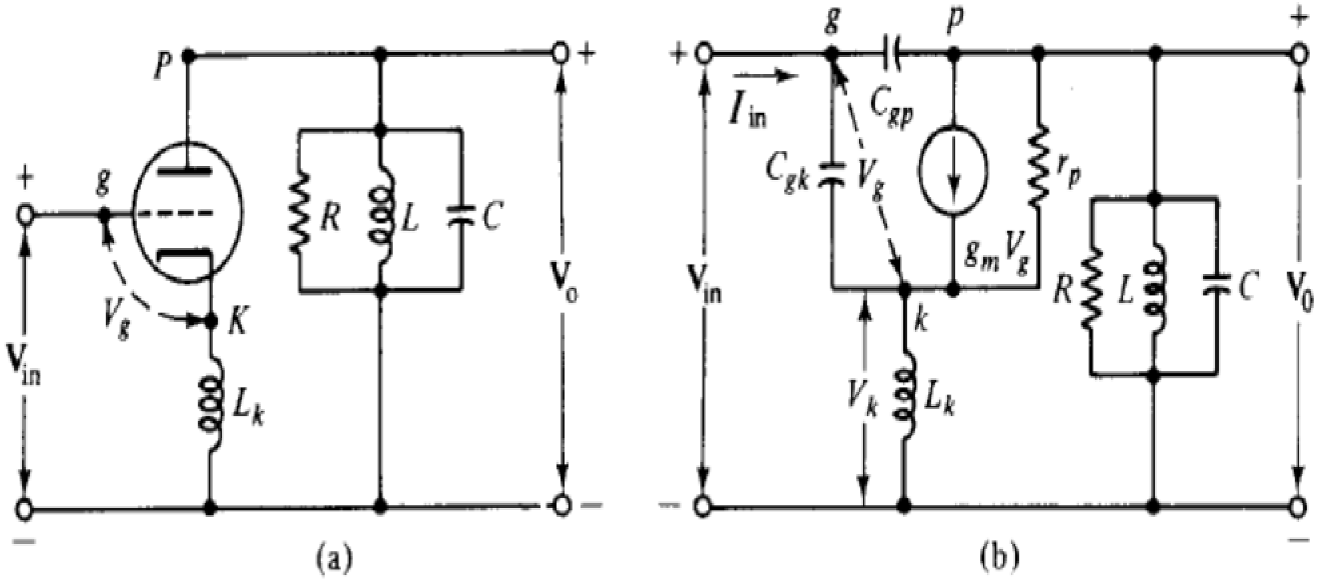
- Due to some characteristics, the conventional tubes and transistors are not used at higher frequencies:

a) Interelectrode Capacitances
b) Lead Inductance Effect
c) Gain Bandwidth Limitation
d) Transit time effect
e) Skin Effect
f) Dielectric Losses

Interelectrode Capacitance and Lead Inductance

- Vacuum has a dielectric constant of 1. As the elements of the triodes are made of metal and are separated by a dielectric, capacitance exists between them. This capacitance is known as interelectrode capacitance.

- The capacitance between the plate and grid is C_{pg}. The grid-to-cathode capacitance is C_{gk}. The total capacitance across the tube is C_{pk}.



a) Triode Circuit, b) Equivalent Circuit

Input voltage Vin and input current Iin is given as:

$$\mathbf{V}_{in} = V_g + V_k = V_g + j\omega L_k g_m V_g$$

$$\mathbf{I}_{in} = j\omega C_{gk} V_g$$

$$\mathbf{V}_{in} = \frac{\mathbf{I}_{in}(1 + j\omega L_k g_m)}{j\omega C_{gk}}$$

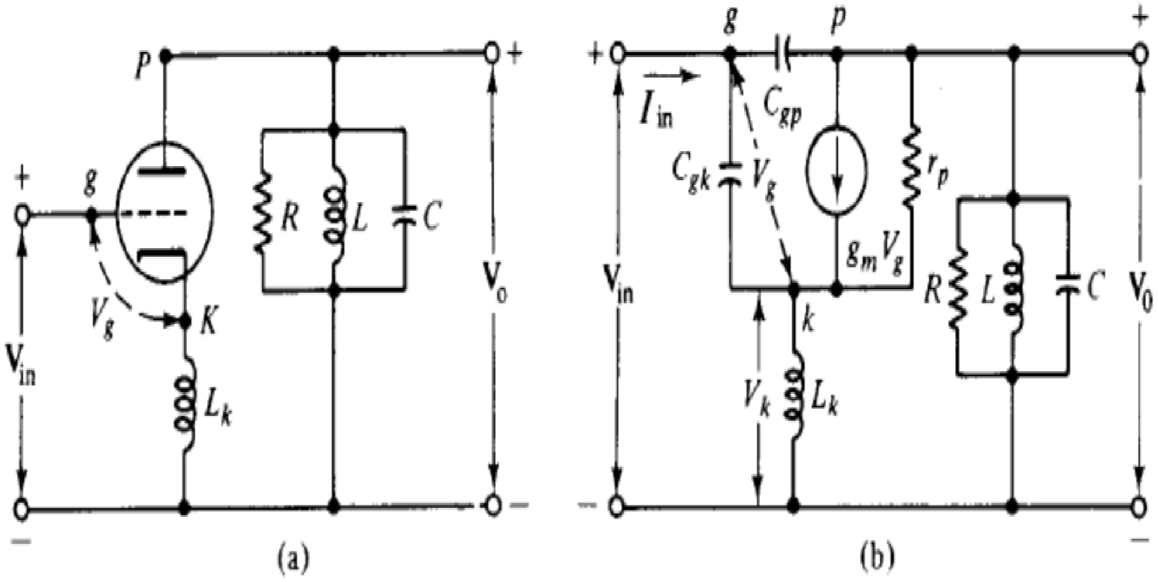
a) Interelectrode Capacitance

The input admittance of the tube is approximately

$$\mathbf{Y}_{in} = \frac{\mathbf{I}_{in}}{\mathbf{V}_{in}} = \frac{j\omega C_{gk}}{1 + j\omega L_k g_m} = \omega^2 L_k C_{gk} g_m + j\omega C_{gk}$$

At higher frequencies, the input impedance of the tube is given by:

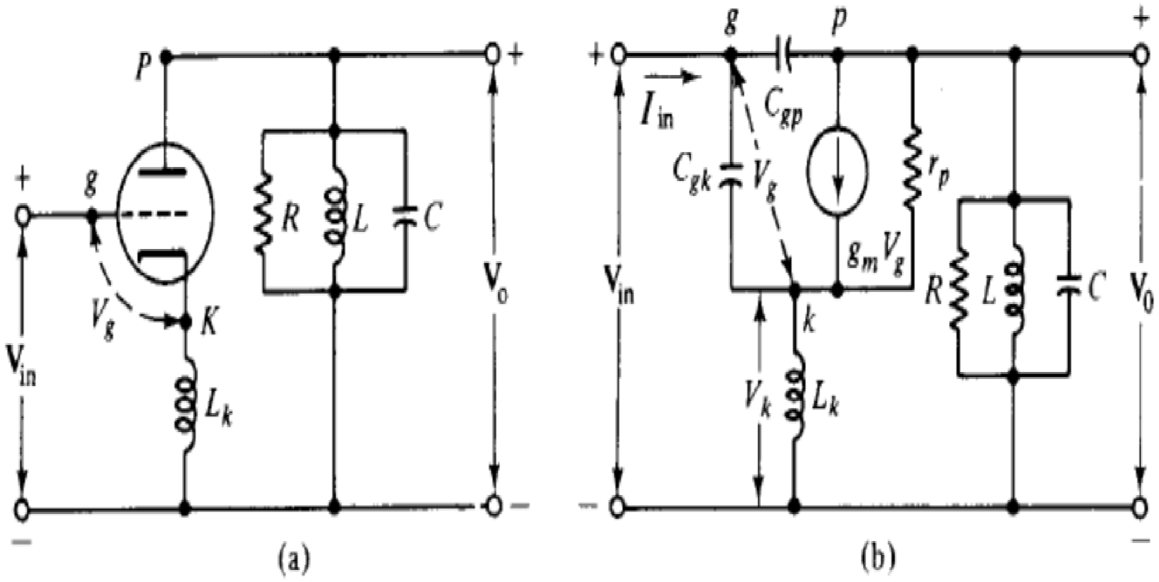
$$\mathbf{Z}_{in} = \frac{1}{\omega^2 L_k C_{gk} g_m} - j\frac{1}{\omega^3 L_k^2 C_{gk} g_m^2}$$



a) Triode Circuit, b) Equivalent Circuit

- The real part of the impedance is inversely proportional to the square of the frequency and imaginary part is inversely proportional to the cube of the frequency.
- At frequencies > 1 GHz, Z_{in} is very small.
- As the interelectrode capacitance increases, reactance between interelectrodes decreases which cause short circuiting of the signal within the tube.

a) Interelectrode Capacitance

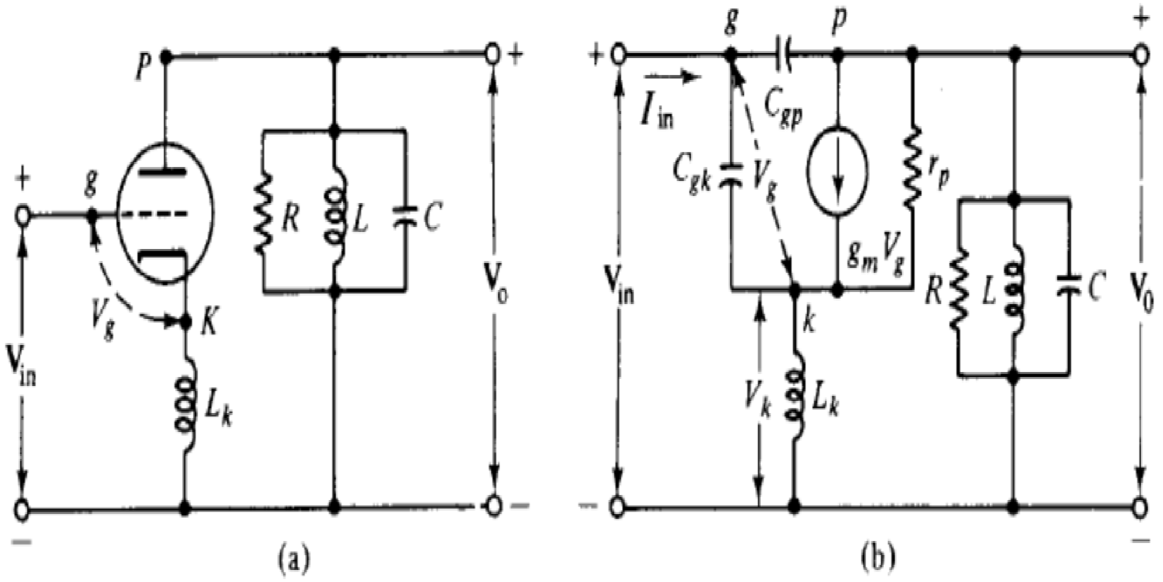


a) Triode Circuit, b) Equivalent Circuit

- Since interelectrode capacitances are in parallel with the tuned circuits, this will affect the resonant frequency of the circuit.
- At frequencies > 1 GHz, Z_{in} is very small.
- As the interelectrode capacitance increases, reactance between interelectrode decreases which causes short-circuiting of the signal within the tube.
- This effect is minimized by using smaller electrodes and by increasing the distance between electrodes. This minimization again decreases the power handling capacity of the device.

b) Lead Inductance

$$\mathbf{Z}_{\text{in}} = \frac{1}{\omega^2 L_k C_{gk} g_m} - j\frac{1}{\omega^3 L_k^2 C_{gk} g_m^2}$$

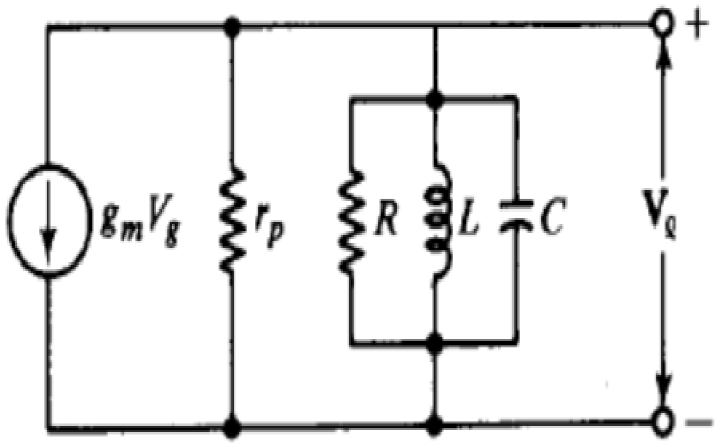


a) Triode Circuit, b) Equivalent Circuit

- At frequencies > 1 GHz, Z_{in} is very small.
- As the lead inductance increases, reactance of the circuit increases which results in the open circuit and a degenerative feedback is created which results in the decrease of efficiency of the device.
- This effect is minimized by using reduction in lead length. This minimization again decreases the power handling capacity of the device.

c) Gain-Bandwidth Limitation

To achieve the maximum gain, the vacuum tubes use the circuit as shown in figure. The output voltage is given by:



a) Output tuned circuit of a pentode circuit

$$V_\ell = \frac{g_m V_g}{G + j[\omega C - 1/(\omega L)]}$$

where $G = 1/r_p + 1/R$
r_p = plate resistance
R = load resistance
L, C = tuning elements

The resonant frequency is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

The maximum voltage gain at resonance Amax is given by:

$$A_{max} = \frac{g_m}{G}$$

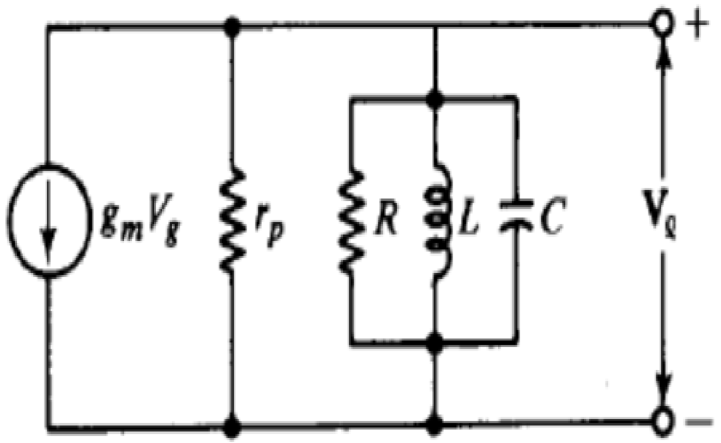
Where, $G = \omega C - \dfrac{1}{\omega L}$

c) Gain Bandwidth Limitation

The roots of quadratic equation is given by:

$$\omega_1 = \frac{G}{2C} - \sqrt{\left(\frac{G}{2C}\right)^2 + \frac{1}{LC}}$$

$$\omega_2 = \frac{G}{2C} + \sqrt{\left(\frac{G}{2C}\right)^2 + \frac{1}{LC}}$$



a) Output tuned circuit of a pentode circuit

The resonant frequency is given by:

$$\mathrm{BW} = \omega_2 - \omega_1 = \frac{G}{C} \qquad \text{for } \left(\frac{G}{2C}\right)^2 \gg \frac{1}{LC}$$

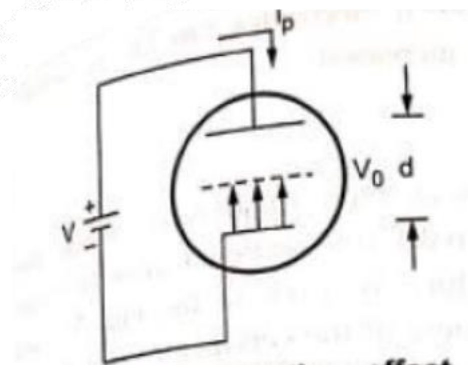
The maximum voltage gain at resonance Amax is given by: $$A_{\max} = \frac{g_m}{G}$$

Gain Bandwidth product is given by: $$A_m(\mathrm{BW}) = \frac{g_m}{C}$$

- ❖ Gain Bandwidth product is independent of frequency. As gain increases, bandwidth decreases. This restriction is applicable to resonant circuits only.
- ❖ To obtain overall high gain over broader bandwidth, slow wave structures are used in microwave tubes.

d) Transit Time effect

- Transit time is the time required by the electrons to travel from the cathode to the anode plate.



d= distance between 2 plates
i_p= Plate current
V= applied input voltage
V_0= output voltage

Transit time is given by: $\tau = \dfrac{d}{v_0}$ where, v_o is the velocity of electrons

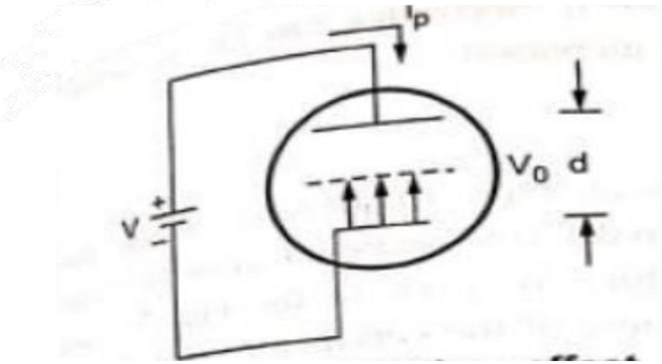
Static energy of electrons is given by: eV

Kinetic energy of electrons is given by: $\frac{1}{2} m v_0^2$

Under equilibrium condition: $eV = \frac{1}{2} m v_0^2$ $v_0 = \sqrt{\dfrac{2eV}{m}}$

d) Transit Time effect

$$\tau = \frac{d}{\sqrt{\frac{2eV}{m}}}$$



- ❖ At lower frequencies, the transit time effect is negligible because the distance between the cathode and anode is negligible concerning wavelength.

- ❖ But at higher frequencies, transit time is large as compared to the period of the microwave signal. Therefore, the potential between the cathode and grid may vary from 10 to 100 times during the electron transmission.

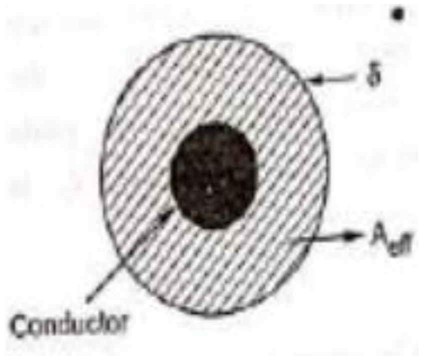
- ❖ The grid potential during the negative half cycle removes energy given to the electron during the positive half cycle. Therefore, the electrons oscillate back and forth in the cathode grid space or return to the cathode.

- ❖ This leads to the reduction of the overall efficiency of the vacuum tube.

- ❖ To minimize this effect, the separation between cathodes ‘d’ can be reduced or plate to cathode potential ‘V’ can be increased.

e) Skin effect

- This effect introduces at higher frequencies when the current flows from the smaller cross-sectional area to the outer surface of the conductor.



$$\delta = \text{skin depth} = \sqrt{2/\omega\mu\sigma}$$

$$\delta \propto \frac{1}{\sqrt{\omega}}$$

$$\delta \propto A_{eff}$$

$$A_{eff} \propto \frac{1}{\sqrt{f}}$$

Resistance is given by relation

$$R = \frac{\rho l}{A_{eff}}$$

$$R = \rho l \cdot \sqrt{f}$$

❑ At higher frequencies, the resistance of the conductor also increases which results in the production of high frequency losses.

f) Dielectric Losses

- There are different insulating materials which are used e.g., glass envelopes in different microwave devices.

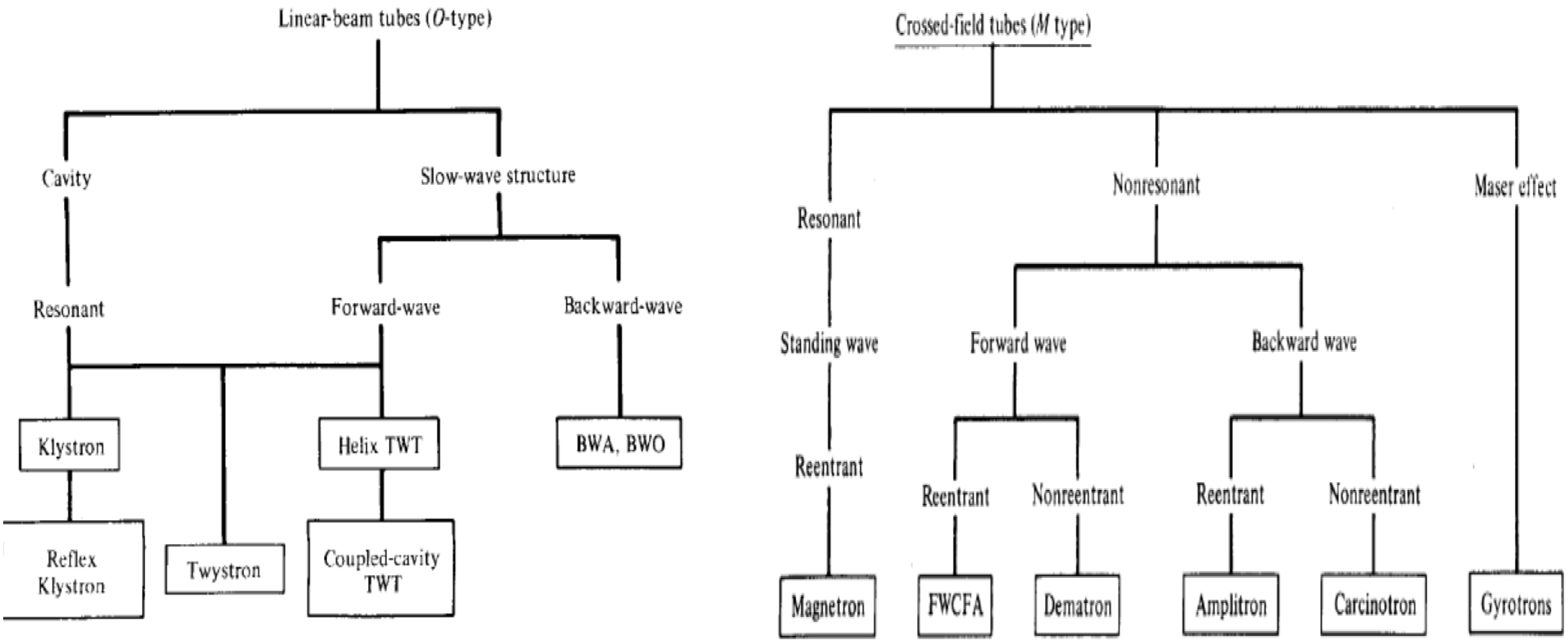
- The loss in these materials is related to power loss by:

$$P = \pi f . V_0^2 \varepsilon_r \tan\sigma$$

- At higher frequencies, the power loss also increases.

- To eliminate these losses, the surface area of glass should be decreased which again limits the power handling capacity.

Classification of Microwave Tubes

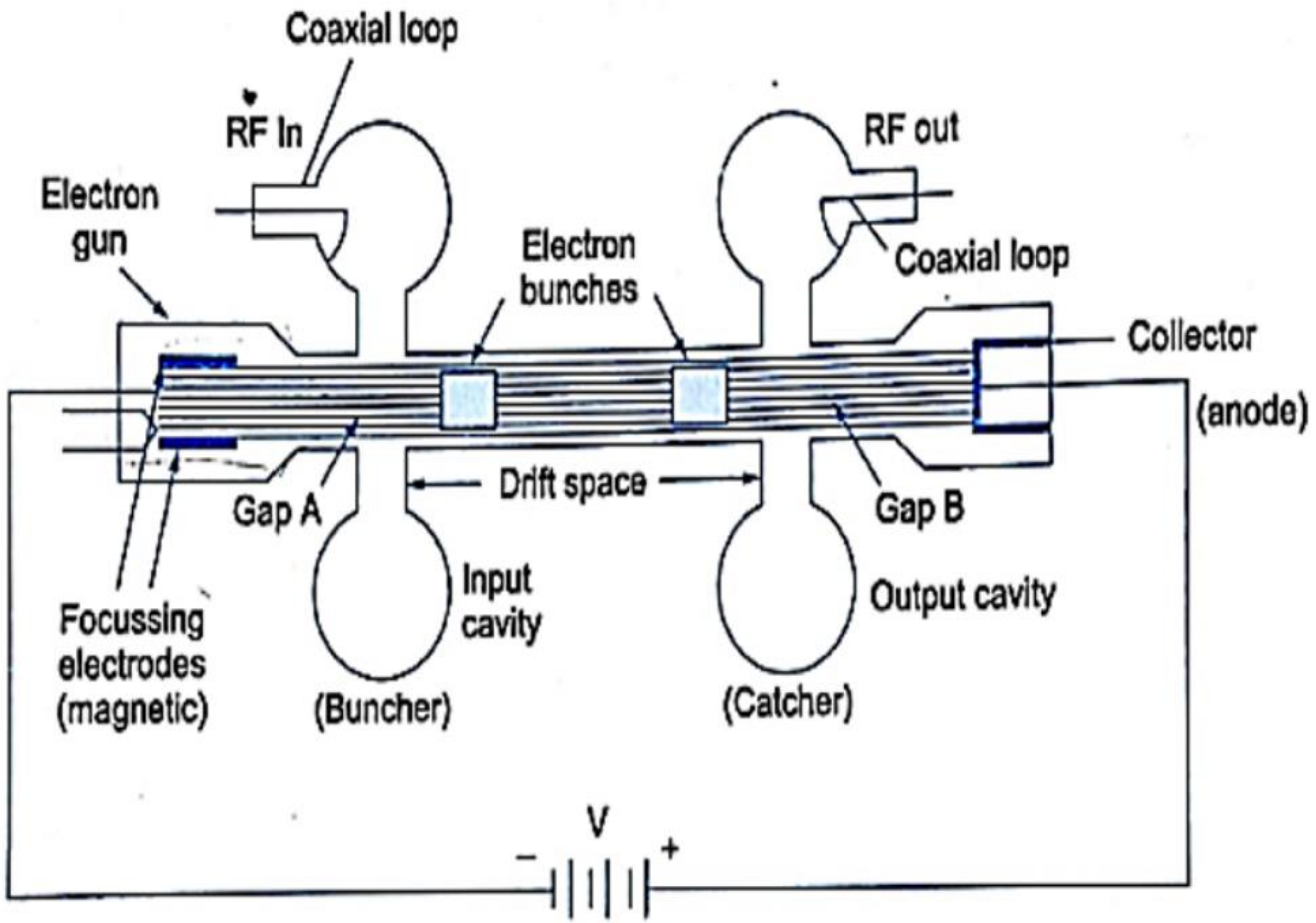


Klystrons

- Klystrons are a special type of vacuum tube that find applications as amplifiers and oscillators at **microwave frequencies**.
- Its principle of operation is **Velocity Modulation**. The variation in the velocity of electrons while moving inside the tube is known as **velocity modulation**.
- Basically, the operating principle of Klystron is such that the kinetic energy of a moving electron beam is utilized for amplifying and generating microwave signals.
- The device used for amplifying microwave signals is known as the **Two-cavity Klystron amplifier**.
- The device used for generating microwave signals is known as **Reflex klystron**.

Two-Cavity Klystron Amplifier: Construction

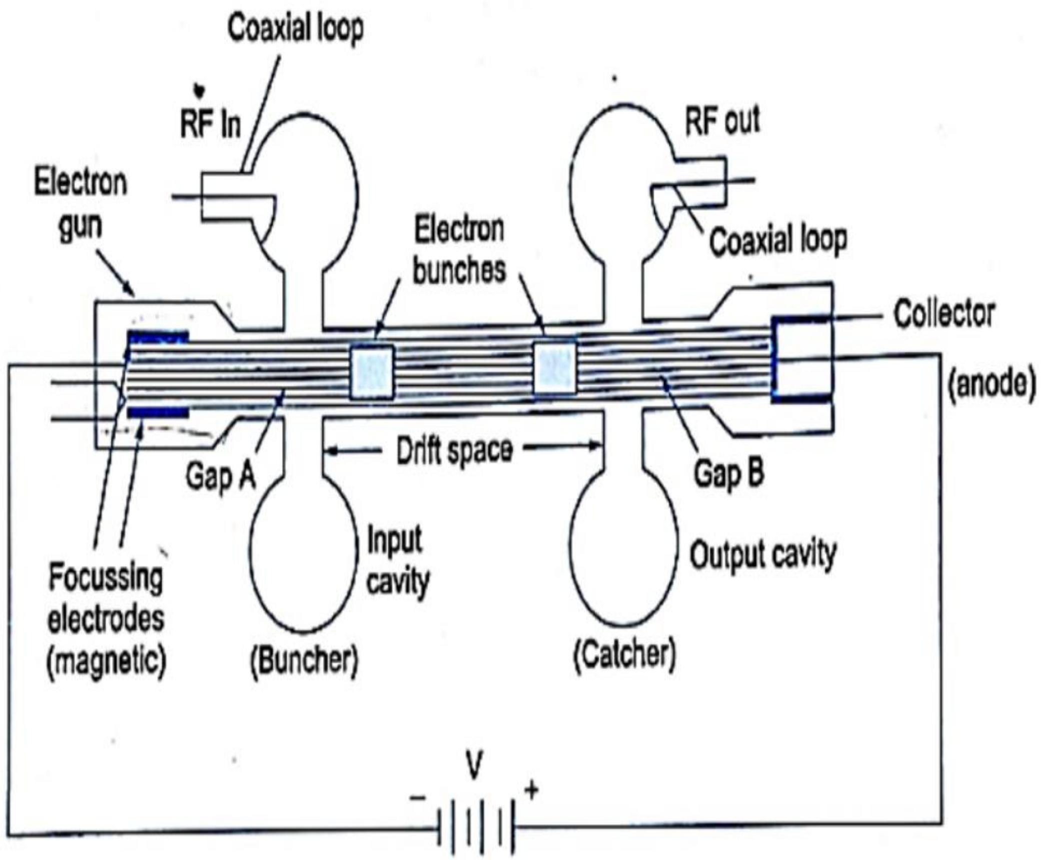
1) Electron Gun
2) Focussing electrodes
3) Buncher Cavity
4) Catcher cavity
5) Drift Space
6) Collector

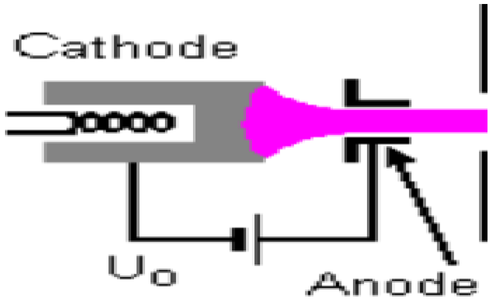


Two-Cavity Klystron Amplifier

1) Electron Gun

- The main function of the electron gun is to produce and accelerate the beam of an electron.
- The electron gun comprises of the cathode, heating element, and anode.
- The electron beam is produced by the cathode by making use of a heating element and the high positive potential at the anode provides the required acceleration to the electron beam initially.





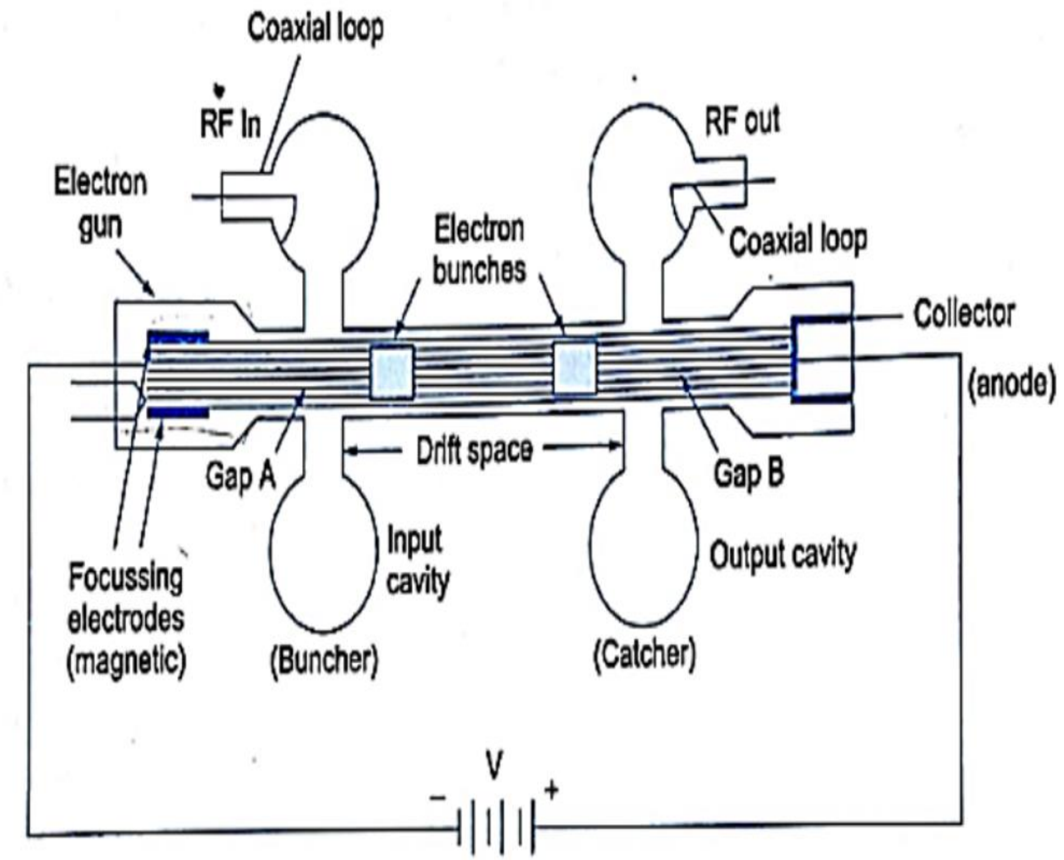
Two-Cavity Klystron Amplifier

2) Focussing electrodes

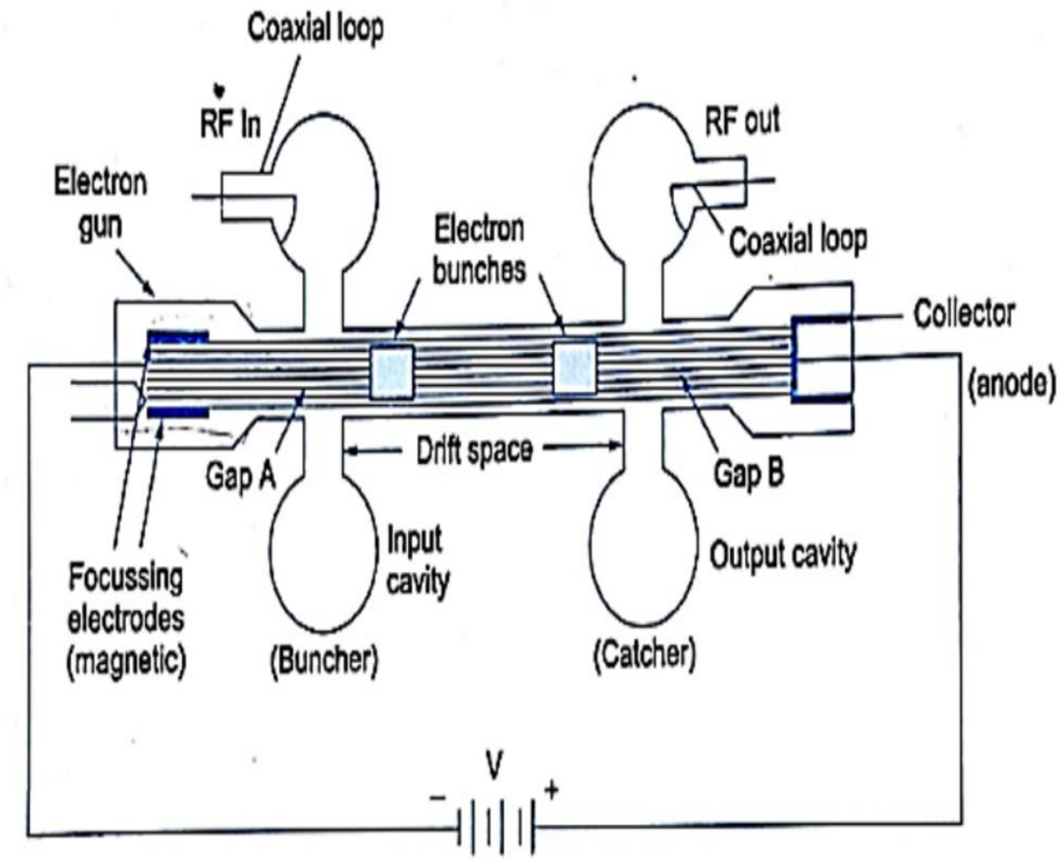
- To allow focussed propagation of electron beam inside the tube, an external electromagnetic winding is used that generates a longitudinal magnetic field.
- This is done in order to prevent the spreading of the beam inside the tube.

3) Buncher cavity

- The RF signal to be amplified is provided at the buncher cavity.
- It is also known as the input cavity.



Two-Cavity Klystron Amplifier



4) Catcher Cavity

- The amplified RF signal is achieved at the catcher cavity.
- It is also known as the output cavity.

5) Drift Space

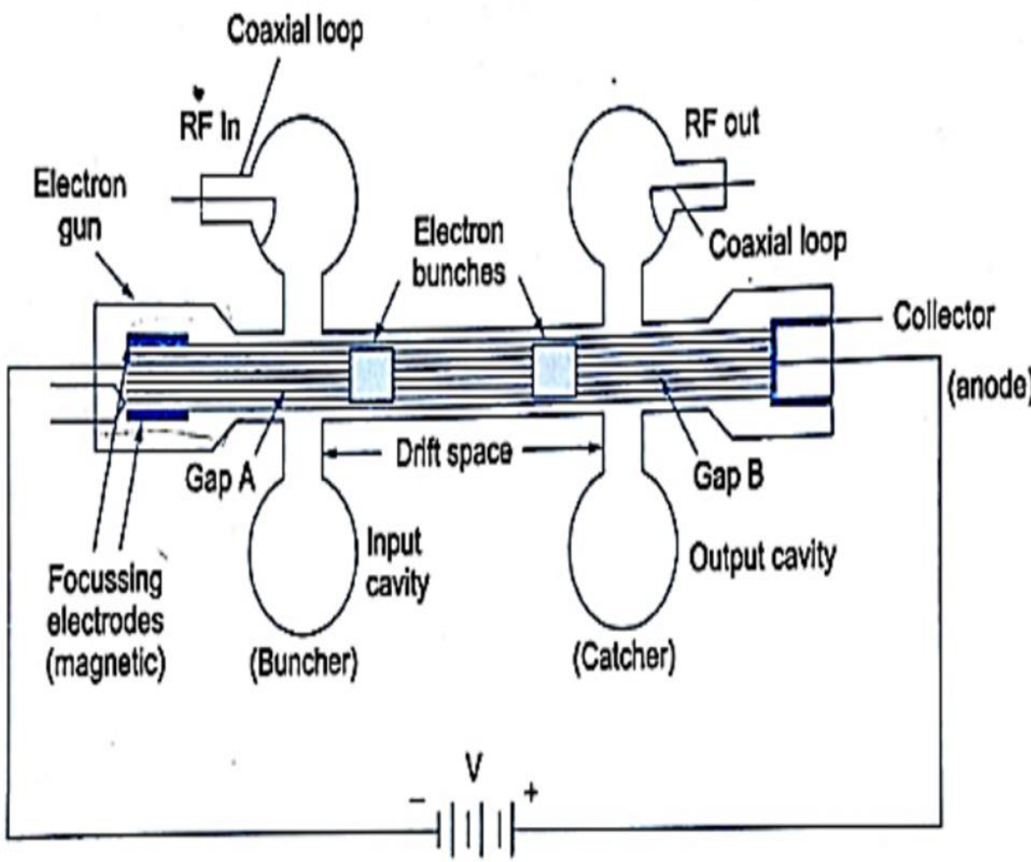
- The region between the two cavities is known as **drift space**.

6) Collector

- The main function of the collector is to collect the bunched electron beam.

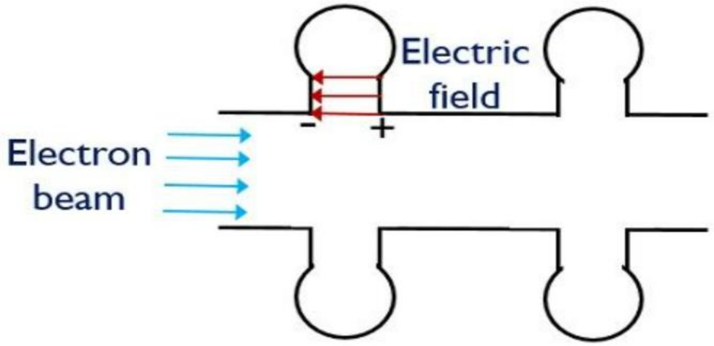
Two-Cavity Klystron Amplifier: Working

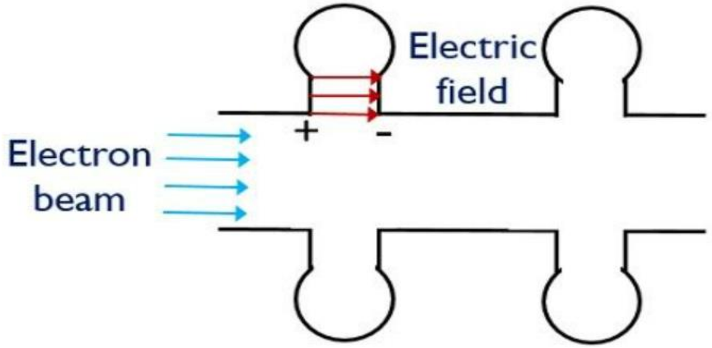
- Initially, electrons are emitted from the electron gun and the anode present in the structure provides the desired acceleration to the beam.
- In the absence of any RF input, the electron will tend to move with their respective uniform velocities to reach the catcher cavity and get collected at the collector.
- The beam first passes through the "buncher" cavity resonator, through grids attached to each side. When the RF input signal is applied to the buncher cavity, standing wave oscillations are produced within the cavity, at the cavity's resonant frequency.



Two-Cavity Klystron Amplifier: Working

- The oscillations within the cavity produce an oscillating electrostatic field between the buncher grids.
- This electric field causes the bunching of electrons as the field applies acceleration and deceleration to the moving electron, according to the polarity of the signal by which the field is generated.



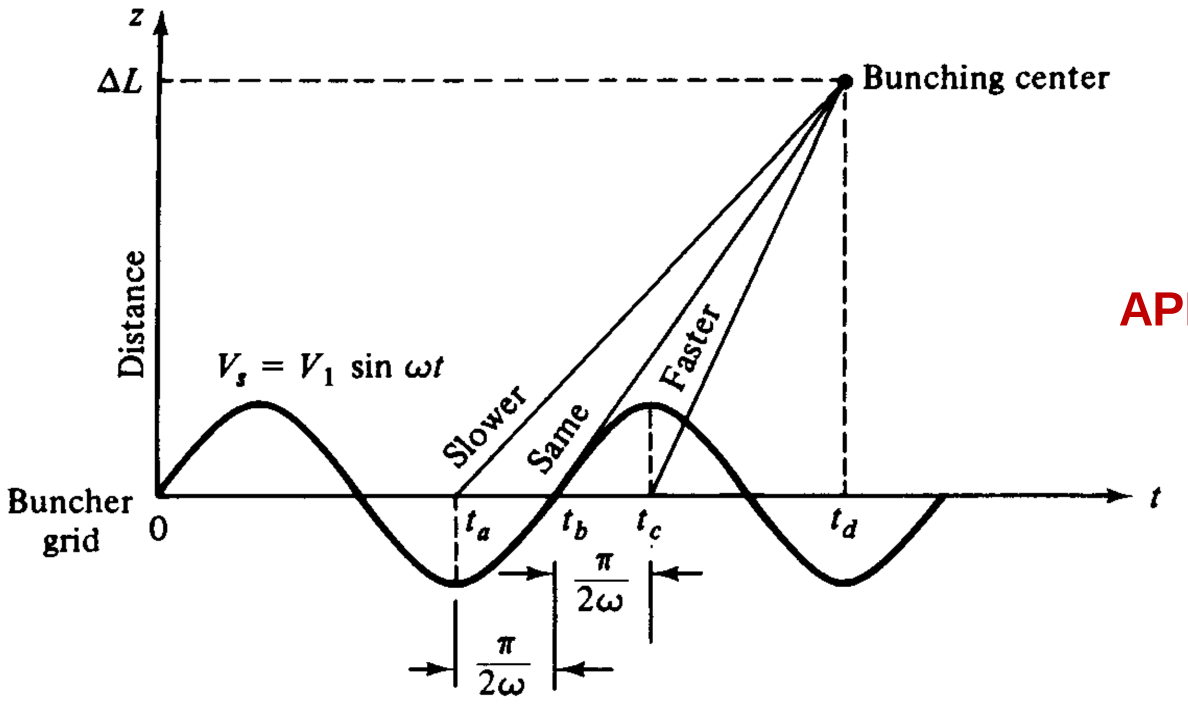


- Negative half of the RF input signal
- Negative charge at the entering plate of the buncher cavity.
- moving electrons experience a repulsive force and get deaccelerated.

- Positive half of the RF input signal
- Positive charge at the entering plate of the buncher cavity.
- moving electrons experience an attractive force and get accelerated.

Two-Cavity Klystron Amplifier: Working

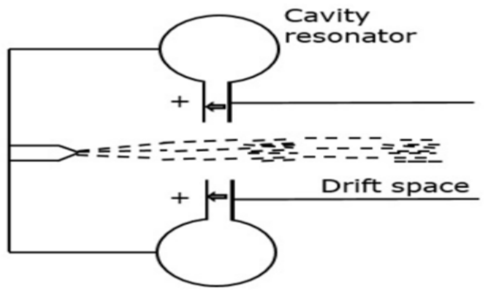
- Thus, the electrons that were emitted earlier by the gun will get decelerated. While the electrons emitted later will get accelerated. Thus all the electrons while moving with different velocities get bunched in the drift space.
- ***This change in the velocity of electrons while moving due to RF input is known as velocity modulation.***



APPLEGATE DIAGRAM

Two-Cavity Klystron Amplifier: Working

- The area beyond the buncher grids is called the drift space. The electrons form bunches in this area when the accelerated electrons overtake the decelerated electrons.
- The drift space length is chosen to allow maximum bunching at the resonant frequency.



Formation of electron bunches

- The electrons then pass through a second cavity, called the "catcher", through a similar pair of grids on each side of the cavity. The function of the catcher grids is to absorb energy from the electron beam.
- The catcher grids are placed along the beam at a point where the bunches are fully formed. The location is determined by the transit time of the bunches at the natural resonant frequency of the cavities (the resonant frequency of the catcher cavity is the same as the buncher cavity).
- The location is chosen because maximum energy transfer to the output (catcher) cavity occurs when the electrostatic field is of the correct polarity to slow down the electron bunches.

Two-Cavity Klystron Amplifier: Working

- Thus, their kinetic energy is converted to electric potential energy, increasing the amplitude of the oscillating electric field in the cavity.
- Thus the oscillating field in the catcher cavity is an amplified copy of the signal applied to the buncher cavity. The amplified signal is extracted from the catcher cavity through a coaxial cable or waveguide.
- After passing through the catcher and giving up its energy, the lower energy electron beam is absorbed by a "collector" electrode, a second anode which is kept at a small positive voltage.

Two-Cavity Klystron Amplifier: Applications

- Satellite communication
- High-energy physics
- Wideband high-power communication
- Radars
- Medical application
- Particle accelerators

Two-Cavity Klystron Amplifier: Parameters

$\mathbf{V_o}$ = DC voltage between cathode and buncher cavity.

$\mathbf{V_1}$ = Amplitude of input RF signal, $\mathbf{V_{1} \ll V_o}$

$\boldsymbol{\omega = 2\pi f}$ = Input signal angular frequency. It is also equal to resonant frequency of both the cavities.

$\boldsymbol{u_o}$ = Uniform velocity of electrons between cathode and buncher cavity.

t_o = Time at which electrons enter the buncher cavity

t_1 = Time at which electrons leave the buncher cavity

τ = Transit time of electrons in the buncher cavity = $t_1 - t_o$

θ_g = Angle /Phase vaiation of input signal during the tansit time

β = Beam Coupling Coefficient of the buncher / Catcher Cavity

Two-Cavity Klystron Amplifier: Formulas

1) Initial velocity of electron

$$v_0 = (0.593 \times 10^6)\sqrt{V_0}$$

2) Gap Transit angle

$$\theta_g = \frac{\omega d}{v_0}$$

Where, d = gap spacing in either cavity

3) Beam Coupling Coefficient

$$\beta_i = \beta_0 = \frac{\sin(\theta_g/2)}{\theta_g/2}$$

4) Bunching parameter of klystron

$$X = \frac{\beta_i V_1}{2V_0}\theta_0$$

5) Optimum spacing between the two cavities "L" optimum is given by (for maximum degree of bunching)

$$L_{optimum} = \frac{3.682 v_0 V_0}{\omega \beta_i V_1}$$

$$L \to L_{optimum} \text{ as } X \to 1.841$$

$$J_1(X) = 0.582$$

Two-Cavity Klystron Amplifier: Formulas

6) Output Current

$$I_2 = 2\beta_0 I_0 J_1(X)$$

7) Output Voltage

$$V_2 = 2\beta_0 I_0 J_1(X) R_{sh}$$

8) Efficiency

$$i_{rms} = \frac{i_{f\,max}}{\sqrt{2}} = \frac{I_2}{\sqrt{2}} = \frac{2I_0\beta_0 J_1(X)}{\sqrt{2}} \qquad Poutput = i^2_{rms}\, Rsh = 2I_0^{\,2}\beta_0^{\,2}J_1^{\,2}(X)R_{sh}$$

$$Efficiency = \eta = \frac{P_0}{p_{dc}} = \frac{2I_0^{\,2}\beta_0^{\,2}J_1^{\,2}(X)R_{sh}}{V_0 I_0}$$

9) Voltage Gain

$$A_v = \frac{V_2}{V_1}$$

$$A_v = \frac{V_2}{V_1} = \frac{2\,\beta_0\ \ I_0\, J_{1(X)}\, R_{sh}}{V_1}$$

$$V_{1\,max} = \frac{2V_0 X}{\beta_i\,\theta_0}$$

$$\theta_0 = \omega T_0 = \omega\frac{L}{v_0}$$

DC Transit angle between the cavities

L= length of drift space

Reflex Klystron: Oscillator

- Reflex klystron is a single cavity low power microwave oscillator. The characteristics of Reflex Klystron are:

  Power output: 10- 500mw

  Frequency range: 1 to 25 GHz

  Efficiency: 10-20%

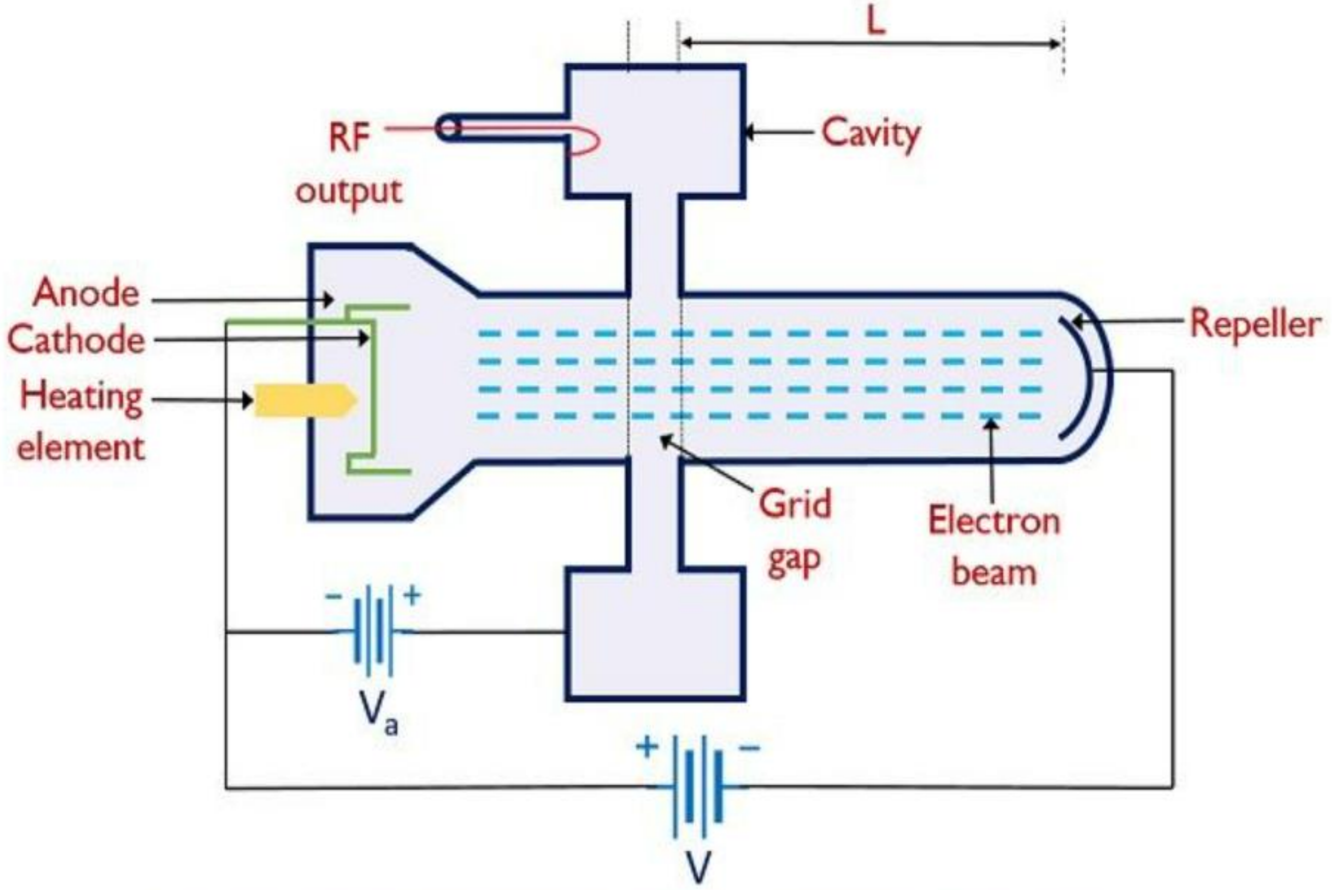
- It mainly overcomes the disadvantages of a two-cavity klystron amplifier. A two-cavity klystron amplifier cannot be used for low power applications in the range of mW.

- Widely used in as a source for microwave experiments

  Local oscillator in microwave receivers

Reflex Klystron: Construction

1) Electron Gun
2) Cavity resonator at the potential of +Va w.r.t cathode
3) Repeller at the potential of - V w.r.t. cathode

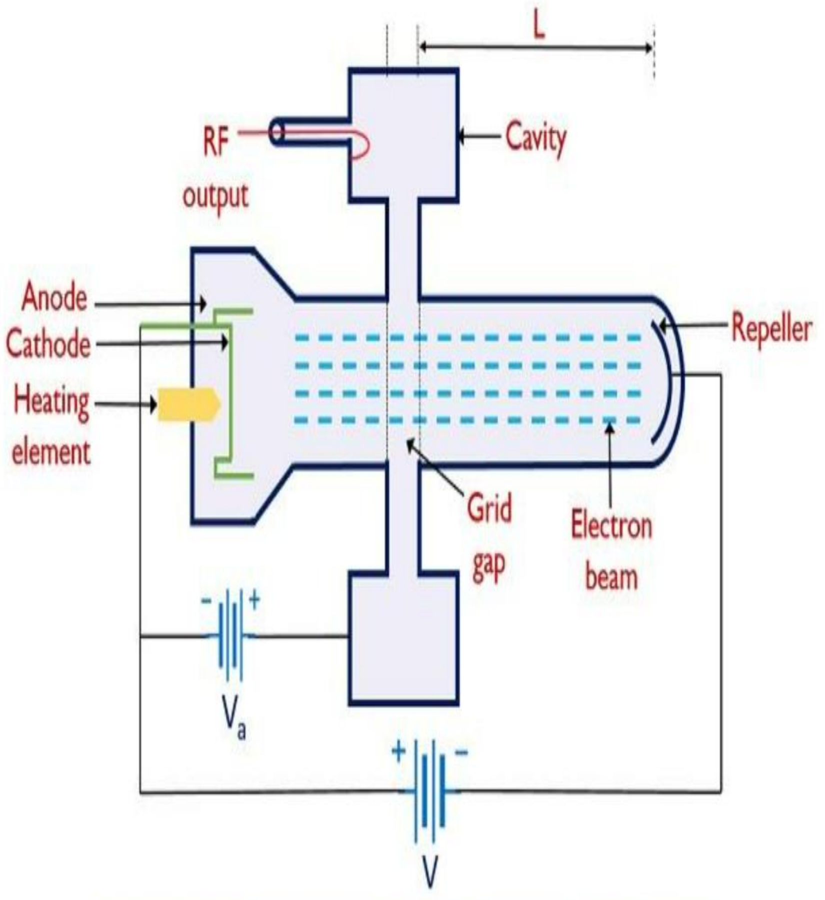


Structure of Reflex Klystron

Reflex Klystron: Construction

1) Electron Gun

- The structure consists of a cathode and focusing anode that combinedly acts as an electron gun for the tube. The cathode emits the electron beam which is focussed inside the tube by the focusing anode.



Structure of Reflex Klystron

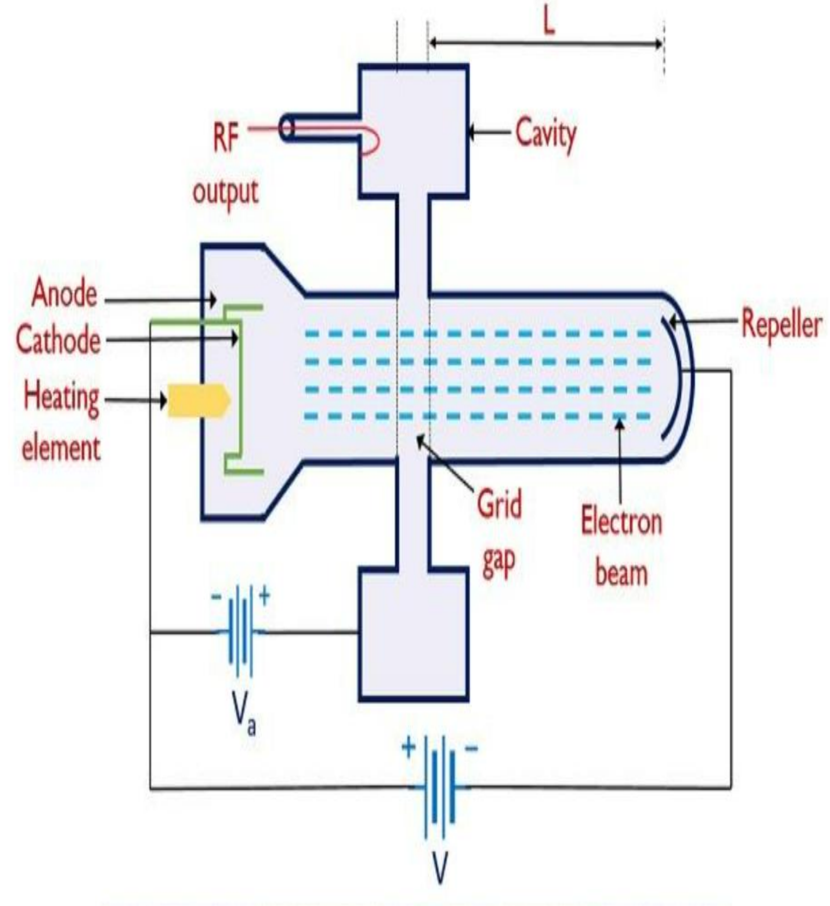
2) Cavity Resonator

- As it is a single cavity structure, thus single cavity act as buncher and catcher cavity separately.
- At the time of forward movement of the electron beam, it acts as a buncher cavity.
- While at the time of backward movement, it is a catcher cavity.
- A positive potential is provided as input w.r.t cathode which sets up an electric field inside the cavity.

Reflex Klystron: Construction

3) Repeller

- A repeller plate that causes backward movement of the electron beam is present at the opposite end of the electron gun.
- L= distance of repeller from cavity gap.
- The potential at the repeller is made extremely negative in order to permit repulsion of like charges.
- Repulsion is necessary in order to build electrical oscillations, as output power must be fed to the input.
- So the velocity modulated electrons must have to travel a backward path in order to provide feedback.
- Thus repeller is used in the structure of the klystron.

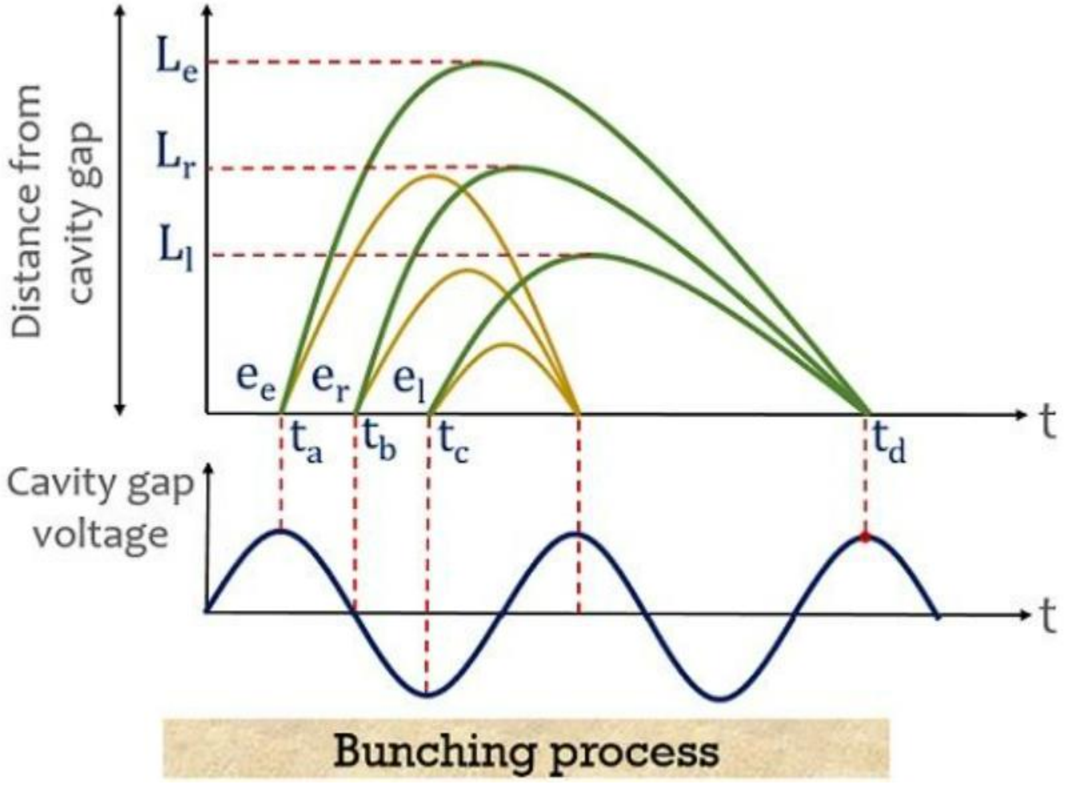


Structure of Reflex Klystron

Reflex Klystron: Working

- Due to dc voltage in the cavity circuit, RF noise is generated in the cavity. This em noise field in the cavity get pronounced at cavity resonant frequency and acts as a small signal microwave voltage source of V1 sin wt.
- The fundamental principle of operation of a reflex klystron is velocity modulation.

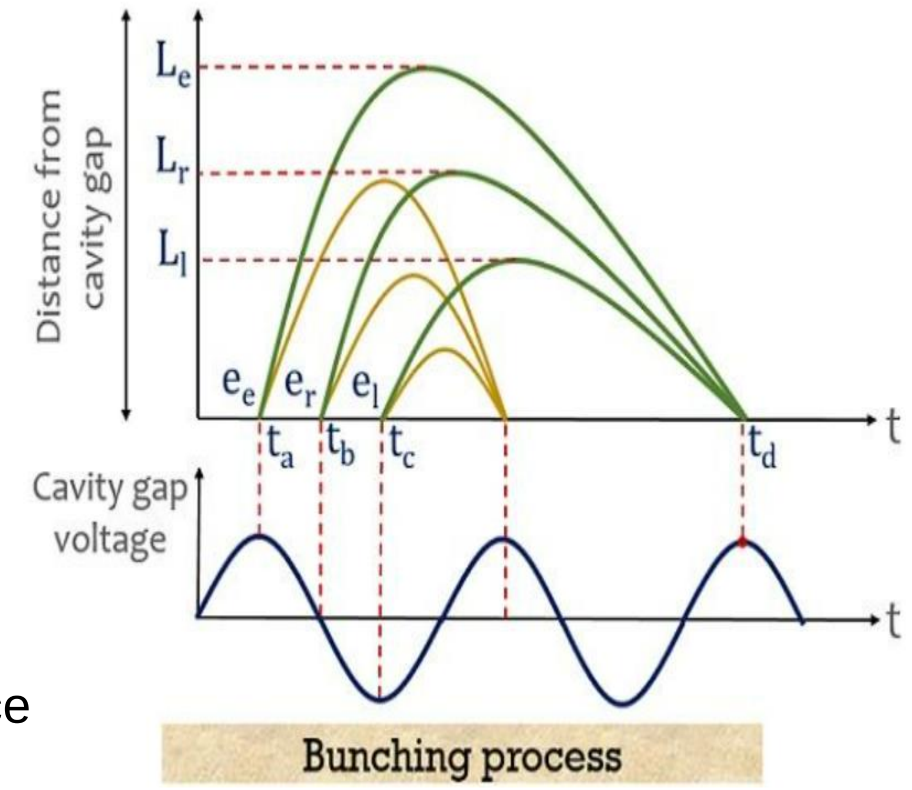
- ❖ Initially when the electron beam is emitted by the electron gun, then the early electrons, ee experience a very high potential.
- ❖ Due to this, a strong electric field gets generated inside the cavity gap, leading to cause movement of electrons towards the repeller with a very high velocity.
- ❖ Due to high velocity, the electrons penetrate deeper into the region of the repeller and thus require greater time to repel back towards the catcher cavity.



Applegate Diagram

Reflex Klystron: Working

- When the externally applied potential is almost 0, then the electron moves with a uniform velocity with which it was emitted by the gun.
- These electrons are generally known as reference electrons er.
- So, in this case, er will not penetrate deeply into the repeller surface and gets repelled by the repeller in a lesser time than the early electron.
- Further, the electron that is emitted by the gun after the reference electron experiences a highly negative potential at the cavity.
- This electron is generally known as late electron el and moves with a very low velocity inside the tube.
- The penetration level of the late electron into the repeller space is the least thus takes a minimal amount of time to get repelled back.



Applegate Diagram

Reflex Klystron: Working

- Due to deep penetration in the repeller region, ee will take more time than er while returning towards the catcher.
- This change in the velocity of moving electrons is known as velocity modulation.
- And due to this velocity modulation, all the electrons get bunched while returning towards the catcher cavity.
- In the case of the 2-cavity klystron, we had seen that the maximum transfer of kinetic energy to the cavity takes place when the electron bunch enters when the field is –ve peak.
- Similarly in the case of reflex Klystron, the bunch must enter the cavity when the field is +ve peak. When the gap voltage is at maximum positive, this lets the maximum negative electrons retard.
- Therefore, at the time of returning, the bunched electrons transfer the maximal of their energy to the catcher cavity. Thereby leading to cause oscillations inside the tube.
- After transferring their energy, the electrons get collected at the walls of the cavity.

Reflex Klystron: Applications

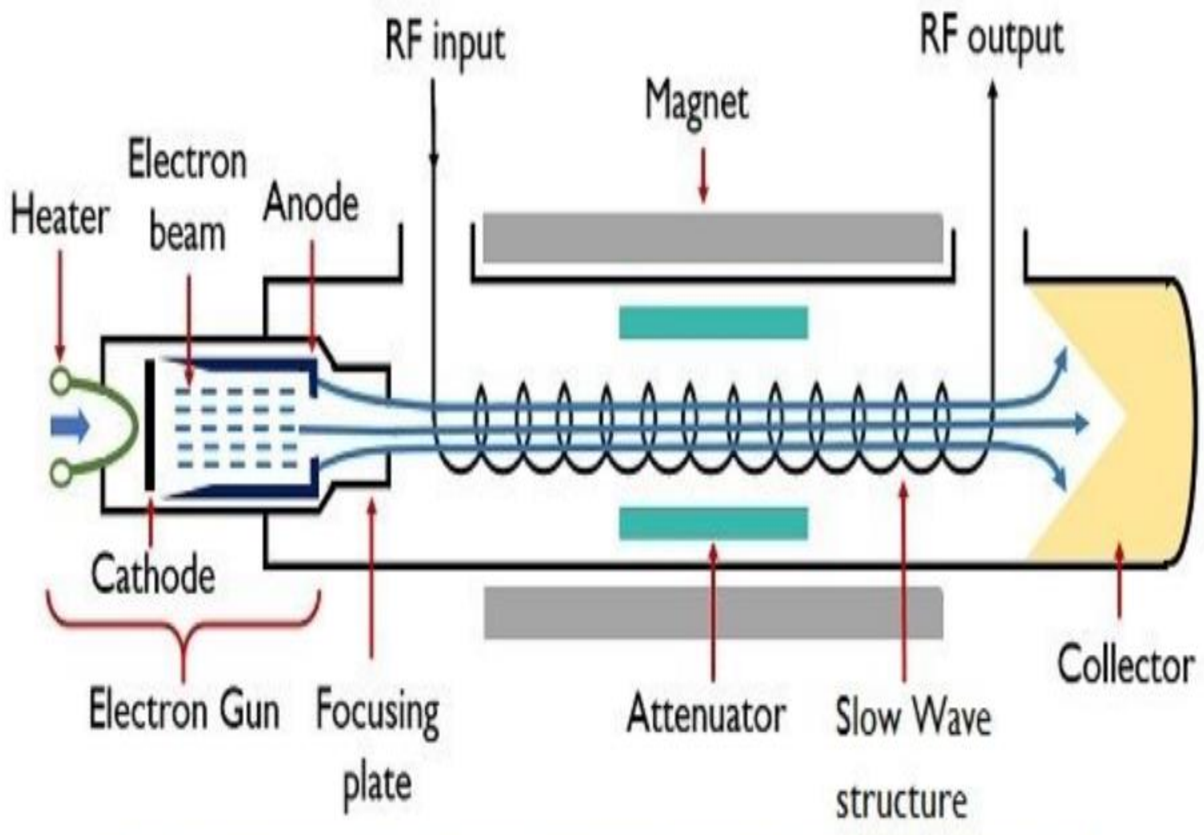
- Source for microwave experiments
- Local oscillator in microwave receivers

Travelling Wave Tube: Amplifier

- A travelling wave tube is a high power amplifier used for the amplification of microwave signals up to a wide range.
- It is a special type of vacuum tube that offers an operating frequency ranging between **300 MHz to 50 GHz.**
- Travelling wave tubes are non-resonant structures that offer continuous interaction of applied RF field with the electron beam over the entire length of the tube. Due to this reason, it provides wider operating bandwidth.

TWT: Construction

1) Electron Gun
2) Slow-Wave Structures
3) Magnet
4) Attenuator
5) Collector



Constructional Structure of Travelling Wave Tube

TWT: Construction

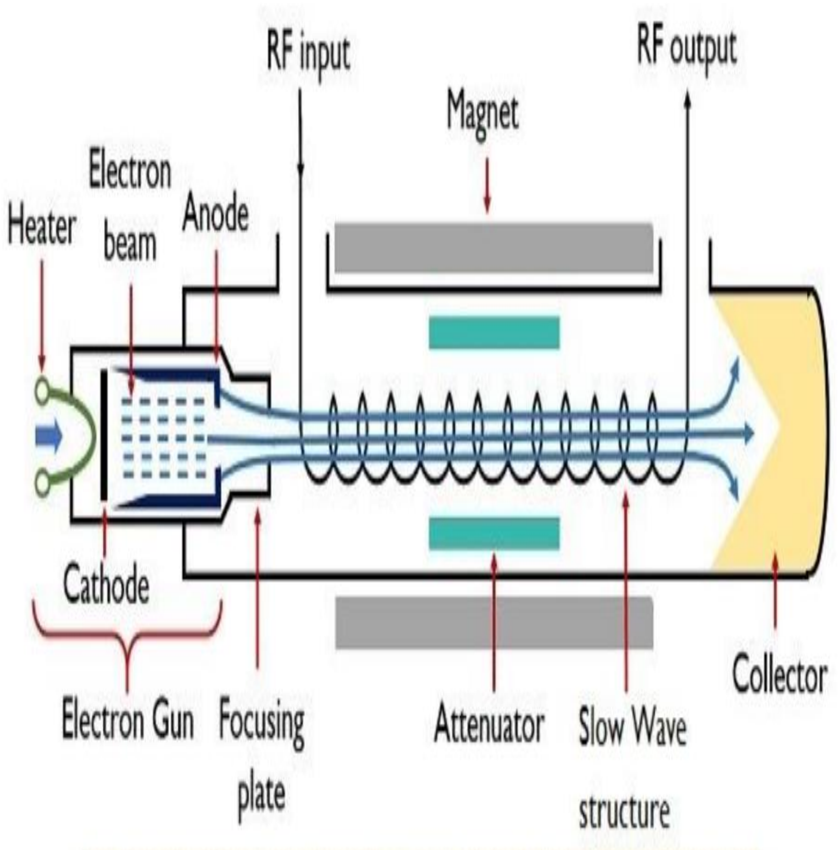
1) Electron Gun

- The structure consists of a cathode and focusing anode that combinedly acts as an electron gun for the tube. The cathode emits the electron beam which is focussed inside the tube by the focusing anode.

2) Magnet

- In order to restrict beam spreading inside the tube. A dc magnetic field is applied between the traveling path with the help of magnets.

❖ *A positive potential is provided to the coil (helix) with respect to the cathode terminal. While the collector is more positive than the coil (helix).*



Constructional Structure of Travelling Wave Tube

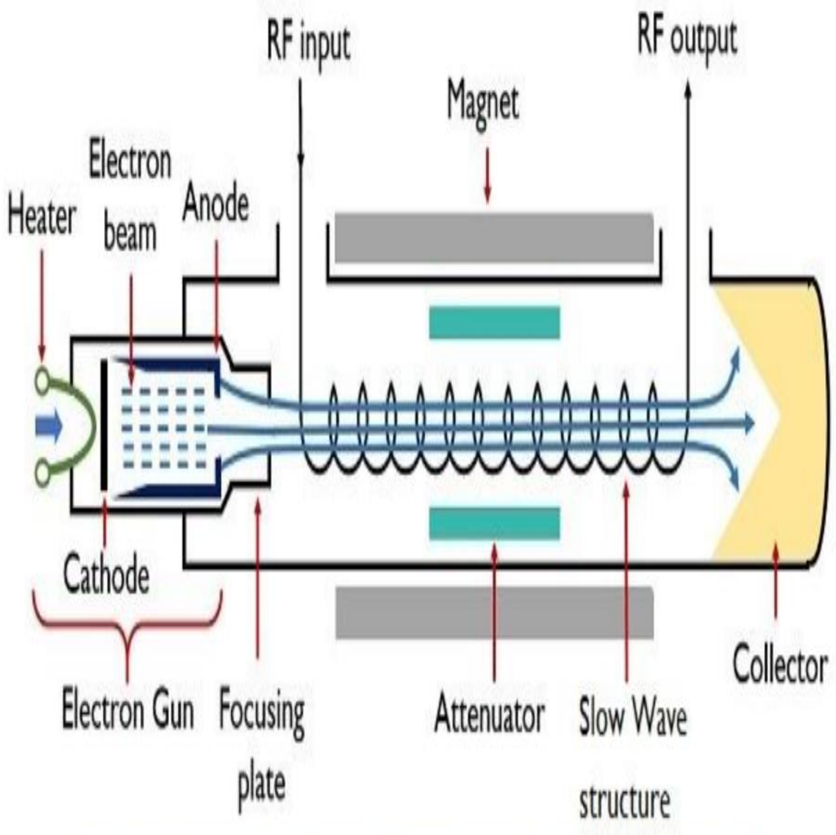
TWT: Construction

3) Slow Wave Structures (Helix)

- The signal which is needed to be amplified is provided at one of the ends of the helix, present adjacent to the electron gun. While the amplified signal is achieved at the opposite end of the helix.
- To maintain the continuous interaction between the traveling wave and electron beam, slow-wave structures are used.

<u>Need of Slow-Wave structures</u>

- The signal which is needed to be amplified is provided at one of the ends of the helix, present adjacent to the electron gun. While the amplified signal is achieved at the opposite end of the helix.



Constructional Structure of Travelling Wave Tube

TWT: Construction

Need of Slow Wave Structures

- We know that the velocity of the electromagnetic wave is very much higher when compared with the phase velocity of the electron beam emitted by the electron gun. Basically the RF wave applied at the input of TWT propagates with the speed of light. While the propagating velocity of the electron beam inside the tube is comparatively smaller than the velocity of RF wave.

- If we try to somehow accelerate the velocity of the electron beam, then it can be accelerated only to a fraction of velocity of light. So it is better to reduce the velocity of the applied RF input in order to match the velocity of the electron beam.

- Therefore, a slow-wave structure is used that causes a reduction in the phase velocity of the RF wave inside the TWT.

TWT: Construction

Need of Slow Wave Structures

- The helical shape of the structure slows the velocity of the wave travelling along its axis to a fraction of about one-tenth of c. This is so because due to the helical shape of the structure, the wave travels a much larger distance than the distance travelled by the beam inside the tube. So, in this way, the speed of wave propagation depends on the number of turns or diameter of the turns. More specifically we can say that change in pitch can vary the speed of wave propagation inside the tube.

- The equation given below shows the relation of phase velocity of the wave with the pitch of the helix:

$$V_P = \frac{cP}{\sqrt{(P)^2 + (\pi d)^2}}$$

: c = velocity of light ($3 * 10^8$ m/s)

V_P = phase velocity in m/s

P = pitch of helix in m

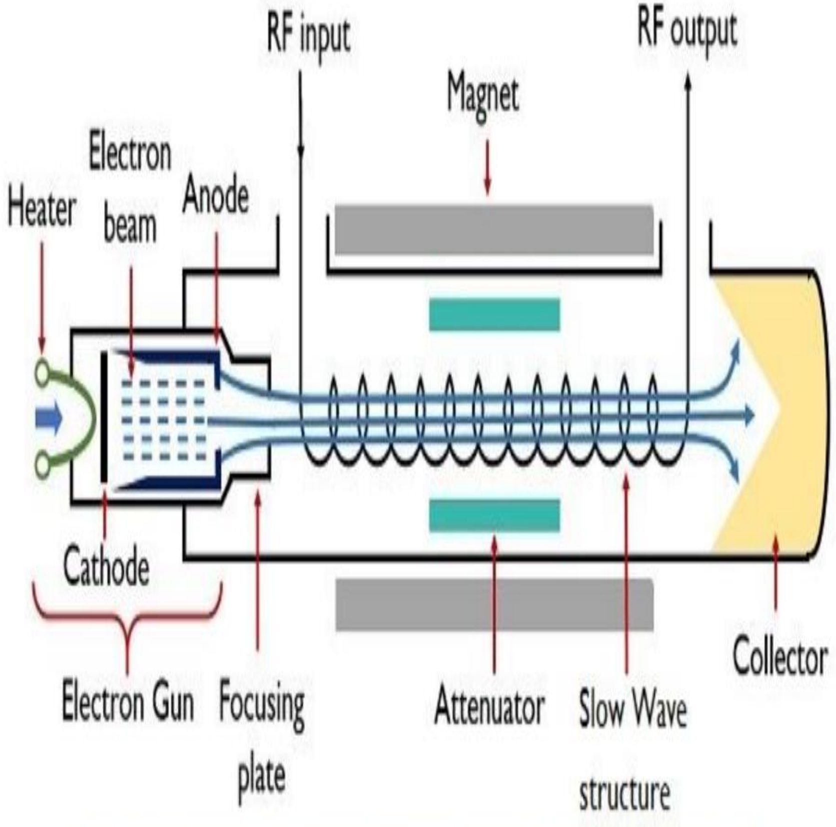
d = diameter of the helix in m

- Therefore, this causes continuous interaction between the RF input wave and the electron beam as the velocity of propagation of the two is not highly different. As such interaction is the basis of working of TWT, thus slow-wave structures are used.

TWT: Construction

4) Attenuator

- Attenuator is present along both the sides of the traveling wave tube.
- Since, traveling wave amplifiers are high gain devices, so in case of poor load matching conditions, oscillations get built up inside the tube due to reflection.
- Thus in order to restrict the generation of oscillations inside the tube attenuators are used.



Constructional Structure of Travelling Wave Tube

5) Collector

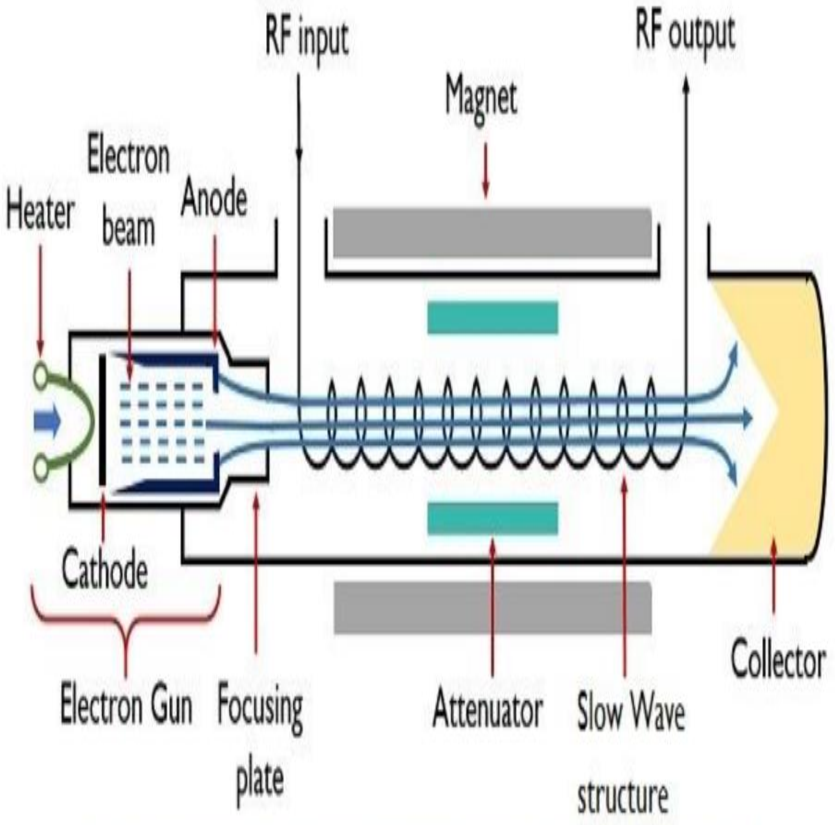
- It is used to collect the electron beam.

TWT: Working

- The applied RF signal produces an electric field inside the tube. Due to the applied positive half, the moving electron beam experiences an accelerative force. However, the negative half of the input applies a de-accelerative force on the moving electrons.

- This is said to be velocity modulation because the electrons of the beam are experiencing different velocities inside the tube. However, the slowly travelling wave inside the tube exhibits continuous interaction with the electron beam.

- Due to the continuous interaction, the electrons moving with high velocity transfer their energy to the wave inside the tube and thus slow down. So with the rise in the amplitude of the wave, the velocity of electrons reduces and this causes bunching of electrons inside the tube.



Constructional Structure of Travelling Wave Tube

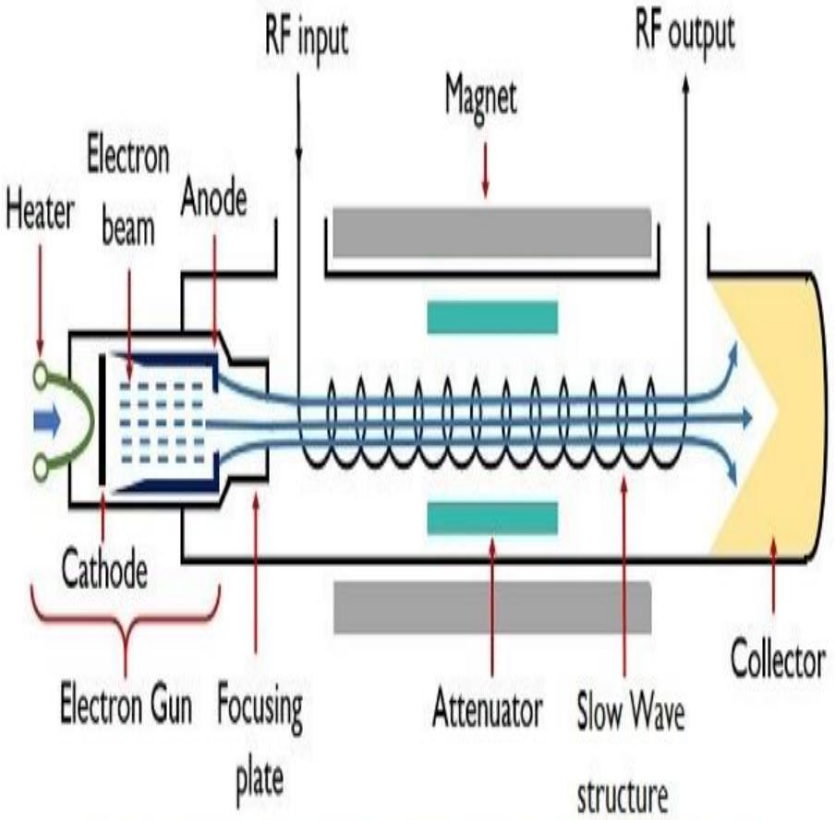
TWT: Working

- The growing amplitude of the wave resultantly causes more bunching of electrons while reaching the end from the beginning. Thereby causing further amplification of the RF wave inside the tube.

- More specifically we can say that forward progression of the field along the axis of the tube gives rise to amplification of the RF wave. Thus at the end of the tube an amplified signal is achieved.

- The magnetic field inside the tube restricts the spreading of the beam as the electrons possess repulsive nature.

- The positive potential provided at the other end causes collection of electron bunch at the collector.



Constructional Structure of Travelling Wave Tube

Magnetron: Oscillator

- A magnetron is a device that generates high-power electromagnetic waves.
- It is basically considered a self-excited microwave oscillator. And is also known as a crossed-field device.
- The reason behind calling it so is that the electric and magnetic fields produced inside the tube are mutually perpendicular to each other thus the two cross each other.
- **A magnetron is basically a vacuum tube of high power having multiple cavities. It is also known as cavity magnetron.**
- *The operating principle of a magnetron is such that when electrons interact with electric and magnetic fields in the cavity, then high power oscillations get generated.*

Magnetron: Construction

1) Cylindrical Cathode and Cylindrical Anode

- A cylindrical cathode of a certain length and radius is present at the center around which a cylindrical anode is present.

2) Resonant Cavities

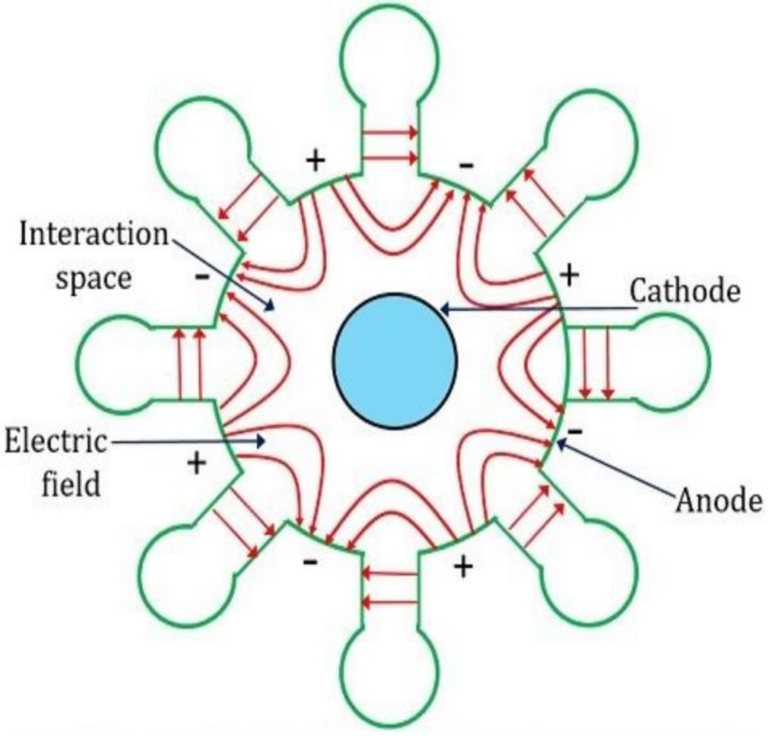
- The cavities are present at the circumference of the anode at equal spacing. There exists a phase difference of 180º between adjacent cavities. if one plate is positive then automatically its adjacent plate will be negative.

3) Interaction Space

- The area existing between the anode and cathode of the tube is known as interaction space/region.

4) Permanent magnet

- Magnetic field is generated.



Structure of Magnetron

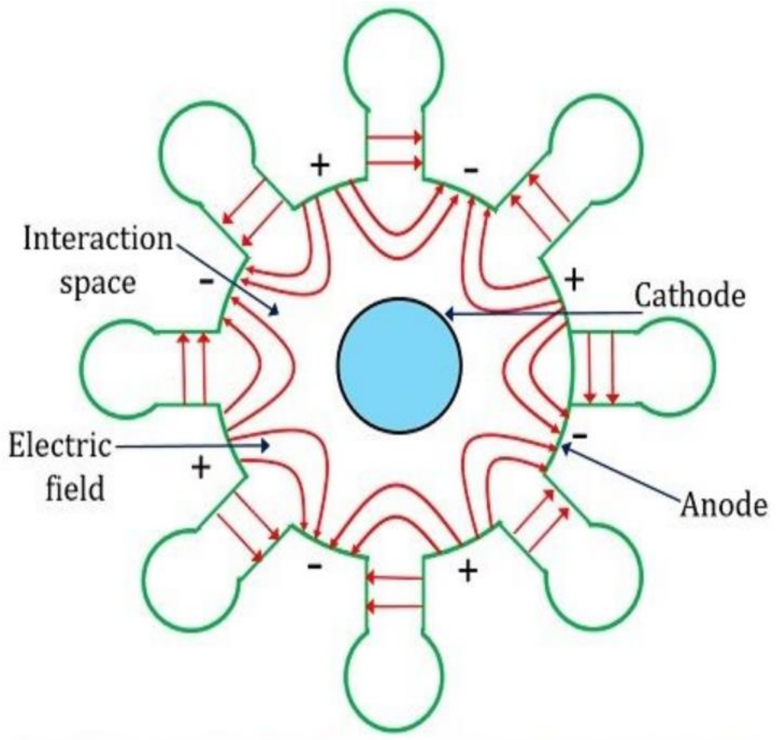
Magnetron: Working

- The excitation to the cathode of the magnetron is provided by a dc supply which causes the emergence of electrons from it.

Working of magnetron under two categories

❖ When Electric Field is not present

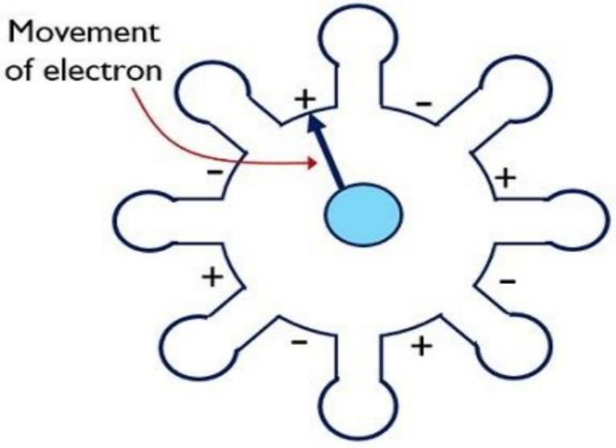
❖ When Electric Field is present



Structure of Magnetron

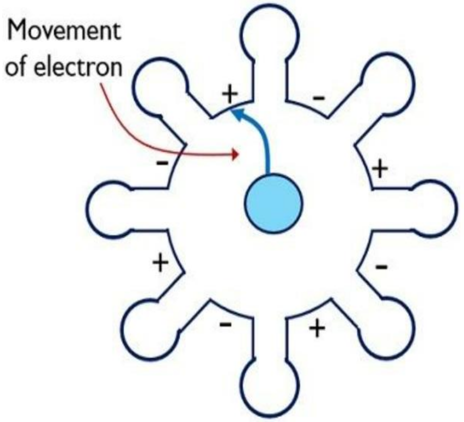
Magnetron: Working

When Electric Field is not present



Case-I: No Magnetic Field

- The electrons travel the straight path and reach the anode.



Case-II: Small Magnetic Field

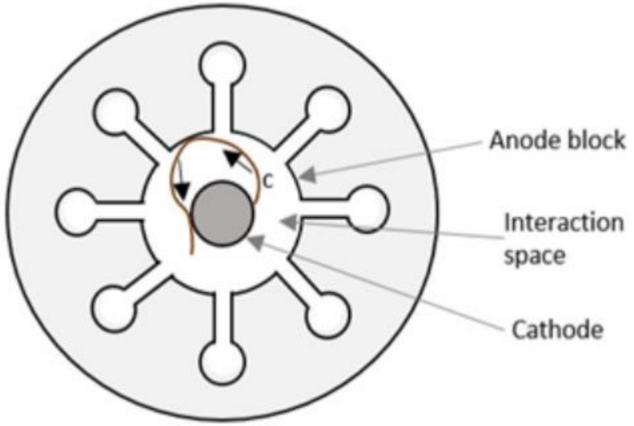
- A lateral force acts on the electrons.
- Electrons take a curved path.

$$R = \frac{mv}{eB}$$

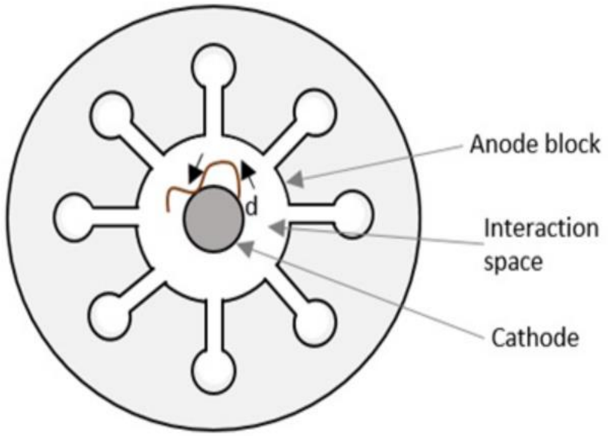
✓ It varies proportionally with the velocity of the electron and it is inversely proportional to the magnetic field strength.

Magnetron: Working

When Electric Field is not present



Movement of electron **c** when the magnetic field is critical magnetic field i.e. $B = B_c$



Movement of electron **d** when excessive magnetic field is present

Case-III: Large Magnetic Field:
Critical Magnetic field (Bc)

- The value of the magnetic field that causes the anode current to become 0 is known as the ***critical magnetic field***.

Case-IV: B>Bc

- The electron jumps back to the cathode, without going to the anode. This causes **"back heating"** of the cathode.

Magnetron: Working

When Electric Field is present

Case 1

- When oscillations are present, an electron **a**, slows down transferring energy to oscillate. Such electrons that transfer their energy to the oscillations are called as **favored electrons**. These electrons are responsible for **bunching effect**.

Case 2

In this case, another electron, say b, takes energy from the oscillations and increases its velocity. As and when this is done,

- It bends more sharply.
- It spends little time in interaction space.
- It returns to the cathode.

These electrons are called as unfavored electrons. They don't participate in the bunching effect. Also, these electrons are harmful as they cause "back heating".

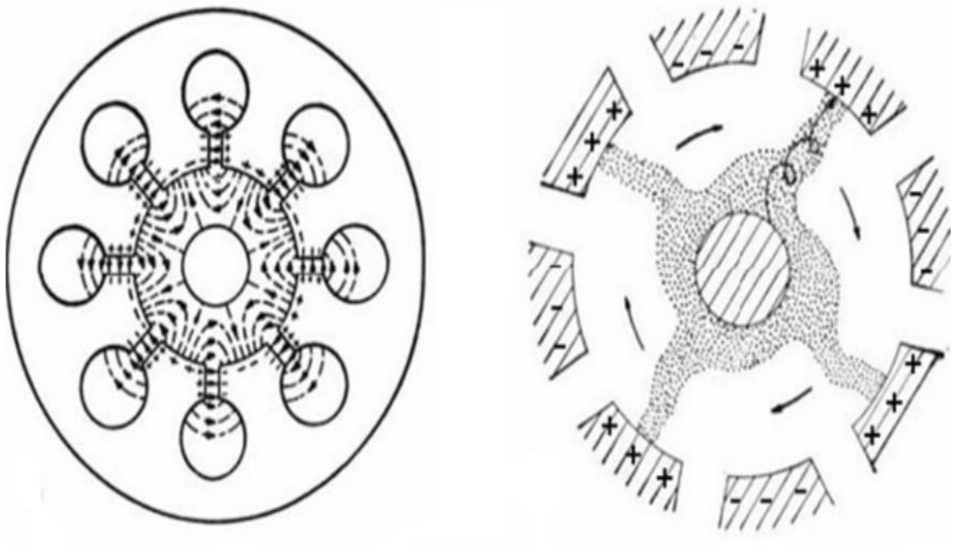
Magnetron: Working

When RF field is present

Case 3

- In this case, electron c, which is emitted a little later, moves faster. It tries to catch up with electron a. The next emitted electron d, tries to step with a. As a result, the favored electrons a, c and d form electron bunches or electron clouds. It called as "Phase focusing effect".

- Figure A shows the electron movements in different cases while figure B shows the electron clouds formed. These electron clouds occur while the device is in operation.
- The charges present on the internal surface of these anode segments, follow the oscillations in the cavities. This creates an electric field rotating clockwise.
- While the electric field is rotating, the magnetic flux lines are formed in parallel to the cathode.
- under whose combined effect, the electron bunches are formed with four spokes, directed in regular intervals, to the nearest positive anode segment, in spiral trajectories.



A B

MAGNETRON: Applications

- Radar Applications
- Microwave Ovens
- Particle Accelerators