UNIT-IV

MICROWAVE TUBES

The principle of operation of a vaccum tube at microwave frequencies (above 1GHz) is different from electronic vaccum tubes such as triodes, tetrodes and pentodes.

These conventional electron vaccum tubes fail to operate above 1GHz due to their limitations at these frequencies.

High Frequency Limitations of conventional tubes:

1) Circuit reactance
   i) Inter.electrode capacitance
   ii) Lead inductance.
2) Transit time effects
3) Gain bandwidth limitation
4) Power loss due to skin effect (I^2R losses), radiation and dielectric losses

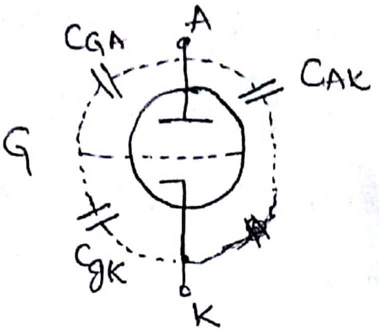
1) Circuit reactance:
   i) Inter electrode capacitance
   ii) Lead capacitance.

$$X_C = \frac{1}{2\pi f C} \quad \text{i.e. } X_C \propto \frac{1}{f}$$

$$X_L = 2\pi f L \quad \text{i.e. } X_L \propto f$$

At low frequencies X_C is high and X_L is low. As X_C is high capacitance acts as open circuit and as X_L is low inductance acts as short circuit.

Thus ~~the~~ ~~effect~~ at low frequencies the effect of inter electrode capacitance and ~~lead~~ lead inductance are less.



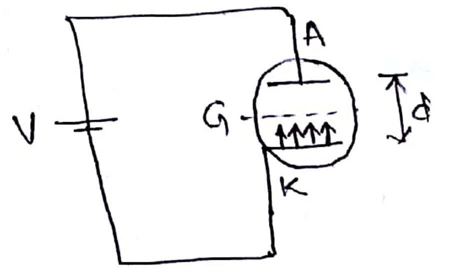
A → Anode
K → Cathode
G → Grid.

At high frequencies reactance of C_{gA}, C_{AK}, C_{gK} are low and begins to short circuit port of i/p and o/p.

$$C_{gA} << C_{gK}.$$

2) <u>Transit Time</u>

Transit time is the time taken for the electron to travel from cathode to anode.



transit time $= \tau = \dfrac{d}{\text{velocity}(v)}$

under equilibrium

Static energy = Kinetic energy

$$qV = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2qV}{m}}$$

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

At low frequencies, transit time is negligible compared to the period of the signal.

At high frequencies, transit time is comparable with the period of the signal which is very small nano seconds.

3) Power loss due to skin effect (I^2R losses), dielectric losses and radiation.

Skin effect losses:

$$\text{Skin depth} = \delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

i.e. $\delta \propto \frac{1}{\sqrt{\omega}}$ and $\delta \approx A_{eff}$

A_{eff} = effective area over which current flows.

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

But $R = \frac{\rho l}{A}$

As 'f' increases A_{eff} decreases then R increases. Hence losses will increases at high frequencies. These losses can be reduced by increased size of the conductors.

Dielectric losses:

This occurs in various types of emulating material used in the device i.e. spacers, glass envelope, silicon or plastic encapsulation etc.

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

As 'f' increases the power loss increases. The remedy for this is to eliminate the tube base and to reduce the surface area of glass.

4) Gain bandwidth product limitations.

In ordinary vaccum tubes the maximum gain is generally achieved by resonating the o/p circuit.

KLYSTRONS

A Klystron is a vaccum tube that can be operated either as an oscillator or as an amplifier of power at microwave frequencies.

Two basic configurations of Klystron tubes such as

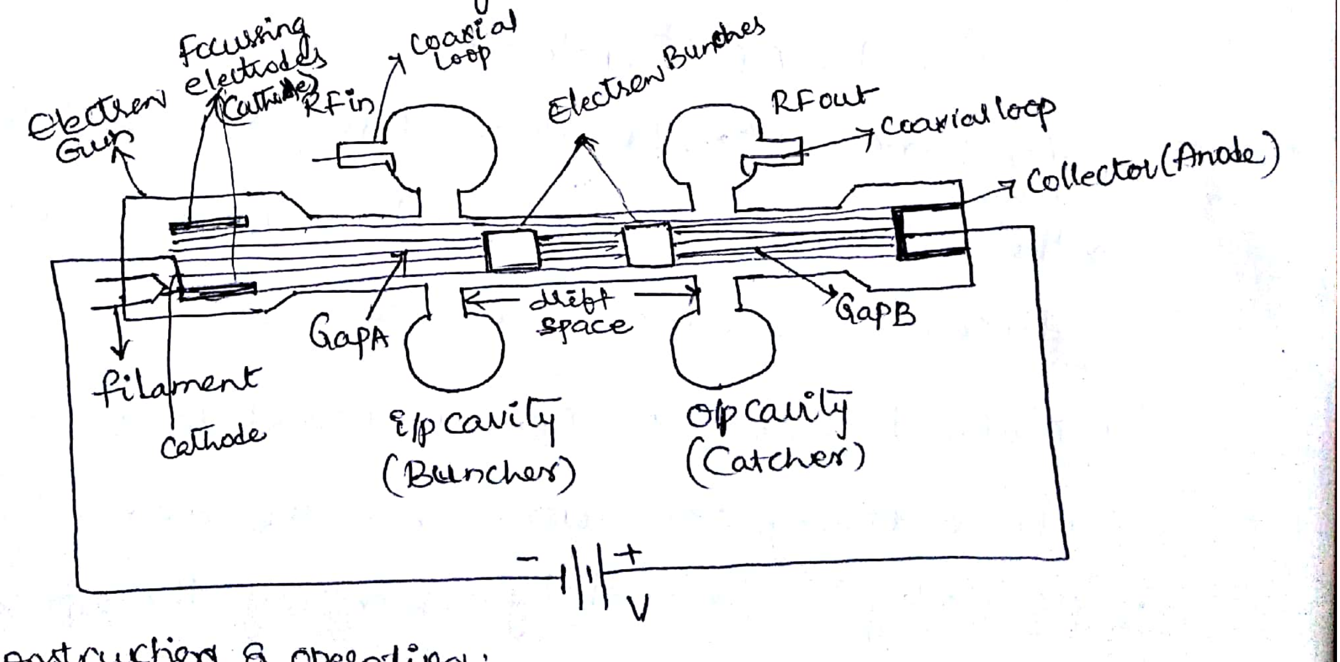
1) Reflex Klystron → used as a low power microwave oscillator
2) Multi cavity Klystron → used as a low power Mew amplifier

Klystrons are velocity modulated tubes that are used in radar and communication system as oscillators and amplifiers. They make use of transit time effect by varying the velocity of an electron beam.

A Klystron uses one or more special cavities, which modulate the electric field around the axis of the tube.

TWO Cavity Klystron Amplifiers:

These are widely used for microwave amplification



Construction & operation:

A two cavity Klystron amplifier is basically a velocity modulated tube. A high velocity electron beam is formed, focussed and sent down along a glass tube through an i/p cavity (buncher) and an o/p cavity (catcher) to a collector electrode/anode. The anode is kept at a positive potential w.r.t cathode. The electron beam passes through gap A consisting of two grids of the buncher cavity seperated by a very small distance and two other grids of the catcher cavity with a small gap B. The i/p and o/p taken from the tube via resonant cavities with the aid of coupling loops.

The beam passes through gap-A in the buncher cavity to which the i/p RF signal to be amplified is applied, and it is then allowed to drift freely without any influence from RF fields until it reaches gap-B at the catcher cavity. The oscillations will be excited in the second cavity which is of a power much higher than those ~~under~~ in the buncher cavity, so that a large o/p can be achieved. Collector electrode will collect the beam.

Characteristics:

1) Frequency : 250 MHz to 100 GHz. (60 GHz nominal)
2) Power : 10 kW – 500 kW (CW)
   30 MW (pulsed)
3) Power Gain : 15 dB – 70 dB (60 dB nominal)
4) Band width : limited
5) Noise figure : 15 – 20 dB
6) Theoritical efficiency : 58% (30–40% nominal)

Applications:

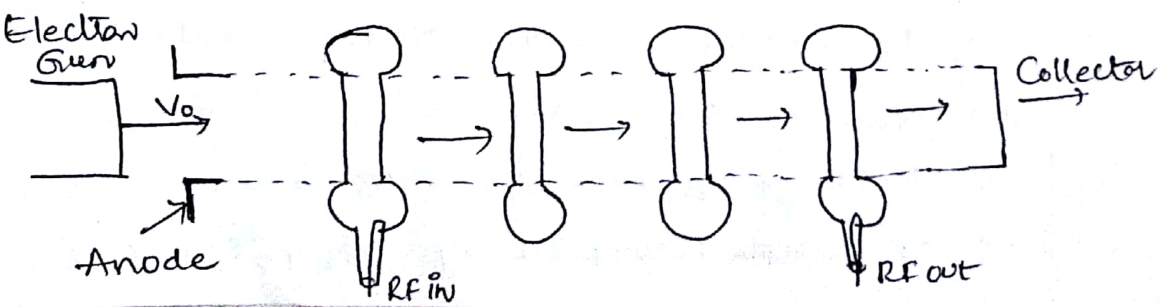
1) As power output tubes
   a) in UHF TV transmitters
   b) In troposphere scatter transmitters
   c) Satellite communication ground stations
   d) Radar transmitters

2) As power oscillators if used as a klystron oscillator

Multicavity Klystron :

A higher overall gain can be achieved by connecting several two cavity tubes in cascade, feeding the o/p of each of the tubes to the i/p of the succeeding one. Multiple number of cavities can be used as in a multicavity klystron.

Here each of the intermediate cavities act as a buncher with the passing electron beam inducing an ~~ex~~ enhanced RF voltage than the previous cavity. With four cavities, power gains of around 50dB can be easily achieved. The cavities can all be tuned to the same frequency (synchronous tuning) for narrow band operation. Bandwidth can be improved by stagger tuning of cavities. This stagger tuning is employed in UHF klystrons for TV transmitter o/p tubes.



Two cavity klystron oscillator

A klystron amplifier can be converted into an oscillator by feeding back a part of the catcher o/p into the buncher in proper phase so as to satisfy Barkhausen criterian.

$$|AB| = 1 \text{ \& } \theta = 2\pi n \quad , n \text{ is an integer.}$$

Reflex Klystron :

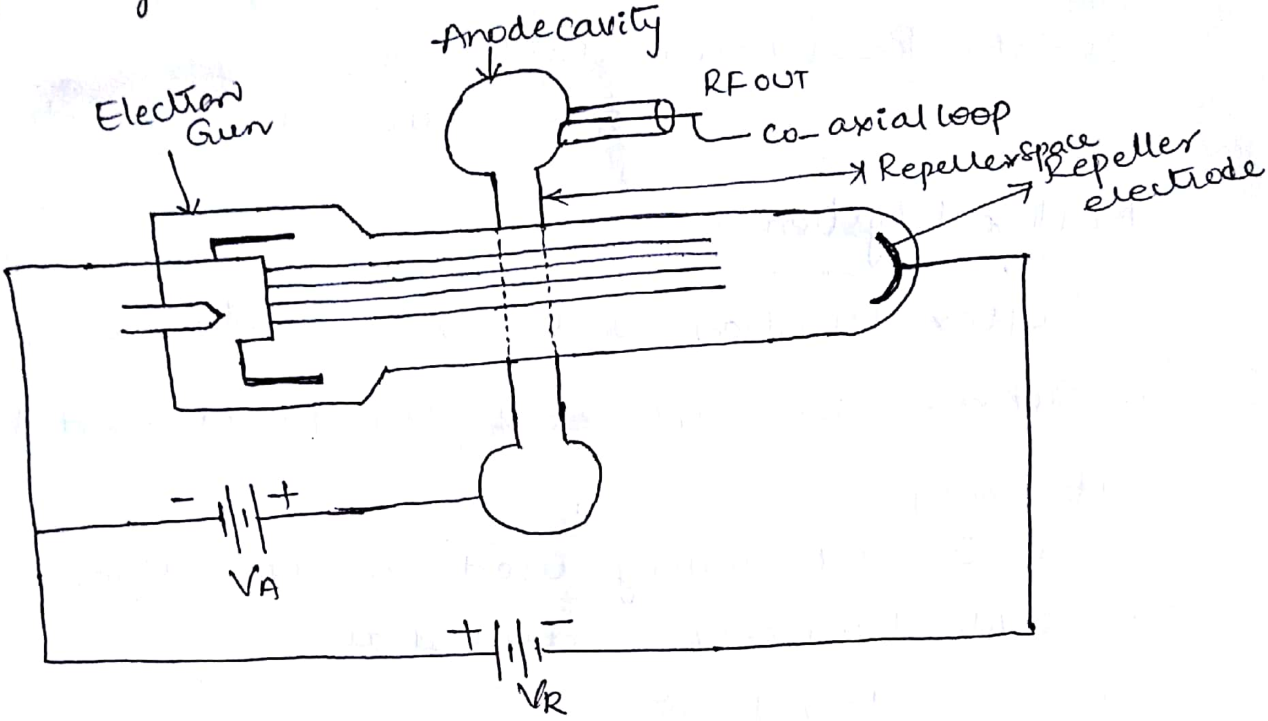
Reflex klystron is a single cavity variable frequency microwave generator ~~at~~ of low power and low efficiency.

This is most widely used in applications where variable frequency is desired as

1) in radar receivers
2) local oscillator in microwave receivers.
3) signal source in microwave generator of variable frequency.
4) portable microwave links
5) pump oscillator in parametric amplifiers.

Construction & operation

It consists of an electron gun, a filament surrounded by cathode and a focussing electrode at cathode potential. The electron beam is accelerated towards the anode cavity (at positive potential) After ~~the~~ passing the gap in the cavity, electron travel towards a repeller electrode which is at a high negative potential V_R. The electrons never reach the repeller because of the negative field and are returned back towards the gap. Under suitable conditions, the electrons give more energy to the gap than they took from the gap on their forward journey and oscillations are sustained.



Characteristics:

1) Frequency Range: 4 to 200GHz
2) o/p power : 1 mw to 2.5 W
3) Theoritical efficiency: 22.78%.
4) practical " " : 10% to 20%.
5) Tuning range: 5 GHz to 80GHz.

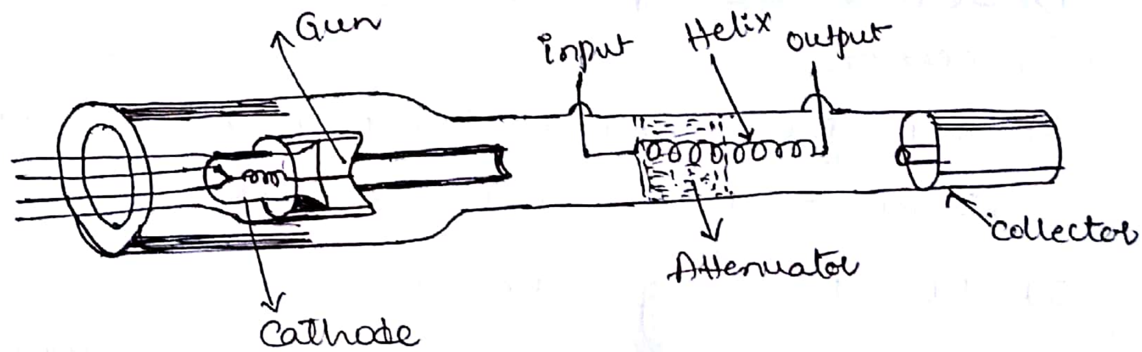
Travelling Wave Tube (TWT)

Klystrons are essentially narrow band devices as they utilise cavity resonators to velocity modulate the electron beam over a narrow gap whereas TWT's are broadband devices in which there are no cavity resonators.

The interaction space in a TWT is extended and the electron beam exchanges energy with the RF wave over the full length of the tube.

The TWT make use of distributed interaction between an electron beam and a travelling wave (RF field), as they are travelling in the same direction with nearly the same velocity.

Construction and Operation :



Electron Gun which is used to produce a narrow constant velocity electron beam. This electron beam is in turn passed through the centre of a long axial helix. A magnetic field is provided to prevent the beam from spreading and to guide it through the centre of the helix. Helix is a loosely wound thin conducting helical wire, which acts as a slow wave structure. The signal to be amplified is applied to the end of the helix adjacent to the electron gun. The amplified signal appears at the o/p or other end of the helix under appropriate operating conditions.

~~Kbsen~~ Characteristics :

1) Frequency : 0.5 GHz to 95 GHz.
2) Power o/p : 5mW (10–40GHz) (low power TWT)
   250kW (CW) at 3GHz (High Power TWT)
   10MW (pulsed) at 3GHz.
3) Efficiency : 5 to 20%
4) Noise figure : 4–6dB (low power TWT)
   25 dB (High power TWT)

Applications of TWT :

1) Low noise RF amplifier in broad band microwave receivers.
2) Repeater amplifier in wide band communication links and coaxial cables. (Long distance Telephony)
3) Due to long tube life (50,000 hrs), TWT is used as power output tube in communication satellites.
4) Continuous wave high power TWT's are used in troposcatter links.

~~5)~~

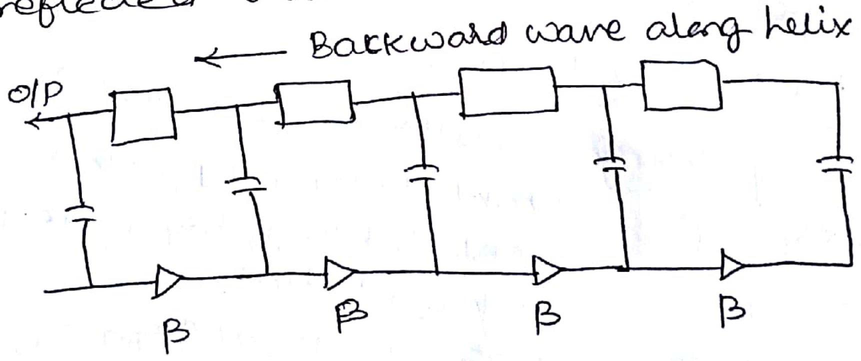
Backward wave oscillator (BWO)

BWO is a microwave continuous wave (CW) oscillator with excellent tuning capability and frequency coverage range.

Operation:

The electron beam from the electron gun cathode is focussed by an axial magnetic field. If transients have resulted in starting RF oscillations, these travel through the helix and interact with the electron beam. Bunching takes place increasing in completeness from the cathode to the collector and interchange of energy between the electron beam and RF wave occurs exactly in the same way as in TWT.

Since BWO does not have an attenuator, there will be oscillations due to reflections from an imperfectly terminated collector end of the helix. The reflected wave results in a backward wave.



The figure shows several regenerative loops that function as an amplifier with β as the feedback factor in the looping of the o/p to the i/p. Each regenerative loop functions as an amplifier or oscillator and is designed such that the phase

Shift around the loop is 2π radians. The forward circuit is the helix along which the wave moves. The feedback circuit is the β-circuit in a feedback amplifier. Connecting the o/p to the i/p when the amplifier gain becomes large, positive feedback takes place and the β-circuit loop oscillates at the frequency for which the total delay is 2π radians.

The RF field velocity modulates the electron beam which ~~be~~ moves towards the collector end of the tube forming a bunch. This bunch now provides energy to the helix RF wave in the backward direction. This looping continuous until there is sufficient energy in the RF wave.

The frequency of oscillation of a BWO can be varied by varying the voltage controlling the beam velocity and the amplitude of oscillations by changing the electron beam current.

Characteristics of BWO :

1) Frequency Range: 1 GHz to 1000 GHz
2) power o/p : 10 mW to 150 mW (CW)
   20 W (at high frequencies).
   250 kW (pulsed)
3) Tuning range: upto about 40 GHz.

Applications of BWO :

1) Signal sources in instruments and transmitters.
2) Broad band noise source
3) A noiseless oscillator with good bandwidth.

Magnetrons :

Klystron, Reflex klystron, TWT and BWO are linear beam tubes generally called 'O' tubes or original type. The other type of microwave tubes are cross field tubes in which the electric and magnetic fields are perpendicular to each other. The principal tube in this type, called the M-type is the magnetron. Magnetrons provide microwave oscillations of very high peak power.

- In klystron that the electrons carrying energy are in contact with the RF field in the resonant cavity only for a short duration. However if the electrons can be made to interact with RF field for a longer duration higher efficiency can be obtained. This has been done in TWT and in magnetron.

There are 3 types of magnetrons

1) Negative Resistance type
2) Cyclotron frequency type
3) Travelling wave (or) cavity type.

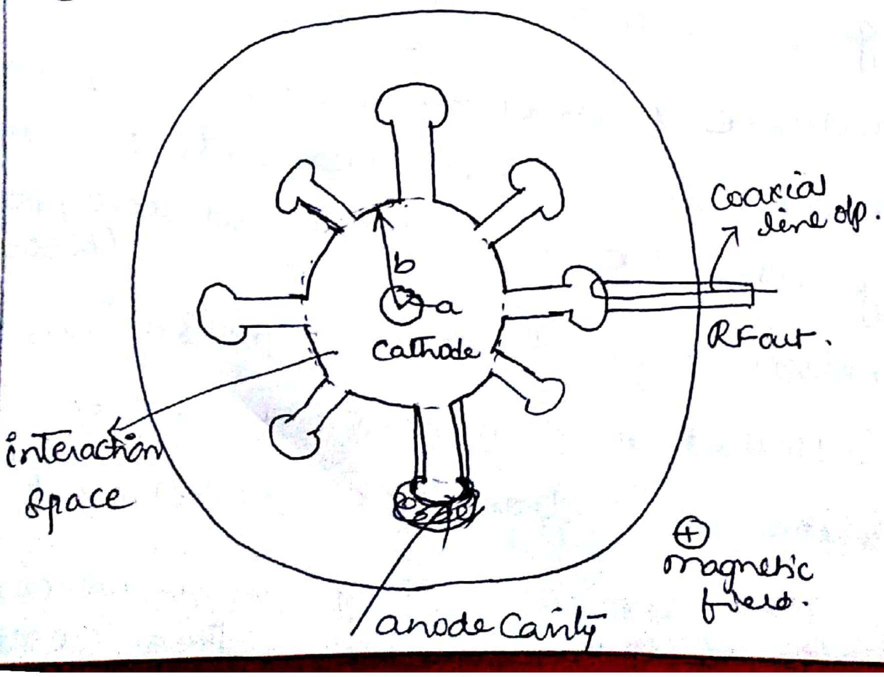
Negative Resistance magnetrons make use of negative resistance between two anode segments but have low efficiency and are useful only at low frequencies (<500MHz)

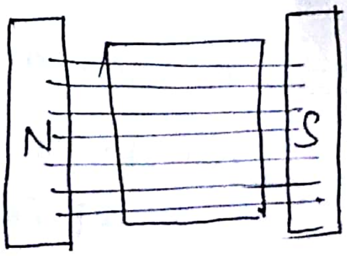
Cyclotron magnetron depends upon synchronism between an alternating component of electric and periodic oscillations of electron in a direction parallel to this field. These are useful only for frequencies greater than 100MHz.

Cavity magnetrons depends upon the interaction of electrons with a rotating electro magnetic field of constant angular velocity.

Cavity magnetrons: [8-cavity magnetron]

It is a diode usually of cylindrical configuration with a thick cylindrical cathode at the centre and a coaxial cylindrical block of copper as anode.
In the anode block are cut a number of holes and slots which act as resonant anode cavities.
The space between the anode and cathode is the interaction space and to one of the cavities is connected a coaxial line or wave guide for extracting the o/p. It is a cross field device as the electric field between anode and cathode is radial whereas the magnetic field produced by a permanent magnets is axial.
The permanent magnet is placed such that the magnetic lines are parallel to the vertical cathode and perpendicular to the electric field between cathode and anode.





Magnetic flux lines in magnetron

Characteristics :

1) power o/p : In excess of 250 kW (pulsed mode)
   10 mW (UHF band)
   2 mW (X-band)
   8 kW (at 95 GHz)

2) Frequency : 500 MHz to 12 GHz

3) Duty cycle : 0.1 %

4) Efficiency : 40% to 70%

Applications :

1) pulsed radar

2) Voltage Tunable magnetrons (VTM) are used in sweep oscillators in telemetry and in missile applications.

3) Fixed Frequency, CW (Continuous Wave) magnetrons are used for industrial heating and microwave ovens.