TRAVELLING WAVE TUBE

Travelling Wave Tubes (TWT) are vacuum tubes used as high gain, low noise, wide bandwidth microwave wideband amplifiers.

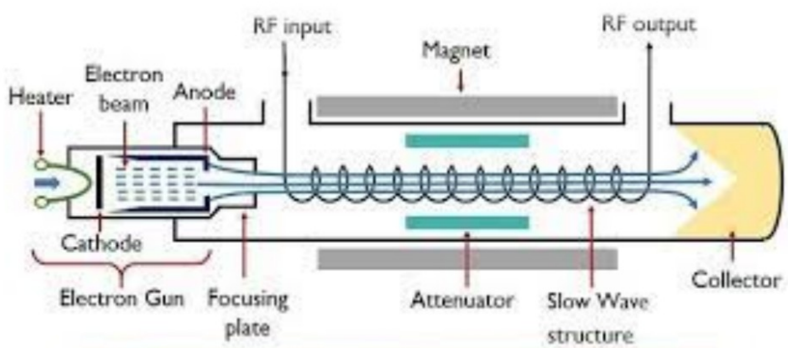
TWTs are mainly classified into two types, helix TWTs and coupled-cavity TWTs.

TWT Fundamentals:

In order to prolong the interaction between an electron beam and an RF field, it is necessary that both must be moving in the same direction with approximately the same velocity. But the velocity of RF field is that of velocity of light, while the Velocity of electron beam is less. Hence it is necessary to retard the RF field with a slow-wave structure. Several such structures are in use, the helix and a waveguide coupled-cavity arrangement being the most common.

Construction:

The schematic diagram of Traveling Wave Tube using a helix is shown in the following Figure.



Constructional Structure of Travelling Wave Tube

Travelling wave tube is a cylindrical structure which contains an electron gun to form a cathode. It has anode plates, helix and a collector. RF input is sent to one end of the helix and the output is drawn from the other end of the helix.

An electron gun focuses the electron beam with the velocity of light. A magnetic field guides the beam to focus, without scattering. The RF field also propagates with the velocity of light which is retarded by a helix. Helix acts as a slow wave structure. Applied RF field propagated in helix, produces an electric field at the center of the helix.

The velocity of electron beam, travelling through the helix, induces energy to the RF waves on the helix.

[Need of Slow-Wave Structure:

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. So it is required 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. AS helical structure is used for this. 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.]

In order to restrict beam spreading inside the tube dc magnetic field is applied between the travelling paths by the help of magnets.

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 obtained at the opposite end of the helix.

An attenuator is present along both the sides of the travelling wave tube. This is because travelling wave amplifiers are high gain devices, so in case of poor load matching conditions, oscillations get build up inside the tube due to reflection. Thus in order to restrict the generation of oscillations inside the tube, attenuators are used.

Working:

The applied RF signal produces an electric field inside the tube. During the positive half of applied RF signal, the moving electron beam experiences accelerative force. However, negative half of the input signal decelerates on the moving electrons.

This is said to be **velocity modulation** because the electrons of the beam are experiencing different velocity 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.

The growing amplitude of the wave causes more bunching of electrons while reaching the end from the beginning, thereby causing further **amplification of the RF wave** inside the tube. i.e., the 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 positive potential provided at the other end causes collection of electron bunch at the collector

Applications of TWT

1. Travelling wave tubes are highly used in continuous wave radar systems.
2. These amplifying tubes also find application in broadband receivers for RF amplification.
3. TWT's are also used to get high power output in satellite transponders
4. TWT is used in microwave receivers as a low noise RF amplifier
5. TWTs are also used in wide-band communication links and co-axial cables as repeater amplifiers to amplify low signals
6. TWTs have a long tube life, due to which they are used as power output tubes in communication satellites
7. TWTs are used in high power pulsed radars and ground based radars.

UNIT-1

MULTICAVITY KLYSTRON

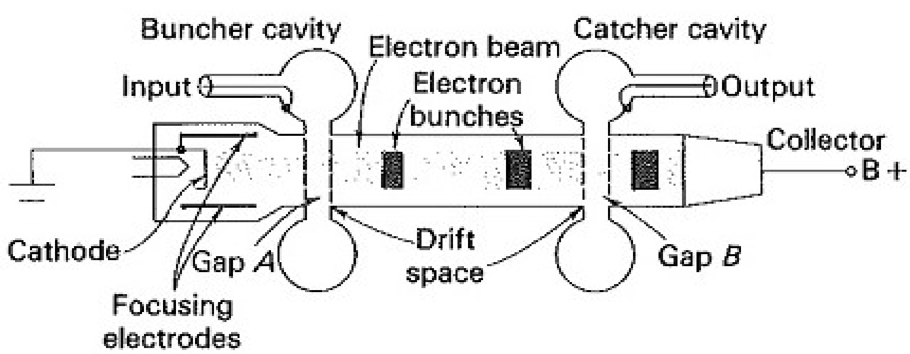
A Klystron is a vacuum tube that converts the energy of a pulse high voltage generated by a pulse modulator into a high power microwave. The microwave output from the klystron is introduced into the accelerating structure through the waveguide.

Principle of operation

A klystron operates on the principle of velocity modulation. That is, the variation in the velocity of a beam of electrons caused by the alternate speeding up and slowing down of the electrons in the beam.

Construction:

The principle features of two cavity klystron amplifier are as shown below.



Klystron amplifier schematic diagram.

It consists of 2 cavities namely the ***buncher cavity*** and ***catcher cavity***.

The RF signal to be amplified is provided at the buncher cavity. The electron gun comprises cathode, heating element and anode. The electron beam is produced by the cathode by heating the filament. A high positive potential is applied to the anode which provides the required acceleration to the electron beam initially. The region between two cavities is known as **drift space**.

To allow focused propagation of electron beam inside the tube, an external electromagnetic winding called focusing electrodes is used. The amplified RF signal is achieved at the catcher cavity. Also, a collector is present near the second cavity that collects the electron bunch.

Working:

The beam passes through the gap A in the buncher cavity to which the RF signal to be amplified is applied. It is allowed to drift freely without the influence of RF fields until it reaches gap B in the catcher cavity.

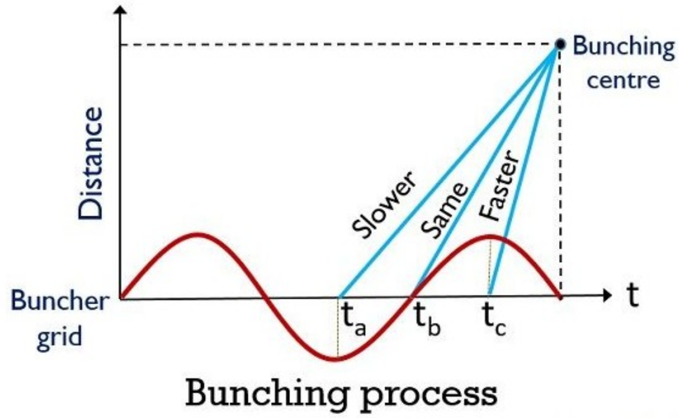
- In the absence of any RF input, the electron will tend to move with their respective uniform velocities to reach the catcher cavity and gets collected at the collector.

- But when external RF signal is applied at the input of the buncher cavity this causes the generation of a local electric field inside the tube. This electric field causes the bunching of electrons because the field applied causes the acceleration and deceleration to the moving electron, according to the polarity of the signal by which the field is generated.

- During the negative half of the applied input RF signal to the buncher cavity, the moving electrons experience a repulsive force due to the presence of a negative charge at the entering plate. Because of the opposition offered by the field, the moving velocity of electrons gets reduced.
- . For the positive half cycle of input, the generated electric field will be in a direction similar to the direction of electron movement. So, this leads to an increase in the moving velocity of the electrons.
- Thus, it is observed that electrons that were emitted earlier by the gun will be decelerated, while the electrons emitted later will be 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*.
- Once the electron bunching is done then the catcher cavity present at another end of the tube absorbs the beam energy. Once the energy is transferred to the catcher cavity then electrons gets collected at the collector.

Applegate Diagram

The figure below shows the Applegate diagram that represents the bunching of electrons moving with different velocities:



The electron travelling inside the tube under the absence of external fields acts as the bunching centre. Also, the electrons moving due to the influence of the positive half cycle of the signal reaches faster. While the movement due to the negative half cycle is retarded. Thus the figure represents the bunching process at a certain point and at a specific distance inside the tube.

Practical Considerations

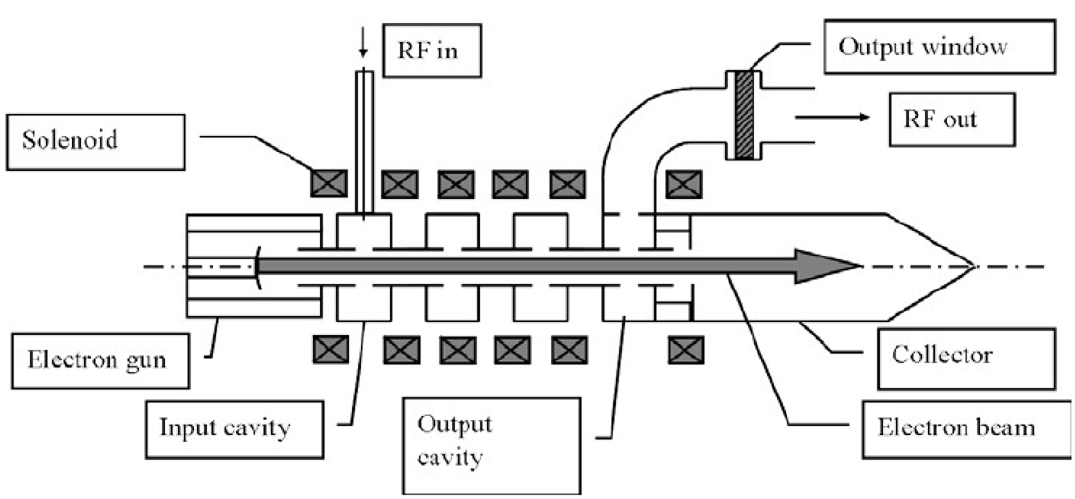
The microwave applications of klystron are

- Multicavity power amplifier
- Two cavity power oscillator

1. **Multicavity klystron amplifier**

The bunching process in a two-cavity klystron is not complete; since there are large numbers of out-of-phase electrons arriving at the catcher cavity between bunches. Consequently, more than two cavities are always employed in practical klystron amplifiers.

The schematic diagram of the Four cavities klystron amplifier is as shown in Figure



Partially bunched current pulses will also excite oscillations in the intermediate cavities, and these cavities in turn set up gap voltages which help to produce more complete bunching. Having the extra cavities helps to improve the efficiency and power gain considerably. The cavities may all be tuned to the same frequency, such synchronous tuning being employed for narrowband operation.

Applications:

The klystron amplifiers are used in

- TV transmitter output tubes
- power amplifiers in satellite station transmitters,

2. Two Cavity Klystron Oscillator:

An electronic oscillator can also be made from a klystron tube if a portion of the signal in the catcher cavity is coupled back to the buncher cavity, with a coaxial cable or waveguide. The conditions for obtaining oscillations are - the feedback must have the correct polarity and sufficient amplitude.

The schematic diagram of such an oscillator is as shown in the above Figure. Oscillations in the two-cavity klystron behave as in any other feedback oscillator. Having been started by a switching transient or noise impulse, they continue as long as dc power is present.

Performance and applications:

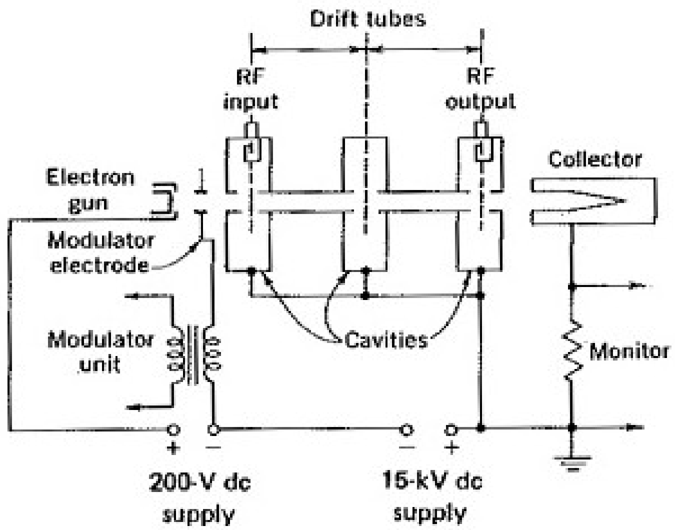
The Multicavity klystron is used as a medium-, high- and very high-power amplifier in the UHF and microwave ranges, for either continuous or pulsed operation. Adequate power is available for the frequency range covered from about 250 MHz to over 95 GHz.

Now a days the two-cavity klystron oscillator is no longer in use and it is replaced by CW magnetrons, semiconductor devices and the high gain of klystron and TWT amplifiers.

Further practical aspects:

Multicavity klystron amplifiers suffer from the noise caused because bunching is never complete and so electrons arrive at random at the catcher cavity. This makes them too noisy for use in receivers.

Since the time taken by a given electron bunch to pass through the drift tube of a klystron is obviously influenced by the collector voltage, this voltage must be regulated. Also when a klystron amplifier is pulsed, such pulses are often applied to the collector. They should be flat, or else frequency drift will take place during the pulse. As an alternative to this and also because collector pulsing takes a lot of power, modulation of a special grid has been developed, as shown in Figure

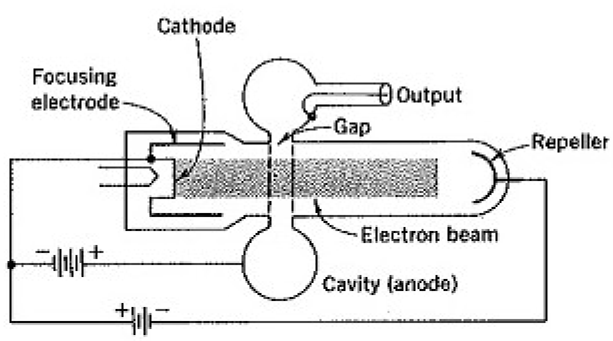


A typical "gain" of 20 is available between this electrode and the collector, thus reducing the modulating power requirements twentyfold.

Reflex Klystron:

It is possible to produce oscillations in a klystron device which has only one cavity, through which electrons pass twice. This is the Reflex Klystron Oscillator.

The schematic diagram of Reflex Klystron oscillator is as shown below



The Reflex Klystron Oscillator is a low-power, low-efficiency microwave oscillator. The electron gun emits the electron beam, which passes through the gap in the anode cavity. The beam is accelerated toward the Anode cavity, which has a high positive voltage applied to it. The electrons overshoot the gap in this cavity and continue on to the Repeller electrode which is at a high negative potential. Hence, electrons in the beam reach some point in the Repeller space and are then turned back, which are e dissipated in the anode cavity. 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.

Operation:

The electron beam is accelerated towards the anode cavity.

Let us assume that a reference electron $\mathbf{e_r}$ crosses the anode cavity but has no extra velocity and it repels back after reaching the Repeller electrode, with the same velocity. Another electron, $\mathbf{e_e}$ which has started earlier than this reference electron, reaches the Repeller first, but returns slowly, reaching at the same time as the reference electron.

Another electron, the late electron $\mathbf{e_l}$, which starts later than both $\mathbf{e_r}$ and $\mathbf{e_e}$, moves with greater velocity while returning back, reaching at the same time as e_r and e_e.

Now, these three electrons, namely $\mathbf{e_r}$, $\mathbf{e_e}$ and $\mathbf{e_l}$ reach the gap at the same time, forming an **electron bunch**. This travel time is called as **transit time**, which should have an optimum value.

Transit Time in Reflex Klystron:

For oscillations to be maintained, the transit time in the repeller space, or the time taken for the reference electron from the instant it leaves the gap to the instant of its return, must have the correct value. This is determined by investigating the best possible time for electrons to leave the gap and the best possible time for them to return.

The most suitable departure time is centered on the reference electron, at the 180° of the sine-wave voltage across the resonator gap. No energy goes into velocity-modulation of the electron beam. It takes some energy to accelerate electrons, but just as much energy is gained from retarding electrons. Energy is spent in accelerating bodies (electrons), but energy is gained from retarding them.

The anode cavity accelerates the electrons while going and gains their energy by retarding them during the return journey. When the gap voltage is at maximum positive, this lets the maximum negative electrons to retard.

The optimum transit time is represented as

$$\mathbf{T= n+}\frac{3}{4} \quad \text{where}$$

n is an integer and

T = transit time of electrons in repeller space, cycles

This transit time depends upon the Repeller and anode voltages.

Modes of Reflex Klystron:

- **Why do different modes of operation exist for a reflex**

  Ans. There are several combinations of Repeller voltage and anode voltage that provide favorable conditions for bunching. Accordingly there may exist several modes of operation, expressed by

  $$N + 3/4 \text{ where N is an integer.}$$

- **What modes are generally used in a reflex klystron?**

  Ans. $1\frac{3}{4}$ and $2\frac{3}{4}$ are the most commonly used modes in a practical reflex klystron.

- **What is transit time?**

  Ans. It is the time taken by the electrons to travel from cathode to anode.

- **What is the operating principle of reflex klystron?**

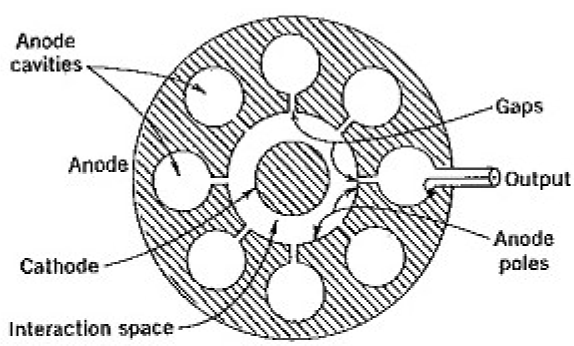
  Ans. It works on the principle of velocity modulation and current modulation

Magnetron:

A magnetron is a device that generates high power electromagnetic wave. It is basically considered as a self-excited microwave oscillator. It is a diode which uses the interaction of magnetic and electric fields in complex cavity to provide oscillations of very high power.

Construction:

The constructional details of magnetron are as shown in the fig.



It is a cylindrical diode. It has a radial electric field, an axial magnetic field and an anode (which is made of copper) with permanent cavities. The cylindrical cathode is surrounded by the anode with cavities and hence a radial DC electric field will exist. The magnetic lines force passes through the cathode and the surrounding interaction space. The lines are at right angles to the cross section. The magnetic field is also DC and since it is perpendicular to the plane of the radial electric field, the magnetron is called a **crossed-field device**.

The output is taken from one of the cavities, by means of a coaxial line or through a waveguide. The rings interconnecting the anode poles are used for strapping

The Cavity Magnetron has 8 resonant cavities tightly coupled to each other and 8 modes of oscillation. These operations depend upon the frequency and the phase of oscillations. The total phase shift around the ring of this cavity resonators should be $2\pi n$ where n is an integer.

If ϕ_V represents the relative phase change of the AC electric field across adjacent cavities, then

$$\phi_V = 2\pi n / N$$

If, $n = N / 2$ then $\phi_V = \pi$

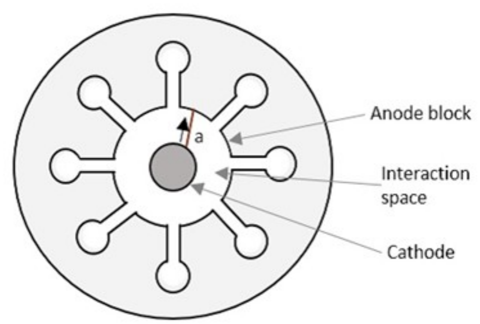
This mode of resonance is called as π−mode

If $n=0$ then $\phi_V = 0$

This is called as the Zero mode.

Operation of Cavity Magnetron: (With no applied RF field)

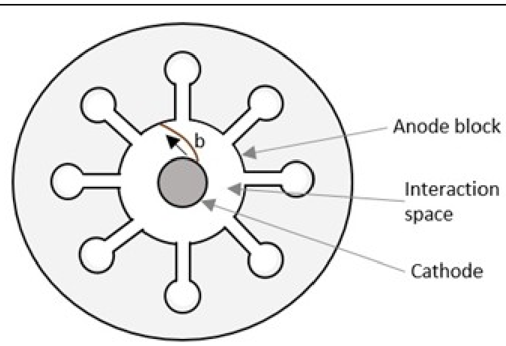
Case 1



Movement of electron **a**, when no magnetic field is present

If the magnetic field is absent, i.e. B = 0, then electron' a' directly goes to anode under radial electric force. This is as shown in the fig.

Case 2



Movement of electron **b** when small magnetic field is present

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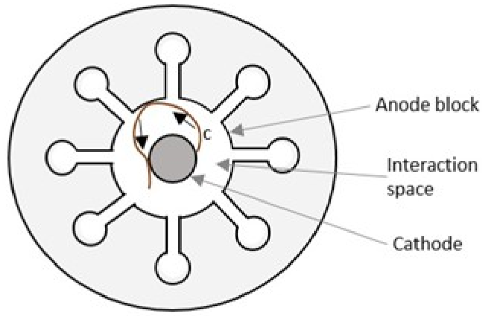
If there is an increase in the magnetic field, a lateral force acts on the electrons. Hence the electron takes a curved path,

Radius of this path is calculated as

$R = mv / eB$

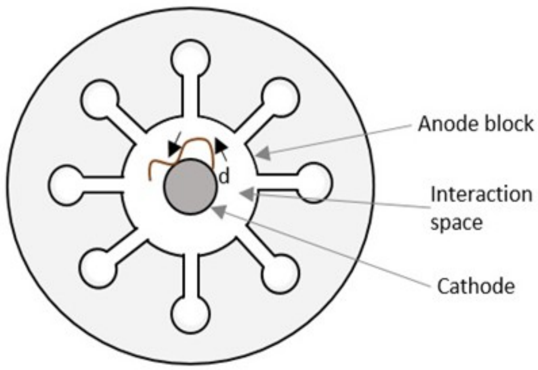
Case 3



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

If the magnetic field B is further increased, the electron follows a path just grazing the anode surface and making the anode current zero. This is called as "Critical magnetic field" (Bc), which is the cut-off magnetic field.

Case 4



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

. If the magnetic field is made greater than the critical field, ie., B > Bc the electron jumps back to the cathode, without going to the anode. This causes "back heating" of the cathode.

This is achieved by cutting off the electric supply once the oscillation begins. If this is continued, the emitting efficiency of the cathode gets affected.

Operation of Cavity Magnetron with Active RF Field

Let us now discuss its operation when we have an active RF field.

Let us assume that initial RF oscillations are present due to some noise transient. The oscillations are sustained by the operation of the device.

There are three kinds of electrons emitted in this process, whose actions are understood as electrons a, b and c, in three different cases.

Case 1

When oscillations are present, say electron 'a' slow down transferring energy to oscillate. Such electron that transfers its energy to the oscillations is called as **favored electron**. This is responsible for bunching effect.

Case 2

In this case, another electron say 'b' take energy from the oscillations and increases its velocity. As and when this is done, the following actions are observed

- It bends more sharply.
- Spends little time in interaction space.
- Return to the cathode.

These electrons are called as **unfavored electrons**. They don't participate in the bunching effect and cause **"back heating".**

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"**.

This whole process is understood better by taking a look at the following figure.

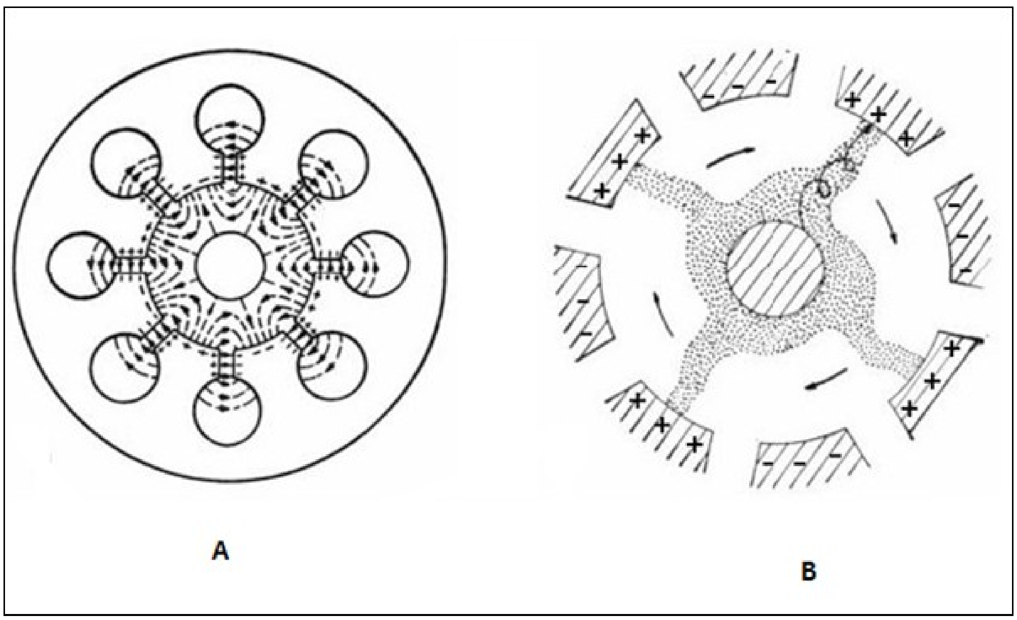


Figure A shows the electron movements in different cases while figure B shows the electron clouds being formed. These electron clouds occur while the device is in operation. The charges present on the internal surface of these anode segments, follow the oscillations in the cavities. This creates an electric field rotating clockwise.

While the electric field is rotating, the magnetic lines are formed in parallel to the cathode. Under this condition, the electron bunches are formed with four spokes, directed in regular intervals, to the nearest positive anode segment, in spiral trajectories.

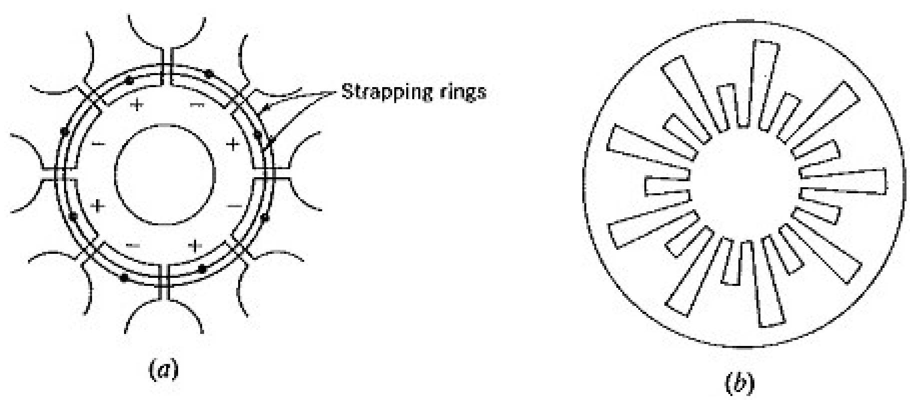
Practical Considerations:

Some of the significant aspects of magnetron operation are –

- Strapping
- Frequency Pulling and Pushing

1. **Strapping:**

Where there is an even number of cavities, two concentric rings can connect alternate cavity walls to prevent inefficient modes of oscillation. This is called pi-strapping because the two straps lock the phase difference between adjacent cavities at π radians (180°). .



(a) Hole-and-slot magnetron with strapping; (b) rising-sun magnetron anode block.

Magnetrons using identical cavities in the anode block normally employ strap-ping to prevent mode jumping. Strapping consists of two rings of heavy-gauge wire connecting alternate anode poles. These poles should be in phase with each other for the π mode. Since the phase difference between alternate anode poles is other than 2π radians in other modes, these modes will quite obviously be prevented. The actual situation is somewhat more complex.

Strapping may become unsatisfactory because of

1) Losses in the straps in very high-power magnetrons or
2) Strapping difficulties at very high frequencies.

In the second case, the cavities are small and it should be ensured that a suitable RF field is maintained in the interaction space. As a result many modes are possible and even strapping may not prevent mode jumping. To avoid this anode block should have a pair of Cavity Magnetron. This gives rise to a rising-sun anode structure is shown in Figure and has the effect of isolating the 7π-mode frequency from the others. Consequently the magnetron will not oscillate at any of the other modes, because the dc fields would not support them. Strapping is not required with the rising-sun magnetron.

2. **Frequency Pulling and Pushing in Magnetron:**

What is frequency pulling and frequency pushing in magnetrons?

.

When the voltage applied at the anode of the magnetron is varied then this causes the variation in the velocity of the electrons moving from cathode to anode. This resultantly changes the frequency of oscillations. This variation in the resonant frequency of the magnetron shows variation due to the change in the anode voltage then it is known as **frequency pushing**

The change in resonant frequency is sometimes a result of the change in the load impedance of the magnetron. The load impedance varies when the change is purely resistive or reactive. This frequency variation is known as **frequency pulling**.

Applications

- A major application of magnetron is present in a pulsed radar system in order to produce a high-power microwave signal.
- Magnetrons are also used in heating appliances like microwave ovens
- Tunable magnetrons find their applications in sweep oscillators.

GUNN DIODE

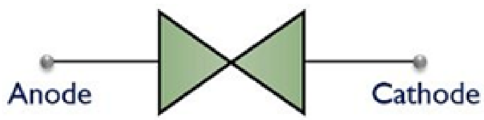
What is the Gunn diode?

A Gunn diode, also known as a transferred electron device (TED), is a passive semiconductor device with two terminals, with negative resistance used in high-frequency electronics

What is Gunn Effect?

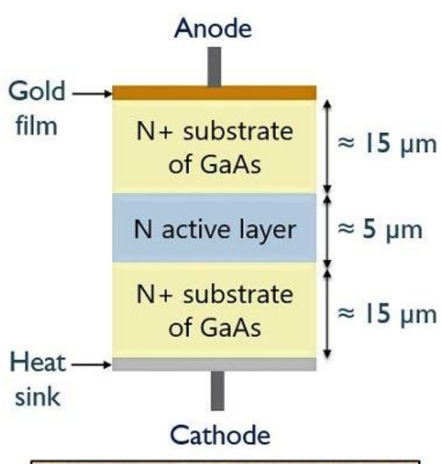
The high-frequency oscillation of the electric current that is flowing through the semiconducting solids is known as the Gunn Effect

Symbol of Gunn diode



Construction :

Gunn diode is not a pn junction diode as it is composed of only n-type semiconductor material. The figure below represents the constructional structure of a Gunn diode



Structure of Gunn Diode

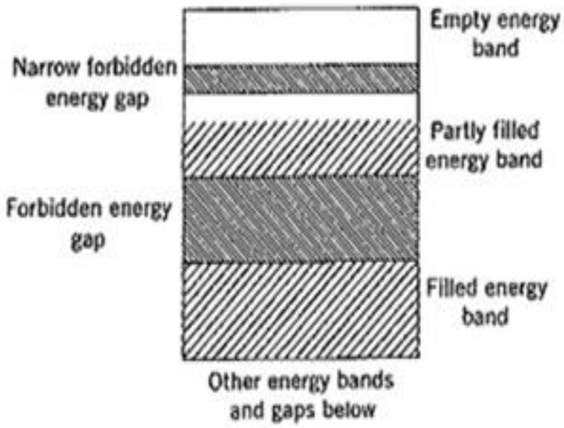
It is made up of three layers of N-type semiconductor. Among these three layers the **top** most and the **bottom** most are **heavily doped** while the **middle layer** is **lightly doped** in comparison to the extreme layers. i.e., a lightly doped n-type semiconductor layer is present between two heavily doped n-type material. The middle portion is termed as an active layer.

The Gunn diode is formed by growing an epitaxial n-type layer over an n+ substrate. The two highly doped regions provide better conductivity to the device.

The whole structure is mounted on a conducting base that acts as a heat sink for the heat produced during operation. Also, the other terminal is formed by connecting a gold film over the top surface of the structure.

Working:

The working of Gunn diode can be explained on the band theory. The energy band diagram is as shown below.

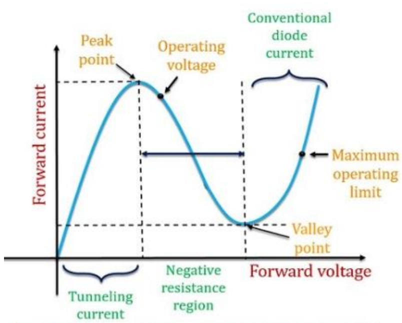


energy levels in gallium arsenide.

GaAs and some other semiconductor materials have one extra-energy band in their electronic band structure instead of having only two energy bands, viz. valence band and conduction band and this extra third band is empty at initial stage.

If a voltage is applied to this device, then most of the applied voltage appears across the active region. The electrons from the conduction band having negligible electrical resistivity are transferred into the third band. The third band of GaAs has mobility which is less than that of the conduction band. **This gives rise to the name transferred-electron effect**. Electrons have been transferred from the conduction band to a higher energy band in which they are much less mobile and the current has been reduced as a result of a voltage rise.

Thus, if the field strength is increased, then the drift velocity will decrease; this creates a negative resistance region in V-I relationship which is as shown below.



V-I Characteristics of Gunn Diode

Applications :

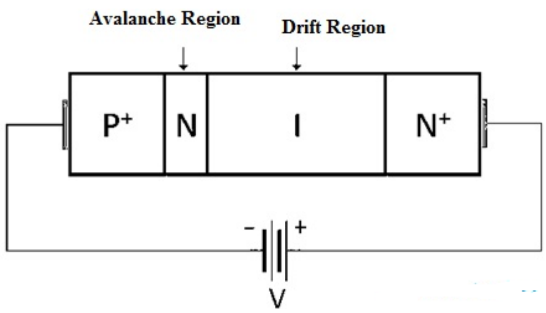
1. Gunn Diodes are used as oscillators and Amplifiers.
2. They are used in radio communication, military and commercial radar sources.
3. It is used in tachometers.
4. Gunn diode is used in sensors for detection in trespass detecting system, in-door opening system, pedestrian safety systems etc.
5. It is also used extensively in microwave relay data link transmitters.

IMPATT Diodes

What is an IMPATT diode?

IMPATT diode which is abbreviation of **Impact-Ionization Avalanche Transit-Time Diode** is a solid-state device that operates by a reverse bias to cause avalanche breakdown. This is a high-power diode and is used in high-frequency electronics and microwave devices. The IMPATT diode exhibits a dynamic negative resistance that is required for microwave oscillation and amplification applications.

Construction

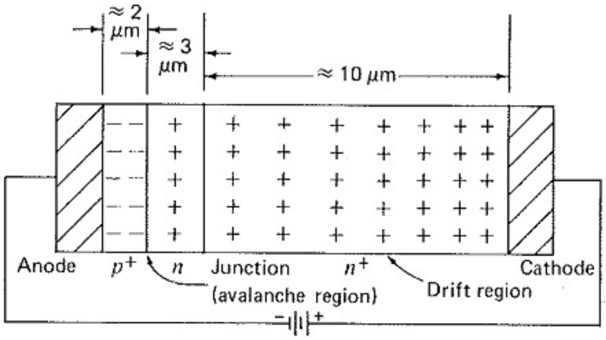


The construction of the IMPATT diode is shown below. This diode includes four regions like P+-N-I-N+. It works on an extremely high voltage gradient of approximately 400KV/cm to generate an avalanche current.

Working:

Working of IMPATT Diode is a combination of delay involved in generating avalanche current multiplication, together with delay due to transit time through a drift space. This provides the necessary 180° phase difference between applied voltage and the resulting output current. The cross section of the active region is shown in Figure. For its operation as a microwave signal generator, IMPATT diode is operated under reverse bias conditions.

The IMPATT diode consists of two areas, namely the avalanche region or injection region, and the drift region. These two regions provide different functions. The avalanche or injection region creates the carriers which may be either holes of electrons and the drift region is where the carriers move across the diode taking a certain amount of time dependent upon its thickness.

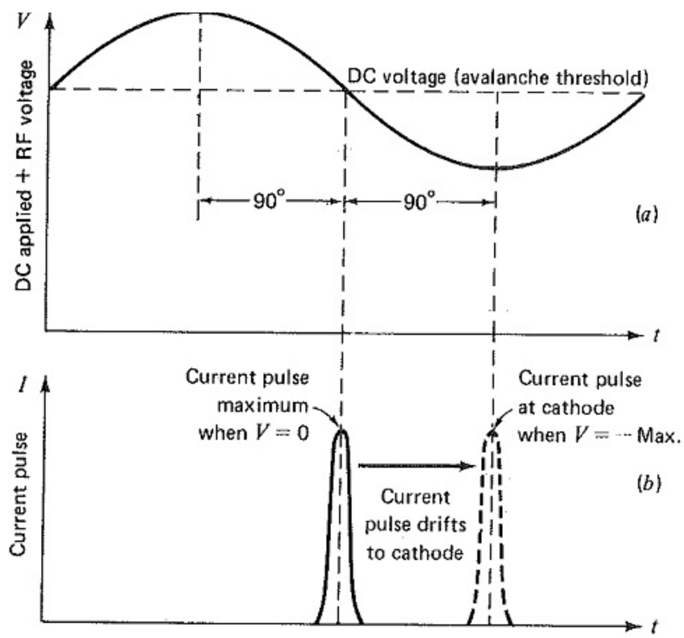


IMPATT diode (single-drift) schematic diagram.

An extremely high voltage of the order of 400 kV/cm, is applied to the IMPATT Diode, which results in a very high current. The thickness of an IMPATT diode's active region is a few micrometers. This will ensure the correct transit time for microwave operation

Such a high potential gradient, reverse-biasing the diode, causes a flow of minority carriers across the junction.

Let us assume that a positive half of the RF voltage is superimposed on top of the high dc voltage. Electron and hole velocity has now become so high that these carriers generate additional holes and electrons by colliding with the crystal lattice and free other charges. These newly freed carriers are similarly accelerated and collide with the crystal lattice freeing more carriers. This process gives rise to avalanche breakdown as the number of carriers multiplies very quickly. . Since it is a multiplication process, it will take certain amount of time to complete the process. The time taken by the process is such that the current pulse is maximum when the RF voltage across the diode is zero and going negative as shown in Figure. Thus 90° phase difference between voltage and current obtained.



IMPATT diode behavior. (*a*) Applied and RF voltage; (*b*) resulting current pulse and drift across diode

The current pulse in the IMPATT Diode is situated at the junction. Because of the reverse bias, the current pulse flows to the cathode, at a drift velocity dependent on the presence of the high dc field. The time taken by the pulse to reach the cathode depends on this velocity and on the thickness of the highly doped (n^+) layer. The thickness of the drift region is so selected so that the time taken for the current pulse to arrive at the cathode corresponds to a further 90° phase differences as shown in Figure

When the current pulse arrives at the cathode, the RF voltage is at its negative peak. Thus the Voltage and current in the IMPATT diode are 180° out of phase and a dynamic RF negative resistance exists. This negative resistance lends to use in oscillators or amplifiers. Because of the short times involved, these can be microwave.

Applications:

- IMPATT diodes are used as microwave oscillators in microwave generators, in modulated output oscillators.
- They are used in microwave links, continuous-wave radars, and electronic countermeasures.
- IMPATT diodes are used in electronic warfare systems for generating high-power microwave signals to jam enemy communication systems or disrupt their radar systems

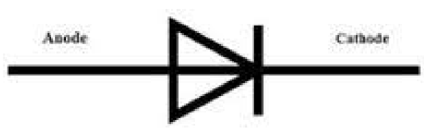
.**PIN diodes**

The PIN diode receives its name from the fact that is has three main layers

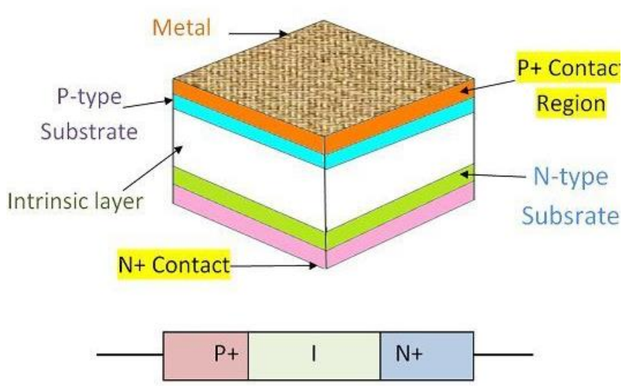
- **P**-type layer
- **I**ntrinsic layer
- **N**-type layer

A **Pin diode** is a special type of diode that contains an undoped intrinsic semiconductor between the p-type semiconductor and n-type semiconductor regions.

The symbolic representation of the PIN diode is shown below:



Construction:



Pin diode consists of two layers of semiconductors and one layer of intrinsic material in between them. The Semiconductor layer are usually of P-type and n-type. Pin diode can be constructed in two ways using **planar structure** and mesa structure. In a planar structure, a very thin epitaxial layer is fabricated on the P-type substrate. This epitaxial layer consists of P^+ regions.

Similarly, an epitaxial layer is fabricated on N-type substrate, and that will be comprised of N^+ region. And in between these semiconductors, a layer of intrinsic material is introduced. Semiconductor layer provides ohmic contacts

Working

In PIN diode, a depletion region is formed at NI- junction (N region & intrinsic region) because of the concentration gradient of charge carriers.. As compared to N-region, the thickness of the 'I' region is higher because the n-region doping level is higher as compared to the 'I' region

Forward biased Condition

In a forward bias condition, when the voltage is applied to the PIN diode, then charge carriers in both the regions will be injected into the intrinsic layer.

So the applied forward potential will decrease the width of the depletion region. Because of this, the resistance of the diode will start decreasing due to forward biasing. When the forward voltage is enhanced, a high number of charge carriers will be injected into the intrinsic layer. Thus, generating a large current through the device will result in decreasing the resistance. Thus, in this biasing condition, this diode works as a variable resistance device.

Reverse Biased Condition

When the reverse bias voltage is supplied to the diode then the width of the depletion region will increase. When the reverse voltage is raised, then the width of the depletion region will increase until the carriers move away from the intrinsic layer. This specific voltage is called **swept out voltage**. In this biasing, the diode works like a capacitor. Here both the regions like P & N serve like the capacitor's two plates.

Applications:

The following are some of the applications of PIN diodes

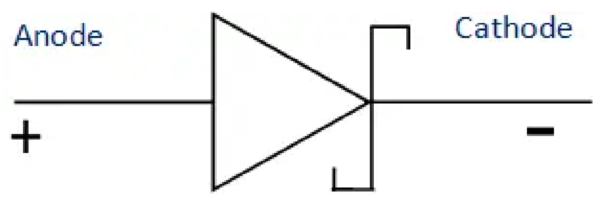
- It is used as a high voltage rectifier.
- The PIN diodes are an excellent radio frequency transition.
- The PIN diodes are used as a photodetector to transform light into current that exists in the depletion layer of a photodiode
- It is primarily used in RF design applications, as well as switching or attenuating elements in RF attenuators and RF switches.

Schottky-Barrier diodes

A **Schottky diode** (also known as the hot-carrier diode or Schottky barrier diode) is a semiconductor diode formed by the junction of a semiconductor with a metal. Schottky diodes have a low forward voltage drop (0.15 to 0.45 V) and a very fast switching action.

This is a simple diode that exhibits non-linear impedance. These diodes are mostly used at microwave detection and mixing.

The **symbol of the Schottky diode** is shown in the figure below.



Construction :

At one end, there is a junction formed between the metal and lightly doped n-type semiconductor. This is a unilateral junction. At the other ending, the metal and heavily doped semiconductor contact are present. It is called **Ohmic bilateral contact**.

When a Schottky diode is in unbiased condition, the electrons lying on the semiconductor side have a very low energy level when compared to the electrons present in the metal. Thus, the electrons cannot flow through the junction barrier which is called the **Schottky barrier**. If the diode is forward biased, electrons present in the N-side get sufficient energy to cross the junction barrier and enters the metal. These electrons enter into the metal with tremendous energy. Consequently, these electrons are known as hot carriers. Thus the diode is called a **hot-carrier diode**.

Applications:

Some of the applications of a Schottky diode are:

- Used in Switched-mode power supplies.
- Used in reverse current protection.
- Used in discharge protection.
- Used in voltage clamping application.
- Used in RF mixer and Detector diode.
- Used in solar cell application