Microwave Tubes

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Introduction

- Microwave devices can be classified into two groups Active and Passive devices
- Active devices

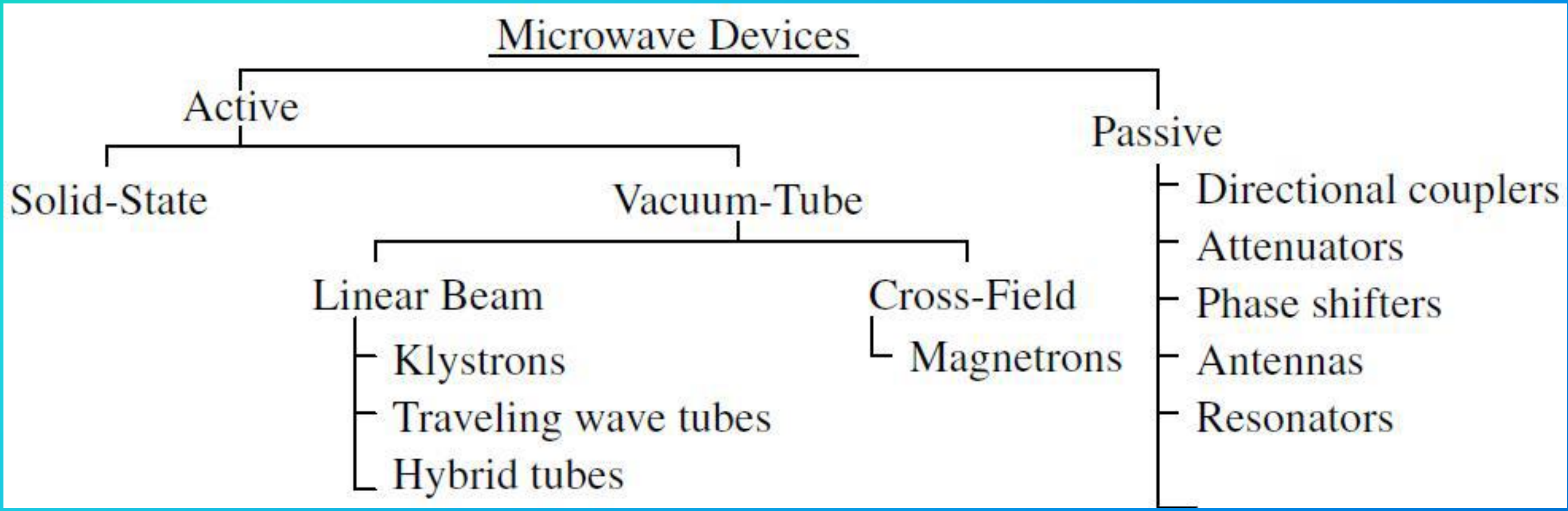
Active devices can be further divided into two groups

1. Microwave solid state devices - e.g microwave transistor, FET's ,Transferred Electron Devices(TED) & Avalanche transit time devices
2. Vacuum tubes - further classified in to two Linear and cross-field

- Passive devices

Directional couplers, attenuators, phase shifters, antennas, resonators etc

Classification



Microwave Tubes

- Microwave tubes are designed to overcome the principle limitations of conventional negative grid electron tubes.
- In microwave tubes the electron transit time is utilized for microwave oscillation or amplification.
- The principle uses an electron beam on which space-charge waves interact with electromagnetic fields in the microwave cavities to transfer energy to the output circuit of the cavity.
- Microwave tubes can be classified into three broad groups
    1. Gridded tubes- triodes
    2. Linear Tubes/O-type tubes- Klystron, Travelling wave tubes etc.
    3. M-Type Tubes- Magnetrons,Cross-field devices

O-Type microwave tubes

- Tubes in the O-type category are sometimes called linear or rectilinear beam tubes in recognition of the straight path taken by the electron beam.
- In this class of devices, both velocity and density modulation takes place, creating the bunching effect.
- The electron bundles thus created have a period in the microwave region.
- Examples of O-type tubes include Klystrons and travelling-wave tubes (TWT)

M-Type microwave tube

- A principle feature of such tubes is that electrons travel in a curved path.
- These are crossed field devices where the static magnetic field is perpendicular to the electric field. e.g. Magnetrons.
- The O-type tubes differ from M-type in that electrons travel in a straight line under the influence of parallel electric and magnetic fields.

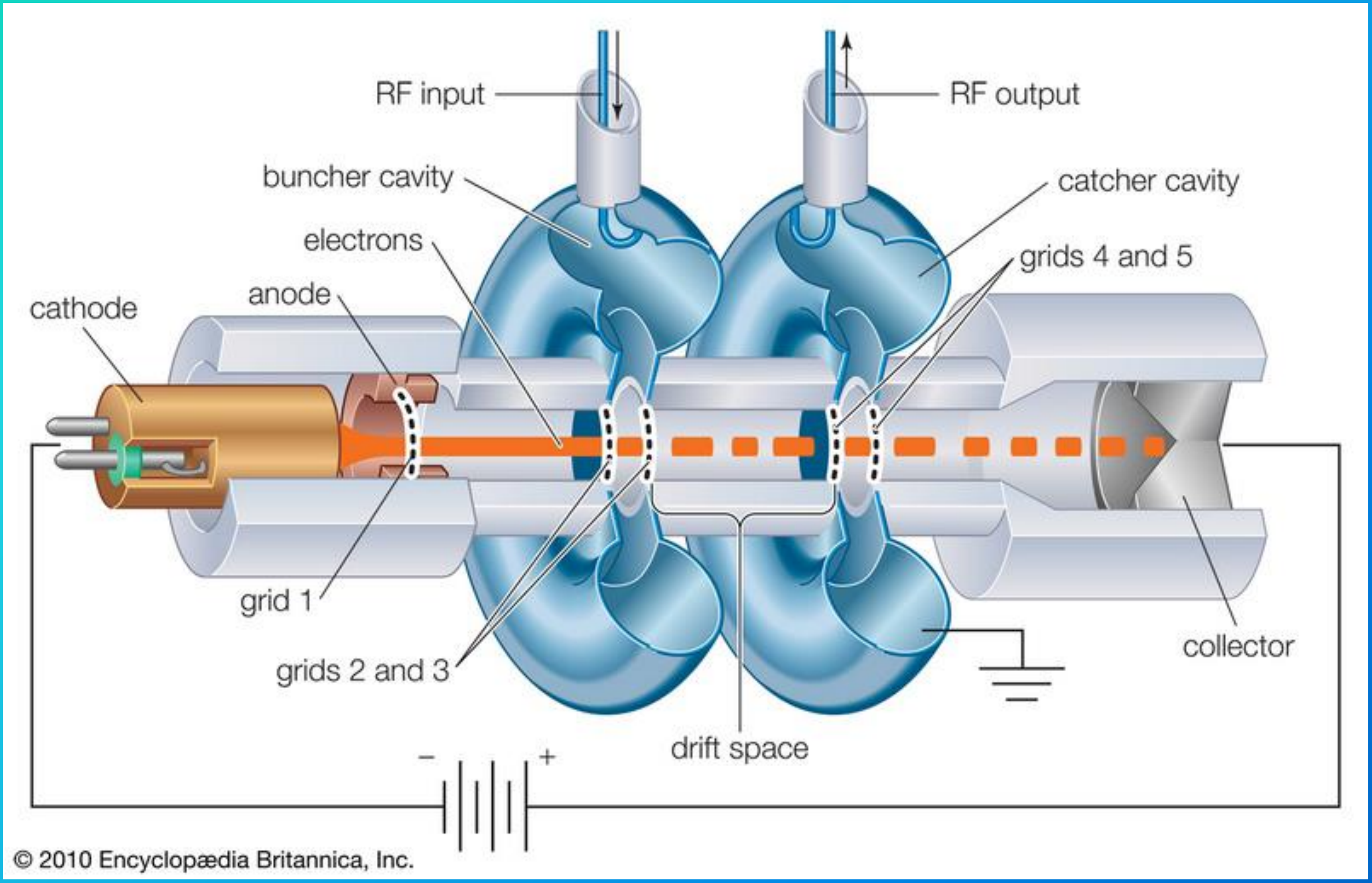
Kylstron

- Klystron is most widely used tube as amplier at microwave frequencies.
- Klystron works on the principle of velocity and current modulation.
- There are two basic configurations of Klystron tubes.
    1. Two cavity or multicavity Klystron- It is used as low power microwave amplifier
    2. Reflex Klystron - It is used as low power microwave oscillator

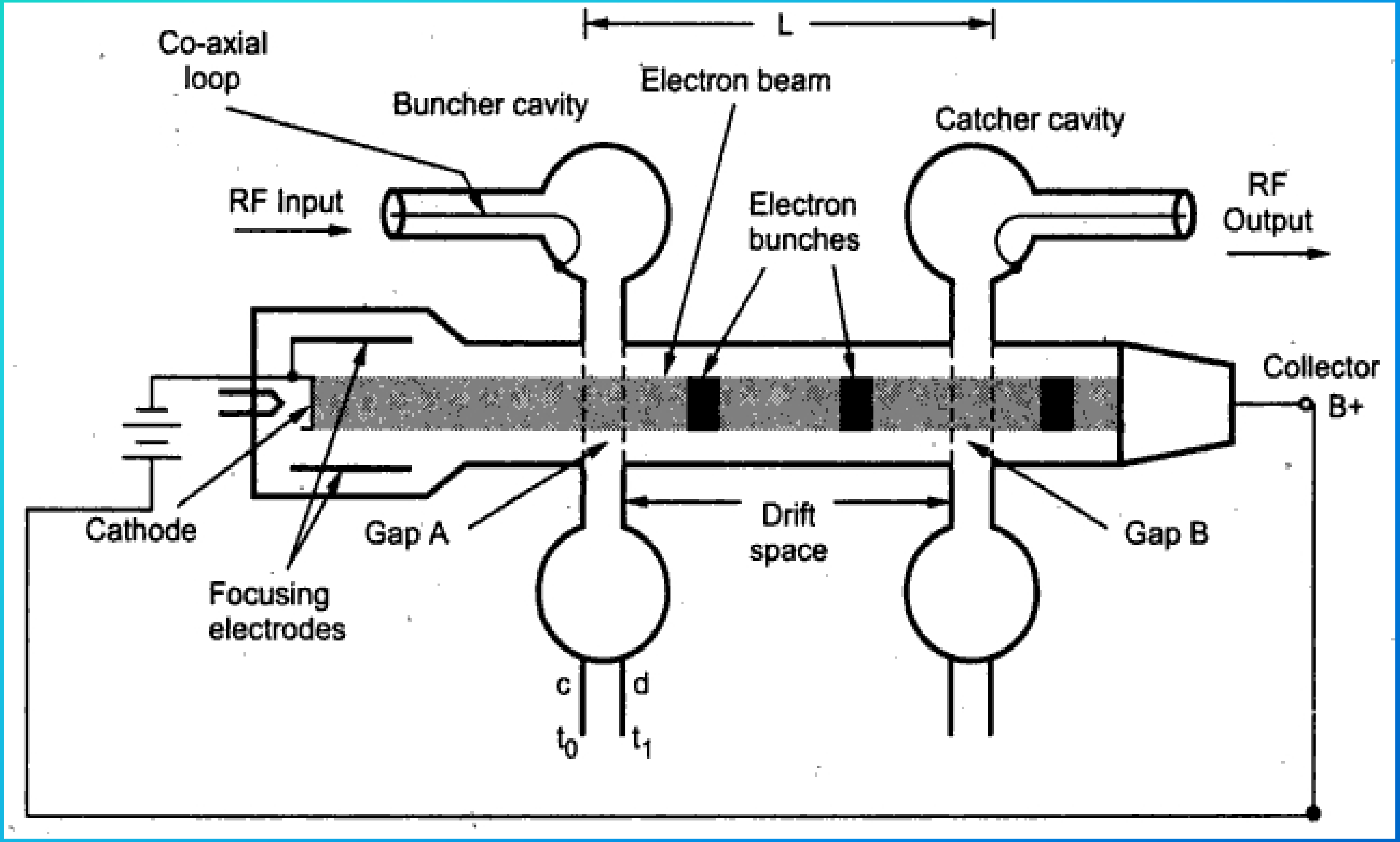
Two Cavity Klystron - Construction

- A two cavity Klystron amplifier consists of a cathode, focusing electrodes, two buncher grids separated by a very small distance forming a gap of two catcher grids with small gap B followed by a collector.
- The cavity close to the cathode is known as the buncher cavity or input cavity, which velocity modulates the electron beam.
- The other cavity is called the catcher cavity or output cavity it catches energy from the bunched electron beam

Two Cavity Klystron - Construction



Two Cavity Klystron - Construction



Two Cavity Klystron - Operation

- Two cavity Klystron amplifier works on the principle of velocity and current modulation.
- A high velocity electron beam is formed, focused and sent down along a glass tube to a collector electrode. The high velocity electron beam generated by cathode arrive at the first cavity with uniform velocity.
- The electron beam passes gap A in the buncher cavity to which RF signal to be amplified is applied and is then allowed to drift freely without any influence from RF fields until it reaches gap B in the output or catcher cavity
- The separation between buncher grid and catcher grid is called drift space.
- The focusing electrode (first grid) controls the numbers of electron beam and serves to focus the beam. The velocity of electrons in the beam is determined by the beam accelerating potential.

Two Cavity Klystron - Operation

- On having the region of first grid, the electrons pass through the grids of buncher cavity. The grids of the cavity allow the electrons to pass through, but limits the magnetic fields within the cavity.

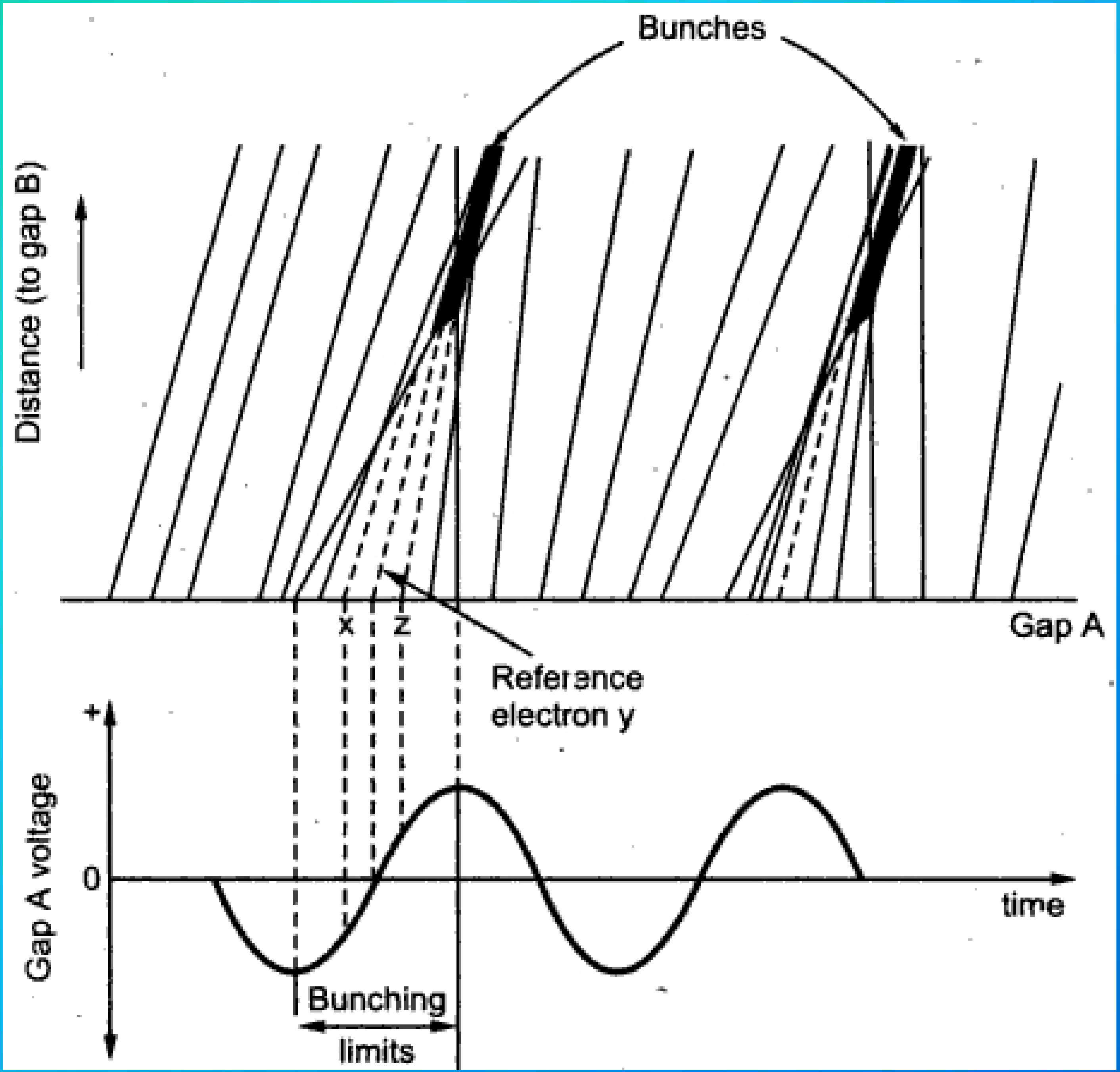
- The space between the grids is referred to as interaction space. When the electrons travel through this space they are subjected to RF potentials at a frequency determined by the cavity resonant frequency or the input frequency.

- The amplitude of this RF potential between the grids is determined by the amplitude of the incoming signal in case of the amplifier, or by the amplitude of the feedback signal from the second cavity it used as an oscillator.

- The cavities are re-entrant type and are tunable.

Two Cavity Klystron - Operation

- Consider when there is no voltage across the gap ; electrons passing the gap are not affected and continue to collector with same constant velocity.
- When an input is applied to the buncher cavity, an electron will pass gap A at the time when the voltage across this gap is zero and going positive, let this be the reference electron y.
- This reference electron is unaffected by the gap, and thus it is shown with the same slope on the apple gate diagram of Fig as electrons passing the gap before any signal was applied to the buncher cavity.


Bunches
Distance (to gap B)
Gap A
x
z
Reference electron y
Gap A voltage
+
0
time
Bunching limits

Two Cavity Klystron - Operation

- Electron z, passes gap A slightly later than y as shown. In absence of gap voltage, both electrons would have continued past the gap with unchanged velocity.
- In presence of positive voltage across *gap A*, however electron z is accelerated slightly and given enough time, will catch up with the reference electron of easily before *gap B* is approached.
- Similarly, electron x passes gap A slightly before the reference electron, and is retarded by the negative voltage, at that instant across the gap, since electron y was not so retarded, it has an excellent chance of catching electron x before *gap B*, this is shown in applegate diagram.

Two Cavity Klystron - Operation

- As a result of these actions, the electrons gradually bunch together as they travel down the drift space. The variation in electron velocity in the drift space is known as velocity modulation.
- The density of the electrons in the second cavity gap varies cyclically with time. Such velocity modulation is not sufficient in itself for amplification, by Klystron.
- While bunching, electrons exchanges energy with the slower electron, giving it some excess energy, and the two bunch together move with the average velocity of the beam.
- As the beam progresses further down along the drift space, the bunching becomes more complete, as more and more of the faster electrons catch up with bunches ahead.
- Eventually, the current passes the catcher gap with quite pronounced bunches and, therefore varies cyclically with time, and this variation in current density (current modulation) enables the Klystron to have a oscillations.

Two Cavity Klystron - Operation

- Applegate diagram shows that the bunching can occur only per cycle, centring on the reference electron.
- The limits of bunching are also shown, any electrons arriving after the second limit are not accelerated sufficiently to catch up with any electron passing through the gap A just before the first limit.
- Bunches, therefore, arrive at the catcher grid, once per cycle and then deliver this energy to this cavity.
- The catcher cavity is excited into oscillations at its resonant frequency (input frequency) and a large sinusoidal output can be obtained because of flywheel effect of the output resonator.
- Bunching therefore, depends upon the following parameters.
    1. Drift space should be adjusted properly.
    2. Signal amplitude should be such that proper bunching takes place.
    3. D.C. anode voltage.
- Above three factors when properly adjusted gives maximum efficiency.

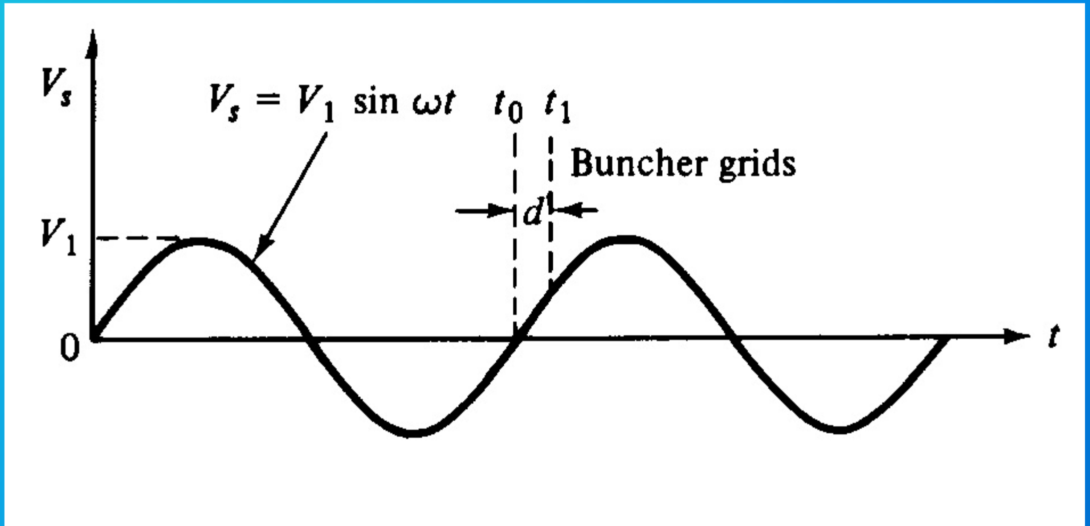
Two Cavity Klystron - Velocity modulation process

- When electrons are first accelerated by the high dc voltage Vo before entering the buncher grids, their velocity is uniform:

$$v_o = \sqrt{\frac{2eV_0}{m}} = 0.593\text{x}10^6\sqrt{V_0}\ \text{m/s} \text{ —— } (1)$$

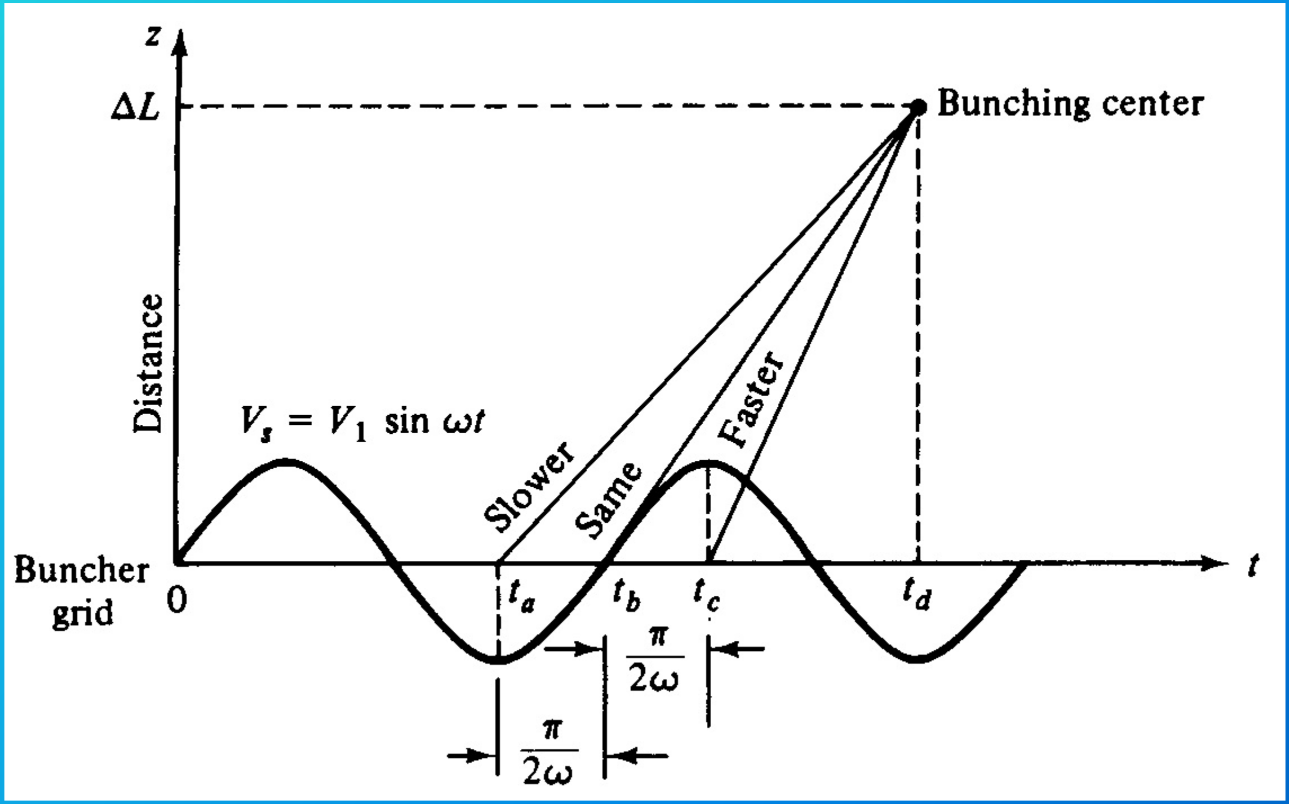
where, V_0 is applied d.c voltage

- In eq(1)it is assumed that electrons leave the cathode with zero velocity.
- When a microwave signal is applied to the input terminal, the gap voltage between the buncher grids appears as Vs = V1sin(wt)
- In order to find the modulated velocity in the buncher cavity in terms of either the entering time to or the exiting time t1 and the gap transit angle θg as shown in Fig.



Two Cavity Klystron - Bunching process

- At a distance of δL along the beam from the buncher cavity, the beam electrons have drifted into dense clusters. Figure shows the trajectories of minimum, zero, and maximum electron acceleration.



APPLICATIONS

As power output tubes

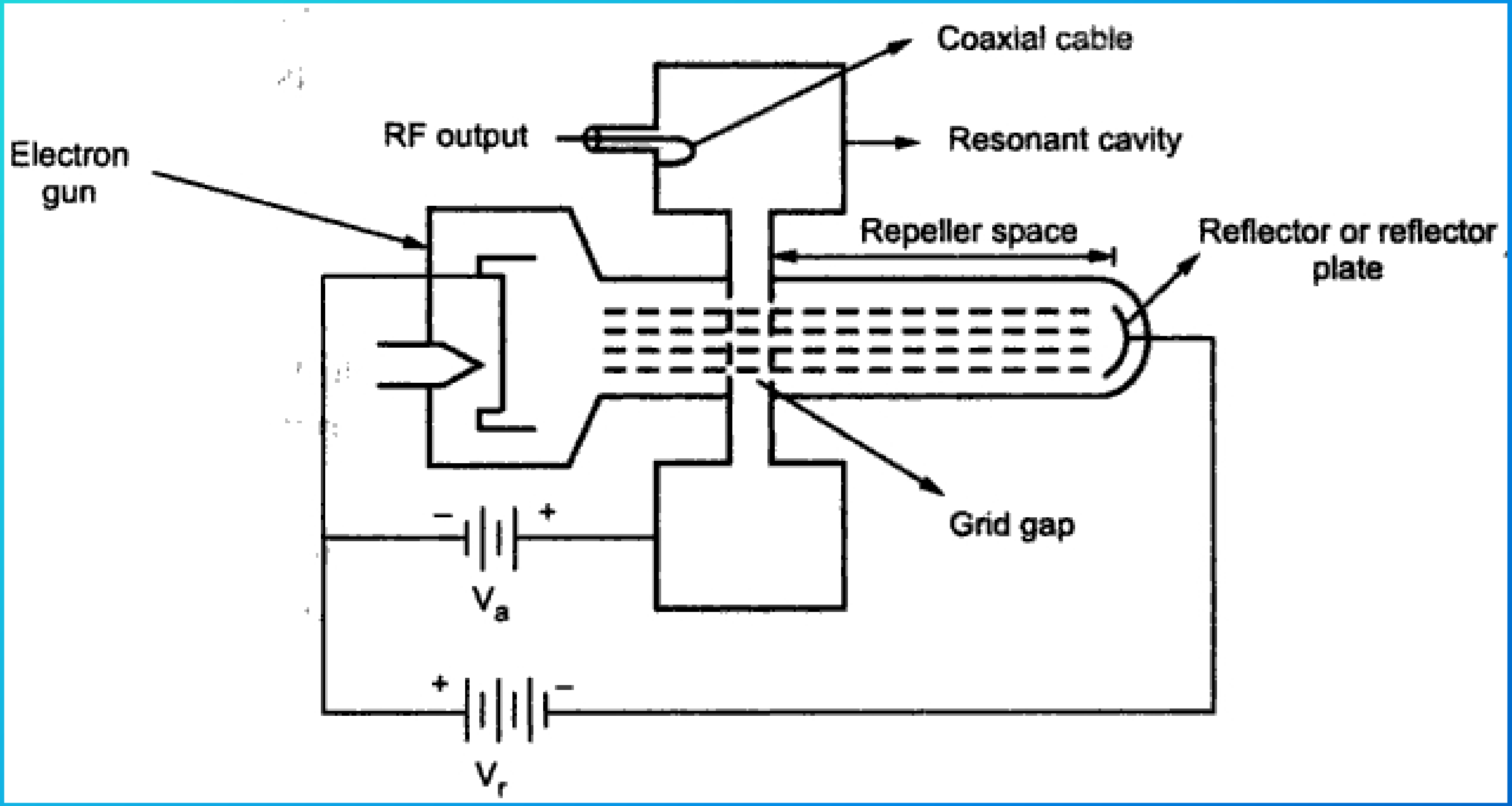
1. In UHF TV transmitters
2. In troposphere scatter transmitters
3. Satellite communication ground station
4. Radar transmitters

As power oscillator

(5 – 50 GHz), if used as a klystron oscillator

Reflex Klystron -Oscillator

- The Reflex Klystron is a single cavity velocity modulated tube in which single cavity does the functions of both the buncher and cavity resonators.

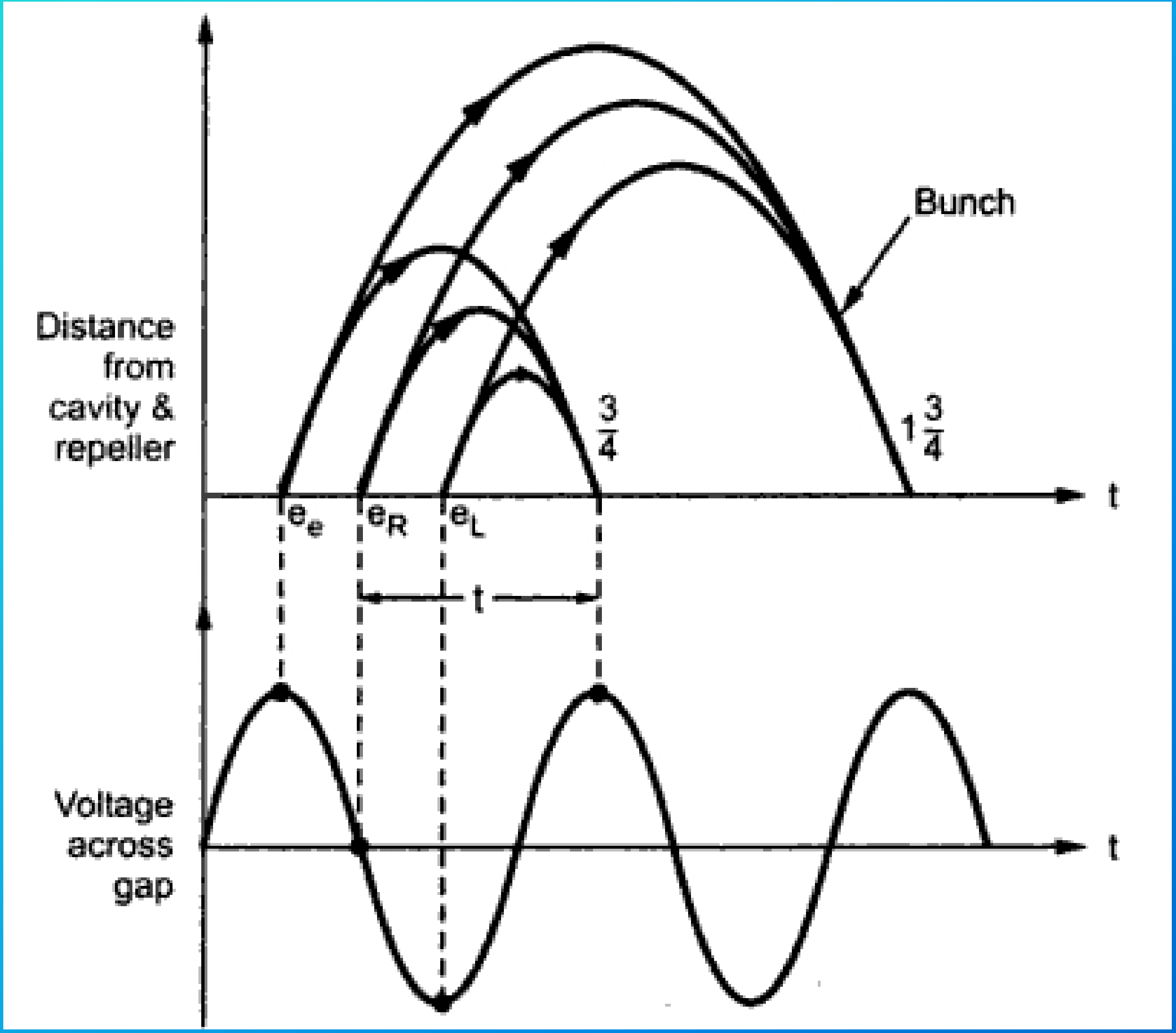


Reflex Klystron -Operation

- The electrons are focused into a beam by electrostatic fields set up by the resonator potential VA. The resonator potential also course the resonant cavity to begin oscillations at its natural frequency when the tube is energized.
- These oscillations causes the RF voltage across the grid gap of the cavity that changes the direction of electrostatic field affects the electrons in the beam as they pass through the grid gap.
- When gap voltage is zero then electron passes through the gap is known as reference electron i.e. er .
- Reference electron er is unaffected by the gap voltage and moves towards the reflector electrode. This electron gets reflected by the negative potential on the reflector electrode. It returns back to the gap.

- The electron which passes through the gap before the reference electron (er) is known as early electron i.e. ee . This electron exhibits the maximum positive potential and accelerated ee moves with great velocity and it penetrates deep into repeller space.
- In return journey from reector electrode to grid gap, the ee takes greater time than er because of more penetration into repeller space. The electron which passes through the gap after the reference electron er is known as the late electron eL.
- It exhibits maximum negative potential on it and moves with the retarding velocity. The return journey time of eL is much shorter than the er and ee electron because of the less penetration into the repeller space. The late electron eL catches up with the reference electron er and early electron ee to form a bunch.
- The bunching of electrons occur once per cycle centred around the reference electron er and these bunches transfer the maximum energy to grid gap.
- Due to this energy of grid gap, the oscillations are sustained in the cavity resonator.

Reflex Klystron - Optimum Transit Time



Reflex Klystron - Optimum Transit Time

- The time taken by the electrons to travel towards the reflector electrode and return back to the grid gap is known as the transit time. In case of reflex Klystron the optimum transit time is most important factor for oscillation to be sustained.
- All the velocity-modulated electrons will be repelled back to the cavity by the repeller due to its negative potential.
- The repeller distance L and the voltages can be adjusted to receive all the voltage-modulated electrons at a same time on the positive peak of the cavity RF velocity cycle.
- Thus the velocity modulated electrons are bunched together and lose their kinetic energy when they encounter the positive cycle of the cavity RF field.

Reflex Klystron - Optimum Transit Time

- The dc potential applied to the repeller is both critical and useful for tuning the reflex klystron operating frequency. A value of the repeller potential must be found that varies the transit time of the repelled bundles so that they arrive back at the cavity in phase with the gap oscillations.
- A condition for oscillation is $$\boxed{t = \left(N + \frac{3}{4}\right) T}$$
- Where,
- t = transit time of electrons
- T = period of arriving bunches
- N = integer (0,1,2,3,...) etc.
- The reflex klystron will continue to oscillate if the electrons remain in the repeller field longer than 3/4 cycle (as long as the electrons return to the grid gap when the field is of the proper polarity to decelerate the electrons).

Reflex Klystron - Optimum Transit Time

- The difference in transit time (such as 1 ¾, 2 ¾) causes the change in performance characteristics of the reflex Klystron. The reflex Klystron operates in different modes for different characteristics caused by transit time.
- If the electrons remain in the field for longer than 3/4 cycle, the difference in electron transit time causes the tube performance characteristics to change. The differences in operating characteristics are identified by Modes of operation.
- The reflex klystron operates in a different mode for each additional cycle that the electrons remain in the repeller field.
- Mode 1 is obtained when the repeller voltage produces an electron transit time of 3/4 cycle
- Mode 2 has an electron transit time of 1 ¾ cycles; mode 3 has an
- electron transit time of 2 3/4 cycles; etc.

Reflex Klystron - Output power

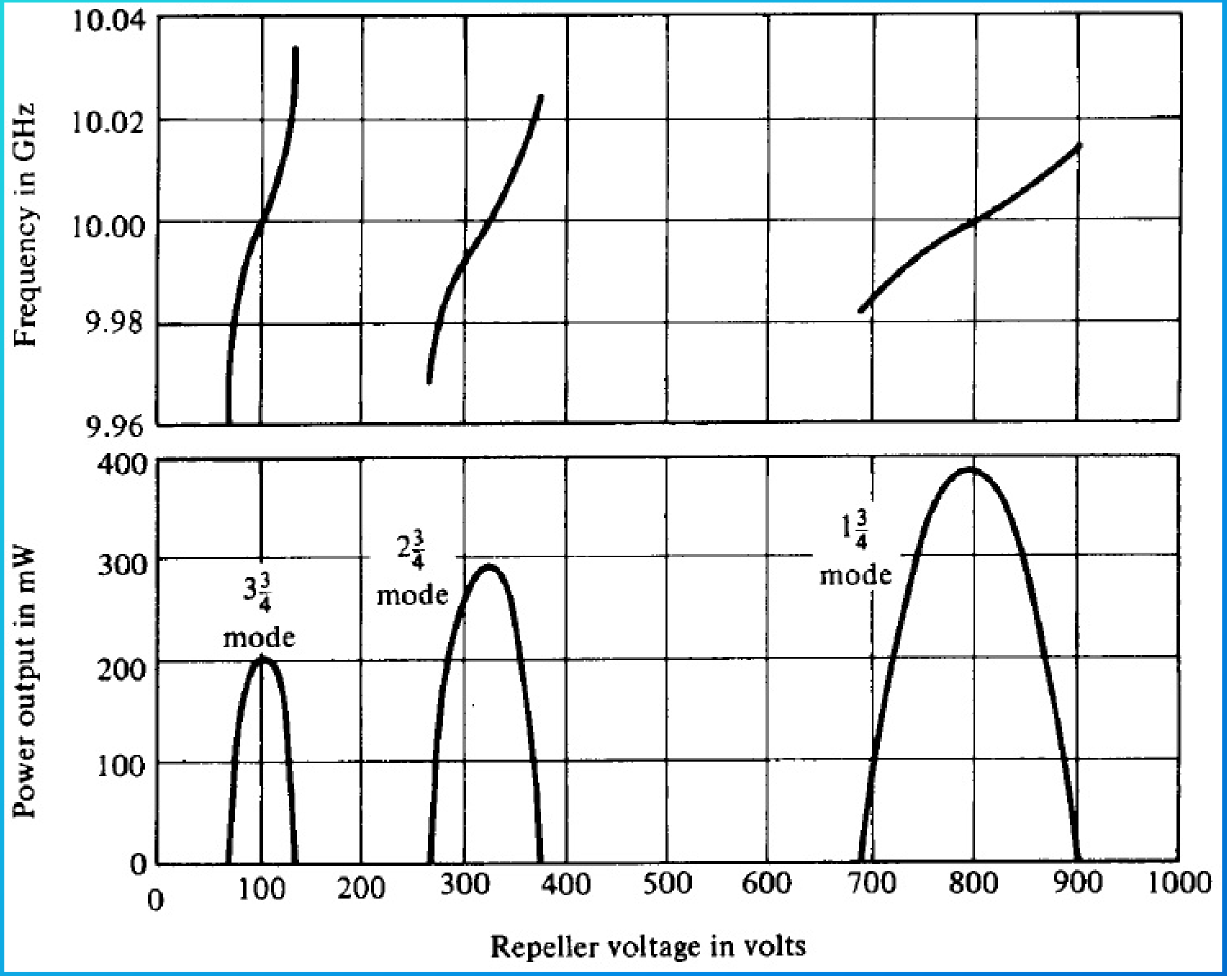
- The variation in output power for different modes of operation can be explained by examining the factors which limit the amplitude of oscillations.
- Power and amplitude limitations are caused by the DEBUNCHING process of the electrons in the repeller field space.
- Debunching is simply the spreading out of the electron bunches before they reach electrostatic fields across the cavity grid.
- The lower concentration of electrons in the returning bunches provides less power for delivery to the oscillating cavity. This reduced power from the bunches, in turn, reduces the amplitude of the cavity oscillations and causes a decrease in output power.

Reflex Klystron - Output power

- In higher modes of operation the electron bunches are formed more slowly. They are more likely to be affected by debunching because of mutual repulsion between the negatively charged electrons.
- The long drift time in the higher modes allows more time for this electron interaction and, as a result, the effects of debunching are more severe. The mutual repulsion changes the relative velocity between the electrons in the bunches and causes the bunches to spread out.
- Variation in repeller voltage changes output frequency. The frequency of resonance of output cavity decides the oscillation frequency. Also the output power can be changed by varying repeller voltage. This is called electronic tuning. Therefore reflex Klystron can be used as voltage tuned oscillator or frequency modulated oscillator.

Reflex Klystron - Output power

- The nature of variation of output power and frequency with repeller voltage for different modes are shown in Fig. These are known as mode curves of reflex Klystron.

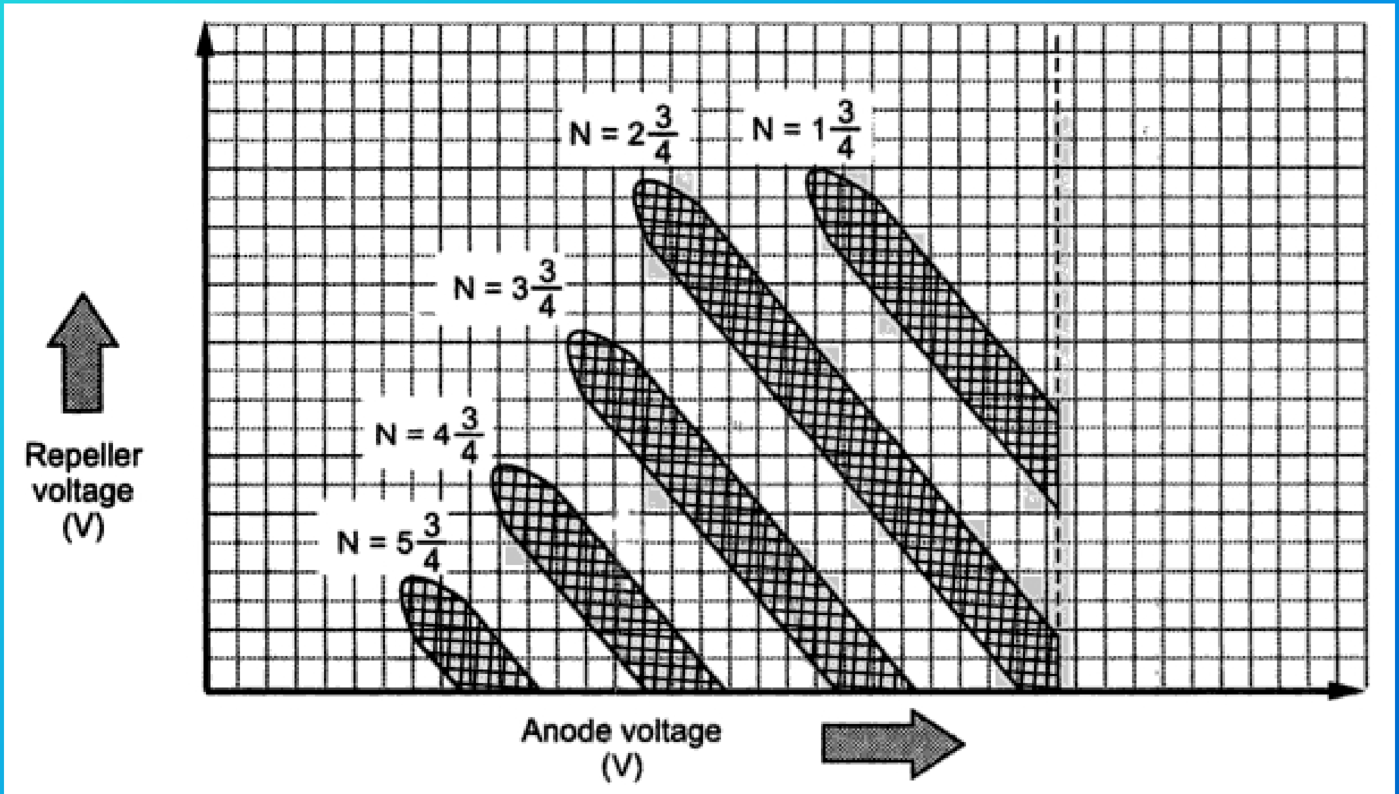


Reflex Klystron - Output power

- Electronic tuning does not change the centre frequency of the cavity, but does vary the frequency within the mode of operation.
- The amount the frequency can be varied above or below the centre frequency is limited by the half-power points of the mode.
- The centre frequency can be changed by one of two methods One method, GRID-GAP TUNING, varies the cavity frequency by altering the distance between the grids to change the physical size of the cavity. This method varies the capacitance of the cavity by using a tuning screw to change the distance between the grids mechanically.
- The cavity can also be tuned by PADDLES or SLUGS that change the inductance of the cavity.

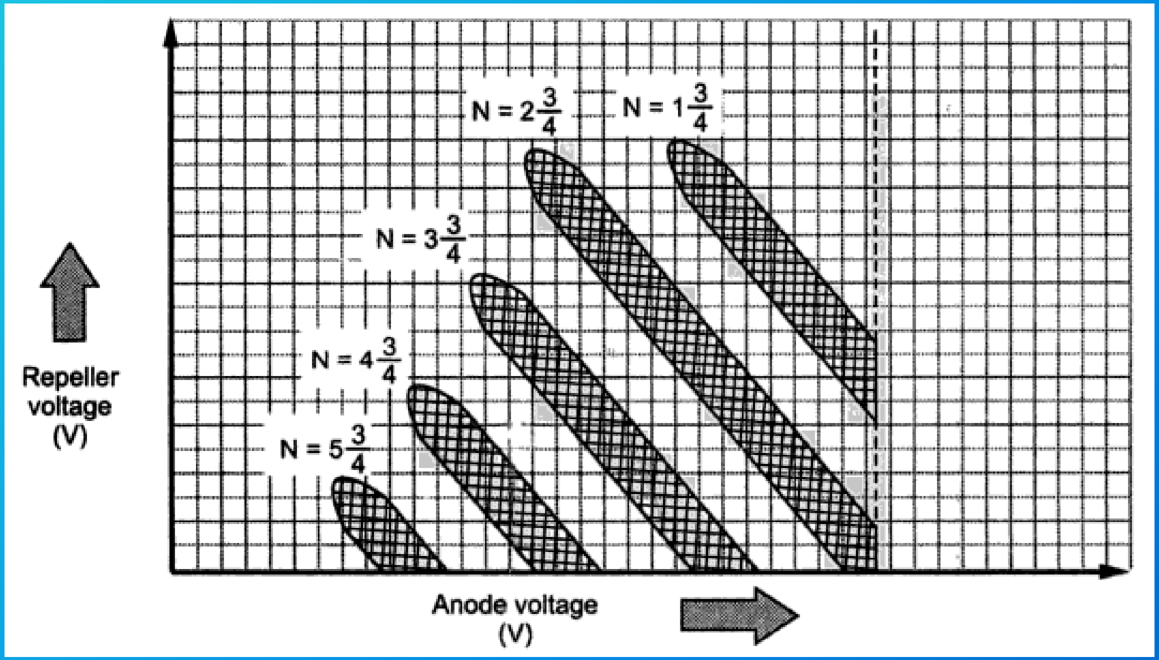
Reflex Klystron - Operating characteristics

- The repeller and anode voltage must be adjusted such that the bunch appears exactly at any of the positive maximum voltage of RF signal.
- This is necessary for reflex Klystron to undergo into oscillations.
- Only for a certain combination of anode voltage (beam voltage) and repeller voltage, the oscillations are developed. Fig. shows this voltage characteristics or operating characteristics of reflex Klystron.



Reflex Klystron - Operating characteristics

- The shaded portion corresponds to oscillations for suitable repeller and beam voltage combinations. These diagram are drawn for a fixed frequency.
- For other frequencies, pattern remains the same, but the positions of the regions are shifted because of changed values of n.
- Lower modes gives larger power output but requires larger values of repeller and beam voltages. Usually modes corresponding to n = 2 or n = 3 are preferred.



Reflex Klystron - characteristics & applications

- Performance characteristics
  1. Operating frequency range : 4 GHz to 200 GHz
  2. Output power : 10 mW to 2.5 W
  3. Efficiency : 20%
  4. Bandwidth : 25 MHz

- Applications
  1. Pump oscillator for parametric amplifiers.
  2. Frequency-modulated oscillator in portable microwave links.
  3. Local oscillator in microwave receivers.
  4. Signal source in microwave generators.

Travelling Wave Tube(TWT)

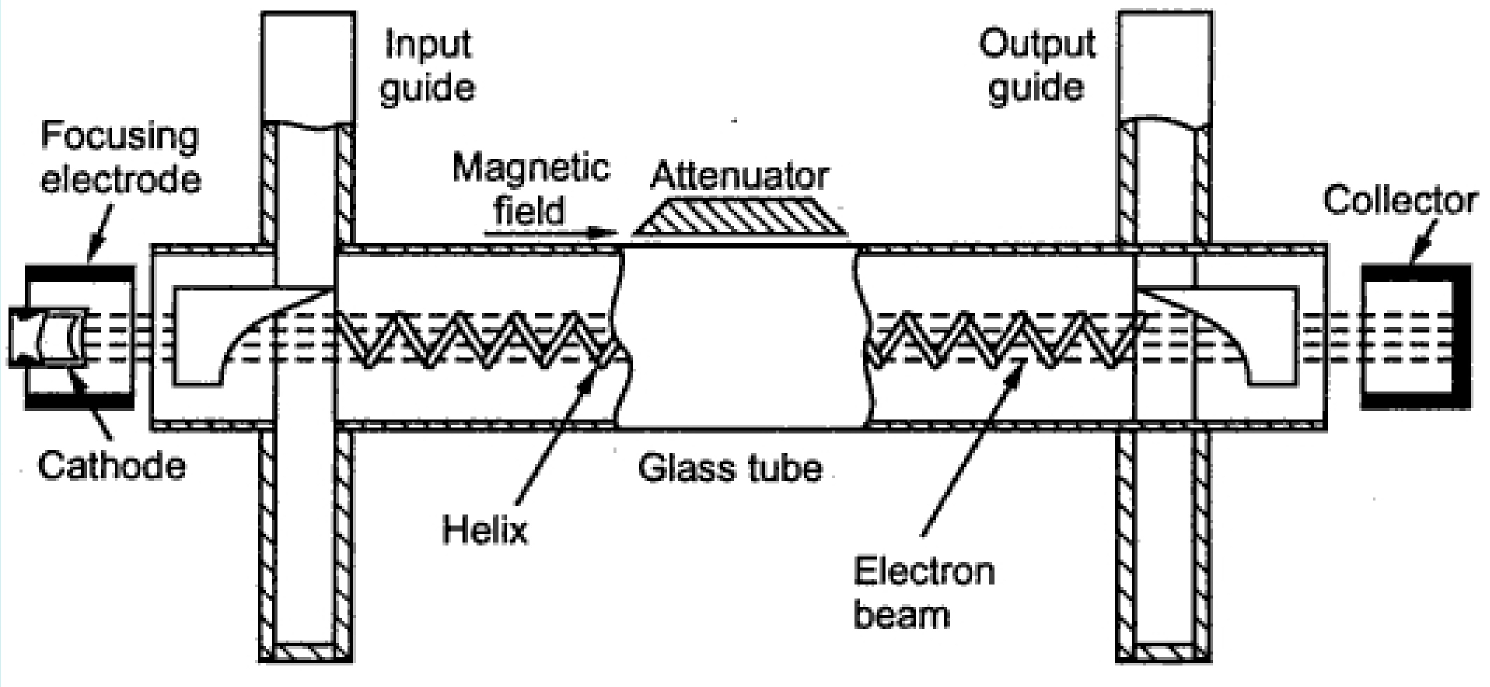
- In the past few years, several (radio) amateurs have employed travelling wave tubes (TWTS), colloquially known as 'twits', as microwave power amplifiers.
- The main attraction of these devices is their very high gain (30-60 dB), linear characteristics and 1-2 octave bandwidth
- The history of the twt goes back to the second world war, when research into radar devices and techniques was at a particularly intense level. The twt was invented in the Nueld Laboratory Physics Department, Birmingham University (also the birthplace of the cavity magnetron) by Rudolf Kompfner in 1946.
- He was seeking an alternative which had a better noise performance than the klystron.
- One of the main reasons for the lack of sensitivity of the klystron as an amplifier is the inevitable energy exchange between the electron beam and the electric field in the rhumbatrons (resonators).

Travelling Wave Tube(TWT)

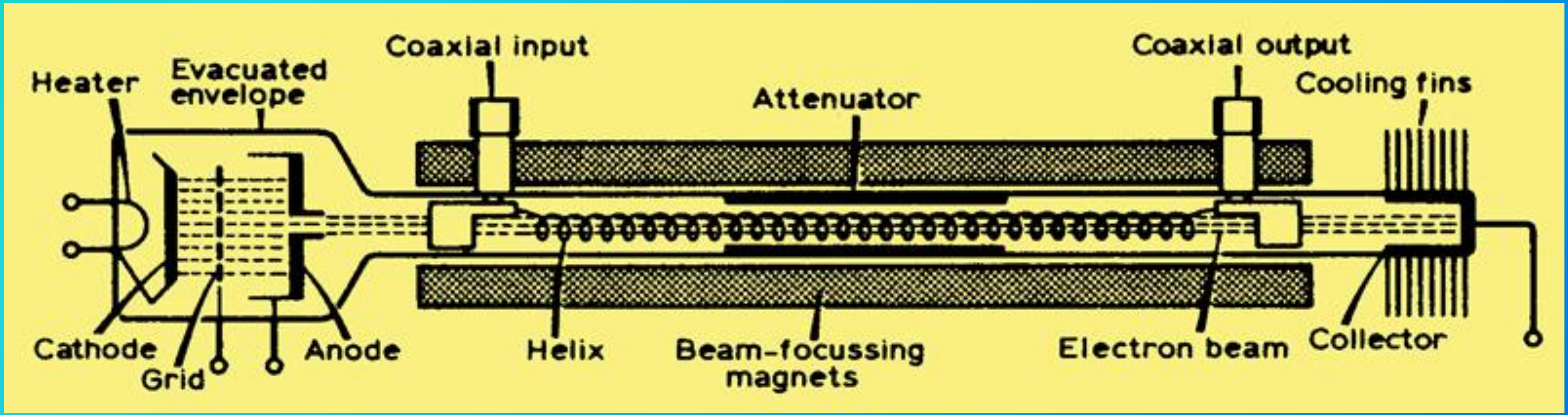
- It was therefore a very inviting thought to use the signal in the form of a travelling electric eld (instead of a stationary one) and utilize the energy exchange between the travelling eld and electrons which travel at about the same velocity.
- In December 1943 the rst tube gave a gain of about 8 dB at a 9.1 cm wavelength, with a 13 dB noise gure. The work was later transferred to the Clarendon Laboratory, Oxford. Much of the mathematical analysis of twt operation was developed by John R. Pierce, of Bell Labs [1], and in 1947 Kompfner joined Pierce to continue twt research.
- Nowadays, TWTS are by far the most widely-used of microwave tubes, and are employed extensively in communication and radar systems.
- They are especially suited to airborne applications, where their small size and low weight are valuable. Satellite communication systems are another extremely important application, for the same reasons.

Helix Travelling Wave Tube

- The physical construction of a typical travelling wave tube using a helix is shown in Fig.



Travelling Wave Tube(TWT)



Travelling Wave Tube(TWT)- Construction

- The electron beam is provided by an electron gun which is very similar to those used in CRTs, though the beam current is much larger.

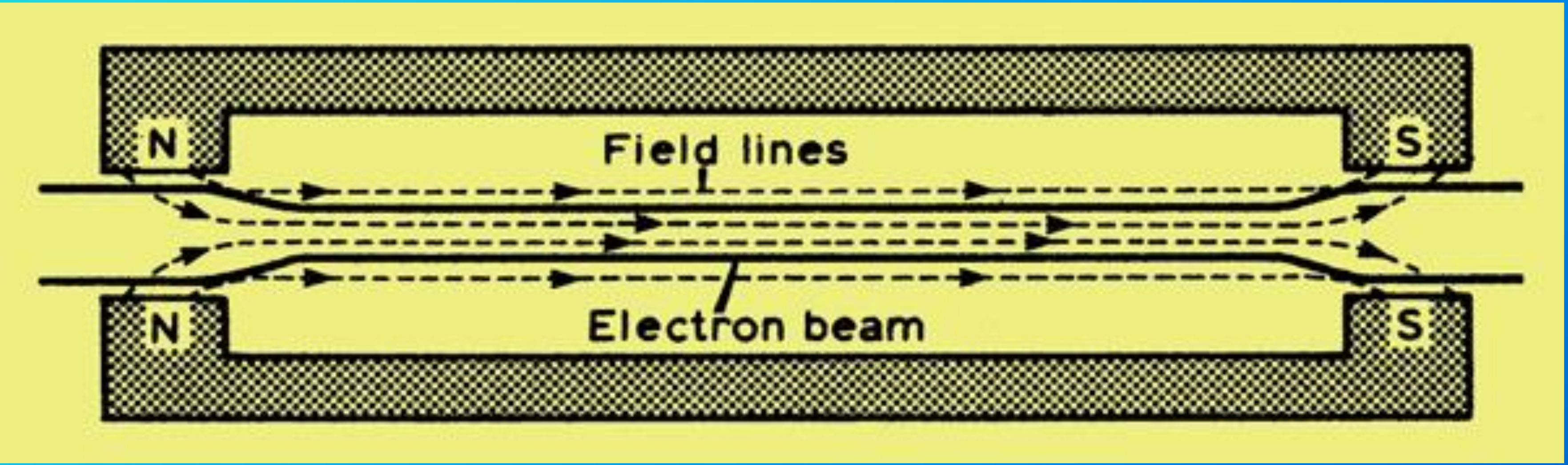
- Electrons from a heated cathode are accelerated towards the anode, which is held at a high positive potential with respect to the cathode, and a proportion pass through a hole in the anode to produce the beam.

- Some tubes have a grid between the cathode and anode, at a few tens of volts (adjustable) negative with respect to the cathode, the function of which is to control the beam current. The electron beam travels down the tube, inside the helix, to the collector, which is maintained at a high voltage referred to the cathode.

- The helix is also held at a high potential, but the helix current is low because of the beam focusing.

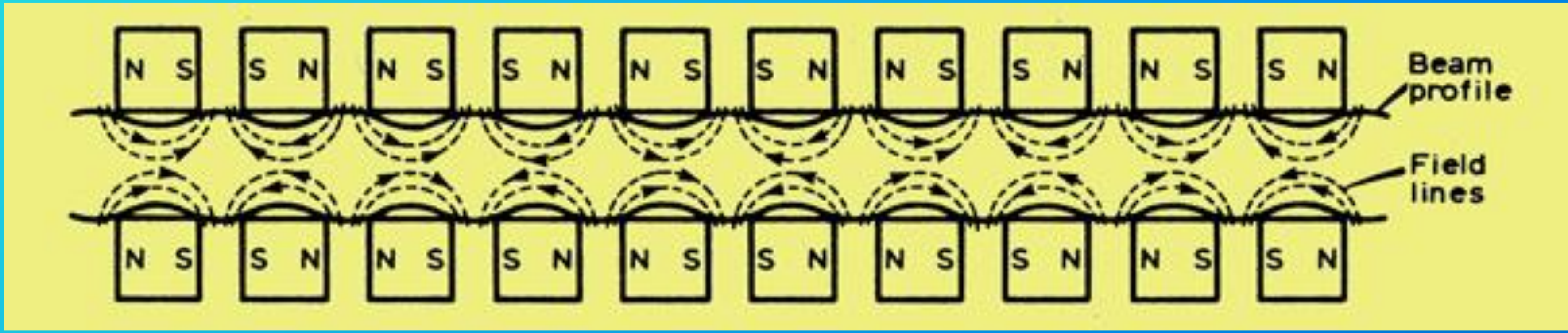
Travelling Wave Tube(TWT)- Construction

- As is shown below, this focusing is achieved by a magnet (either a solenoid electromagnet or permanent magnets) round the outside of the tube.
- An electron with a component of velocity perpendicular to the magnetic field lines experiences a restoring force tending to bring back its direction parallel to the field lines.



Travelling Wave Tube(TWT)- Construction

- To achieve good focusing by this method requires a very large magnetic field, which can mean a bulky, heavy magnet. However, the arrangement usually employed is called periodic permanent magnet (PPM) focusing, in which a number of toroidal permanent magnets of alternating polarity is arranged along the tube, as is shown below; this figure also shows the contour of the beam.



Travelling Wave Tube(TWT)- Construction

- The input to, and output from, the helix are via coaxial connectors, or occasionally via waveguide.

- In practice, it is impossible to provide a perfect match at these transitions, especially over a wide bandwidth, so an attenuator is used to prevent the energy reflected back down the helix causing instability. This usually takes the form of a resistive coating on the outside of the central portion of the tube, though a physical discontinuity in the helix is also used in some cases.

- The attenuator reduces the RF input signal, as well as any reflected signal, to nearly zero, but the electron bunches set up by the signal are unaffected.

- The helix itself is a fairly delicate structure, and must be provided with adequate thermal dissipation to prevent damage. In medium-power tubes, the helix is often supported on a beryllia or alumina substrate, but for high-power TWTS, alternative slow-wave structures are employed (eg coupled cavities), though usually at the expense of bandwidth.

Travelling Wave Tube(TWT)- Construction

- The essential principle of operation of a TWT lies in the interaction between an electron beam and an RF signal. The velocity, v, of an electron beam is given by:

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

- where Va = accelerating anode voltage

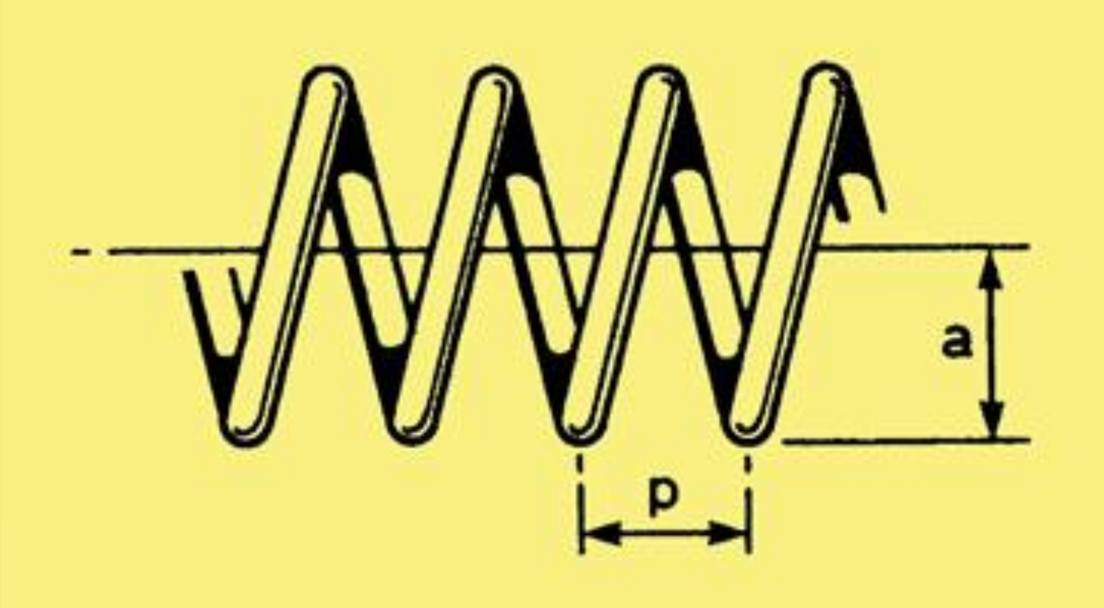
10^7

e = charge on the electron, m= mass of the electron

- An anode voltage of 5 kV gives an electron velocity of 4.2 x 10^7 m/s.
- The signal would normally travel at c, the velocity of light (3 x 10^8 m/s), which is much faster than any 'reasonable' electron beam (relativistic effects mean that the electron mass actually increases as its velocity approaches c, so that achieving electron velocities approaching c is a complicated business).

Travelling Wave Tube(TWT)- Construction

- If, however, the signal can be slowed down to the same velocity as the electron beam, it is possible to obtain amplification of the signal by virtue of its interaction with the beam. This is usually achieved using the helix electrode, which is simply a spiral of wire around the electron beam.



Travelling Wave Tube(TWT)- Construction

- Without the helix, the signal would travel at a velocity c.
- With the helix, the axial signal velocity is approximately c x (p /2a)
- where a, p are shown above, so the signal is slowed by the factor (p/2a).
- Note that this is independent of signal frequency. The signal travelling along the helix is known as a slow wave, and the helix is referred to as a slow-wave structure.

- The condition for equal slow wave and electron-beam velocities is therefore approximately

$$\frac{c * p}{2\pi a} = \sqrt{\frac{2eV_a}{m}}$$

Travelling Wave Tube(TWT)- Construction

- The interaction between the beam and the slow wave takes the form of ‘velocity modulation' of the beam (ie some electrons are accelerated and some retarded) forming electron bunches within the beam.
- The beam current therefore becomes modulated by the RF signal, and the bunches react with the RF fields associated with the slow wave travelling down the helix, resulting in a net transfer of energy from the beam to the signal, and consequent amplification.
- Since, there are no resonant structures involved in this interaction, amplification is obtained over a wide bandwidth.
- In fact the principal factors which limit bandwidth are the input/output coupling arrangements.

Helix Travelling Wave Tube(TWT) - Construction & Operation

- A helix travelling wave tube consists of an electron gun and a slow wave structure. The electron beam is focused by magnetic focusing field and guide it through the centre of the long axial helix.
- The slow wave structure is either the helical type or folded backlive.
- Helix is a loosely wound thin conducting helical wire. This is termed as O-type TWT.
- The signal to be amplied is applied to the end of the helix adjacent to the electron gun.
- The applied signal propagates around the turns of the helix and produces an electric field at the centre of the helix, directed along the helix axis.
- The amplied signal appears at the output or other end of the helix under appropriate operating conditions.

Helix Travelling Wave Tube(TWT) - Construction & Operation

- The helix is made positive with respect to cathode and collector more so. Thus the beam is attracted to the collector and acquires a high velocity.
- The speed with which the electric eld advances axially is equal to the velocity of light multiplied by the ratio of helix circumference.
- Electrons leaving the cathode at random quickly encounter the weak axial RF field at the input end of the helix, which is due to the input signal.
- As electrons passes across the gap, velocity modulation and bunching takes place.
- When the electrons enter the helix tube, an interaction takes place between the moving axial electric eld and the moving electrons.
- The electrons transfer energy to the wave on the helix. This interaction causes the signal wave on the helix to become larger.

Helix Travelling Wave Tube(TWT) - Construction & Operation

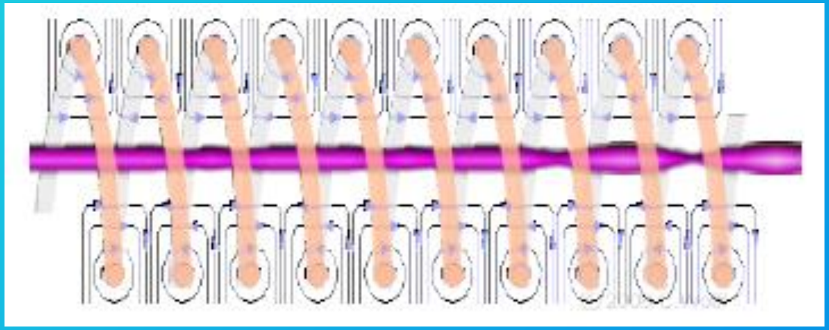
- The electrons entering the helix at zero field are not affected by the signal wave, those electrons entering the helix at the accelerating field are accelerated, and those at the retarding field are de-accelerated.
- As the electrons travel further along the helix, the bunching process continues and the bunching shifts the phase by $\pi/2$.
- Each electron in the bunch encounters a stronger, also the microwave energy of the electrons is delivered by electron bunch to the wave on the helix and the RF wave on the helix grows exponentially and also reaches its maximum at the output end. Thus amplification of RF wave is accomplished.

Helix Travelling Wave Tube(TWT) - Construction & Operation

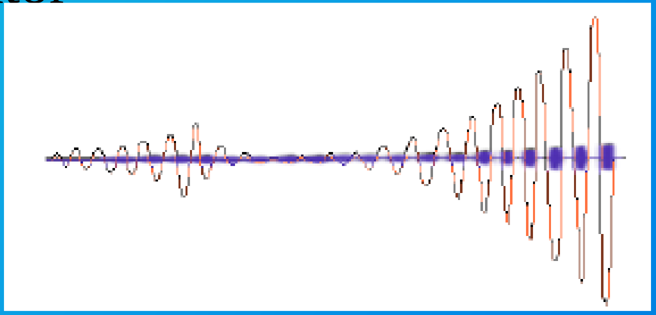
- The following figure shows the electric fields that are parallel to the electron beam inside the helical conductor.
- The electron- beam bunching already starts at the beginning of the helix and reaches its highest expression on the end of the helix.
- If the electrons of the beam were accelerated to travel faster than the waves traveling on the wire, bunching would occur through the effect of velocity modulation.
- Velocity modulation would be caused by the interaction between the traveling-wave fields and the electron beam.
- Bunching would cause the electrons to give up energy to the traveling wave if the fields were of the correct polarity to slow down the bunches.
- The energy from the bunches would increase the amplitude of the traveling wave in a progressive action that would take place all along the length of the twt.

Helix Travelling Wave Tube(TWT) - Construction & Operation

- The following figure shows the electric fields that are parallel to the electron beam inside the helical conductor.

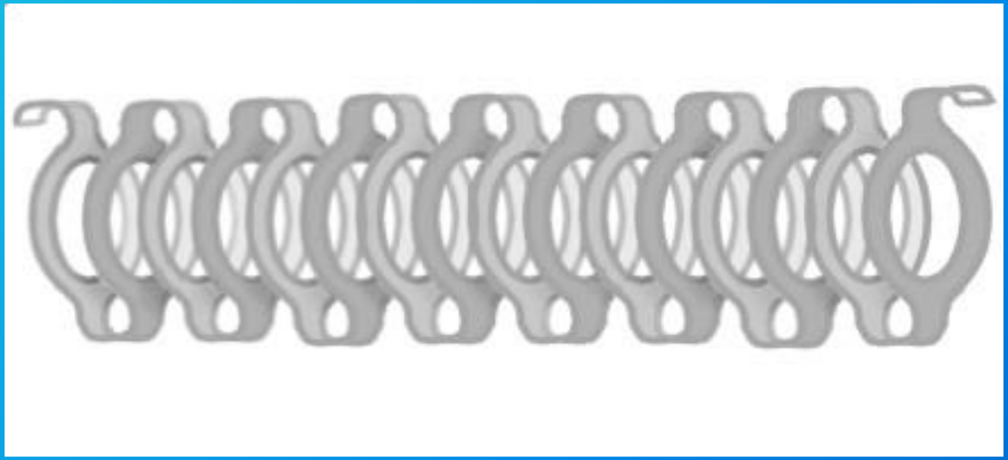


- Influence of attenuator



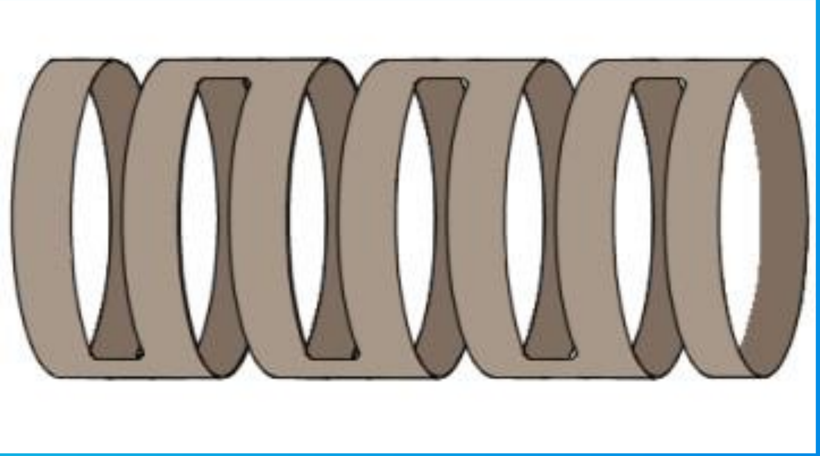
Slow wave structure

- A Ring Loop TWT uses loops as slow wave structure to tie the rings together. These devices are capable of higher power levels than conventional helix TWTs, but have significantly less bandwidth of 515 percent and lower cut-o frequency of 18 GHz.
- The feature of the ring-loop slow wave structure is high coupling impedance and low harmonic wave components. Therefore ring-loop traveling wave tube has advantages of high gain (40-60 Decibels), small dimension, higher operating voltage and less danger of the backward wave oscillation.



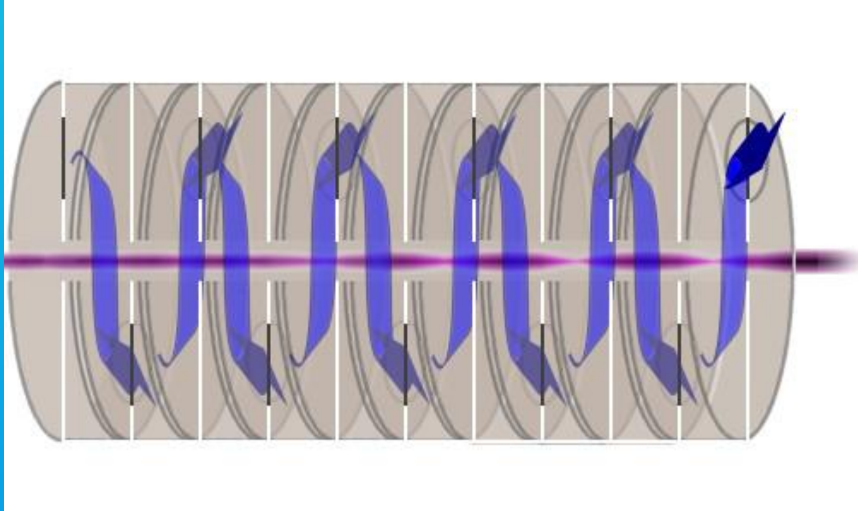
Slow wave structure

- The Ring-Bar TWT has got characteristics likely the Ring-Loop TWT.
- The slow wave structure can be made easier by cut-out the structure of a copper tube.



Slow wave structure

- The Coupled-cavity TWT uses a slow wave structure of a series of cavities coupled to one another. The resonant cavities are coupled together with a transmission line. The electron beam (shown in figure9 as red beam) is velocity modulated by an RF input signal at the first resonant cavity. This RF energy (displayed as blue arrow) travels along the cavities and induces RF voltages in each subsequent cavity.
- If the spacing of the cavities is correctly adjusted, the voltages at each cavity induced by the modulated beam are in phase and travel along the transmission line to the output, with an additive effect, so that the output power is much greater than the power input.



TWT’s characteristics

1. Efficiency = 20%
2. Power output = 10 kW (average)
3. Power gain = 60 dB
4. Operating frequency > 3 GHz
5. Bandwidth = 0.8 GHz
6. Noise figure = 4 to 8 dB.

TWT’s applications

1. Low noise tubes are used in RF amplifiers in broadband microwave receivers.
2. Repeater amplifier in wideband communication links.
3. Medium and high power satellite transponder output.
4. CW radar and radar jamming.
5. Pulsed high power tubes are used in airborne and shipborne radar.
6. Power output = 10 kW (average)

TWT museum

high-power twt VTR 572B

Russian low-power twt UV-1B (cyrillic: -1)

Prasenjeet

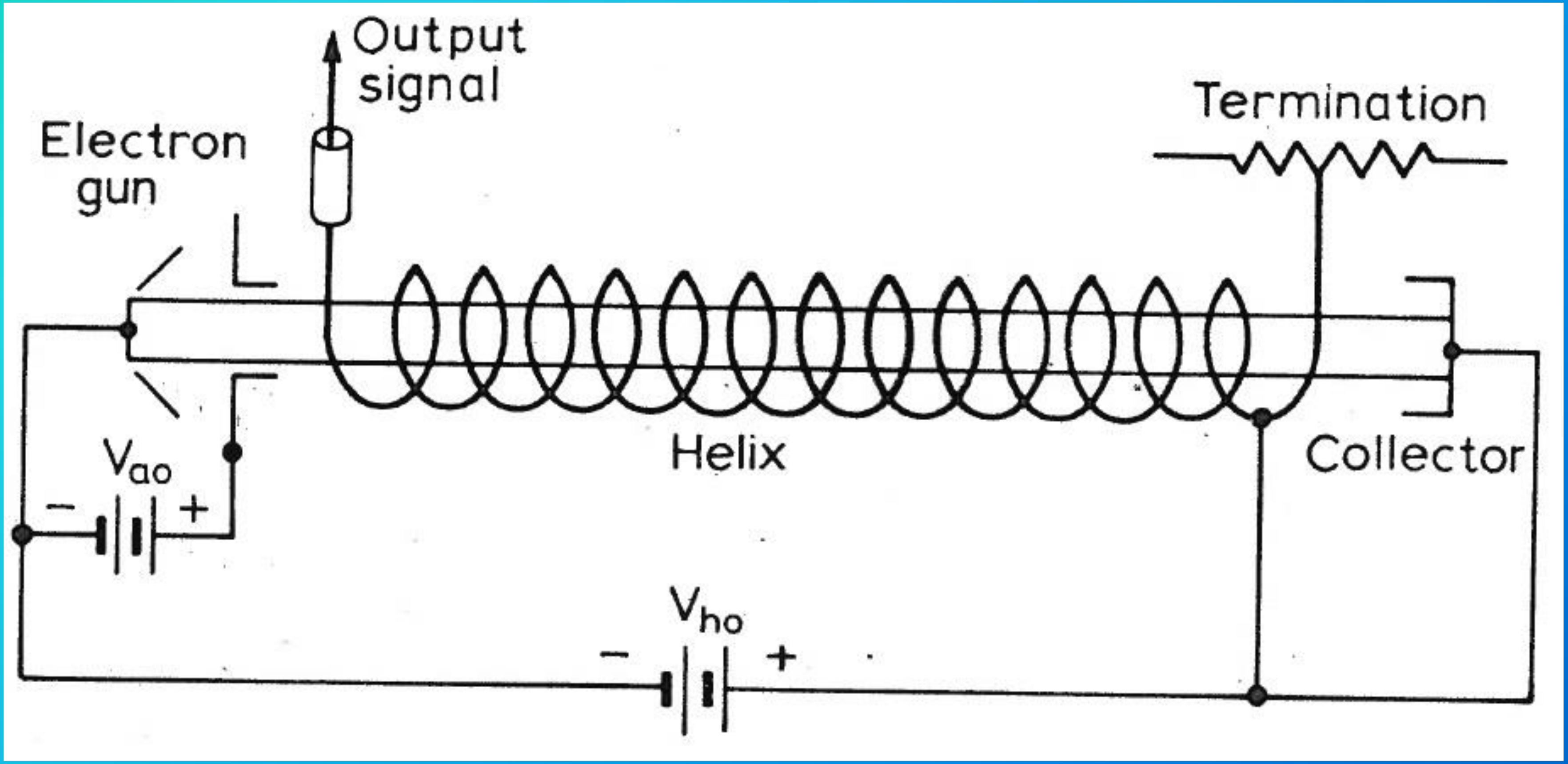
Backward Travelling wave tubes Amplifier/Oscillator

- Backward Wave Oscillator (BWO) is the name usually given to the oscillator version of a travelling wave tube amplifier though the cross field amplifiers are also sometimes operated in this mode
- The TWT backward wave oscillator has the advantage of an enormous frequency tuning range that can be conveniently achieved by varying a voltage.
- Helix is the commonly used slow wave structure.
- The operational principle of a BWO is similar to that of TWT amplifier with the difference that the electron beam transfers its energy, present in the form of electron bunches and acquired due to the velocity modulation caused by RF field propagating in the slow wave structure, to the backward moving RF field.
- The backward moving RF field grows in strength and is taken out from the electron gun end of the tube.

Backward Travelling wave tubes Amplifier/Oscillator

- The collector end is terminated in a passive termination.
- Oscillations can always be assumed to start due to some transient and the presence of an imperfect termination.
- The backward wave is further aided by absence of attenuator which is present in case of a TWTA.
- To increase the interaction BWO uses a ring cathode that emits a hollow beam having maximum intensity near the helix.
- The oscillation frequency primarily depends upon beam velocity which is turn depends upon helix voltage and the associated cavity arrangement.
- Amplitude of oscillations is governed by beam current which can be controlled by varying the electron gun anode voltage.

Backward Travelling wave tubes Amplifier/Oscillator



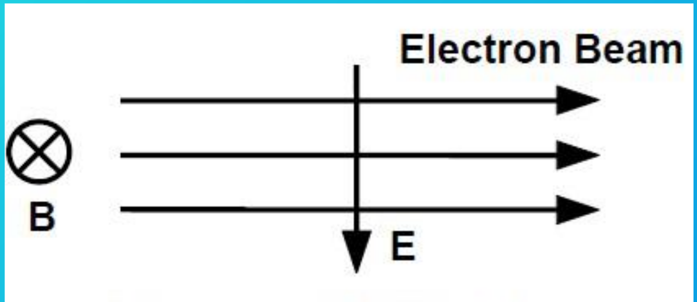
Backward Travelling wave tubes Amplifier/Oscillator

- Backward wave oscillators are widely used as voltage controlled microwave oscillators because of the following features:

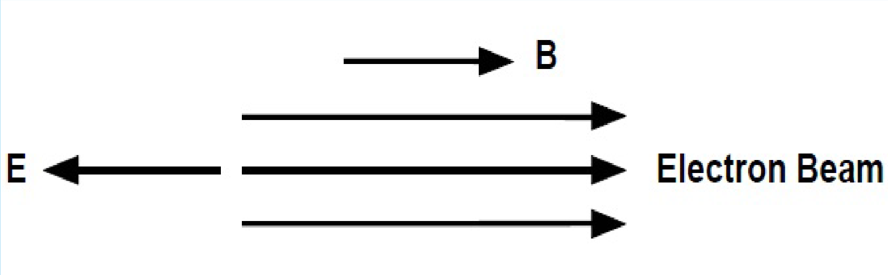
1. BWO can be tuned rapidly over a very wide range of frequencies by changing voltage. The tuning range is as large as l00 percent (i.e.one octave) up-to 50 GHz which reduces to about half octave at higher frequencies primarily due to use of multiple helix's or coupled cavity slow wave structures.
2. BWO produces a very clean signal with the desired output signal being aL least 60 dB larger than the total power of all spurious signals.
3. The frequency of oscillation is extremely stable
4. BWO can be used at frequencies beyond 1000 GHz

Cross field tubes M-type tubes

- In crossed-field tubes, the dc electric field is perpendicular to the magnetic field as is indicated in Figure
- The general motion of the electron beam is perpendicular to both fields.
- This is in contrast to linear-beam tubes (such as klystrons and TWTs)
- Crossed-field tubes are referred to as M-type tubes, which in English means tubes for propagation of waves in a magnetic field.



(a) Crossed-Field Tubes



(b) Linear-Beam Tubes

Magnetron

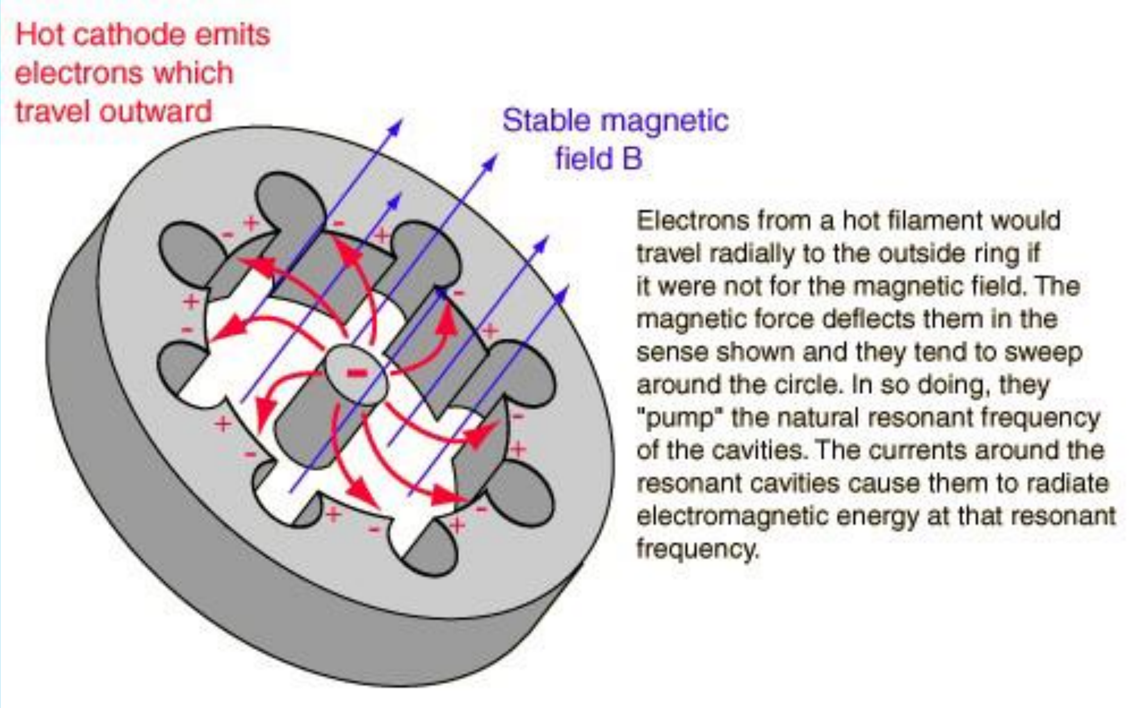
- Magnetron is a type of high power microwave oscillator and it forms the basis of many a microwave radar transmitter systems
- It makes use of magnetic field for producing oscillations at microwave frequencies.
- They are capable of producing megawatts of peak power in the centimeter wavelength range and may be operated at wavelengths extending down to millimeter range.
- All magnetron's consist of some form of anode and cathode operated in a magnetic field that is normal to the electric field between the cathode and the anode.
- The magnetic field causes electrons emitted from the cathode to move in curved paths.
- In case the flux density of the magnetic field is sufficiently strong, the electrons do not strike the anode but return to the cathode and the anode current is cut off.

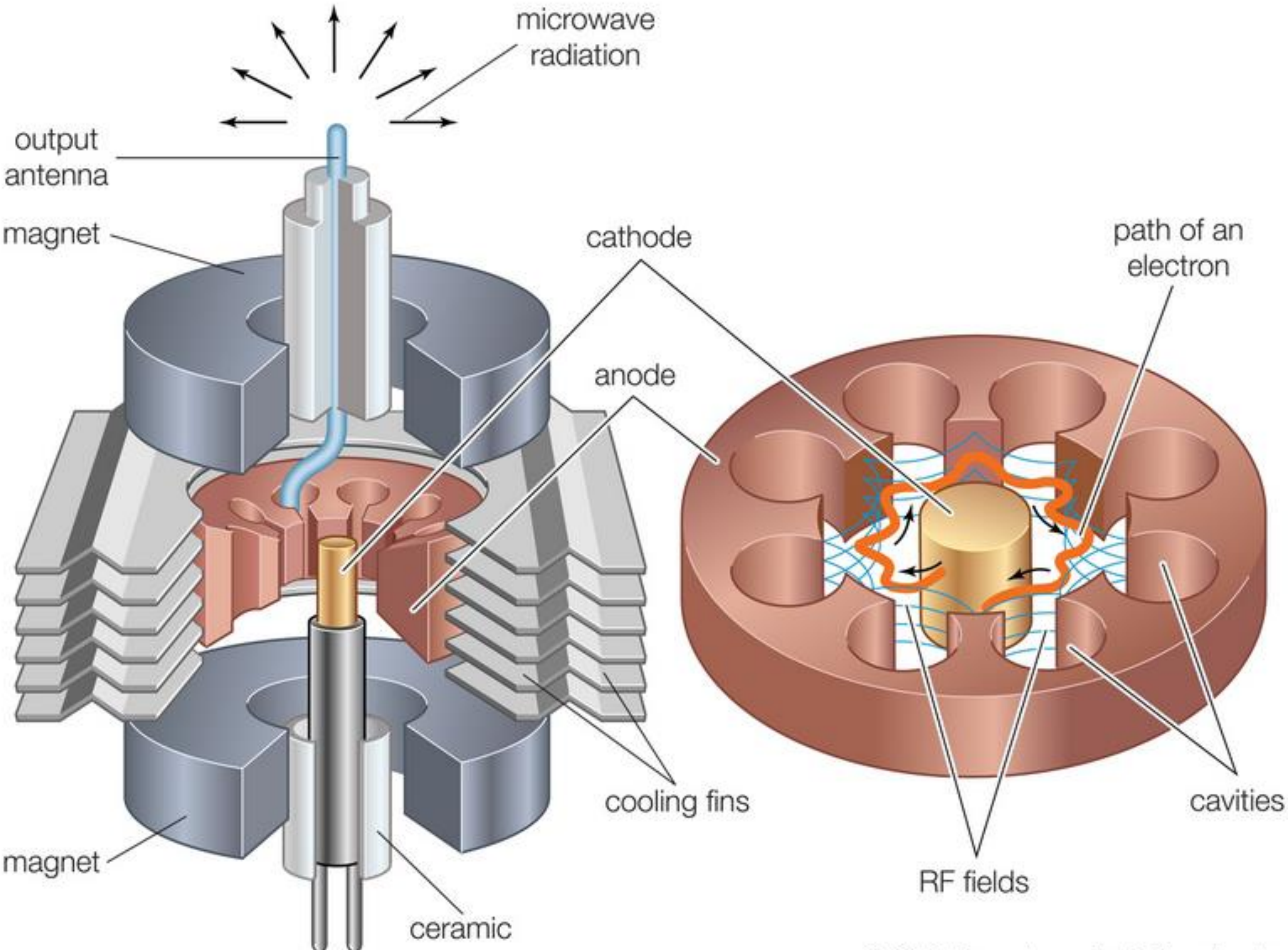
Magnetron

- There are three broad categories of magnetrons.
  1. Negative resistance magnetrons
  2. Cyclotron frequency magnetrons
  3. Traveling wave magnetrons
- Negative resistance magnetrons make use of a static negative resistance present between two anode electrodes/plates.
- Cyclotron frequency magnetrons depend on synchronism between an alternating component of electric field and periodic oscillations of electrons in a direction parallel to this electric field
- The third type, i.e. traveling wave magnetrons depend on interaction of moving electrons with a traveling electro-magnetic field traveling with a constant angular or linear velocity.
- Most modern magnetrons come under the category of traveling wave magnetrons.

Magnetron Construction

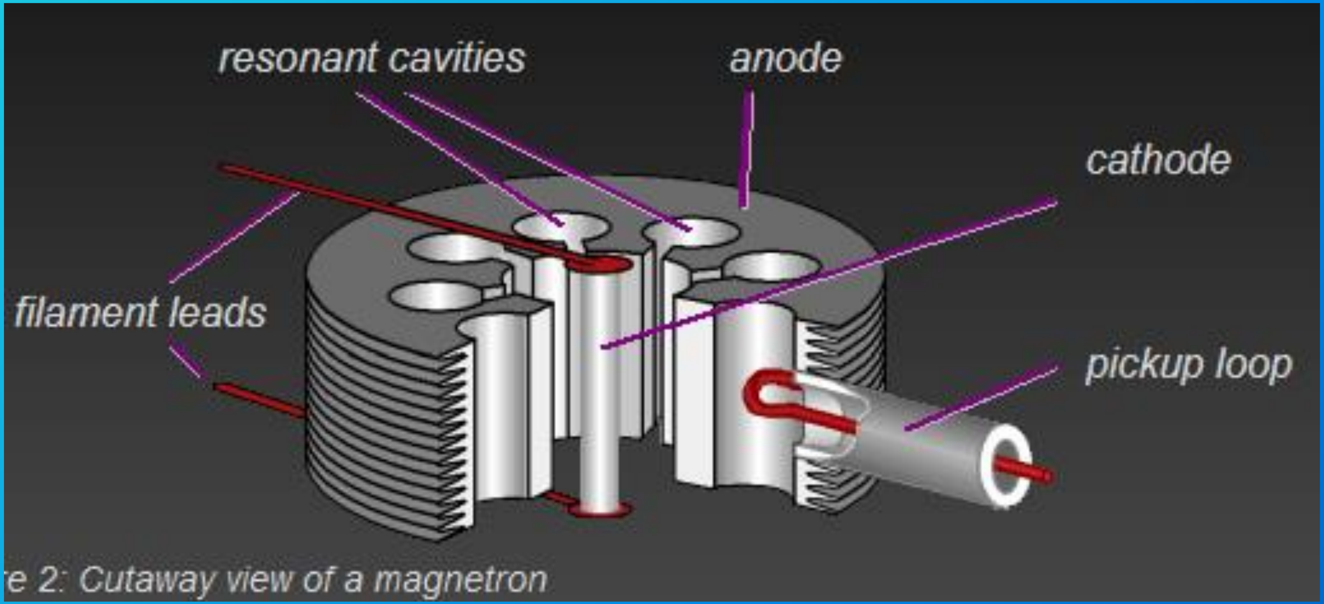
- The Cavity Magnetron or a Traveling Wave Magnetron or simply a magnetron has cylindrical construction employing a radial electric field, an axial magnetic field and an anode structure with permanent resonant cavities.
- The cylindrical cathode is surrounded by the anode with cavities and thus a radial D.C. electric field will exist.




microwave
radiation
output
antenna
magnet
cathode
path of an
electron
anode
cooling fins
cavities
magnet
RF fields
ceramic

Magnetron Construction

- The open space between the plate and the cathode is called the *interaction space*. In this space the electric and magnetic fields interact to exert force upon the electrons.
- The magnetic field is also D. C and since it is perpendicular to the plane of the radial electric field, the magnetron is referred to as a *Crossed Field Device.*



Magnetron Operation

- When a magnetron is first turned on, the only signal that is present is the noise (random fluctuations in electron velocity and density) in the electron cloud circling about the cathode. However, the noise consists of signals of all frequencies including the frequency at which the cavities resonate.
- The oscillations in a magnetron build up very rapidly (in nanoseconds) by amplification of the noise signal of the correct frequency

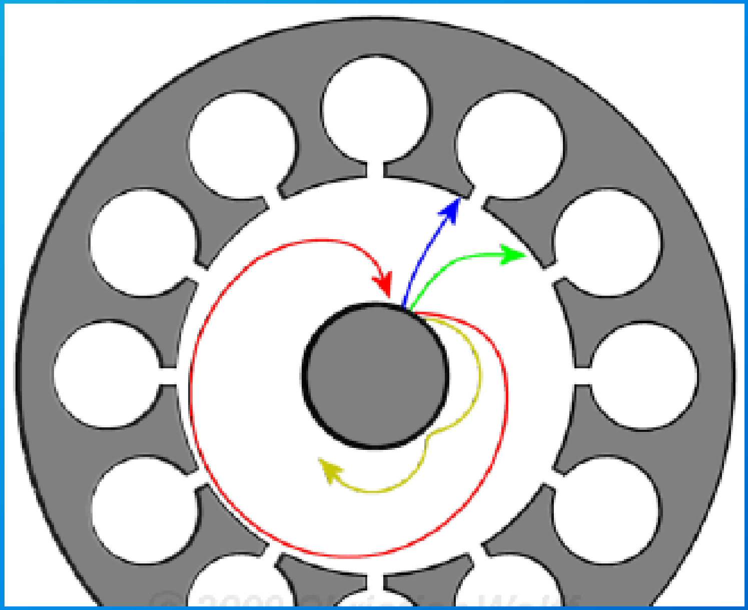
Magnetron Operation

- The production microwave frequencies at a Magnetron can be subdivided into four phases

1. Phase1: Production and acceleration of an electron beam in a dc field
2. Velocity-modulation of the electron beam
3. Formation of electron bunches by velocity modulation(in form of a Space-Charge Wheel)
4. Dispense energy to the ac field

Production and acceleration of an electron beam

- When no magnetic field exists, heating the cathode results in a uniform and direct movement of the field from the cathode to the plate (the blue path in figure).
- The permanent magnetic field bends the electron path. If the electron flow reaches the anode, it contributes to large current
- If the strength of the magnetic field is increased, the path of the electron will have a sharper bend.

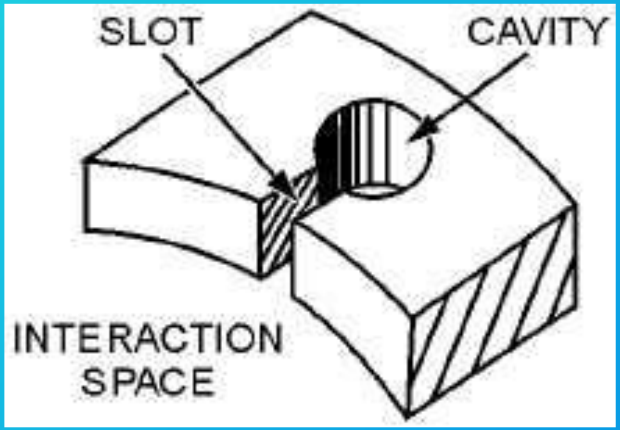


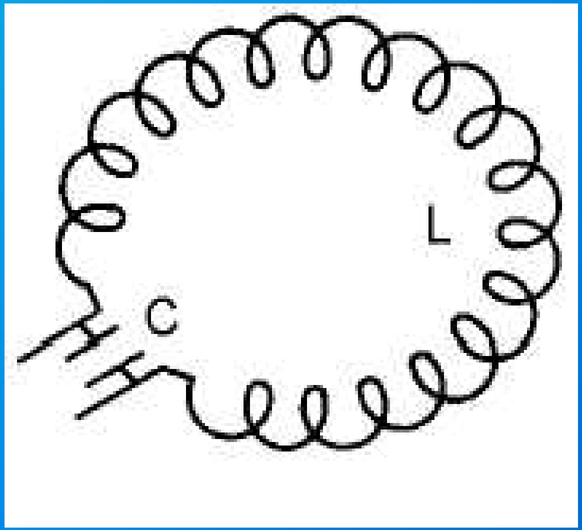
Production and acceleration of an electron beam

- Likewise, if the velocity of the electron increases, the field around it increases and the path will bend more sharply.
- However, when the critical field value is reached, as shown in the figure as a red path, the electrons are deflected away from the anode and the anode current then drops quickly to a very small value.
- When the field strength is made still greater, the plate current drops to zero.
- When the magnetron is adjusted to the cutoff, or critical value of the anode current and the electrons just fail to reach the anode in their circular motion, it can produce oscillations at microwave frequencies.

Resonant cavity as a tank circuit

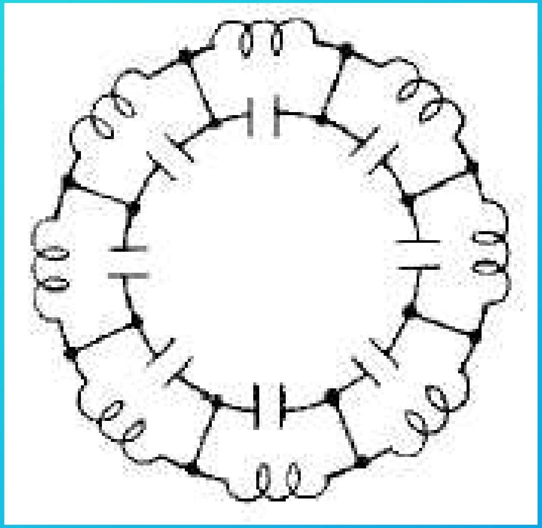
- The cavity consists of a cylindrical hole in the copper anode and a slot which connects the cavity to the interaction space
- The parallel sides of the slot form the plates of a capacitor while the walls of the hole act as an inductor.
- The hole and slot thus form a high-Q, resonant LC circuit. As shown in figure.

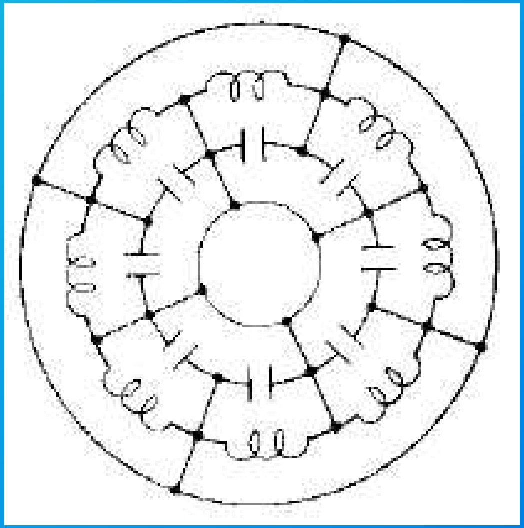




Resonant cavity as a tank circuit

- The anode of a magnetron has a number of these cavities.
- An analysis of the anodes in the hole-and-slot block reveals that the LC tanks of each cavity are in series (assuming the straps have been removed)





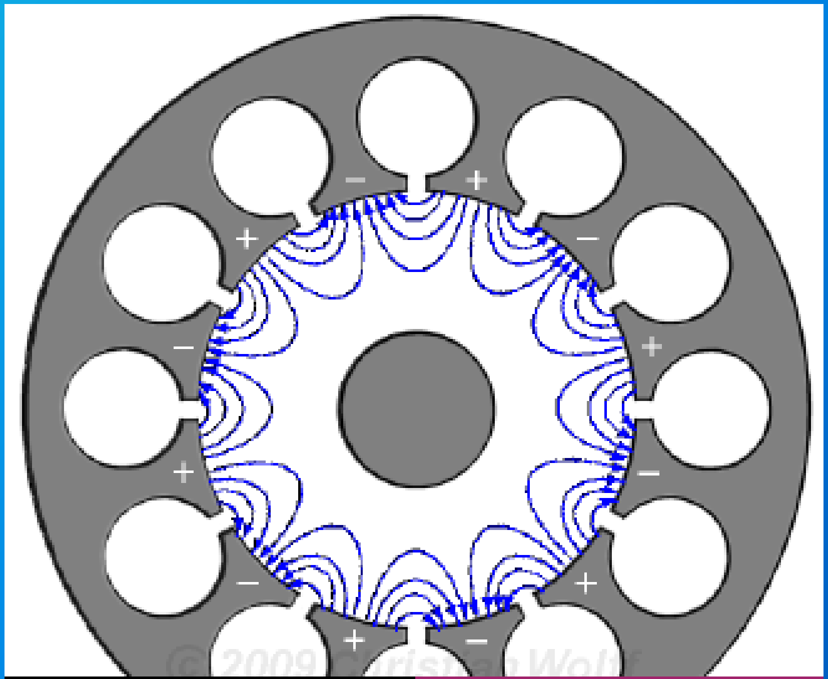
- However, an analysis of the anode block after alternate segments have been strapped reveals that the cavities are connected in parallel because of the strapping.

Velocity-modulation of the electron beam

- The electric field in the magnetron oscillator is a product of ac and dc fields.
- The dc field extends radially from adjacent anode segments to the cathode. The ac fields, extending between adjacent segments, are shown at an instant of maximum magnitude of one alternation of the RF oscillations occurring in the cavities.
- In the figure is shown only the assumed high-frequency electrical ac field. This ac field work in addition to the to the permanently available dc field.
- The ac field of each individual cavity increases or decreases the dc field like shown in the figure.

Velocity-modulation of the electron beam

- The electrons which y toward the anode segments loaded at the moment more positively are accelerated in addition. These get a higher tangential speed.
- On the other hand the electrons which y toward the segments loaded at the moment more negatively are slow down. These get consequently a smaller tangential speed.



Forming of a Space-Charge Wheel

- The different speeds of the electron groups the velocity modulation leads to a density modulation
- The cumulative action of many electrons returning to the cathode while others are moving toward the anode forms a pattern resembling the moving spokes of a wheel known as a Space-Charge Wheel, as indicated in figure.
- The space-charge wheel rotates about the cathode at an angular velocity of 2 poles (anode segments) per cycle of the ac field. This phase relationship enables the concentration of electrons to continuously deliver energy to sustain the RF oscillations.

Forming of a Space-Charge Wheel

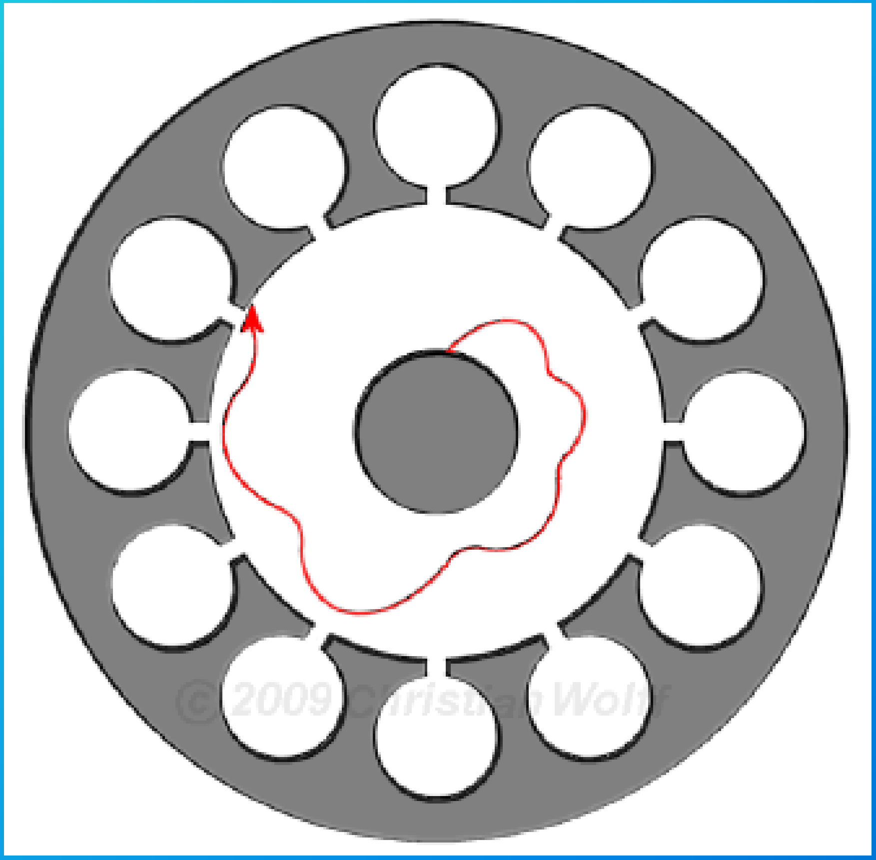
- One of the spokes just is near an anode segment which is loaded a little more negatively. The electrons are slowed down and pass there energy on to the ac field. This state isn't static, because both the ac- field and the wire wheel permanently circulate. The tangential speed of the electron spokes and the cycle speed of the wave must be tuned properly.
- The electrons which fly toward the anode segments loaded at the moment more positively are accelerated in addition. These get a higher tangential speed.
- On the other hand the electrons which y toward the segments loaded at the moment more negatively are slow down. These get consequently a smaller tangential speed.

Dispense energy to the ac field

- An electron moving against an E field is accelerated by the field and takes energy from the field.
- Also, an electron dispenses energy to a field and slows down if it is moving in the same direction as the field (positive to negative).
- The electron spends energy to each cavity as it passes and eventually reaches the anode when its energy is expended. Thus, the electron has helped sustain oscillations because it has taken energy from the dc field and given it to the ac field.

Dispense energy to the ac field

- This electron describes the path shown in figure over a longer time period looked. By the multiple breaking of the electron the energy of the electron is used optimally. The effectiveness reaches values up to 80%.



Transient oscillation in magnetron

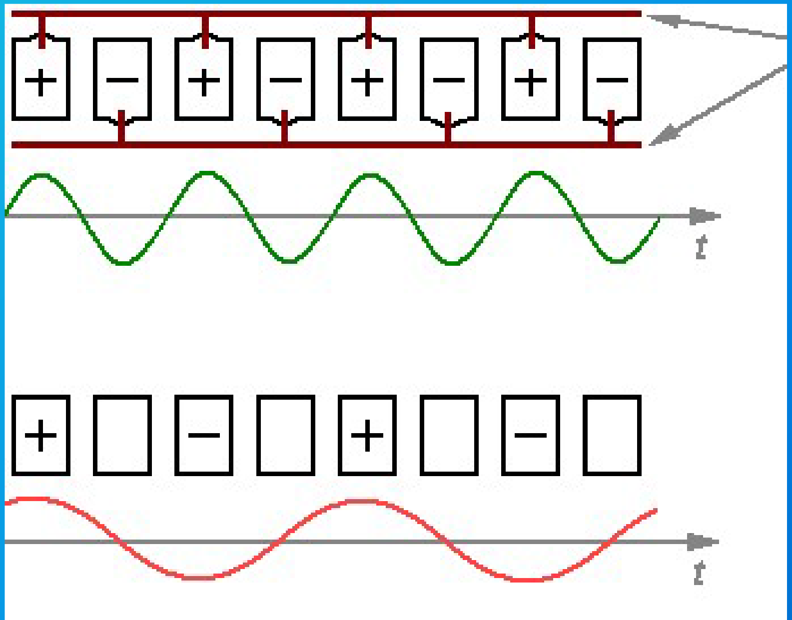
- After switching the anode voltage, there is still no RF field.
- The single electron moves under the influence of the static electric field of the anode voltage and the effect of the magnetic field as shown in Figure 1 by the red electron path.
- Electrons are charge carriers: during the flyby at a gap, they give off a small part of energy to the cavities. (Similar to a flute: A flute produces sound when a stream of air is owing past an edge of a hole.)
- The cavity resonator begins to oscillate at its natural resonant frequency.
- Immediately begins the interaction between this RF field (with an initial low power) and the electron beam.

Transient oscillation in magnetron

- The electrons are additionally influenced by the alternating field.
- It begins the process described in sequence of phase 1 to 4 of the interaction between RF field and the now velocity-modulated electrons.
- Unfortunately, the transient oscillation doesn't begin with a predictable phase. Each transient oscillation occurs with a random phase.
- The transmitting pulses that are generated by a magnetron are therefore not coherent.

Modes of Oscillations

- The operation frequency depends on the sizes of the cavities and the interaction space between anode and cathode. But the single cavities are coupled over the interaction space with each other. Therefore several resonant frequencies exist for the complete system. Two of the four possible waveforms of a magnetron with 8 cavities are in the figure represented.
- Several other modes of oscillation are possible (3 /4π, 1 /2π, 1 /4π) but a magnetron operating in the mode has greater power and output and is the most commonly used.



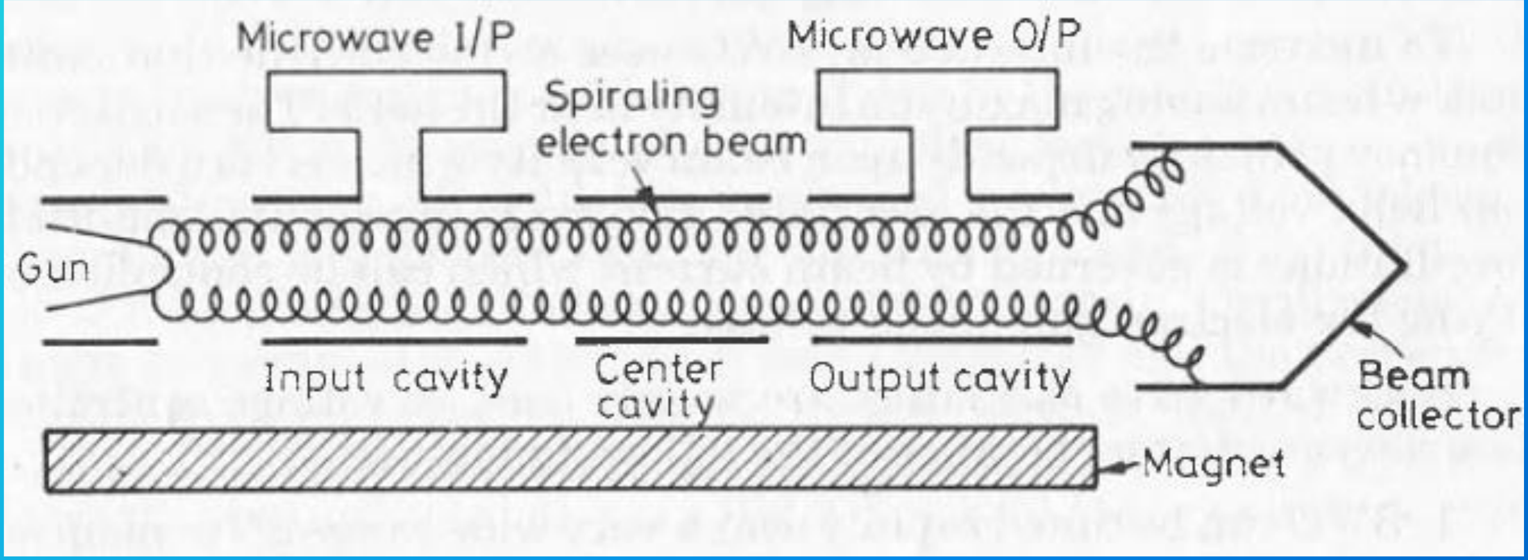
Characteristics & applications

- Characteristics
  1. Efficiency : very high 40 to 70%
  2. Power output: 800 kW (pulsed)
  3. Operating frequency: up to 10 GHz.

- Applications
  1. Magnetrons are widely used in radars with high output power.
  2. In satellite and missiles for telemetry.
  3. Industrial heating.
  4. Microwave ovens.
  5. In oscillators with great power and pulsed operation at 100 GHz and greater.

Gyratron

- The size or dimensions of the interaction structure, where the microwave field couples with the electron beam, in case of klystrons, magnetrons,
- TWTs and their associates namely Reflex klystron, CFA, and Backward wave oscillator, becomes smaller as the frequency of operation increases



Gyratron

- The operation of a Gyrotron is based on the interaction of a static magnetic field and the moving electron beam. The moving electrons traverse a spiraling path as they advance due to the effect of magnetic field
- The spiraling frequency called the cyclotron frequency depends upon the strength of the magnetic field, mass of electron and the velocity component perpendicular to the magnetic field.