

BAPUJI POLYTECHNIC, SHABANUR, DAVANGERE
ELECTRONICS AND COMMUNICATION ENGG.
V SEMESTER

ADVANCED COMMUNICATION

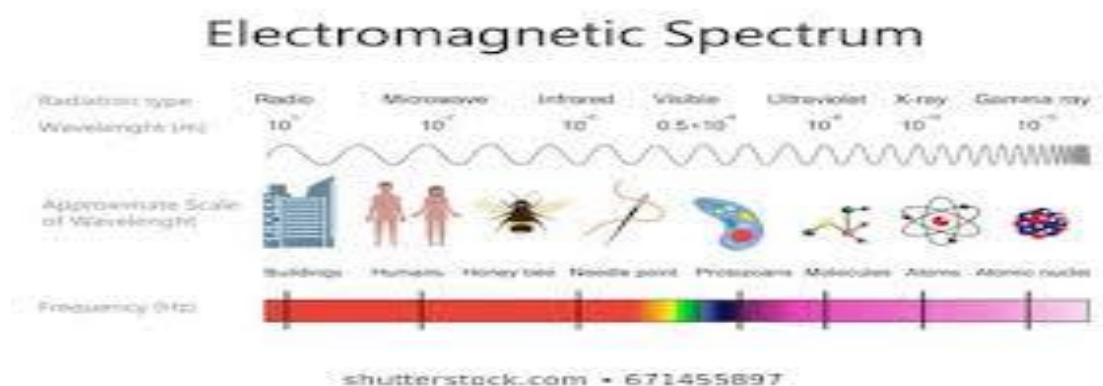
SHARATH KUMAR.U

SEL.GR.LECTURER

Unit 1-Microwave Devices

Introduction

Electronic communication uses electronic circuits to transmit, process, and receive information between two or more locations. The basic components of an Electronic communication system include a transmitter, a communication medium or channel, a receiver and noise. Information is transmitted into the system in analog or digital form, it is then processed and decoded by the receiver. Advanced Communication can be done with the help of advanced technology such as Microwave devices, Satellite Technology, Mobile Communication and Optical Fiber Cable. The Electromagnetic spectrum is the range of frequencies (the spectrum) of electromagnetic radiation and their respective wavelengths and photon energies. The electromagnetic spectrum covers electromagnetic waves with frequencies ranging from below one hertz to above 1025 hertz, corresponding to wavelengths from thousands of kilometers down to a fraction of the size of an atomic nucleus. This frequency range is divided into separate bands, and the electromagnetic waves within each frequency band are called by different names; beginning at the low frequency (long wavelength) end of the spectrum these are: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays at the high frequency (short wavelength) end. The electromagnetic waves in each of these bands have different characteristics, such as how they are produced, how they interact with matter, and their practical applications.



The types of electromagnetic radiation are broadly classified into the following classes (regions, bands or types) 1. Gamma radiation 2. X-ray radiation 3. Ultraviolet radiation 4. Visible light 5. Infrared radiation 6. Microwave radiation 7. Radio waves

Microwave Signal The microwave spectrum is usually defined as electromagnetic energy ranging from approximately 1 GHz to 1000 GHz in frequency, but older usage includes lower frequencies. Most common applications are within the 1 to 40 GHz range.

Band (GHz)	Range (GHz)	Distances*	Comments
2	1.7 - 2.7		Move to higher end due to mobile
4	3.8 - 4.2		PTT High Capacity
6	5.9 - 6.4, 6.4 - 7.1		PTT High Capacity
7.8	7.1 - 8.5	50km	Medium to high capacity provide user
10	10.5 - 10.88		Low capacity, efficient modulation
11	10.7 - 11.7		High capacity
13	12.75 - 13.25	45km	Low to medium capacity
15	14.4 - 15.35	40km	Low to medium capacity
18	17.7 - 19.7	25km	Low to medium capacity
23	21.2 - 23.6	10km	Low to medium capacity
39	37 - 39.5	8km	Low to medium capacity

* Depending on antenna size, terrain, and rainfall, distances shown are typically the maximum for the given frequency.

Radio Frequency Spectrum: Ranges

Designation	Abbreviation	Frequencies	Wavelengths
Very Low Frequency	VLF	3 kHz - 30 kHz	100 km - 10 km
Low Frequency	LF	30 kHz - 300 kHz	10 km - 1 km
Medium Frequency	MF	300 kHz - 3 MHz	1 km - 100 m
High Frequency	HF	3 MHz - 30 MHz	100 m - 10 m
Very High Frequency	VHF	30 MHz - 300 MHz	10 m - 1 m
Ultra High Frequency	UHF	300 MHz - 3 GHz	1 m - 100 mm
Super High Frequency	SHF	3 GHz - 30 GHz	100 mm - 10 mm
Extremely High Frequency	EHF	30 GHz - 300 GHz	10 mm - 1 mm

www.rfpage.com

Advantage of using Microwave Signal:

Large Bandwidth: The Bandwidth of Microwaves is larger than the common low-frequency radio waves. Thus more information can be transmitted using Microwaves. It is very good advantage, because of this, Microwaves is used for Point to Point Communications.

Better Directivity: At Microwave Frequencies, there are better directive properties. This is due to the relation that as Frequency Increases, Wavelength decreases and as Wavelength Decreases Directivity Increases and Beam width decreases. So it is easier to design and fabricate high gain antenna in Microwaves

Small Size Antenna: Microwaves allows to decrease the size of antenna. The antenna size can be smaller as the size of antenna is inversely proportional to the transmitted frequency. Thus in Microwaves, we have waves of much higher frequencies and hence the higher the frequency, the smaller the size of antenna.

Low Power Consumption: The power required to transmit a high frequency signal is lesser than the power required in transmission of low frequency signals. As Microwaves have high frequency thus requires very less power.

Effect of Fading: The effect of fading is minimized by using Line of Sight propagation technique at Microwave Frequencies. While at low frequency signals, the layers around the earth causes fading of the signal.

Disadvantage of using Microwave Signal

- At microwave frequency circuit design is complex.
- Working with microwave equipment requires special knowledge and skills.
- There will be power loss due to “skin effect”.
- Microwave signals are easily reflected and diverted by large and small objects.
- Even rain, snow, fog, and other atmosphere conditions, greatly absorb and attenuate the microwave signals

Applications of Microwave Signal: There are many industrial, Scientific, Medical and Domestic Applications of microwaves. The great example of application of microwave is microwave oven which we use in our daily life. Major applications areas of microwaves are

- Communication
- Remote Sensing
- Heating
- Medical Science

Communication: Microwave is used in broadcasting and telecommunication transmissions.→

Remote Sensing: it used to illuminate an object by using a transmitter and receiver to detect→ its position and velocity. Radiometry is also one of the remote sensing applications.

Heating: Microwave oven is use to bake and cook food. It is very convenient electronic→ machine which performs the heating task very cleanly and in a very less time.

Medical Science: Microwave heating properties are also used in medical science.→ Microwave also has medical applications such as diagnosis and various therapies.

Introduction to Waveguide

A waveguide is a structure that guides waves, such as electromagnetic waves or sound, with minimal loss of energy by restricting the transmission of energy to one direction. Without the physical constraint of a waveguide, wave amplitudes decrease according to the inverse square law as they expand into three dimensional spaces. An electromagnetic field can propagate along a waveguide in various ways. Two common modes are known as transverse-magnetic (TM) and transverse-electric (TE). In TM mode, the magnetic lines of flux are perpendicular to the axis of the waveguide. In TE mode, the electric lines of flux are perpendicular to the axis of the waveguide. Either mode can provide low loss and high efficiency as long as the interior of the waveguide is kept clean and dry. Waveguides are most often used with horn antenna and dish antenna.

To function properly, a waveguide must have a certain minimum diameter relative to the wavelength of the signal. If the waveguide is too narrow or the frequency is too low (the wavelength is too long),

the electromagnetic fields cannot propagate. At any frequency above the cutoff (the lowest frequency at which the waveguide is large enough), the feed line will work well, although certain operating characteristics vary depending on the number of wavelengths in the cross section. The main characteristics of a Waveguide are – the tube wall provides distributed inductance.

- The empty space between the tubes walls provide distributed capacitance.
- These are bulky and expensive.

Advantage of Waveguide

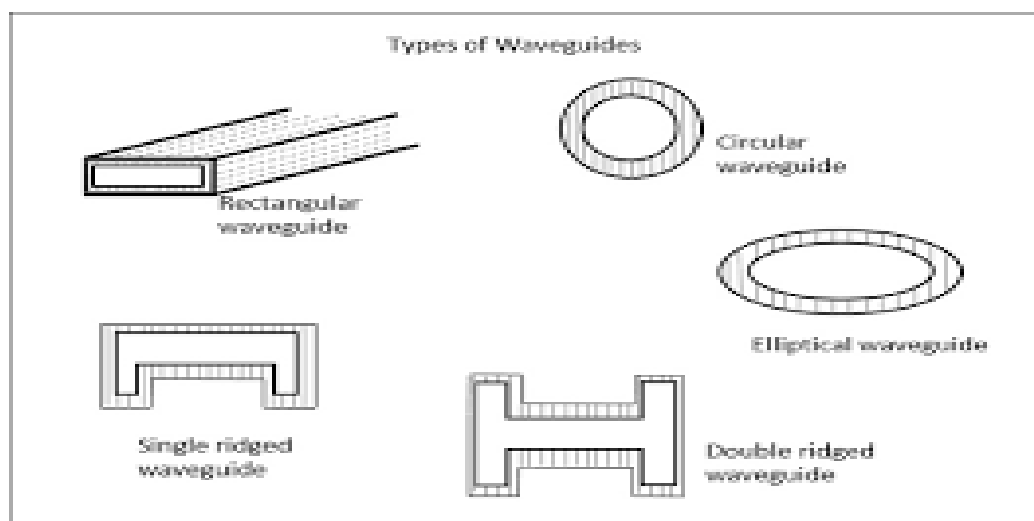
Waveguides are easy to manufacture

- They can handle very large power
- Power loss is very negligible in waveguides.
- They offer very low loss.
- When microwave energy travels through waveguide, it experiences lower losses than a
- Coaxial cable.

Different type of Waveguide There are five types of waveguides.

Rectangular waveguide

- Circular waveguide
- Elliptical waveguide
- Single-ridged waveguide
- Double-ridged waveguide
- Advanced Communication-15EC



Differentiate between Transmission Lines Vs Waveguides

The main difference between a transmission line and a wave guide is – A two conductor structure that can support a TEM wave is a transmission line.

- A one conductor structure that can support a TE wave or a TM wave but not a TEM
- Wave is called as a waveguide.

Applications of Waveguides

- In a microwave oven, a waveguide transfers power from the magnetron, where waves are formed, to the cooking chamber.
- In a radar, a waveguide transfers radio frequency energy to and from the antenna, where the impedance needs to be matched for efficient power transmission.
- It commonly used to connect feeds of parabolic dishes to their electronics.
- It used in scientific instruments to measure optical, acoustic and elastic properties of materials and objects.

Coupling Mechanisms

The three devices used to inject or remove energy from waveguides are PROBES, LOOPS, and SLOTS. Slots may also be called APERTURES or WINDOWS. When a small probe is inserted into a waveguide and supplied with microwave energy, it acts as a quarter-wave antenna. Current flows in the probe and sets up an E field

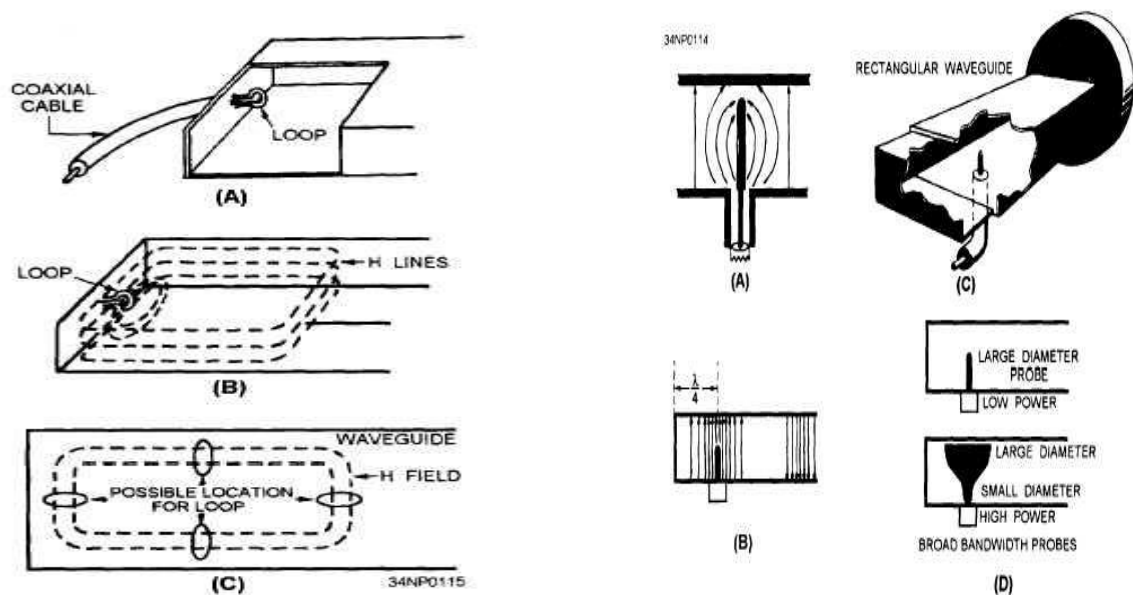
The E lines detach themselves from the probe. When the probe is located at the point of highest efficiency, the E lines set up an E field of considerable intensity. The most efficient place to locate the probe is in the center of the "a" wall, parallel to the "b" wall, and one quarter-wavelength from the shorted end of the waveguide. This is the point at which the E field is maximum in the dominant mode. Therefore, energy transfer (coupling) is maximum at this point. Note that the quarter-wavelength spacing is at the frequency required to propagate the dominant mode. In many applications a lesser degree of energy transfer, called loose coupling, is desirable. The amount of energy transfer can be reduced by decreasing the length of the probe, by moving it out of the center of the E field, or by shielding it. Where the degree of coupling must be varied frequently, the probe is made retractable so the length can be easily changed. The size and shape of the probe determines its frequency, bandwidth, and power-handling capability. As the diameter of a probe increases, the bandwidth increases. A probe similar in shape to a door knob is capable of handling much higher power and a larger bandwidth than a conventional probe. The greater power-handling capability is

directly related to the increased surface area. For the most efficient coupling to the waveguide, the loop is inserted at one of several points where the magnetic field will be of greatest strength.

When less efficient coupling is desired, you can rotate or move the loop until it encircles a smaller number of H lines. When the diameter of the loop is increased, its power-handling capability also increases. The bandwidth can be increased by increasing the size of the wire used to make the loop. When a loop is introduced into a waveguide in which an H field is present, a current is induced in the loop. When this condition exists, energy is removed from the waveguide. Slots or apertures are sometimes used when very loose (inefficient) coupling is desired. In this method energy enters through a small slot in the waveguide and the E field expands into the waveguide. The E lines expand first across the slot and then across the interior of the waveguide. Minimum reflections occur when energy is injected or removed if the size of the slot is properly proportioned to the frequency of the energy.

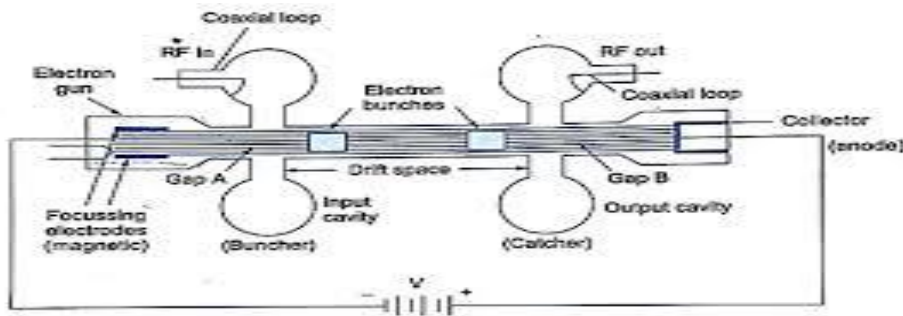
After learning how energy is coupled into and out of a waveguide with slots, you might think that leaving the end open is the simplest way of injecting or removing energy in a waveguide. This is not the case, however, because when energy leaves a waveguide, fields form around the end of the waveguide. These fields cause an impedance mismatch which, in turn, causes the development of standing waves and a drastic loss in efficiency.

Frequency limitations of Conventional Tubes before Transistors were invented; all electronic circuits were implemented with vacuum tubes. Tubes are the devices used for amplification, oscillation, switching and many other operations. Following are the reasons for limitation of conventional active devices like transistors or tubes at microwave frequency: 1. Inter electrode capacitance and lead inductance effect. 2. Transit time effect. 3. Gain-Bandwidth product limitation. 4. RF losses.



TWO CAVITY KLYSTRON

Construction: - The two cavity klystron is an amplifier of microwave and it is one of the earlier forms of velocity modulation device. The structure of two cavity klystron is shown in the figure below. It is seen that high velocity electron beam is formed, down a long glass tube to a collector electrode, with respect to the cathode. As it is clear from the figure, a two cavity klystron amplifier consists of a cathode, very small distance forming a gap A (Input cavity or buncher cavity), two catcher grids with a small gap B (output or catcher cavity) followed by a collector. And output are taken from the tube is via resonant cavity with the help of loops. The region between buncher cavity and catcher cavity is called drift space. The first electrode (focusing grid) controls the number beam and serves to focus the beam. Interaction space.



Operation:- The operation of two cavity klystron is based on the following three processes.

1. Velocity modulation
2. Bunching
3. Current density modulation

The velocity modulation is a process of altering the velocity of electrons with respect to the instantaneous RF voltage present at Gap A

Consider a reference electron B entering gap A when voltage is zero and electron beam. Consider another electron C entering gap a accelerated by the positive electron B in drift space. Similarly electron A passes the gap A slightly before reference electron B, it is get retarded by the negative voltage present at gap A. Thus electron B also catches electron A in the drift space. This is known as when electrons catch up, the faster move on with average velocity of the beam. Eventually the electrons pass the catcher gap in bunches resulting in gap once per cycle and deliver energy to this cavity. The catcher cavity is excited into oscillations at its resonating frequency which is equal to input frequency. A small RF power applied to the buncher cavity considerable power gain. The distance from buncher grid to the initially we consider for electron B.

Applications

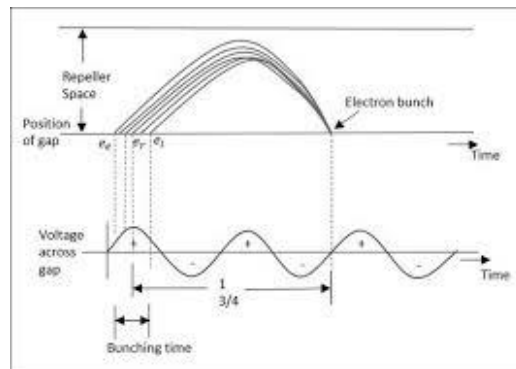
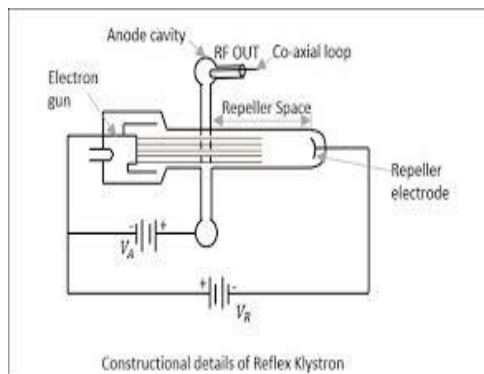
1. UHF TV Transmitters

2. Long Range Radar
3. Linear Particle Accelerator
4. Troposcatter Links
5. Earth Station Transmitters

Reflex klystron

Reflex klystron is low power, low efficiency microwave oscillator having a single cavity.

Construction: The construction detail of Reflex klystron is as shown in the fig. Reflex klystron consists of a small electron gun similar to that of multi cavity klystron. Since the device is short, the beam generated by electron gun does not necessarily need a focusing. The beam is accelerated towards the cavity (anode) which is at a high positive potential. The electrons overshoot the gap in the cavity and continue towards the repeller which is at a negative potential. After reaching some point in the repeller space, electrons are turned back to anode cavity.



Operation: - It is assumed that oscillations are started by noise or switching transients. Consider a reference electron B which enters the gap when the voltage is zero and is beginning to go negative as shown in the fig. It continues past the gap with unchanged velocity, penetrates some distance in the repeller space and returns to the gap. Consider another electron C which passes the gap slightly later than B. Electron C gets retarded by the negative voltage across the gap resulting in shortened stay in repeller space and returns to the gap. Similarly electron A passes the gap slightly before the reference electron and it is accelerated by the positive potential present across the gap. Therefore it is pushed deeper into the repeller space and it takes longer time than the reference electron to return to the gap. Thus the conditions are favorable for the bunching to take place. Velocity modulation, bunching and current density modulation takes place in the same gap. So the cavity is excited into oscillations at its resonant frequency. For sustained oscillations, transit time must be correct value and is given by $T = n + 3/4$

Where T = transit time of electron in repeller space n = any integer Each value of n corresponds to a different reflex klystron mode.

Applications

1. Signal source in microwave oscillator
2. Local oscillator in microwave receivers
3. Frequency modulated oscillator in microwave links
4. Pump oscillator for parametric amplifier

Magnetron

Magnetron is a high power oscillator usually in cylindrical shape. It employs radial electric field and axial magnetic field anode structure with permanent cavities.

Construction: - Fig. Shows the construction details of magnetron. As shown in Figure, the cylindrical cathode is surrounded by the anode with cavities, and thus a radial dc electric field will exist. The magnetic field is axial i.e., has lines of magnetic force passing through the cathode and the surrounding interaction space. Since the magnetic field 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, depending on the power and frequency.

Operation: The cylindrical cathode placed at the centre of the interaction chamber that emits electrons. The cathode is surrounded by the anode and thus radial dc electric field exists. It is assumed that an RF field exists in each cavity. The electron emitted by the cathode travel straight to the anode without much interaction with the RF field. For sustained oscillations, it is essential that the moving electrons impart energy to the RF field by remaining in the interaction space for longer time. This is achieved by means of an axial magnetic field .

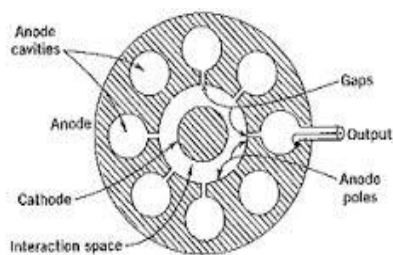


FIGURE 11-10 Cross section of hole-and-slot magnetron.

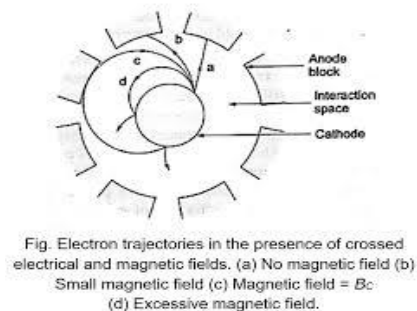


Fig. Electron trajectories in the presence of crossed electrical and magnetic fields. (a) No magnetic field (b) Small magnetic field (c) Magnetic field = B_c (d) Excessive magnetic field.

Performance

Power- 10KW to 5MW depending on the application

Frequency range- UHF band upto 100GHz

Efficiency-50%

Duty cycle-0.1% 1.2

Application

Pulsed Radar

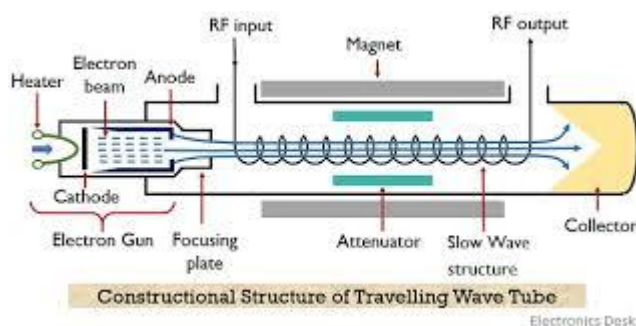
Linear particle accelerators

Microwave ovens

Travelling wave tube

A Traveling-Wave Tube or TWT Amplifier is a high power, high-frequency amplifier. A traveling-wave tube is a type of vacuum tube used to amplify high frequency signals. Travelling wave tube has been designed for wide bandwidth frequencies as low as 300 MHz and high as 50 GHz. Construction The construction details of TWT using helix is as shown in the fig. It is a linear beam tube in which the interaction between the beam and the RF field is continuous. But in Klystron, the electron beam travels where as the RF field is stationary. This is the main difference between TWT and multi cavity Klystron. The RF field travels with the velocity of light, while the electron beam velocity is around 10% of that even with a high anode voltage. The RF field should be retarded with a slow wave structure. Helix is a common type of slow wave structure used in TWTs. It is a non-resonant structure and supports large bandwidths.

The RF signal grows exponentially along the travelling wave tube due to high gain. If the impedance matching is poor at the load oscillations will result. Therefore some attenuator is used in order to reduce the gain. TWT is very long and therefore focusing by means of a permanent magnet or solenoid like structure is employed.



Operation

The electron gun produces a narrow electron beam which is then sent through the centre of a helix. The helix is positive with respect to the cathode. The collector is at even more positive potential. The beam is attracted to the collector and acquires a high velocity. The applied RF signal propagates around the turns of the helix, and it produces an electric field at the centre of the helix. The axial electric field propagates with velocity of light. When the electrons enter the helix tube, an interaction takes place between the moving axial electric field and the moving electrons. The interaction takes

place between them in such a way that on an average the electron beam delivers or transfer energy to the RF wave on the helix. This interaction causes the signal wave grows amplified and becomes larger.

Velocity Modulation- When the axial field is zero, electron velocity is unaffected. This happens at the point of node of the axial electric field. Those electrons entering the helix, when the axial field is positive antinodes, at the accelerating field are accelerated. At a later point where the axial RF field is negative antinodes, retarding field, the electrons are decelerated. The electrons get velocity modulated.

As the electrons travel further along the helix, bunching of electrons occur at the end which shifts the phase of $\pi/2$. Magnet produces axial magnetic field prevents spreading of electron beam as it travels down the tube.

Convection Current- the convection current induced in the electron beam by the axial electronic field and the microwave axial field produced by the beam must first be developed? When the space charge effect is considered the electron velocity, charge density, current density and axial electric field will be perturbed about their average DC values.

The electrons entering the retarding field are decelerated and those in the accelerating field are accelerated. They begin forming a bunch centered about those electrons that enter the helix during the zero fields

Since the dc velocity of the electrons is slightly greater than the axial wave velocity, more electrons in the retarding field than in the accelerating field, and a great amount of energy is transferred from the beam to the electromagnetic field. The microwave signal voltage is amplified by the amplified field. The bunch continues to become more compact, and a larger amplification of the signal voltage occurs at the end of the helix. The magnet produces an axial magnetic field to prevent spreading the electron beam as it travels down the tube. An attenuator placed near the centre of the helix reduces all the waves travelling along the helix to nearly zero so that the reflected waves from the mismatched loads can be prevented from reaching the input and causing oscillation. The bunched electrons emerging from the attenuator induce a new electric field with the same frequency. This field in turn induces a new amplified microwave signal on the helix. The magnitude of the velocity fluctuation of the electron beam is directly proportional to the magnitude of the axial electric field.

Applications of TWT

- Radar and microwave receivers.
- Laboratory instruments.
- Drives for more powerful tubes.
- Power amplifiers in satellite transponders.

Microwave Semiconductor Devices

Introduction

- Special electronics effects encountered at microwave frequencies severely limit the usefulness of transistors in most circuit applications.
- Using vacuum tubes for low power applications become impractical.
- Need for small sized microwave devices have caused extensive research in this area.
- This research has produced solid-state devices with higher and higher frequency ranges.
- The new solid state microwave devices are predominantly active, two terminal diodes, such as tunnel diodes, varactors, transferred-electron devices, and avalanche transit-time diodes

IMPATT DIODE

The IMPATT diode or IMPact Avalanche Transit time diode is an RF semiconductor device that is used for generating microwave radio frequency signal, with the ability to operate at frequencies between about 3 to 100 GHz or more, one of the main disadvantages is the relatively high power capability of the IMPATT diode.

IMPATT Structures There is a variety of structures that are used for the IMPATT diode like p^+n , n^+p , p^+n^+n , and p^+n^+p diode, all are variations of a basic pn junction IMPATT diode is semiconductor device which generate microwave signal from 3 to 100 GHz. In IMPATT diode, negative resistance effect phenomenon is taken into account

A cross-section of p^+n IMPATT diode structure is shown in Fig.7.47. Note that it is a diode, the junction being between p^+ and then n layer. An extremely high voltage gradient is applied in reverse bias to the IMPATT diode of order of 400kV/cm eventually resulting in very high current.

Such a high potential gradient, back-biasing the diode, causes a flow of minority carriers across the junction. If it is now assumed that oscillations exist. Now we may consider the effect of a positive swing of the RF voltage superimposed on top of the high DC voltage

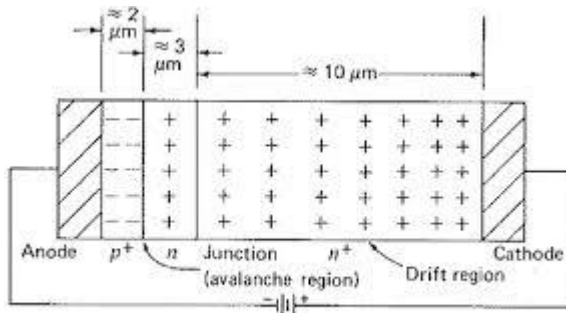
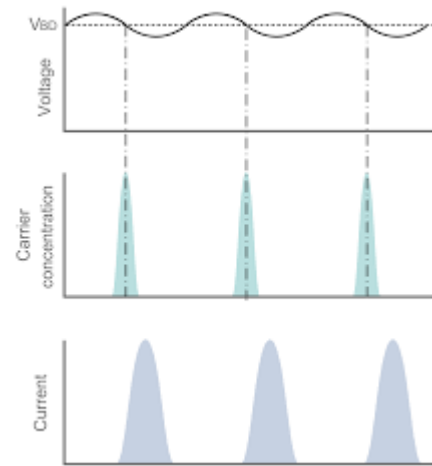


FIGURE 12-28 IMPATT diode (single-drift) schematic diagram.



Advantages of IMPATT Diode:

IMPATT diodes are at present most powerful solid-state microwave power sources. Some of the major advantages of IMPATT diode are

1. Higher operating range are obtain (up to 100 G Hz
2. Above about 20 GHz, the IMPATT diode produces a higher CW power output per unit than any other semiconductor device. Higher operating range (up to 100 GHz) can be obtained from IMPATT diode.

Disadvantage of IMPATT Diode: The major disadvantages of IMPATT diode are:

1. Since DC power is drawn due to induced electron current in the external circuit, IMPATT diode has low efficiency (RF power output/DC input power).
2. Tend to be noisy due primarily to the avalanche process and to the high level of operating current. A typical noise figure is 30 dB which is worse than that of Gunn diode.
3. Tuning is difficult as compare to Gunn diode
4. To run an IMPATT diode, a relatively high voltage is required.

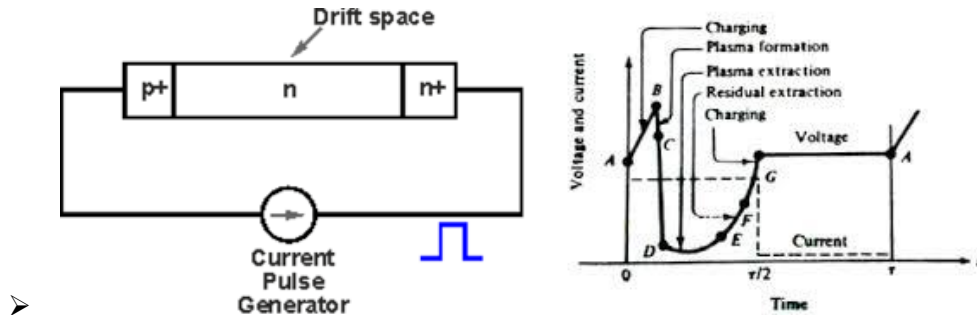
Applications of IMPATT Diode

IMPATT diodes are used as microwave oscillators such as:

1. Used in final power stage of solid state microwave transmitter for communication purpose.
2. Used in transmitter of TV system.
3. Used in FDM/TDM system.
4. Used in microwave source in laboratory for measurement purpose.

TRAPATT Diode

- The TRAPATT (Trapped Plasma Avalanche Triggered Transit) diodes are— manufactured from Si or GaAs, and have p+nn+ (or n+pp+) configuration
 - TRAPATT diode is derived from IMPATT diode.
 - In TRAPATT diodes the doping level between the junction and anode changes— gradually.



Operation

A TRAPATT in operation is placed in a high resonant cavity and is biased to avalanche threshold. When the RF oscillations begin, they build up extremely rapidly due to the resonant structure thus taking the voltage across the diode to a value much above the avalanche threshold

The avalanche zone velocity v_z is given by $V_z = dx/dt = J/qNA$ where, J is current density, q is the charge of electron and NA is doping concentration. Thus the avalanche zone or avalanche shock front will quickly sweep across most of the diode, the electrons and holes will drift at velocities determined by the low-field mobilities, and the transit time of the carriers is given

$$\text{by } \tau = L / v_s$$

Where, v_s = Saturated carrier drift velocity L = Length of the specimen

Advantages& Disadvantages of TRAPATT Diode

The major advantages of TRAPATT are:

1. Low power dissipation
2. High efficiency (up to 60%)
3. TRAPATT is a pulse device capable of operating at much larger pulse powers.

Disadvantages of TRAPATT Diode

The major disadvantages of TRAPATT are:

1. High noise figure (60 dB) limits its use as an amplifier.
2. It generates strong harmonics due to the short duration current pulse.
3. Operating frequency is limited below 10 GHz.