Details of the frequency range of microwave.

Microwave Frequencies

- HF 0.003 GHz to 0.030GHz
- VHF 0.030 GHz to 0.3GHz
- UHF 0.3 GHz to 1 GHz
  (420-450MHz - P Band; Mobile Application : 890-945 MHz)
- L Band 1-2 GHz (1 – 2.6 GHz)
- S Band 2-4 GHz (2.6 – 3.95 GHz)
- C Band 4-8 GHz (C : 3.95-5.85 & J: 5.85-8.2)
- X Band 8-12 GHz (8.2 – 12.4 GHz)
- Ku Band 12-18 GHz (12.4 – 18 GHZ)
- K Band 18- 27 GHz (18 to 26.5 GHz)
- Ka Band 27-40 GHz (26.5 – 40 GHz)
- Millimeter 40-300 GHz (W band 75 to 110 GHz)
- Submillmeter above 300 GHz

Importance of Frequency ranges of microwave.

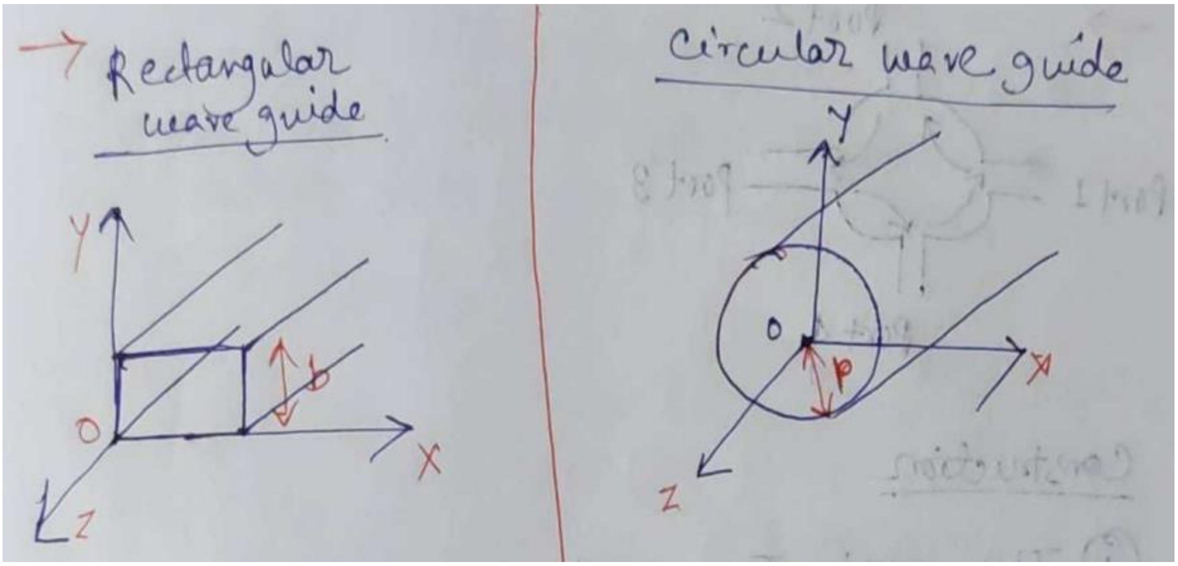
- Supports larger bandwidth and hence more information is transmitted. For this reason, microwaves are used for point-to-point communications.
- More antenna gain is possible.
- Higher data rates are transmitted as the bandwidth is more.
- Antenna size gets reduced, as the frequencies are higher.
- Low power consumption as the signals are of higher frequencies.
- Effect of fading gets reduced by using line of sight propagation.
- Provides effective reflection area in the radar systems.
- Satellite and terrestrial communications with high capacities are possible.
- Low-cost miniature microwave components can be developed.
- Effective spectrum usage with wide variety of applications in all available frequency ranges of operation.

Applications:

Wireless communication
Electronics
Commercial uses
Navigation
Military and Radar
Research application
Radio astronomy
Food industry
Industrial Uses
Spectroscopy

Medical science

Comparison of the performance of rectangular waveguide and circular waveguide.



1 TE10 dominant mode	1 TE11 dominant mode
2 Propagation mode is easier in rectangular waveguide to visualize and analise.	2 Propagation mode is less in circular waveguide to visualize and analise.
3 Joint between two wave guide is complex	3 Here it is easy
4 Rectangular waveguide requires less space	4 It requires more space.
5 Tapering accuracy is easy to get in rectangular waveguide	5 whereas in circular waveguide it is difficult to get but low cost

Definition of the term “dominant mode” and “degenerate mode” as applied to waveguide.

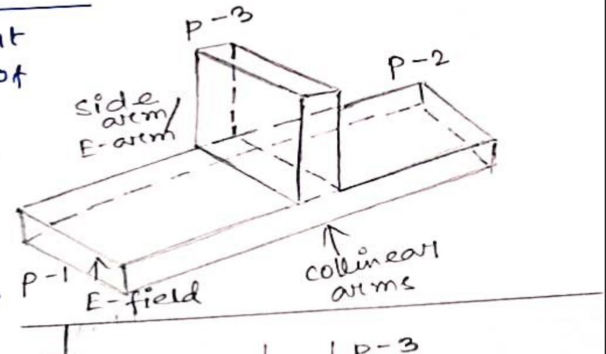
The dominant mode in a particular waveguide is the mode having the lowest cutoff frequency. For rectangular waveguide this is the TE_{10} mode.

In a waveguide when two or more modes have the same cut off frequency but in different field configuration, then they are said to be degenerate modes. In a rectangular waveguide the TE_{mn} and TM_{mn} with $m \neq 0$ and $n \neq 0$ are degenerate modes.

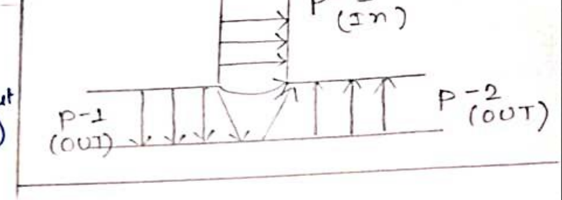
Define the working of an E - plane Tee? Give its S-matrix.

(4) Define the working of an E-plane Tee. Give its S-matrix.

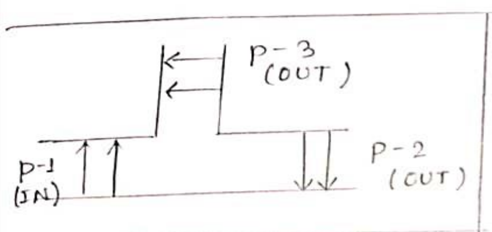
Working of an E-plane Tee :-



A waveguide Tee is a 3-port device. When the ~~the~~ axis of the side arm is parallel to the Electric field (E), of the collinear arms, then the Tee is known as E-plane Tee. The outputs are 180° out of phase with each other, irrespective of from which port the input is fed.

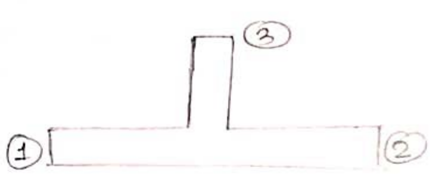


- If the signal is fed to port 3 (P-3), the the output will be split across port 1 (P-1) & port-2 (P-2) & will be 180° out of phase with each other.



- If the input signal is fed to port 1, then the output will be split across port 2 & port 3 & will be 180° out of phase with each other.

S-matrix of E-plane Tee :-



The S-matrix is given as,

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

$S_{11} = S_{22} = S_{33} = 0.$

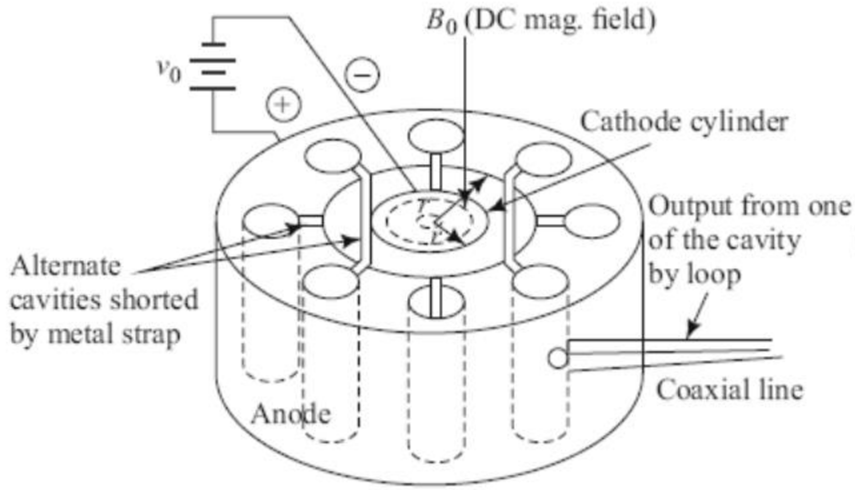
$S_{12} = -S_{21}$

$S_{13} = -S_{31}$

$S_{23} = -S_{32}.$

$$= \begin{bmatrix} 0 & S_{12} & S_{13} \\ -S_{12} & 0 & S_{23} \\ -S_{13} & S_{23} & 0 \end{bmatrix}$$

Details of the working principle of Magnetron oscillator (with the help of a diagram).



All magnetrons consist of some form of anode and cathode operated in a dc magnetic field normal to a dc electric field between the cathode and anode. Because of the crossed field between the cathode and anode, the electrons emitted from the cathode are influenced by the crossed field to move in curved paths. If the dc magnetic field is strong enough, the electrons will not arrive in the anode but return instead to the cathode. Consequently, the anode current is cut off. Magnetrons can be classified into three types:

1. *Split-anode magnetron:* This type of magnetron uses a static negative resistance between two anode segments.
2. *Cyclotron-frequency magnetrons:* This type operates under the influence of synchronism between an alternating component of electric field and a periodic oscillation of electrons in a direction parallel to the field.
3. *Traveling-wave magnetrons:* This type depends on the interaction of electrons with a traveling electromagnetic field of linear velocity. They are customarily referred to simply as *magnetrons*.

Negative-resistance magnetrons ordinarily operate at frequencies below the microwave region. Although cyclotron-frequency magnetrons operate at frequencies in microwave range, their power output is very small (about 1 W at 3 GHz), and their efficiency is very low (about 10% in the split-anode type and 1% in the single-anode type). Thus, the first two types of magnetrons are not considered in this text. In this section, only the traveling-wave magnetrons such as the cylindrical magnetron, linear (or planar) magnetron, coaxial magnetron, voltage-tunable magnetron, inverted coaxial magnetron, and the frequency-agile magnetron will be discussed.

Details of the frequency measurement technique with the help of suitable diagram.

(4) Details of frequency measurement technique with the help of suitable diagram.

Ans Freq. measurement by –

(I) Oscilloscope :

- to observe in time domain
- periodic signals
- burst and transient signals with arbitrary waveforms
- application - direct observation of signals from a test generator or other sources.
- visualizes the shape of waveform
- limited performance for the evaluation of non-linear effects.

(II) Spectrum analyzer :

- to observe signals in frequency domain.
- sweeps in equidistant steps through a given frequency range.
- application - observation of spectrum from the beam, or from signal generator.
- requires periodic signals.

Difference between microwave from other low frequency systems.

Difference between Radio wave, Microwave, and Infrared waves:

Sr. No.	Basis	Radio wave	Microwave	Infrared wave
1.	Direction	These are omni-directional in nature.	These are unidirectional in nature.	These are unidirectional in nature.
2.	Penetration	At low frequency, they can penetrate through solid objects and walls but high frequency	At low frequency, they can penetrate through solid objects and walls. at high frequency,	They cannot penetrate through any solid object and walls.

Sr. No.	Basis	Radio wave	Microwave	Infrared wave
		they bounce off the obstacle.	they cannot penetrate.	
3.	Frequency range	Frequency range: 3 KHz to 1GHz.	Frequency range: 1 GHz to 300 GHz.	Frequency range: 300 GHz to 400 GHz.
4.	Security	These offers poor security.	These offers medium security.	These offers high security.
5.	Attenuation	Attenuation is high.	Attenuation is variable.	Attenuation is low.
6.	Government License	Some frequencies in the radio-waves require government license to use these.	Some frequencies in the microwaves require government license to use these.	There is no need of government license to use these waves.
7.	Usage Cost	Setup and usage Cost is moderate.	Setup and usage Cost is high.	Usage Cost is very less.
8.	Communication	These are used in long distance communication.	These are used in long distance communication.	These are not used in long distance communication.

Write the advantages and disadvantages of microwaves.

Following are the advantages of Microwave Communication:
➡The microwave spectrum has larger bandwidth and hence large amount of information can be transmitted using it.
➡Day by day radio frequency spectrum is getting crowded. Microwave technology helps to manage crowded spectrum with the use of high selective receivers, modulation (SSB, PSK, QAM etc.) and spread spectrum techniques, data compression etc.
➡Microwave spectrum is divided into different channels as per application. The center frequencies for these channels are allocated with gaps between them so that channels will not overlap and do not cause interference to nearby channels.
➡Microwave communication is used since earlier days as one of the Line of Sight Communication in hilly

remote areas where other means of wired communication is not possible to be installed. Microwave and satellite communications are prefect choice in such places.

Following are the disadvantages of Microwaves:

➡For the frequencies which are below 30MHz standard circuit analysis can be applied. For the frequencies in the microwave range, E-H wave analysis need to be applied.

➡As we know lumped components such as resistors, inductors and capacitors do not have same characteristics at microwave frequencies as they have at lower frequencies. Hence it is difficult to implement these components at microwave frequencies.

➡At microwave frequencies, transit time of current carrier i.e. electron is higher which takes large percentage of actual signal. Due to this fact, conventional transistors do not function properly at microwave frequency compare to lower frequency.

➡As microwave communication is limited to line of sight mode only, Other modes of communication are not possible.

Explain the different characteristics of microwaves.

- Microwaves are the waves that radiate electromagnetic energy with shorter wavelength.
- Microwaves are not reflected by Ionosphere.
- Microwaves travel in a straight line and are reflected by the conducting surfaces.
- Microwaves are easily attenuated within shorter distances.
- Microwave currents can flow through a thin layer of a cable.

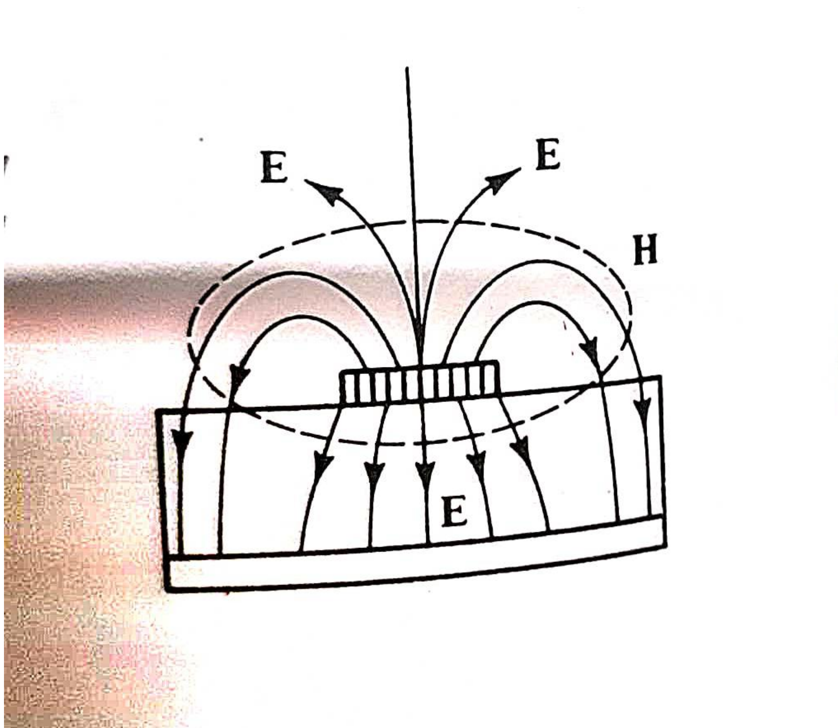
Explain the TE_{10} mode in a rectangular waveguide.

1) Explain the TE_{10} mode in a rectangular waveguide.

⇒ The dominant mode in a waveguide is the mode that has the lowest cut-off frequency. For a rectangula waveguide TE_{10} mode is that dominant mode. It has $f_{c10} = \frac{c}{2a}$. The electric field of the dominant mode is

$E = E_0 \sin\left(\frac{\pi x}{a}\right) e^{-jk_z z} e_y$. Mostly this mode is used in the waveguide. It is then crucial to make sure that the frequency is low enough such that only the dominant mode can propagate. Otherwise there will be more than one mode in the waveguide, & since the modes travel with different speeds, one cannot control the phase of the wave.

Give the field pattern of E-field and H- field in a Micro-strip Line.

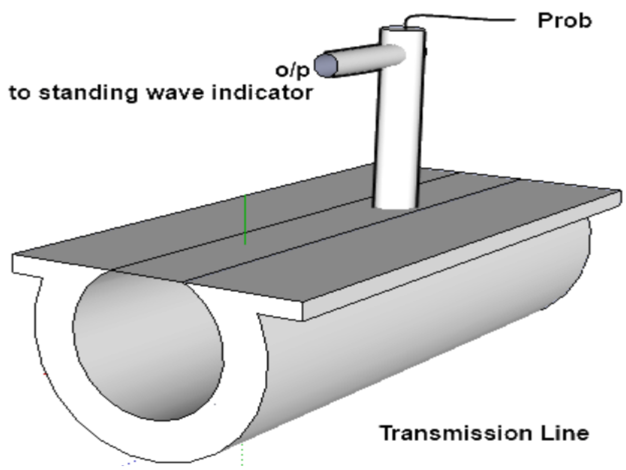


(b) Field lines

What do you mean by slot line? Explain with the help of a suitable diagram.

The slotted line is one of the basic instruments used in radio frequency test and measurement at microwave frequencies. It consists of a precision transmission lines, usually coaxial but waveguide implementations are also used, with a movable insulated probe inserted into a longitudinal slot cut into the line.

As shown in the below diagram, the slatted line consists of minimum λ/2 piece having a slot in its longitude and a circular shape internally. The test probe is kept inside the slot in such a way that it is parallel to the electric field and the transmission line. The output of the probe is provided to standing wave indicator in order to measure the voltage standing wave ratio. The transmission lie is kept inside the slotted line for measurement of values of maximum voltage point and minimum voltage location.



Describe the basic operating principle of a two - hole directional coupler.

4-5-1 Two-Hole Directional Couplers

A two-hole directional coupler with traveling waves propagating in it is illustrated in Fig. 4-5-3. The spacing between the centers of two holes must be

$$L = (2n + 1)\frac{\lambda_g}{4} \tag{4-5-3}$$

where n is any positive integer.

$(2n+1)\frac{\lambda g}{4}$

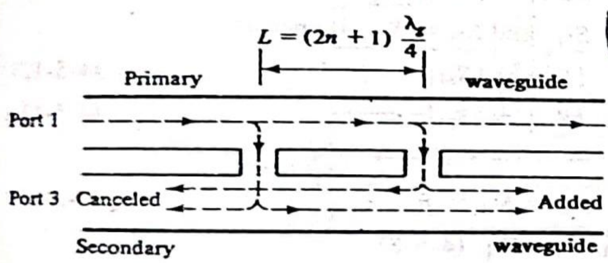
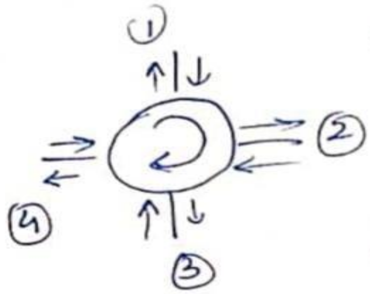


Figure 4-5-3 Two-hole directional coupler.

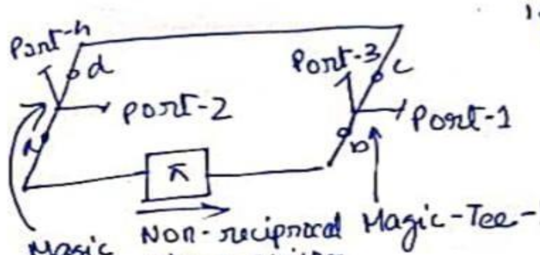
A fraction of the wave energy entered into port 1 passes through the holes and is radiated into the secondary guide as the holes act as slot antennas. The forward waves in the secondary guide are in the same phase, regardless of the hole space, and are added at port 4. The backward waves in the secondary guide (waves are progressing from right to left) are out of phase by $(2L/\lambda_g)2\pi$ rad and are canceled at port 3.

Explain how a circulator can be designed using two magic and a 180º phase shifter with the help of suitable diagram.



→ A four port circulator is made by two Magic-Tees and a non-reciprocal 180° phase shifter

→ So from the diagram we can see that in a four-port circulator if input is from port-1 output will be in port-2, if input is from port-2 output will be from port, input from port-3 output from port-4, and input from port-4 output from port-1



→ An input signal at port 1 is split into two-inphase and equal amplitude waves in the collinear arms b and c of magic Tee-1

→ These waves added and given as output at port 2 of magic Tee-2

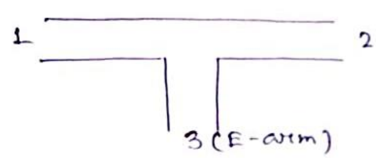
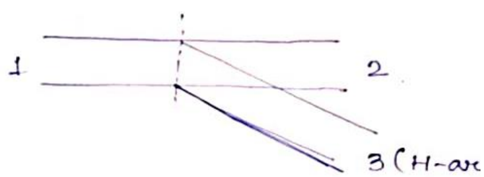
→ A signal at port-2 will split into two equal amplitude and in-phase waves in collinear arms a and d of magic-Tee-2

→ Due to the presence of the non-reciprocal 180° phase shifter, the waves appeared at 'b' and 'c' are out of phase

→ These waves add up and move out from port-3

Give the differences between E-plane and H-plane Tee with the help of suitable diagrams.

(33) Give the differences between E-plane & H-plane Tee with the help of suitable diagrams.

E - plane Tee	H - plane Tee.
(I) It is also known as series Tee.	(I) It is also known as shunt Tee.
(II) E-plane Tee side arm (E-arm) is parallel to the electric field.	(II) H-plane Tee side arm (H-arm) is parallel to the magnetic field.
(III) E-plane Tee junction is known as voltage junction.	(III) H-plane Tee junction is known as current junction
	

List the limitations of conventional vacuum tubes for the application in high frequency operations.

6.1. High Frequency Limitations of Conventional Vacuum Tubes

With increasing frequency (> 1GHz) the conventional vacuum tubes (triodes, tetrodes and pentodes) are less useful in amplification and generation because of two important limitations (i) parasitic circuit elements such as interelectrode- capacitances and lead inductances and (ii) effects due to transit time of electrons between elecrodes. These two effects have been analyzed in sections 6.1.1. and 6.1.2 respectively.

Other Limitations

In addition to these two effects there is

(1) **Increase of Power Losses** resulting from

(a) **Skin effect** : As the frequency is increased, the current flows more and more on the surface of the conductor because of the skin-effect. This results in ohmic losses in lead wires. This can be minimised by the use of conductors having low resistivity and large surface areas : planer electrodes.

(b) **Electro magnetic radiation from the circuit** : Lead wires become small antennas with a resulting radiation power loss. Radiation losses can be minimised by the use of electrode lead spacing of the order of 1/100 of a wave length or less.

(c) **Dielectric losses** : As variety of insulating materials are used inside the tube.

and (d) **Charging current losses** : I^2R losses caused by capacitance charging currents. These losses could be reduced by reducing interelectrode capacitance and by increasing the number of shunt paths along with the charging currents flow.

(2) Gain Bandwidth Product Limitation

Another limitation is caused by gain bandwidth product of the circuit which is given by

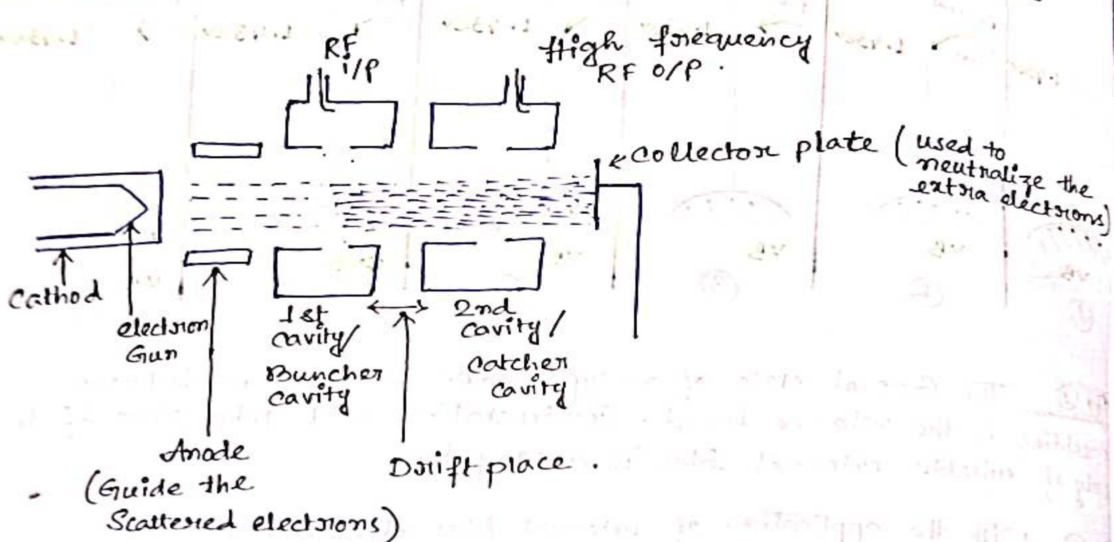
$$A_m (BW) = \frac{g_m}{C}$$

where A_m the maximum voltage gain at resonance, g_m = trans conductance and C=the capactance of the tank circuit. We note that gain band width product is indepedent of frequency. For a given tube a higher gain can be achieved only at the expense of .bandwidth or higher bandwidth can be achieved only at the expense of gain. This restriction is applicable to a resonant circuit only.

With the help of suitable diagram, describe the basic construction and operation of a two-cavity Klystron.

Two Cavity Klystron Amplifier.

17/2



Like

TUBE LIGHT STRUCTURE.

The two cavity klystron utilizes an electron source (heater), an anode, & a cathode like a conventional vacuum tube. It is also utilizes a collector element at the end of the electron stream. The heater boils off electron when heated & the electrons are ejected from the cathod & accelerate towards the anode due to the high DC potential between two element. A focused beam of electrons is thus produced.

In the case of the two-cavity klystron, the electron beam passes through a central hole in the first toroid-shaped cavity (Buncher cavity) through a similar second cavity (Catcher cavity), terminating at the collector.

On each side of the cavity hole is a grid that the electrons pass through. It is the interaction of the cavities with the beam that provides the high levels of amplification that the device can produce.

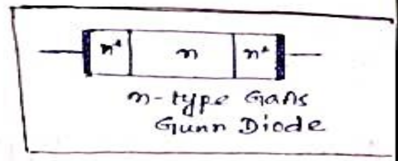
What is Gunn effect?

It is the production of rapid fluctuations of current when the voltage applied to a semiconductor device exceeds a critical value with the result that microwave power is generated.

Describe the RWH theory to explain Gunn effect.

Solid State Microwave Source.

Gunn Diode (—⋈—)



→ It does not have any physical p-n junction

→ It has n-type GaAs / n-type InP

→ It has satelite valley.

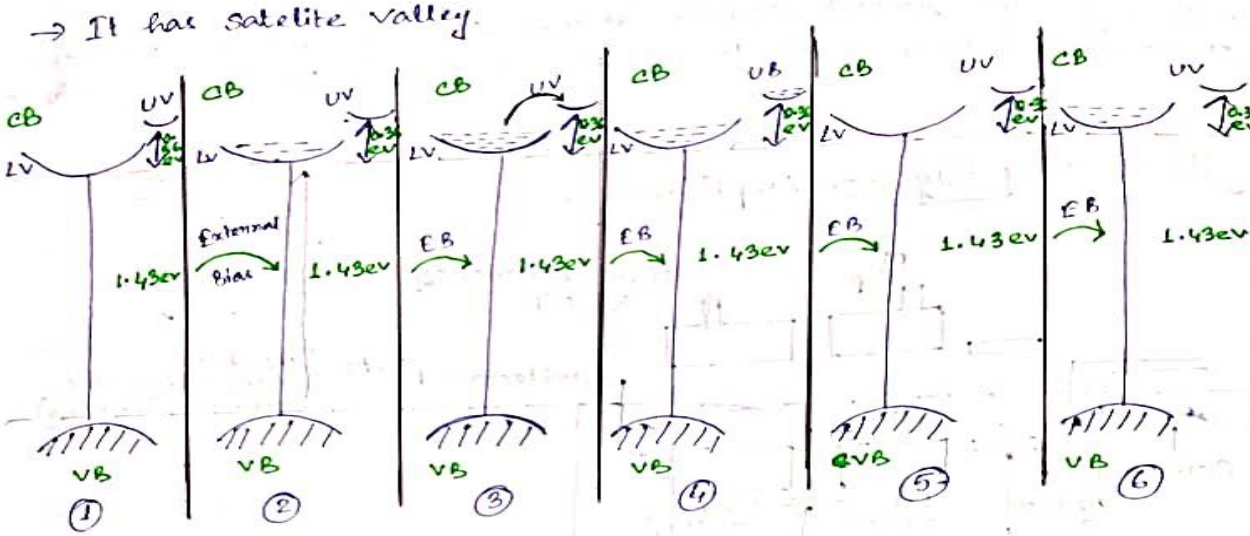


Fig ① The Ground state of n-type GaAs showing all electrons presiding in the valance band. Conducration will take place if & only if suitable external bias is arranged.

Fig ② With the application of external bias electrons will start moving from the valance band to the conduction band's Lower valley & the process will continue in the pressence of external bias when the electrons stand accross the barrier of 1.43 ev.

Fig ③ The Lower valley of conduction band will continue getting the electron from valance band untill it is ~~tott~~ totally filled up. After the Lower valley is completely filled up & ~~the~~ in the presence of external bias the electron would required only 0.36 eV of ~~frequency~~ energy to reach the upper valley of conduction band, & this local conduction from lower valley to upper valley will continue untill any single electron is left in the lower valley.

Fig ④ When no electron is left in the lower valley & in the presence of external bias no fresh condlection start from valance band. In this situation although the external bias is present no further conduction takes place. The electron in the upper

Short notes on:

a) **Classification of Microwave devices**

Semiconductor Microwave Devices

Most microwave devices are fabricated on a GaAs substrate because of its high mobility. A silicon substrate, on the other hand, has the advantages of low cost and high yield. The following table summarizes the various microwave solid-state devices and their applications.

Device	Frequency Limitation	Substrate Material	Major Applications
IMPATT	< 300 GHz	Si, GaAs, InP	Transmitters Amplifiers
Gunn	< 140 GHz	GaAs, InP	Local oscillators, Amplifiers Transmitters
FET&HEMT	< 100 GHz	GaAs, InP	Amplifiers , Oscillators, Switches, Mixers, and Phase shifters
p-i-n	< 100 GHz	Si, GaAs	Switches, Limiters, Phase shifters, Modulators, and Attenuators
Varactor	< 300 GHz	GaAs	Multipliers, Tuning, Phase shifters, and Modulators

b) **Rectangular waveguide**

(4) Rectangular Wave Guide :-

A rectangular wave guide is a hollow metalic tube with a rectangular cross section. The conducting walls of the guide confine the electromagnetic fields & thereby guide the electromagnetic wave. A number of distinct field configurations or modes can exist in wave guide. When the waves travel logitudinally down the guide, the plane waves are reflected from the wall to wall. This process results in a component of either electric or magnetic field in the direction of propagation of the resultant wave; therefore the wave is no longer a transverse electromagnetic (TEM) wave.

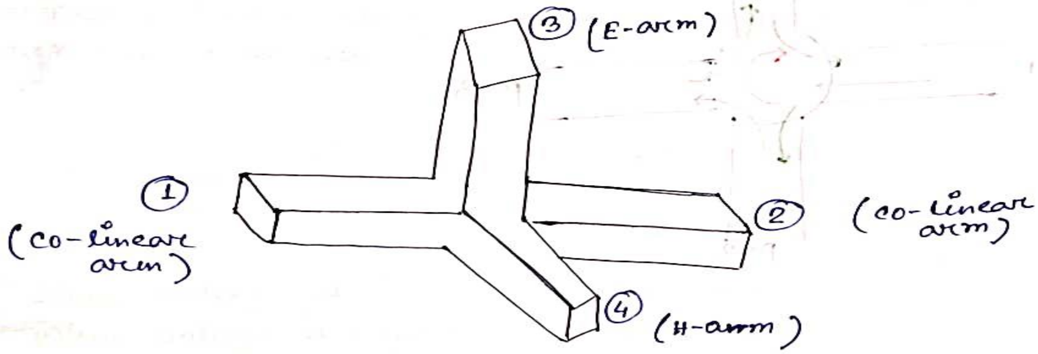
A plane wave in a wave guide resolves into 2 components : one standing wave in the direction normal to the reflecting walls of the guide & the other one travelling wave in the direction parallel to the reflecting walls. In lossless waveguides the modes may be classified as either transverse electric (T.E) mode or transverse magnetic (TM) mode. In rectangular guides the modes are designated TEmn or TMmn. The integer m denotes the no. of half waves of electric or magnetic intensity in the x direction, & n is the number of half waves in the y direction if the propagation of the wave is assumed in the positive z-direction.

c) **Magic Tee**

28/3

Hybrid Tee Junction
(Magic Tee).

It is the combination of E plane & H plane Tee.



* In the above structure of Magic Tee, when the signal comes from port 4 (H-arm), after reaching to the centre, the centre gets separated into port 1 & port 2. But the signal does not go to port 3 (E-arm).

* On the other hand, when two opposite phase signals (P.D - 180°) ~~are~~ come from port 1 & port 2, after reaching at the center, the signals combine with each other & then move towards port 3 [E-arm].

* Magic Tee is used for adding & spliting ~~two~~ signals. It is also used to design a 4-port circulator.

d) **Helix-TWT**

(5) Travelling Wave Tube (TWT)

Travelling Wave Tubes (TWTs) are broadband microwave devices which have no cavity resonators like klystron. Amplification is done through the prolonged interaction between an electron beam & RF field.

CONSTRUCTION :- Travelling Wave Tube has a cylindrical structure which contains an electron gun from a cathode tube. It has anode plates, helix & a collector. RF input is sent to one end of the helix & the o/p is drawn from the other end of the helix.

An electron gunn focusses an 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 retared by a helix. Helix acts as slow wave structure.

The resultant electric field due to applied RF signal, travels with the velocity of light multiplied by the ratio of helix pitch to helix circumference. The velocity of electron beam, travelling through the helix, induces energy to the RF wave's on the helix.

OPERATION :- The anode plates, when at zero potential, which means when the axial electric field is at a node, the electron beam velocity remains unaffected. When the wave on the axial electric field is at positive antinode, the electron from the electron beam moves opposite direction. This electron ~~beam~~ being accelerated, tries to catch up with the late electron, which encounters the node of RF axial field.

At the point where the RF axial field is at negative antinode, the electron referred ~~et~~ earlier, tries to overtake due to negative field effect. The electron receives modulated velocity. As a cumulative result, a second wave is induced in the helix. The o/p becomes larger than the i/p & results in amplification.

e) **Microwave Power measurement**

(29) Microwave Power Measurement.

The Microwave Power measured is the average power at any position in waveguide. Power measurements can be of three types :

(I) Measurement of Low Power :-

The measurement of Microwave power around 0.01 mW to 10 mW, can be understood as the measurement of low power.

Bolometer is a device which is used for low microwave power measurements. The element used in bolometer could be of positive ~~or~~ negative temperature co-efficient whose. The Thermistor has negative temperature co-efficient of temperature. The resistance decreases with the increase of microwave power change in resistance is proportional to microwave power applied for measurement.

(II) Measurement of Medium Power :-

The measurement of Microwave Power around 10 mW to 1 W, can be understand as the measurement of medium power.

A special load is employed, which usually maintains a certain value of specific heat. The power to be measured, is applied at its input ~~&~~ which proportionally changes the ~~o/p~~ output temperature of the load that it already maintains. The difference in temperature rise, specifies the input microwave power to the load. The bridge balance technique is been used here to get the output.

(III) Measurement of High Power :-

The measurement of microwave Power around 10 W to 50 kW, can be understood as the measurement of high power.

The High microwave power is normally measured by Calorimetric watt meters, which can be of dry & flow type. The dry type is ~~so~~ named so as it uses a coaxial cable which is filled with dielectric of high hysteresis loss, whereas the flow type is named so as it uses water or oil or some liquid which is a good absorber of microwaves.

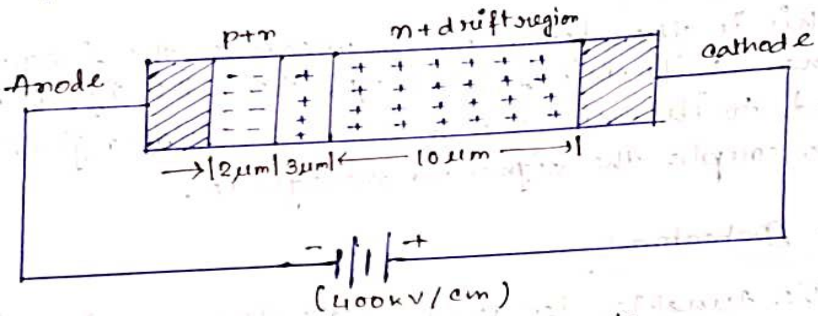
f) **IMPATT diode**

(22) IMPATT Diode.

This is a high-power semiconductor diode, used in high frequency microwave applications. The full form of IMPATT is IMPact ionization Avalance Transit Time diode.

A voltage gradient when applied to the IMPATT diode, results in a high current. A normal diode will eventually breakdown by this. However, IMPATT diode is developed to withstand all this. A high potential gradient is applied to bac bias the diode & hence minority carriers flow across the junction.

Application of an RF AC voltage if superimposed on a high DC voltage, the increased velocity of holes & electrons results in additional holes & electrons by thrashing them out of the crystal structure by impact ionization. If the original DC field applied was at the ~~thresso~~ threshold of ~~xxx~~ developing this situation, then it leads to the avalanche current multiplication & this process continues. This can be understood by the following figure.



IMPATT diode schematic.

Due to this effect, the current pulse takes a phase shift of 90°. However, instead of being there, it moves towards cathode due to the reverse bias applied. The time taken for the pulse to reach cathode, depends upon the ~~*~~ n+ layer, which is adjusted to make it 90° phase shift. Now, a dynamic RF negative resistance is proved to exist. Hence, IMPATT diode acts both as an oscillator & an amplifier.