PET ENGINEERING COLLEGE

An ISO 9001:2015 Certified Institution

Accredited by NAAC, Approved by AICTE, Recognized by Government of Tamil Nadu and Affiliated to Anna University

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – 4

PASSIVE AND ACTIVE MICROWAVE DEVICES

CLASS : **S7 ECE**

SUBJECT CODE : **EC8701**

SUBJECT NAME : **ANTENNA AND MICROWAVE ENGINEERING**

REGULATION : **2017**

MICROWAVE JUNCTIONS.

UNIT IV (a)

TEE JUNCTION:

Waveguide tees are three port junction. They are used to connect a branch or section of the waveguide in series or in parallel with the main waveguide transmission line for providing means of splitting and combining power in a waveguide s/m. There are two basic types

1) E plane (series) T
2) H plane (shunt) T

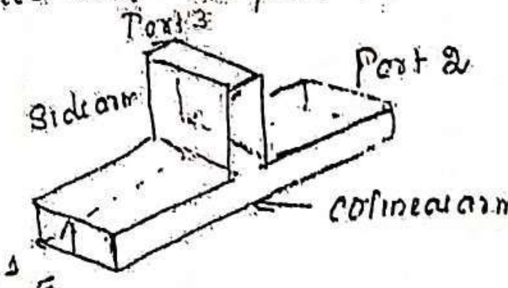
The general s-matrix for tee junction

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

E plane T :-

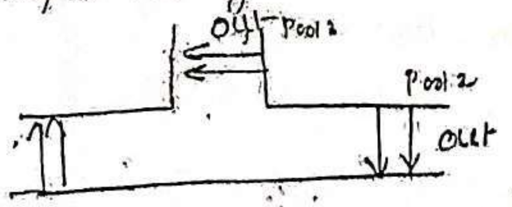
E plane T is the named because the axis of the side arm is parallel to the E field in the collinear arms respectively.

- An E-plane tee is a waveguide tee in which the axis of its side arm is parallel to the E field of the main guide.

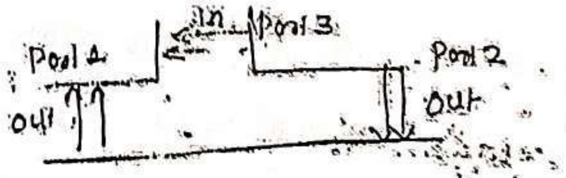


- If the collinear arms are symmetric about the side arm there are two different transmission characteristics.

Input through main arm



Input from side arm



- If the E plane tee is perfectly matched the diagonal elements of scattering matrix becomes zero when the waves appearing at port 1 and port 2 of the collinear arm will be opposite phase & same magnitude. Therefore $S_{13} = -S_{23}$.

* For a matched junction, the S matrix is given by

$$S = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

* From the symmetry property of S-Matrix

$$S_{12} = S_{21},\quad S_{13} = S_{31},\quad S_{23} = S_{32} \quad \text{—} (1)$$

* From the unitary property of S matrix

~~$S_{12}S_{12}^* + S_{13}S_{13}^* = 1$~~

$$S_{21} S_{21}^* + S_{31} S_{31}^* = 1 \quad \text{—} (2)$$

$$S_{12} S_{12}^* + S_{32} S_{32}^* = 1 \quad \text{—} (3)$$

$$S_{13} S_{13}^* + S_{23} S_{23}^* = 1 \quad \text{—} (4)$$

From the (4) if $S_{13} = 0$, S_{23}

$\Rightarrow |S_{13}|^2 + |S_{23}|^2 = 1$

$S_{13} = 0$, we $S_{13} = -S_{23}$

$\therefore S_{23} = 0$

So eqn (4) becomes false.

This inconsistency proved the Tee junction cannot be matched to the three arms. In other words, the diagonal elements of S Matrix of a Tee junction are not all zero, $S_{11} \neq S_{22} \neq S_{33} \neq 0$.

Hence since the collinear arm is usually symmetric about the side arm $S_{13} = -S_{23}$ & $S_{11} =$

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

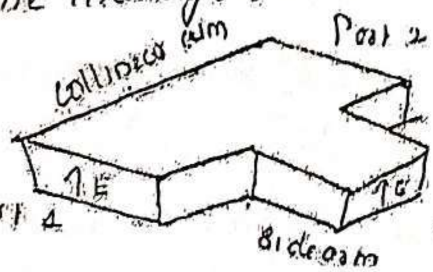
$S_{11} = S_{22}$, $S_{13} = S_{31}$, $S_{12} = S_{21}$, $S_{13} = -S_{23}$

$S_{32} = S_{23}$
$= -S_{13}$

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{11} & -S_{13} \\ S_{13} & -S_{13} & S_{33} \end{bmatrix}$$

H-Plane Tee

An H-Plane tee is a waveguide tee in which the axis of its side arm is shunting the E field or parallel to the H field of the main guide



* If the H plane tee is perfectly matched the diagonal elements are zero $S_{11} = S_{22} = S_{33} = 0$
* If two i/p waves are fed into port 1 and port 2 of the collinear arm, the o/p wave at port 3 will be in phase and additive
* If the i/p is fed into port 3, the wave will split equally into port 1 and port 2 in phase and in same magnitude

$\therefore S_{13} = S_{23}$

* For a matched junction, S matrix is given by

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

* From the symmetry property $S_{12} = S_{21}, S_{13} = S_{31}$
$S_{23} = S_{32}$

$$S = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$$

* From unitary property of S matrix

$S_{21} S_{21}^* + S_{31} S_{31}^* = 1$

$S_{12} S_{12}^* + S_{32} S_{32}^* = 1$

$S_{13} S_{13}^* + S_{23} S_{23}^* = 1$

if $S_{13} = 0 \Rightarrow |S_{13}|^2 + |S_{23}|^2 = 1$ —— (A)

~~His~~ since $S_{13} = S_{23}$

$S_{13} = 0$,. $S_{23} = 0$

eqn (A) become false , so the junctions are not matched $\therefore S_{11} = S_{22} = S_{33} \neq 0$

* collinear arm is usually symmetric, hence $S_{13} = S_{23}$, $S_{11} = S_{22}$

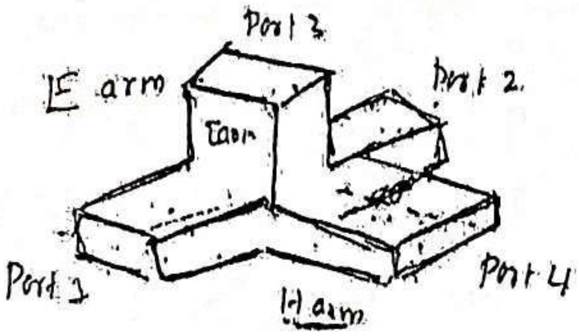
$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

$S_{12} = S_{21}$, $S_{11} = S_{22}$, $S_{13} = S_{23}$ $S_{32} = S_{23} = S_{13}$

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{11} & S_{13} \\ S_{13} & S_{13} & S_{33} \end{bmatrix}$$

Magic Tees (Hybrid Tees)

A magic tee is a combination of E plane tee and H plane tee. The Magic tee has several characteristics.



Tee.

1) If two waves of equal magnitude and same phase are fed into port 1 and port 2, the o/p will be zero at port 3 and additive at port 4.
2) If a wave is fed into port 4 (the H-arm) will be divided equally between port 1 and Port 2 of collinear arms and will not appear at port 3.
3) If a wave is fed into port 3 (the E arm), it will produce an output of equal magnitude and opposite phase at port 1 and port 2. The o/p of port 4 is zero

$$S_{43} = S_{34} = 0$$

4) If a wave is fed into one of collinear arms at port 1 or port 2, it will not appear in the other collinear arm at port 2 or port 1 because the E arm causes a phase delay while the H arm causes a phase advance $S_{12} = S_{21} = 0$

S matrix of a magic tee

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

in the E and H arms without destroying the symmetry of the junction

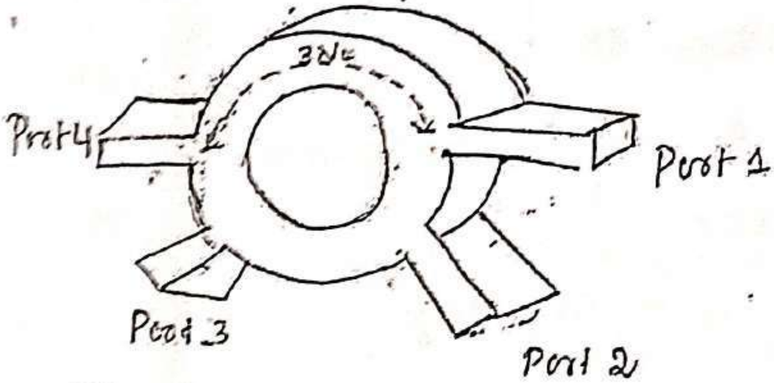
$\therefore S_{11} = S_{22} = S_{33} = S_{44} = 0$

$$[S] = \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{bmatrix}$$

* The magic T is commonly used for mixing duplexing & impedance measurements.
* A Magic Tee can be used for the application which requires twice more i/p power to an antenna than either transmitter can deliver
* A Magic tee may be used to couple the two transmitter to the antenna in such a way that the transmitter do not load each other
* The two transmitters should be connected to ports 3 and Port 4 respectively
* Transmitter 1, connected to port 3 causes a wave to emanate from Port 1 and another to emanate from port 2. These waves are equal in magnitude but opp in phase.
* Transmitter 2, connected to port 4, give rise to a wave at port 1 and another at Port 2, both equal in mag and in phase.
* At Port 1 the two opp. wave cancel each other ... the two in phase ... add together ...

Hybrid Rings (Rat Race circuits)

A hybrid Ring consists of an annular line of proper electrical length to sustain standing waves, to which four arms are connected at proper intervals by means of series or parallel junctions



* The distance between port 1 and Port 2, Port 2 & Port 3, Port 3 & Port 4 is $\lambda/4$ whereas the distance between Port 4 and Port 1 is $3\lambda/4$
* consider a wave incident in Port 1, This wave splits into two waves travelling around the circuit in opposite direction
* The wave reaches at Port 2 & Port 4 are in phase becos the distance travelled is $\lambda/4$ and $3\lambda/4$
* The wave reaches at Port 3 is out of phase becos distance travelled is $\lambda/2$. So ~~is~~ ~~This~~ No wave emerges out of Port 3. Therefore Port 1 and Port 3 are uncoupled

$$S_{13} = S_{31} = 0$$

* For above reason, when wave incident on Port 2 will not get emerged from port 4. So Port 2 and

* A Magic Tee can be matched by tuning screw in E and H arms without destroying the symmetry of the junction

$S_{11} = S_{22} = S_{33} = S_{44} = 0$, $S_{13} = S_{31} = 0$
$S_{24} = S_{42} = 0$

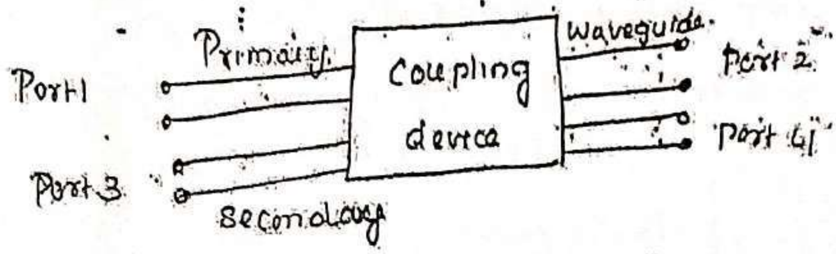
$$[S] = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

This is the S. Matrix for Hybrid Ring

Directional coupler

A directional coupler is a four port passive device used for coupling a known fraction of the microwave power to a port in the auxiliary line while flowing from i/p port to o/p port in the main line

* It consists of a primary waveguide 1-2 & a secondary waveguide 3-4. When all ports are terminated in their characteristic impedances, there is free transmission of power without reflection between Port 1 and Port 2 and there is no transmission of power between Port 1 and port 3 or port 2 and port 4 because no coupling exist between the two pairs of ports



The characteristics of a directional coupler can expressed in terms of its coupling factor and directivity.

Assuming that the wave is propogating from port 1 to port 2 in the primary line, the coupling factor and directivity are defined.

$$\text{coupling factor (dB)} = 10 \log_{10} (P_1/P_4)$$

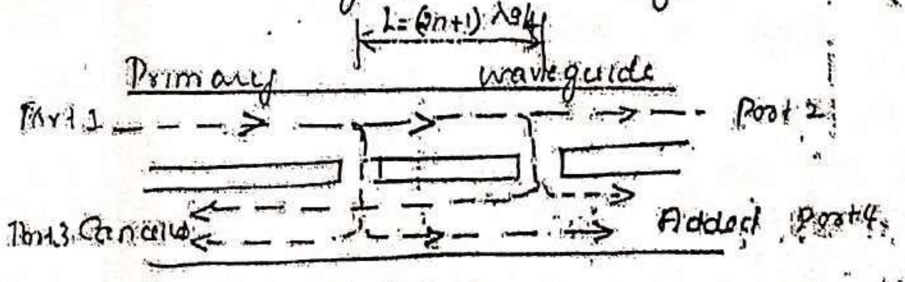
$$\text{Directivity (dB)} = 10 \log_{10} (P_4/P_3)$$

* Coupling factor is a measure of ratio of power levels in the primary & secondary lines.
* The directivity is a measure of how the forward travelling wave in the primary waveguide couples only to a specific port of the secondary waveguide.

Two hole Directional couplers

A two hole directional coupler with travelling wave propogating in it. The spacing between the centres of two holes must be $L = (2n+1)\lambda g/4$

where n is any positive integer



A fraction of the wave energy entered into port 1 passes through the holes and is radiated into the secondary waveguide.

The forward wave in the secondary waveguide are in same phase, regardless of hole space and are added at port 4.

The backward wave in the secondary waveguide are out of phase and are cancelled at port 3.

S matrix for a 4 port =

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

* In a directional coupler all port are perfectly matched. Thus the diagonal element of S matrix are zeros

$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

* There is no coupling between port 1 and 3 and between port 2 & 4

$$S_{13} = S_{31} = S_{24} = S_{42} = 0$$

Consequently S matrix of a directional coupler becomes

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

by zero property ...

$S_{21} S_{23}^* + S_{41} S_{43}^* = 0$ —— (B1)

$|S_{12}| |S_{14}| = |S_{32}| |S_{34}|$ —— (A2)

$|S_{21}| |S_{23}| = |S_{41}| |S_{43}|$ —— (B2)

by symmetry property: $S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{14} = S_{41}$

$S_{23} = S_{32}$, $S_{24} = S_{42}$, $S_{43} = S_{34}$

Sub above value in (A2) & (B2)

$|S_{12}| |S_{14}| = |S_{23}| |S_{34}|$ —— (A3)

$|S_{12}| |S_{23}| = |S_{14}| |S_{34}|$ —— (B3)

multiply (A3) & (B3)

$$|S_{12}|^2 \times |S_{14}| \times |S_{23}| = |S_{23}| \times |S_{34}|^2 \times |S_{14}|$$

$$|S_{12}|^2 = |S_{34}|^2$$

$$\boxed{|S_{12}| = |S_{34}|} \quad \text{—— (A4)}$$

Divide A_3 & B_3

$$\frac{|S_{12}| |S_{14}|}{|S_{12}| |S_{23}|} = \frac{|S_{23}| |S_{34}|}{|S_{14}| |S_{34}|}$$

$$|S_{14}|^2 = |S_{23}|^2 \qquad \boxed{|S_{14}| = |S_{23}|} \quad \text{—— (B4)}$$

$S_{12} = S_{21}$, $S_{14} = S_{23}$, $S_{32} = S_{23} = S_{14}$, $S_{34} = S_{12}$

$S_{41} = S_{14}$ $\quad S_{43} = S_{34} = S_{12}$

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{14} & 0 \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}$$

Let $S_{12} = P$ where P is real and posi.

From Unitary property

$$S_{12} \cdot S_{12}^{*} + S_{14} \cdot S_{14}^{*} = 1$$

$$|S_{12}|^2 + |S_{14}|^2 = 1.$$

Generally ~~$p^2 + (z j q)^2 = 1$~~ $p^2 + q^2 = 1$

since $|S_{12}| = |P|$ $|S_{14}| = |q|$

$S_{12} = P$ $S_{14} = jq$

The S Matrix of a directional coupler

$$S = \begin{bmatrix} 0 & P & 0 & jq \\ P & 0 & jq & 0 \\ 0 & jq & 0 & P \\ jq & 0 & P & 0 \end{bmatrix}$$

FERRITES

* Ferrite is a family of $MeO \cdot Fe_2O_3$ where Me is a divalent iron metal
* when a piece of ferrite is affected by a dc Magnetic the ferrite exhibits Faraday rotation.
* The ferrite is nonlinear material and its permeability an asymmetric tensor

$$B = \mu H$$

where

$$\mu = \mu_0(1 + X_m)$$

$$X_m = \begin{bmatrix} X_m & jk & 0 \\ jk & X_m & 0 \end{bmatrix}$$

UNIT IV : MICROWAVE SEMICONDUCTOR DEVICES - UNIT IV-(b)

TRANSFERRED ELECTRON DEVICES (TED)

The difference between microwave transistors and transferred electron devices are fundamental

* Transistor operates with gates or junctions.
  TED are bulk devices having no gates or junctions
* Transistors are fabricated from elemental semiconductors such as silicon or germanium
  TED are fabricated from compound semiconductor such as Gallium Arsenide (GaAs), Indium Phosphide (InP).
* Transistor operates with warm electrons whose energy is not much greater than thermal energy.
  TED operates with hot electrons whose energy is much greater than thermal energy.

GUNN DIODES

* GUNN diode are negative resistance devices which are normally used as low power oscillator at microwave frequencies in transmitter and also as local oscillator in receiver front ends
* GUNN Diodes are observed using Ridley Watkins Hilsum (RWH) theory.
  RWH theory consists of, 1) Differential Negative Resistance theory
  2) Two valley ...

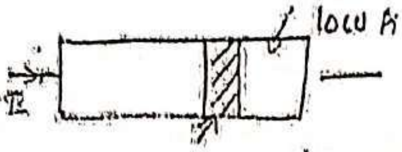
1) Differential Negative Resistance theory

There are two modes of Negative Resistance

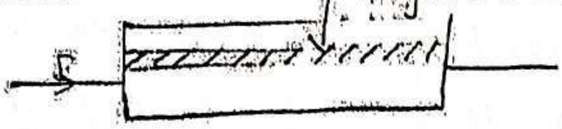
a) voltage controlled modes

b) current controlled modes

* In the voltage controlled negative resistance high field domains are formed, separating two low-field



* In the current controlled negative resistance high current filament are formed, separating two low current regions



* In the above two modes, increase in voltage decreases the current density or increase in current density decreases the voltage via the negative resistance phenomenon.

2) Two-valley model theory

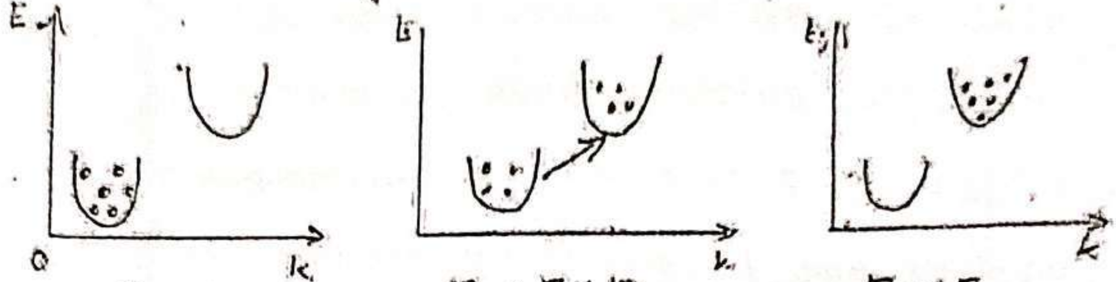
Electron densities in the lower and upper valley remain the same under an equilibrium condition.

* when the applied electric field is lower than the electric field of the lower valley ($E < E_l$), no electron will transfer to the upper valley

* when the applied electric field is higher than the

the lower valley and lower than that of the upper valley ($E_l < E < E_u$), electrons will begin to transfer to the upper valley.

* When the applied electric field is higher than the upper valley ($E_u < E$), all electrons will transfer to the upper valley



$E < E_l$ $E_l < E < E_u$ $E_u < E$

On the basis of RWH theory, band structure must satisfy three criteria

1) The separation energy between the bottom of the lower valley and the bottom of the upper valley must be several times larger than the thermal energy.
2) The separation energy between valleys must be smaller than the gap energy between conduction and valence band
3) Electron velocities in the lower valley must be much larger than in the upper valleys.

PRINCIPLE

Gallium Arsenide (GaAs), Indium phosphide are the semiconductors having a closely spaced energy valley in the conduction band

* When a dc voltage is applied across the material,

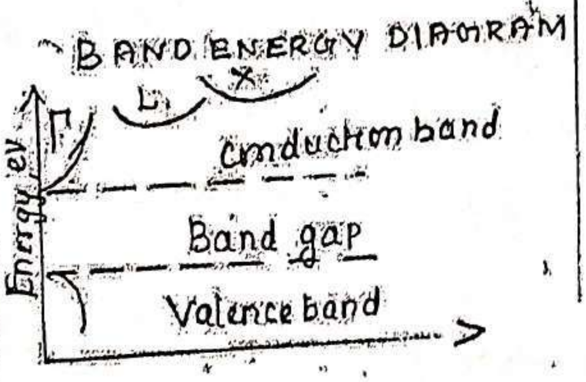
an

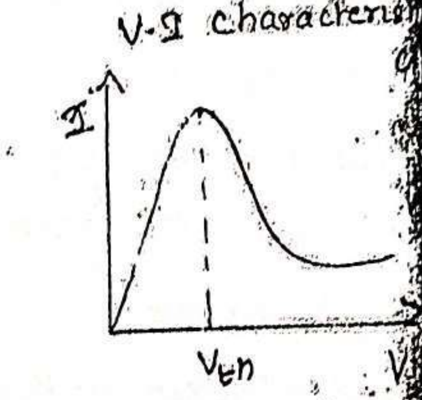
an electric field is established across the

* At low E-field in the material, most of the will be located in the lower energy central valley

* At higher E-field, most of the electrons be transferred into the high energy L and where the effective electron mass is large and hence electron mobility is lower in

* When the E-field increases, electron mobility decreases and the conductivity decrease, the current value also decreased, beyond threshold value V_{th} is called transferred electron effect and the device is called transferred electron device (TED) or GUNN diode.

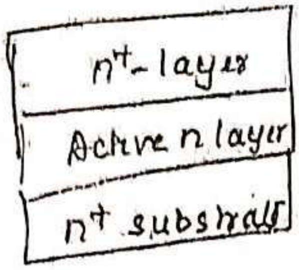




Thus the material behaves as negative device over a range of applied voltages.

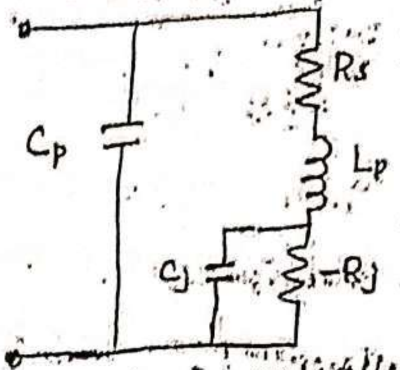
Working

The basic structure of a Gunn diode of n-type GaAs semiconductor with a of high doping (n^+)



Gunn diode

equivalent ckt of Gunn



- When a lower voltage is applied initially, current increases, It reaches to the maximum level at threshold voltage V_{th}
- When the diode voltage exceeds V_{th}, a high electric field is produced across the active region and electrons are excited from their initial lower valley to their higher valley
- When the electrons reaches upper valley, the current decreases with increase in voltage leads to negative resistance effect
- The equivalent ckt of Gunn diode is shown where C_j, $-R_j$ are diode capacitance & Resistance

  R_s → total resistance

  C_p & L_p are package capacitance & Inductance

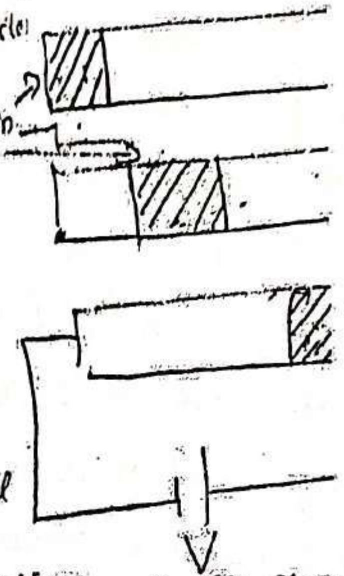
MODES OF OPERATION

There are four modes of operation that result in microwave oscillation in a Gunn diode.

They are
1) Gunn mode or transit time (TT) mode
2) Limited space charge (LSA) mode
3) Quenched domain mode
4) delayed mode

Gunn or TT mode :-

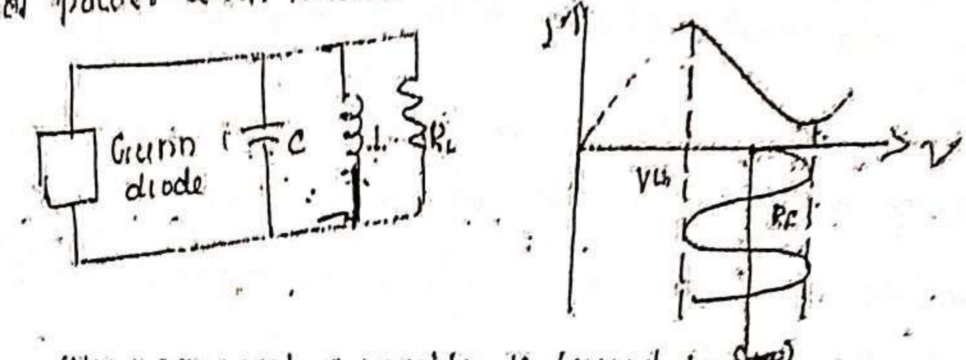
When electrons the voltage applied across GaAs crystal exceeds a threshold level, are transferred from the low energy, high conduction band to the high energy, low conduction band, where these heavier electrons bunch together to form a dipole domain.



* The electric field across the domain is greater than Vth.
* The consequent electric field remains below the Vth across rest of the crystal.
* This prevents the formation of further
* Dipole domain is a bunched electron having reduced velocity, therefore current in of domain gets decreased.
* After the domain had travelled into contact, the current returns to its
* Each domain results in a pulse of current the output and the time period of to transit time.
* This mode of oscillation has a low efficiency of power generation.

LSA Mode

LSA mode of operation can produce several watts of power with minimum efficiency of 20%.



* The resonant circuit is tuned to a frequency several times greater than that of the TT mode. So that dipole domains do not have sufficient time to form and circuit operates as a negative resistance oscillator, when the d.c. voltage is adjusted to a value greater than the threshold voltage and nearly at the mid point of the negative resistance region.
* The amplitude of oscillation builds up and becomes steady when the avg negative resistance of the Gunn diode become equal to the load resistance R_L.

Quenched domain mode

* If the resonant circuit is tuned to a value slightly above that of TT mode, the dipole domain will be quenched before it arrives at the anode

Delayed mode

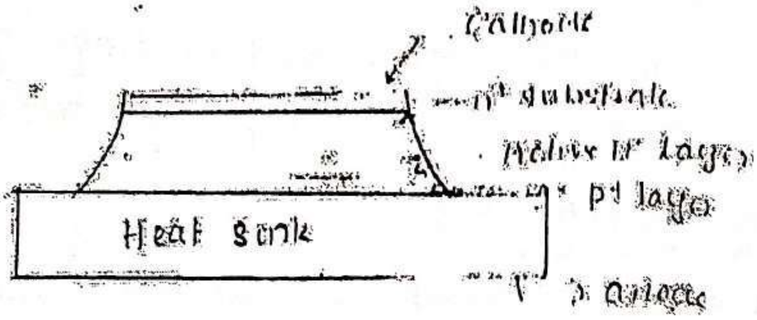
(The domain will arrive at the anode well in time but) If the resonator is tuned below TT mode, the formation of a new dipole domain will be delayed until the vge increases above the threshold value.

AVALANCHE TRANSIT TIME DEVICES

Avalanche transit time devices are p-n junction diode with highly doped P and n regions. They could produce a negative resistance at microwave frequency by using a carrier impact ionisation avalanche breakdown and carriers drift in the high field intrinsic region under reverse biased condition.

① IMPATT DIODES

IMPATT is a Impact Ionization Avalanche Transit Time device. This read diode consists of n^+pip^+ or p^+nin^+ structure. Its basic physical mechanism is the interaction of the impact ionization avalanche and the transit time of charge carriers.



An n-type epitaxial layer is formed over the n+ substrate. On top of this is the diffused p+ layer. A metallised cathode and plated heat sink as anode.

Dc operating principle (n+np+):

When the reverse bias voltage exceeds the breakdown voltage V_B, a maximum electric field of very high valu

The drift time is given by $t_d = L/v_d$

$L \rightarrow$ length of 'i' region

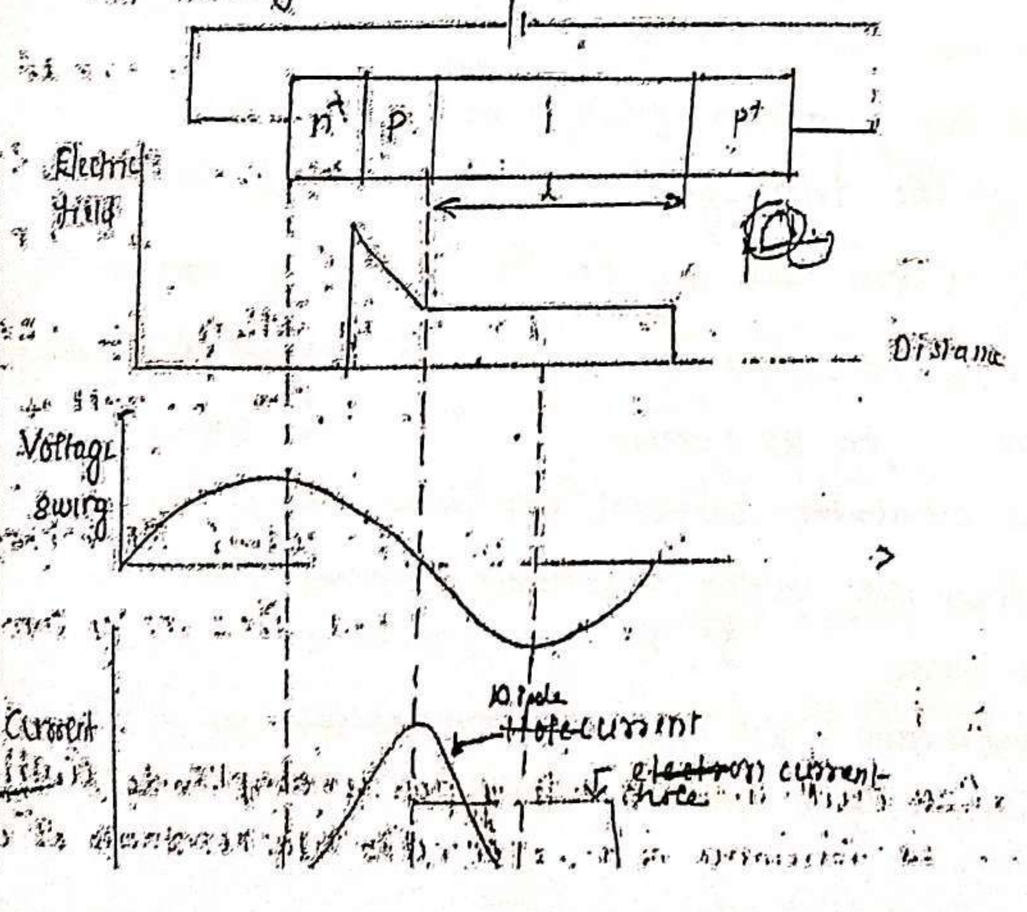
$V_d \rightarrow$ drift velocity of holes.

Mechanism of Oscillation

* If an BARITT diode is placed in a cavity and a reverse bias somewhat smaller than the breakdown voltage is applied, along with a small RF voltage then breakdown will occur when the RF voltage becomes positive
* When breakdown is initiated a large no. of holes and electrons are created at the n^+p junction
* The holes are swept across the p region into the intrinsic semiconductor drift region 'i'
* After a transit time delay holes are collected at the p^+ region.
* When the time for avalanche charges build up at the junction plus the time that for charge transit through the drift region exceeds one half RF period, the o/p current will lag the RF voltage by more than 90
* With these conditions, the diode will exhibit a negative resistance for RF currents
* In an oscillator circuit, the initial RF voltage comes from the cavity resonant frequency component of the noise.
* Once oscillation start, they grow in amplitude until avg. negative-resistance of diode equal to total resistance of cavity.

appears at n^+p junction. The holes moving in this high field region acquire sufficient energy to excite valence electrons of the atom into the conduction band resulting in avalanche multiplication of electron hole pairs.

* By designing doping profile, E field can be made to have very sharp peak, so that 'impact avalanche' multiplication occurs only in the junction.
* This impact avalanche is cumulative and carrier density increases very rapidly.
* The diode current is contributed by the conduction electrons which move to the n^+ region and the associated holes which drift through 'i' space charge region to the p^+ region, under the influence of lower but steady electric field

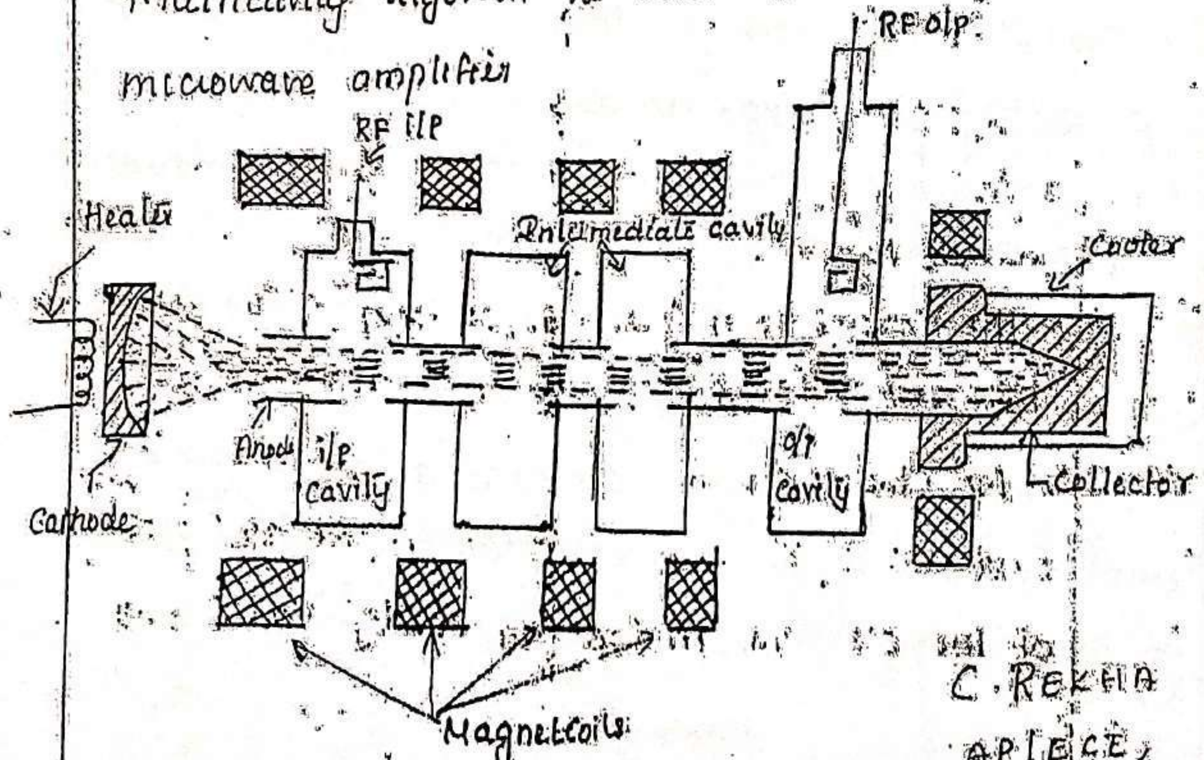


MICROWAVE TUBES

* In a linear beam tube a magnetic field whose axis coincides with that of the electron beam is used to hold the beam together as it travels along the length of the tube.
* In these tubes electrons receives potential energy from the dc beam voltage before they arrive in the microwave interaction region and this energy is converted to kinetic energy
* O type travelling wave tubes are suitable for amplification. klystron and TWT amplifiers can deliver a peak output upto 80 MW with a beam voltage on the order of 100 kV at the frequency of 10 GHz.

Multicavity klystron Amplifiers

Multicavity klystron is used as a low power microwave amplifier



C. REKHA
AP/ECE,
PET Engg College

It consists of input cavity, output cavity & the intermediate cavities. Cathode which is used to produce electron beam is placed before the input cavity at one end and collector is placed at the other end. It is operated by the principle of velocity and current modulation. RF signal voltage is given as i/p in the input cavity.

* All electrons injected from the cathode arrive at the first cavity with uniform velocity.
* Those electrons passing the first cavity (i/p cavity) at zeros of RF signal voltage pass through with unchanged velocity
* The electrons passing through the positive half of RF signal undergo an increase in velocity
* The electrons passing through the negative half of RF signal undergo an decrease in velocity
* As a result of these actions, the electrons gradually bunch together as they travel down the drift tube
* The variation in electron velocity in the drift space tube is called velocity modulation
* Now the electron beam contains an ac component and is said to be current modulated, because the density of the electrons in the o/p cavity varies with time.

* At the o/p cavity, the kinetic energy of bunched electron is transferred to the field of cavity. The electrons then emerge from the last cavity with reduced velocity and finally terminate at the collector.

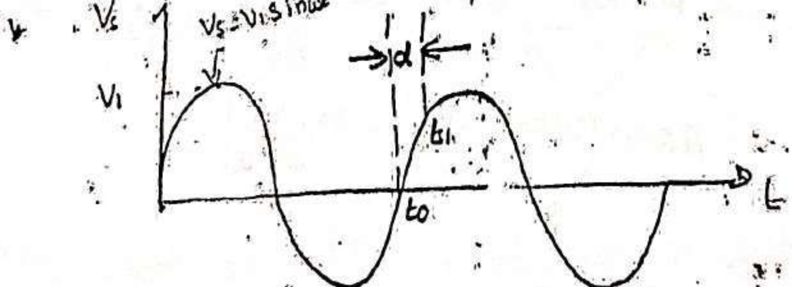
Velocity Modulation process

When electrons are first accelerated by the high dc voltage V_0, before entering the cavity their velocity is uniform

$$v_0 = \sqrt{\frac{2eV_0}{m}}$$

* When a microwave signal is applied at the input, the signal voltage between the buncher grids appears as $V_s = V_1 \sin\omega t$

$V_1 \rightarrow$ amplitude of the signal



The average transit time is $\tau = d/v_0 = t_1 - t_0$ — (A)

The average transit angle $\theta_g = \omega\tau = \frac{\omega d}{v_0} = \omega(t_1 - t_0)$ — (B)

The average microwave vge is

$$\langle V_s \rangle = \frac{1}{\tau}\int_{t_0}^{t_1} V_1 \sin(\omega t)\, dt$$

$$\langle V_s \rangle = \frac{1}{\tau}\left[V_1\left(-\frac{\cos \omega t}{\omega}\right)\right]_{t_0}^{t_1}$$

$$= \frac{-V_1}{\omega\tau}\left[\cos \omega t_1 - \cos \omega t_0\right)$$

$$\langle V_s \rangle = \frac{V_1}{\omega\tau}\left[\cos \omega t_0 - \cos \omega t_1\right] \quad \text{—(C)}$$

from (B) $\Rightarrow$ $\frac{\omega d}{v_0} = \omega(t_1 - t_0)$

$$\omega t_0 = \omega t_1 - \frac{\omega d}{v_0}$$

$$\omega t_1 = \omega t_0 + \frac{\omega d}{v_0} \quad \text{—(D)}$$

Sub (D) in (C)

$$\langle V_s \rangle = \frac{V_1}{\omega\tau}\left[\cos \omega t_0 - \cos\left(\omega t_0 + \frac{\omega d}{v_0}\right)\right]$$

Let $\omega t_0 + \frac{\omega d}{2v_0} = A$, $\Rightarrow \left[A - B = \omega t_0 + \left(\frac{\omega d}{2v_0} - \frac{\omega d}{2v_0}\right) = \omega t_0\right]$

$\frac{\omega d}{2v_0} = B$, $\Rightarrow \left[A + B = \omega t_0 + \frac{\omega d}{2v_0} + \frac{\omega d}{2v_0} = \omega t_0 + \frac{\omega d}{v_0}\right]$

$$\left[\cos(A-B) - \cos(A+B) = 2\sin A \sin B\right.$$
$$= 2\sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)\sin\left(\ \right)$$

$$\langle V_s \rangle = \frac{V_1}{\omega\tau}\left[2\sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)\sin\frac{\omega d}{2v_0}\right]$$

$$\tau = d/v_0 \qquad 2\backslash = \frac{1}{1/2} = \frac{V_1}{\frac{\omega d}{2}}$$

$$\langle V_s \rangle = \frac{V_1}{\frac{\omega d}{2v_0}}\, 2\sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)\sin\left(\frac{\omega d}{2v_0}\right)$$

$$\langle V_s \rangle = V_1 \sin\left(\omega t_0 + \frac{\omega d}{2v_0}\right)\frac{\sin\left(\omega d/2v_0\right)}{\left(\omega d/2v_0\right)}$$

$$\boxed{\langle V_s \rangle = V_1 \sin\left(\omega t_0 + \frac{\theta_g}{2}\right)\frac{\sin(\theta_g/2)}{(\theta_g/2)}} \qquad \theta_g = \frac{\omega d}{v_0}$$

$$\alpha = \sin\theta g/2$$

$$\langle V_s \rangle = V_1 \frac{\sin(\theta_g/2)}{(\theta_g/2)} \sin(\omega t_0 + \theta_g/2)$$

where $\theta_g = \omega t/v_0$

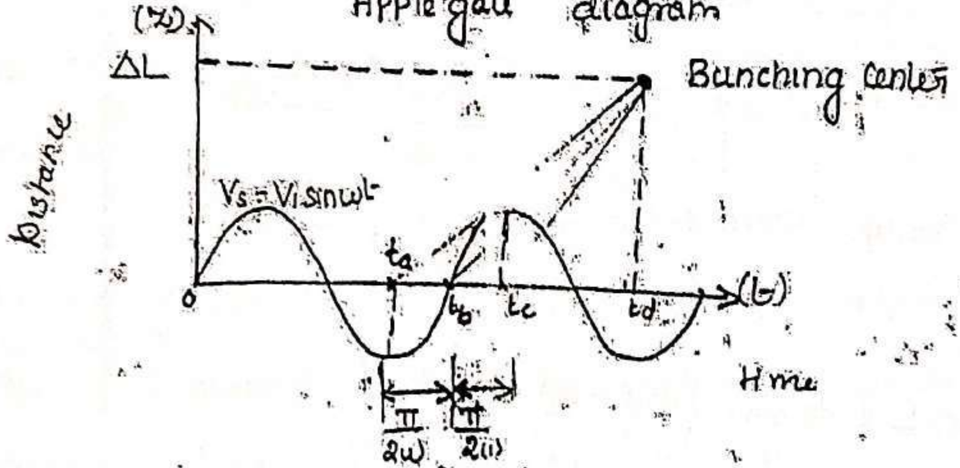
$$\langle V_s \rangle = V_1 \beta_i \sin(\omega t_0 + \theta_g/2)$$

Beam coupling coefficient $\beta_i = \frac{\sin(\theta_g/2)}{\theta_g/2}$

If the transit angle θ_g decreases, coupling between electron beam and cavity get decreases, ie velocity modulation for a microwave signal is decreased.

Bunching process

Apple gate diagram



* The effect of velocity modulation produces bunching of electron beam or current modulation.
* The electrons that passes the buncher at $V_s = 0$ travel with unchanged velocity v_0 and become the bunching center (time t_b)
* During (+)ve half of V_s, electrons velocity increases (time t_c)
  During (−)ve half of V_s, electron velocity decreases (time t_a)

At a distance of ΔL from the buncher cavity, the beam electrons have drifted into bunching electrons

At time $t_b \Rightarrow \Delta L = v_0(t_d - t_b)$ — (1)

At time $t_c \Rightarrow \Delta L = V_{max}(t_d - t_c)$ — (E)

At time $t_a \Rightarrow \Delta L = V_{min}(t_d - t_a)$ — (F)

(E) $\Rightarrow \Delta L = V_{max}\left(t_d - \left(t_b + \frac{\pi}{2\omega}\right)\right)$

$\Delta L = V_{max}\left[t_d - t_b - \pi/2\omega\right]$ — (G)

(F) $\Rightarrow \Delta L = V_{min}\left(t_d - (t_b - \pi/2\omega)\right)$

$\Delta L = V_{min}(t_d - t_b + \pi/2\omega)$ — (H)

At max velocity $V_{max} = v_0\left(1 + \frac{\beta_i V_1}{2V_0}\right)$ — (G1)

min velocity $V_{min} = v_0\left(1 - \frac{\beta_i V_1}{2V_0}\right)$ — (H1)

sub (G1) in (G)

$$\Delta L = V_{max}\left[(t_d - t_b) - \frac{\pi}{2\omega}\right]$$

$$\Delta L = \left[v_0 + \frac{\beta_i V_1 v_0}{2V_0}\right]\left[(t_d - t_b) - \frac{\pi}{2\omega}\right]$$

$$\Delta L = v_0(t_d - t_b) + \left[\frac{\beta_i V_1 v_0}{2V_0}(t_d - t_b)\right] - \frac{\pi}{2\omega}v_0 - \frac{\pi}{2\omega}\left(\frac{\beta_i V_1 v_0}{2V_0}\right)$$ — (2)

To make (2) = (1)

$$\frac{\beta_i V_1 v_0}{2V_0}(t_d - t_b) - \frac{\pi}{2\omega}v_0 - \frac{\pi}{2\omega}\frac{\beta_i V_1 v_0}{2V_0} = 0$$

$$\frac{\beta_i V_1 v_0}{2V_0}(t_d - t_b) = \frac{\pi}{2\omega} v_0 + \frac{\pi}{2\omega} \frac{\beta_i V_1 v_0}{2V_0}$$

$$\frac{\beta_i V_1 v_0}{2V_0}(t_d - t_b) = \frac{\pi}{2\omega} v_0 \left(1 + \frac{\beta_i V_1}{2V_0}\right)$$

$$v_0 (t_d - t_b) = \frac{\pi V_0 v_0}{\omega \beta_i V_1}\left(1 + \frac{\beta_i V_1}{2V_0}\right)$$

$$t_d - t_b = \frac{\pi V_0}{\omega \beta_i V_1} + \frac{\pi}{2\omega} \quad \left(\text{neglect } \frac{\pi}{2\omega}\right)$$

$$t_d - t_b = \frac{\pi V_0}{\omega \beta_i V_1}$$

from ① $\Rightarrow \Delta L = v_0 (t_d - t_b)$

electron get bunches at $\boxed{\Delta L = v_0 \left(\frac{\pi V_0}{\omega \beta_i V_1}\right)}$

The optimum distance at which maximum current occurs at $\boxed{L_{op} = \frac{3.682\, v_0 V_0}{\omega \beta_i V_1}}$

Output power :- H.C klystron produces a power gain of 40 to 60 dB

(i) For the four cavity klystron, the current at the second cavity $|i_2| = \frac{1}{2}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)\beta_i |V_1|$

$V_1 \rightarrow$ mag. of signal voltage. Then the mag. of induced current and voltage in the second cavity. Beam coefficient $\beta_i = \beta_0$

$$|I_2| = \beta_0 |i_2|$$

$$= \frac{1}{2}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)\beta_i |V_1| \times \beta_i$$

$$\Rightarrow |I_2| = \frac{I_0 \omega}{2V_0 \omega_q}\beta_i^2 |V_1|$$

Induced voltage $|V_2| = |I_2| R_{sh}$

$R_{sh} \rightarrow$ total shunt resistance of the i/p cavity

$$|V_2| = \frac{I_0 \omega}{2 V_0 \omega_q} \beta_i^2 |V_1| R_{sh}$$

(ii) Current at the third cavity is

$$|i_3| = \frac{1}{2}\left(\frac{I_0 \omega}{V_0 \omega_q}\right) \beta_i |V_2|$$

$$|I_3| = \beta_i |i_3|$$

$$= \beta_i \left(\frac{1}{2}\right)\left(\frac{I_0 \omega}{V_0 \omega_q}\right)(\beta_i)\left(\frac{1}{2}\right)\left(\frac{I_0 \omega}{V_0 \omega_q}\right) \beta_i^2 |V_1| R_{sh}$$

$$|I_3| = \beta_i^4 \left(\frac{1}{4}\right)\left(\frac{I_0 \omega}{V_0 \omega_q}\right)^2 |V_1| R_{sh}$$

$$|V_3| = |I_3| R_{sh}$$

$$|V_3| = \frac{1}{4}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)^2 \beta_i^4 R_{sh}^2 |V_1|$$

(iii) Current at the fourth cavity is

$$|i_4| = \frac{1}{2}\left(\frac{I_0 \omega}{V_0 \omega_q}\right) \beta_i |V_3|$$

$$|I_4| = \beta_i |i_4|$$

$$|I_4| = \beta_i \left[\frac{1}{2}\left(\frac{I_0 \omega}{V_0 \omega_q}\right) \beta_i\right]\left(\frac{1}{4}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)^2 \beta_i^4 R_{sh}^2 |V_1|\right)$$

$$|I_4| = \beta_i^6 \left(\frac{1}{8}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)^3 R_{sh}^2 |V_1|\right)$$

$|V_4| = |I_4| R_{shL}$ ($R_{shL} \rightarrow$ total shunt resistance at o/p cavity)

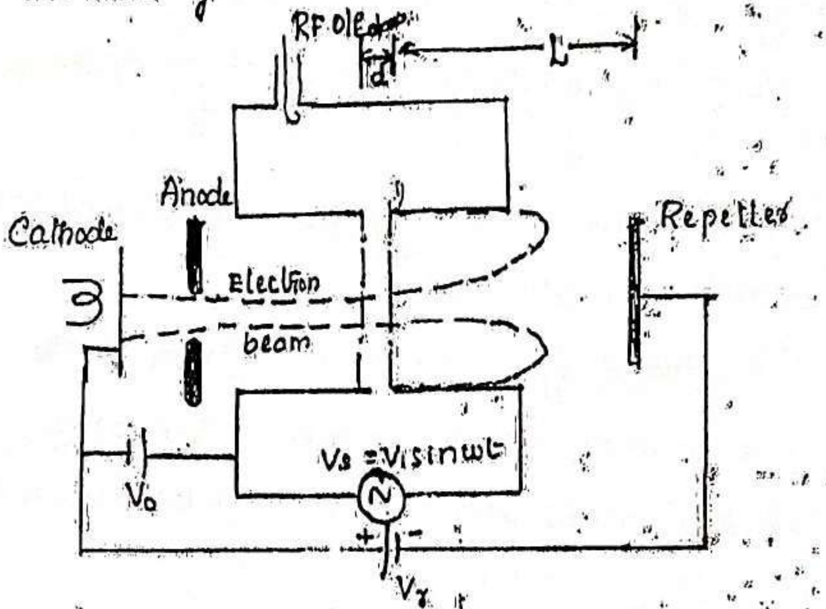
$$|V_4| = \frac{1}{8}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)^3 \beta_i^6 R_{shL} R_{sh}^2 |V_1|$$

o/p power $P_{out} = |I_4|^2 R_{shL}$

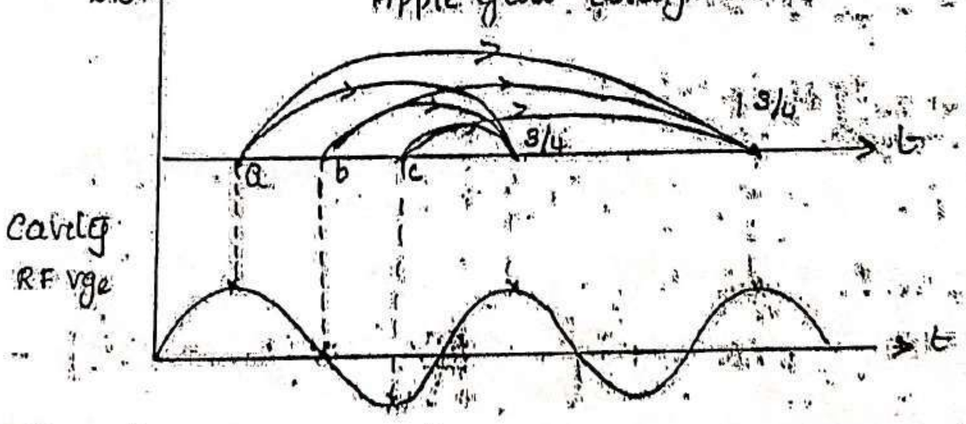
$$P_{out} = \left[\frac{1}{64}\left(\frac{I_0 \omega}{V_0 \omega_q}\right)^6 R_{sh}^4 |V_1|^2 \beta_i^{12}\right] R_{shL}$$

REFLEX KLYSTRON

The reflex klystron is a single cavity klystron, used in microwave measurements and in microwave receiver. its a low power generator of 10 to 500 mW o/p & its efficiency is 20 to 30%.



Apple gate diagram (1 3/4 mode



* The electron beam injected from the cathode is first velocity modulated by the RF i/p voltage
* Some electrons accelerated by the (+)ve half of RF signals enter the repeller space with high velocity

* Some electrons decelerated by the negative half of RF voltage enter the repeller space with less velocity
* All these electron get bunches and turned around by the repeller voltage then pass through the cavity gap
* On their return journey, the bunched electrons pass through the gap and give up their kinetic energy when they encounter the positive cycle of cavity RF field.
* This given up kinetic energy is transferred to the cavity to conserve the total power
* If the power delivered by the bunched electrons to the cavity is greater than the power loss in the cavity, the emf of the cavity increase to produce microwave oscillation
* These oscillation occurs at resonant frequency of cavity

Velocity Modulation

After velocity modulation, the exit velocity from the buncher gap is given by

$$v(t_1) = v_0\left(1 + \frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right) \quad \text{—(1)}$$

At time t_0 = time for electron entering cavity gap at $z=0$

t_1 = time for same electron leaving cavity gap at z

t_2 = time for same electron returned to cavity gap at $z=d$

The retarding electric field $E = \frac{V_r + V_0}{L}$

The force equation for one electron in the repelled region is

$$m \frac{d^2 z}{dt^2} = -eE = -e\left(\frac{V_r + V_0}{L}\right)$$

$$\frac{d^2 z}{dt^2} = -e\left(\frac{V_r + V_0}{mL}\right)$$

on integrating

$$\Rightarrow \frac{dz}{dt} = -e\left(\frac{V_r + V_0}{mL}\right) \int dt$$

$$\frac{dz}{dt} = -e\left(\frac{V_r + V_0}{mL}\right)(t - t_1) + k_1 \quad \text{—(A)}$$

$$\frac{m\, d^2 z}{d(t-t_1)^2} = -e\left(\frac{V_r + V_0}{L}\right)$$

$$\frac{d^2 z}{d(t-t_1)^2} = \frac{e}{mL}(V_r + V_0)(t - t_1) + k_1$$

$t = t_1$, $\frac{dz}{d(t-t_1)} = V(t_1)$

$\frac{dz}{dt}$: $V(t_1) = 0 + k_1$

$z = \frac{-e}{m}\frac{(V_r + V_0)}{L}(t-t_1)^2 + V(t_1)(t - t_1) + k_2$

$t = 0$, $k = V(t_1)$

at $t = t_1$, $\frac{dz}{dt} = k_1$, ∴ also $\frac{dz}{dt} = V(t_1) = k_1$

on integrating (A) —

$$\int_{t_1}^{t} \frac{dz}{dt}\,dt = \int_{t_1}^{t} -e\left(\frac{V_r + V_0}{mL}\right)(t - t_1)\,dt + \int_{t_1}^{t} V(t_1)\,dt$$

$$z = -e\left(\frac{V_r + V_0}{mL}\right)\left[\frac{(t-t_1)^2}{2}\right] + V(t_1)(t - t_1) + k_2$$

$$z = -e\left(\frac{V_r + V_0}{2mL}\right)(t - t_1)^2 + V(t_1)(t - t_1) + k_2$$

At $t = t_1$

$$z = 0 + 0 + k_2 \quad \therefore z = k_2$$

we know at $t = t_1$, $z = d$ ∴ $\boxed{z = d = k_2}$

$$k_2 = \left[-e\left(\frac{V_r + V_0}{2mL}\right)(t - t_1)^2 + V(t_1)(t - t_1)\right] + k_2$$

$$0 = -e\left(\frac{V_r + V_0}{2mL}\right)(t - t_1)^2 + V(t_1)(t - t_1) \quad \text{—(B)}$$

sub $t = t_2$ in (B)

$$e\left(\frac{V_r+V_0}{2mL}\right)(t_2-t_1)^2 = v(t_1)(t_2-t_1)$$
(t_2+t_1)

The transit time in repeller region is

$$T_0' = (t_2 - t_1)$$

$$t_2 - t_1 = \frac{v(t_1)\,2mL}{e(V_r+V_0)} \Rightarrow \boxed{T_0' = \frac{2mL\,v(t_1)}{e(V_r+V_0)}}$$

[from (1) $\Rightarrow$ $\left[v(t_1) = v_0\left(1+\frac{\beta_i V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)\right)\right]$ (eqn I)]

x' ply $\omega \Rightarrow \omega v(t_1) = \omega v_0 + \frac{\beta_i \omega v_0 V_1}{2V_0}\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)$

$$\omega v(t_1) = \theta_0' + X'\sin\left(\omega t_1 - \frac{\theta_g}{2}\right)$$

where

$$\boxed{\theta_0' = \omega v_0, \quad X' = \frac{\beta_i \omega v_0 V_1}{2V_0}}$$

$\theta_0' \rightarrow$ dc transit angle

$X' \rightarrow$ Bunching parameter of Reflex klystron

Power Output and Efficiency

For a maximum energy transfer, the round trip transit angle referring to the centre of bunch m at. It can be given as $1\frac{3}{4}, 2\frac{3}{4}, 3\frac{3}{4}$ ... $[2 - 1/4] = 1\,3/4$

$$\theta_0' = \omega T_0' = 2\pi (n - 1/4)$$

$$\theta_0' = \omega T_0' = 2\pi n - \pi/2 \quad \text{—— (C)}$$

Magnitude of fundamental current is $I_1 = 2I_0\beta_i J_1(X')$

⇒ The dc power supplied by beam voltage V_0 is

$$P_{dc} = V_0 I_0$$

⇒ The ac power delivered to load is

$$P_{ac} = \frac{V_1 I_1}{2}$$

$$P_{ac} = \frac{V_1 (2 I_0 \beta_i J_1(x'))}{2} \quad \text{— (D)}$$

we know $x' = \frac{\beta_i \omega \vartheta_0 V_1}{2V_0}$ $\qquad V_1 = \frac{X' 2V_0}{\beta_i \omega \vartheta_0}$ — (E)

sub: (E) in (D)

$$P_{ac} = \frac{x' 2(V_0 I_0) \beta_i J_1(x')}{\beta_i \omega \vartheta_0}$$

$$\omega \vartheta_0 = \theta_0' = 2\pi n - \pi/2$$

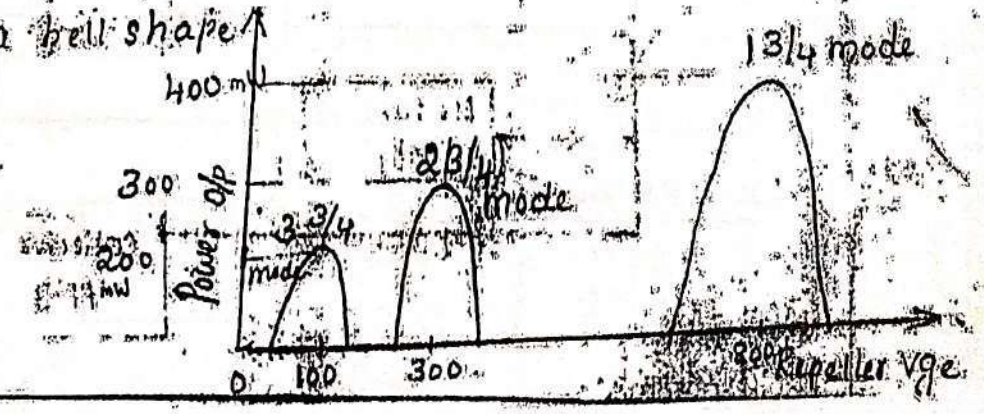
$$\therefore P_{ac} = \frac{x' 2 P_{dc} J_1(x')}{2\pi n - \pi/2}$$

$$\boxed{\frac{P_{ac}}{P_{dc}} = \frac{2x' \cdot J_1(x')}{2\pi n - \pi/2}}$$

$$\text{efficiency } \eta = \frac{P_{ac}}{P_{dc}} = \frac{2x' J_1(x')}{(2\pi n - \pi/2)}$$

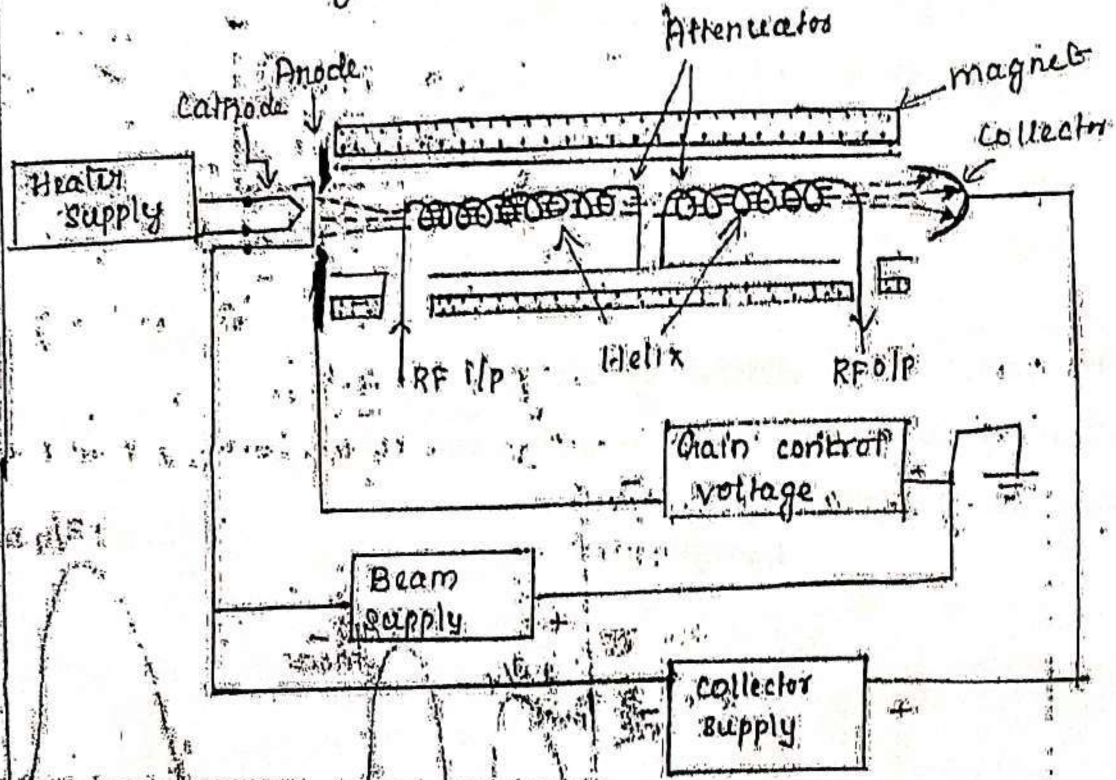
At $n=2$, max efficiency is 22.7%

→ When repeller voltage vary about centre voltage, Power o/p will vary as a bell shape

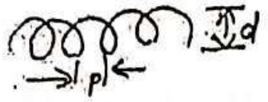


HELIX TRAVELLING WAVE TUBE (TWT)

- A helix travelling wave tube consists of an cathode which produces electron beam and a slow wave structure.
- The electron beam from the cathode continuously interacts with an axial RF i/p field over long distance inside the helix where both velocity and current modulation of electron beam occurs
- An attenuator is placed over a part of the helix near the output end to attenuate any reflected waves due to impedance mismatch that can be fed back to the input to cause oscillation
- TWT is used for application at frequencies above 1 GHZ with a power gain upto 60 dB



The applied input signal propogates around the turns of the helix and produces an electric field at the center of the helix, directed along the helix axis.



$$\frac{\text{Helix Pitch}}{\text{Helix circumference}} = \frac{P}{\pi d}$$

* The electric field progresses with a velocity very close to velocity of light multiplied by ratio of Helix pitch to helix circumference

$$\text{Velocity } v_p = \frac{c \times P}{\pi d} = \frac{\omega}{\beta}$$

* This electric field modulates the electron beam emerging from the cathode. When the electric field is positive, electron beam accelerates and when the electric field is negative, electron beam decelerates to form electron bunches at the collector end
* Each electron in the bunch encounters a stronger retarding field and a great amount of kinetic energy is transferred from the beam to the electromagnetic field.
* Then the microwaves energy of electrons is delivered by electron bunch to the wave on the helix
* The amplification of the signal wave is accomplished

43 If the travelling wave is propagated in the z direction, the z component of electric field can be expressed as

$$E_z = E_1 \sin(\omega t - \beta_p z)$$

Then the equation of motion of electron is

$$m\frac{dv}{dt} = -eE_z$$

$$m\frac{dv}{dt} = -eE_1 \sin(\omega t - \beta_p z) \quad \text{—(A)}$$

where, $\beta_p = \omega / v_p$

* Assume the velocity of electron as

$$v = v_0 + v_e \cos(\omega_e t + \theta_e) \quad \text{—(B)}$$

$v_0 \rightarrow$ dc electron velocity

$v_e \rightarrow$ mag. of velocity modulated electron beam

$\omega_e \rightarrow$ freq of velocity fluctuation

$\theta_e \rightarrow$ phase angle of velocity fluctuation

differentiate (B)

$$\Rightarrow \frac{dv}{dt} = v_e(-\sin(\omega_e t + \theta_e) \times \omega_e$$

$$\frac{dv}{dt} = -v_e\omega_e \sin(\omega_e t + \theta_e) \quad \text{—(C)}$$

Sub (C) in (A)

$$m\left[-v_e\omega_e \sin(\omega_e t + \theta_e)\right] = \left[-eE_1 \sin(\omega t - \beta_p z)\right]$$

$$m v_e \omega_e \sin(\omega_e t + \theta_e) = eE_1 \sin(\omega t - \beta_p z)$$

The distance z travelled by electron $z = v_0(t - t_0)$

$$\beta_p = \omega / v_p$$

$$m v_e \omega_e (\sin(\omega_e t + \theta_e)) = eE_1 \sin\left(\omega t - \frac{\omega v_0 (t - t_0)}{v_p}\right)$$

$$= eE_1 \sin\left(\omega t - \frac{\omega t v_0}{v_p} + \frac{v_0 \omega t_0}{v_p}\right)$$

$$m v_e \omega_e [\sin(\omega_e t + \theta_e)] = eE_1 \sin\left[\left(\omega - \frac{\omega v_0}{v_p}\right)t + \frac{\omega v_0 t_0}{v_p}\right]$$

equating magnitude

$$m v_e \omega_e = eE_1$$

$$\boxed{v_e = \frac{eE_1}{m\omega_e}}$$

equating angle

(i) $$\omega_e t = \left(\omega - \frac{\omega v_0}{v_p}\right)t$$

$$\omega_e = \omega\left(1 - \frac{v_0}{v_p}\right)$$

$$\boxed{\omega_e = \omega\left(\frac{v_p - v_0}{v_p}\right)} \Rightarrow \boxed{\omega_e = \beta_p (v_p - v_0)}$$

(ii) $$\theta_e = \frac{\omega v_0 t_p}{v_p}$$

$$\boxed{\theta_e = \beta_p v_0 t_p}$$

The magnitude of velocity fluctuation of the electron beam is directly proportional to the magnitude of the axial electric field.

Gain Characteristics

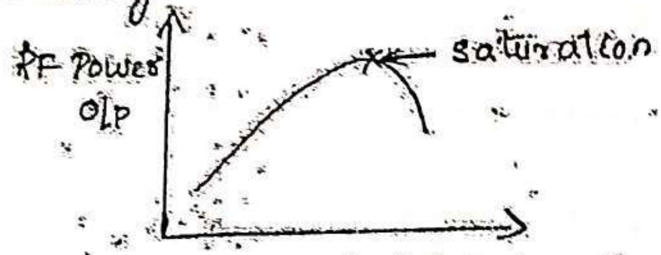
The output of power gain is defined as

$$A_p = 10 \log \left| \frac{o/p \; V_{gr}}{i/p \; V_{gr}} \right|^2 = -9.54 + 47.3 NC \; dB$$

N → length of interaction region, C → gain parameter.

The first term -9.54 dB represents a loss due to the fact that the input wave divides into three waves of equal magnitude and only one of these waves is amplified.

* The peak power output of a single helix type tube is limited to about 3kW because of the difficulty in removing heat due to ohmic loss from helix conductor



When RF power I/P is increased, RF power O/P is also increased.

* After attained max. level of RF power O/P, then it starts to decrease.
* A max level of RF power O/P point is called saturation point and the gain at this point is called saturation gain
* As the operating level approaches saturation, the non-linearity of the transfer characteristics gives rise to intermodulation distortion
* When TWT is operated near or at saturation, harmonic distortion occurs due to more intense electron bunching which produces sharp current peaks rich in harmonics

46

* For low noise operation of TWTs have noise factor of less than 10dB
* For medium power TWT have noise factor in the range 18 to 30dB
* For high power TWTs have noise factor in the range 24 to 27dB.

Applications of TWT

TWT amplifiers are used in medium power satellite and high power satellite transponder o/p.

Major differences between TWT and klystron

1) The interaction of electron beam and RF field in TWT is continuous over the entire length of the circuit, but the interaction in the klystron occurs only at the gaps of a few resonant cavity

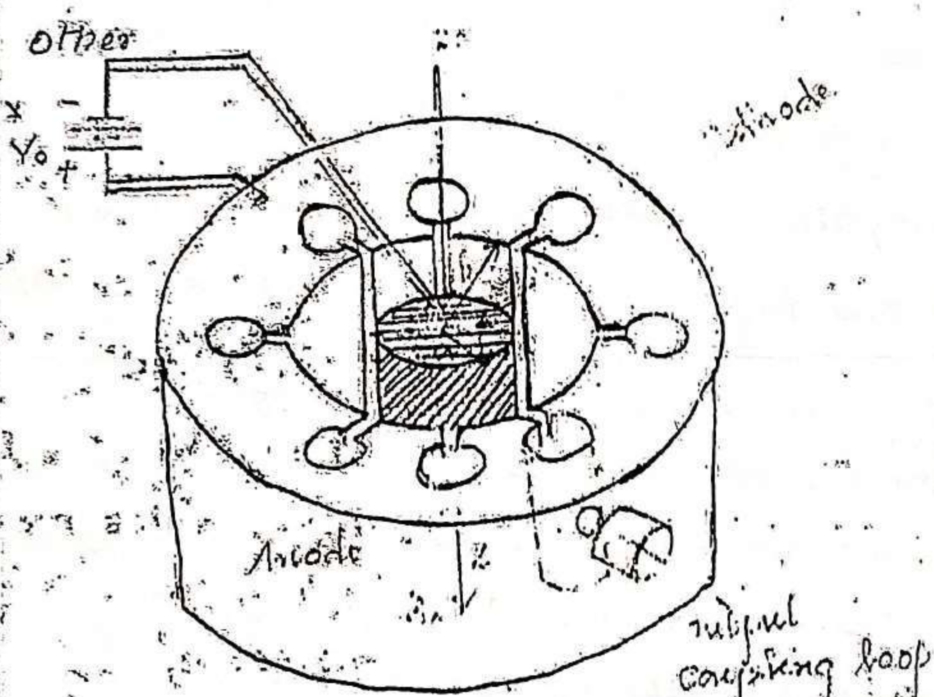
2) The wave in the TWT is a propogating wave, the wave in the klystron is not.

3) In the coupled cavity TWT, there is a coupling effect between the cavities, where each cavity in a klystron, operates independently

M1

MAGNETRON

* A Magnetron Oscillator is used to generate high microwave power. Magnetron are crossed field tubes (M type) in which dc magnetic field and dc electric field are perpendicular to each other



Magnetron

* It consists of a cylindrical cathode of finite length and radius 'a' at the centre, surrounded by a cylindrical anode of radius 'b'

consists of several re-entrant cavities around the circumstances and coupled ...gh the anode - cathode space by means of ...

* Radical electric field is established by dc voltage V_0 is maintained b/w cathode & anode.
* A DC magnetic flux B_0 is maintained in the positive z-direction by means of magnet.
* The electrons emitted from the cathode try to travel to anode, but with the influence of crossed fields E and H in the space b/w anode and cathode, those electrons experiences a force of Lorentz

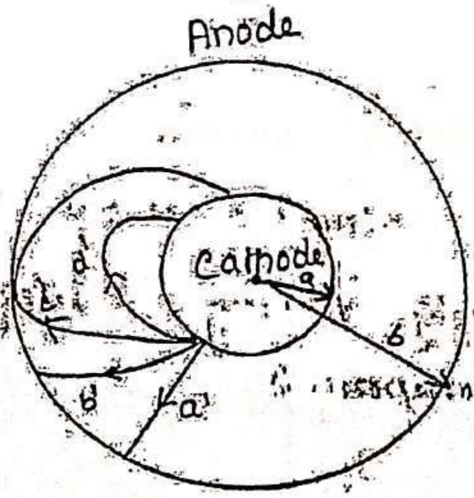
$$F = -eE - e(V \times B)$$

* Due to excitation of anode cavities by RF noise voltage in the biasing circuit, the RF field lines are fringed out of the slot to the space b/w anode and cathode.
* There is an interaction between electrons and RF noise in the space b/w anode and cathode. The accelerated electrons, when retarded by this RF field, transfer energy from the electron to the cavities to grow RF oscillation.

Equations of Electron Trajectory

After emergence from the cathode, the electrons acquire a velocity having a tangential and radial field components.

* In fig trajectories a', b', c', d' of the electrons are shown for different magnetic field strengths.
* At zero magnetic field and when the electric field value is V_0, the electron takes the straight path a'.
* While keeping the value of electric field as V_0 and increasing the magnetic field, the electrons take curved path b' to reach anode
* For the same V_0, at a critical value of magnetic field B_c, the electrons just graze the anode surface at radius of anode and take the path c' to return to the cathode for a given
* This value of B_c is called cut off magnetic flux density
* If the magnetic field is greater than B_c all the electrons returns to the cathode by a path d' without reaching the anode



a → cathode radius
b → anode radius

The equations of motions for electrons in magnetic field for cylindrical co-ordinates can be given by

$$\frac{1}{r}\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right) = -\frac{e}{m}\left(B_r\frac{dz}{dt} - B_z\frac{dr}{dt}\right)$$

since we have only B_z component alone $B_r=0$

$$\therefore \frac{1}{r}\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right) = +\frac{e}{m}B_z\left[\frac{dr}{dt}\right]$$

$$\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right) = \frac{e}{m}B_z r\frac{dr}{dt}$$

on integrating with respect to $t \Rightarrow \left[\int dt\right]$

$$r^2\left(\frac{d\phi}{dt}\right) = \frac{e}{m}B_z r \times r + k \quad \text{——— (A)}$$

$$r^2\frac{d\phi}{dt} = \frac{e}{m}B_z r^2 + k$$

$$r^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c r^2 + k \quad \text{——— (B)}$$

where $\omega_c = 2\left(\frac{e}{m}\right)B_z$

At $r=a$, $\frac{d\phi}{dt} = 0 \Rightarrow 0 = \frac{1}{2}\omega_c a^2 + k$

$$\therefore \boxed{k = -\frac{1}{2}\omega_c a^2}$$

sub k' in (B)

$$r^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c r^2 - \frac{1}{2}\omega_c a^2$$

$$r^2\frac{d\phi}{dt} = \frac{1}{2}\omega_c\left(r^2 - a^2\right)$$

$$r\frac{d\phi}{dt} = \frac{1}{2}\omega_c r\left[1 - a^2/r^2\right] \quad \text{——— (C)}$$

The kinetic energy of electron is given by

$$\tfrac{1}{2} m v^2 = eV$$

$$v^2 = \frac{2eV}{m}$$

Since its a cylindrical coordinate

$$v^2 = v_r^2 + v_\phi^2 + v_z^2$$

Since electron moves in z direction $v_z = 0$

$$\therefore v^2 = v_r^2 + v_\phi^2$$

$$v^2 = \left(\frac{dr}{dt}\right)^2 + \left(r\frac{d\phi}{dt}\right)^2$$

At $r = b$, $V = V_0$, $dr/dt = 0$

$$v^2 = r^2\left(\frac{d\phi}{dt}\right)^2$$

$$\left[\frac{2eV}{m}\right] = r^2\left(\frac{d\phi}{dt}\right)^2$$

$$\frac{2eV_0}{m} = b^2\left(\frac{d\phi}{dt}\right)^2 \quad \text{——— (D)}$$

sub (2) in (D) $\quad \left[\frac{d\phi}{dt} = \frac{1}{2}\omega_c\left(1 - a^2/r^2\right)\right]$

$$\frac{2eV_0}{m} = b^2\left[\frac{1}{2}\omega_c\left(1 - \frac{a^2}{r^2}\right)\right]^2$$

$$\frac{2eV_0}{m} = b^2\left[\frac{1}{4}\omega_c^2\left(1 - a^2/b^2\right)^2\right]$$

$$\omega_c = \frac{eB_c}{m} \Rightarrow B_c = \left(\frac{m}{e}\right)\omega_c$$

$$\frac{2eV_0}{m} = \frac{b^2}{4}\left(\frac{eB_c}{m}\right)^2\left(1 - a^2/b^2\right)^2$$

$$\frac{2eV_0 \times 4}{m\, b^2\left(1 - a^2/b^2\right)^2} = \left(\frac{e}{m}\right)^2 B_c^2$$

$$B_c^2 = \left(\frac{m}{e}\right) \frac{8V_0}{b^2(1-a^2/b^2)^2}$$

$$B_c = \frac{[8V_0(m/e)]^{1/2}}{b(1-a^2/b^2)} \quad \text{--- (I)}$$

This is called the Hull cutoff magnetic equation

To get Hull cut off voltage equation Replace B_c by B_0 and V_0 by V_c in (I)

$$V_c = \frac{e}{8m} B_0^2 b^2 (1-a^2/b^2)^2$$

Modes in magnetron

* For N resonant coupled cavities of the anode, there exist N resonant frequencies or modes.
* The phase shift between two adjacent cavities is given by $\phi_n = \frac{2\pi n}{N}$

  $n = 0, \pm 1, \pm 2 \ldots \pm N/2$ indicates the n^{th} mode of oscillation
* π mode is commonly used for magnetron oscillator where $n = N/2$

Hartree voltage

For strong interaction between the wave on the anode structure and the electron beam, the phase velocity of the wave nearly equal to drift velocity and oscillation for π mode starts at beam vge which is known as Hartree voltage.

$$V_{oh} = \frac{2\pi f}{N}(b^2-a^2) B_0$$

Power o/p and efficiency

A Magnetron can deliver a peak power output of upto 40 MW with the dc voltage of 50kV at 10 GHz. The average power output is of the order of 800kW. The magnetron possess a high efficiency ranging from 40 to 70%.

Applications of Magnetron

1) Used in Radar transmitters
2) Used in Industrial heating
3) Used in Microwave Ovens

Define Average Drift velocity?

The electrons possess drift velocity in ϕ direction given by $V_\phi = \frac{E_r}{B_z}$.

$V_\phi < E_r/B_z$ the electrons will tend to be deflected towards the anode and be collected.

For $V_\phi > E_r/B_z$ the electrons will be deflected towards the cathode.

4.10.6 Problems

1. A reflex Klystron is to be operated at frequency of 10 GHz, with dc beam voltage 300 V, repeller space 0.1 cm for 1 3/4 mode. Calculate $P_{RF\,max}$ and corresponding repeller voltage for beam current of 20 mA.

Ans:

$$P_{RF\,max} = \frac{0.398\,V_0 I_0}{N} = \frac{0.398 \times 300 \times 20 \times 10^{-3}}{1\frac{3}{4}}$$

$$= 1.365 \text{ watts.}$$

$$|V_R| = 6.74 \times 10^{-6} f_{HZ} \;\; L(m) \frac{\sqrt{V_o}}{N - V_o}$$

$$L(m) = 0.1 \times 10^{-2} \text{ m.}$$

$$= 10^{-3} \text{ m.}$$

$$N = 1\frac{3}{4}$$

$$= 1.75$$

$$|V_R| = 6.74 \times 10^{-6} \times 10 \times 10^9 \times 10^{-3} \times \frac{\sqrt{300}}{1.75 - 300}$$

$$|V_R| = -367.08 \text{ volts.}$$

2. A reflex Klystron is operated at 5 GHz with dc beam voltage 350 V, repeller spacing 0.5 cm for N = 3 3/4 mode. Calculate bandwidth over $\Delta V_R = 1$ V.

Ans:

$$N = 3\frac{3}{4} = \frac{15}{4}$$

$$\Delta V_R = 6.7438 \times 10^{-6} \times L_m \times \Delta f_{Hz} \frac{\sqrt{V_o}}{N}$$

$$1 = 6.74 \times 10^{-6} \times 0.5/100 \times \Delta f_{Hz} \times \sqrt{300} \times 4/15$$

$$\Delta f = 5.948 \text{ MHz.}$$

3. A reflex Klystron is operated at 9 GHz with a voltage of 600 V for 1 3/4 mode, repeller space length of and dc beam current of 10 mA. The beam coupling coefficient is assumed to be 1. Calculate the repeller voltage, electronic efficiency and output power.

Ans:

$$|V_R| = 6.74\times10^{-6}\times1\times10^{-3}\times9\times10^{9}\times\frac{\sqrt{600}}{1\frac{3}{4}} - 600$$

$= 249$ V.

$$P_{RF\,max} = \frac{0.398\,V_0 I_0}{N} = \frac{0.398\times600\times10\times10^{-3}}{1\frac{3}{4}}$$

$= 0.2274 \times 600 \times 10 \times 10^{-3}$

$= 1.3644$ watts.

$$\eta_{max} = \frac{X\,J_1(X)}{\pi N} = \frac{0.398}{N} = \frac{0.398}{1\frac{3}{4}} = 22.74\%$$

4. A two cavity Klystron amplifier is tuned at 3 GHz. The drift space length is 2 cm andbeam current is 25 mA. The catcher voltage is 0.3 times the beam voltage. It is assumed that the gap length of the cavity << the drift space so that the input and output voltages are in phase. Compute (a) power output and efficiency for N = 5 1/4, (b) beam voltage, input voltage and output voltage for maximum power output of 5 1/4 mode.

$$\text{Ans: } V_0 = \frac{m}{2e}\left(\frac{Lf}{N}\right)^2 = \frac{9.1\times10^{-31}}{2\times1.6\times10^{-19}}\left[\frac{2\times10^{-2}\times3\times10^{9}}{5+\frac{1}{4}}\right]$$

$= 371.4$ volts.

For maximum power output, the bunching parameter,

$$X = 1.84 = \pi N V_1/V_0.$$

Therefore the buncher voltage magnitude

$$V_1 = \frac{XV_0}{\pi N} = 1.43 \text{ volts.}$$

Catcher voltage $\quad V_2 = 0.3\,V_0 = 111.4$ volts.

Output power, $\quad P_0 = B_2\,I_0\,V_2\,J_1\,(X)\cos\phi$

$$P_{o\,max} = I_2\,V_0\,J_2\,(X)$$

$$P_{o\,max} = I_2\,V_0\,J_2(X)$$

$$P_{0\,max} = 0.582\, I_0 V_2$$
$$= 0.582 \times 25 \times 10^{-3} \times 111.4 \text{ watts}$$
$$= 1.621 \text{ watts.}$$
$$P_{do} = I_0 V_0$$
$$= 25 \times 10^{-3} \times 371.4 \text{ watts}$$
$$= 9.3 \text{ watts}$$

Efficiency $\eta_{max} = 0.582\, V_2/V_0$

$$= 0.582 \times 111.4/371.4$$
$$= 17.46\%.$$

5. **A two cavity Klystron operates at 5 GHz with a dc beam voltage of 10 KV and 2 mm cavity gap. For a given input RF voltage the magnitude of the gap voltage is 100 volts. Calculate the transit time at the cavity gap, the transit angle and the velocity of electrons leaving the gap.**

Ans: dc beam velocity $u_0 = 0.593 \times 10^6 \sqrt{V_o}$

$$= 0.593 \times 10^6 \sqrt{(10 \times 10^3)} \text{ m/s}$$
$$= 0.593 \times 10^8 \text{ m/s.}$$

Gap transit time $t_g = \dfrac{d}{\mu_o} = 33.7 \times 10^{-12} \text{ deg.}$

The gap transit angle, $\theta_s = \omega t_g$

$$= 2\pi \times 5 \times 10^9 \times 33.7 \times 10^{-12} \text{ rad.}$$
$$= 1.059 \text{ rad} = 60.7 \text{ deg.}$$

The beam coupling coefficient $\beta_1 = \dfrac{\sin(\theta_g/2)}{\theta_g/2}$

$$= 0.505/0.5295 = 0.9537.$$

The velocity of electrons leaving the input cavity gap

$$u(t) = u_0\left[1 + \frac{\beta_1 V_1}{2V_0}\sin\left(\omega t + \frac{\theta_g}{2}\right)\right]$$

$$= 0.593 \times 10^8 \left[1 + (0.954 \times 100)/(2 \times 10 \times 10^3)\sin(\omega t + \theta_g/2)\right]$$

$$= 0.593 \times 10^8 \left[1 + 0.00477 \sin(\omega t + 0.5295)\right]$$

is varying sinusoidally at the input cycle.

The maximum velocity

$$u(t)_{max} = u_0\left[1+\frac{m}{2}\right] = 0.593\times10^8\,(1+0.00477)$$

$$= 0.5958 \times 10^8 \text{ m/s.}$$

$$u(t)_{min} = u_0(1 - m/2) = 0.593 \times 10^8\,(1 - 0.00477)$$

$$= 0.5902 \times 10^8 \text{ m/s.}$$

6. In a two cavity Klystron operates at 10 GHz with $I_0 = 3.6$ mA, $V_0 = 10$ KV. The drift space length is 2 cm, the output cavity total shunt conductance is $G_{sh} = 20$ u mho and beam-coupling coefficient $\beta_2 = 0.92$. Find the maximum voltage and power gain.

Ans: Maximum voltage gain $A = \dfrac{B^2\theta_0 I_0 J_1(X)_{max}}{XV_0 G_{sh}}$

DC beam velocity

$$u_0 = 0.593 \times 10^6 \sqrt{V_0} = 0.593 \times 10^6 \sqrt{10} \times 10^3 = 0.593 \times 10^8 \text{ m/s.}$$

Transit angle in drift space

$$\theta_0 = \frac{\omega L}{u_0} = \frac{2\pi\times10\times10^6\times2\times10^{-2}}{0.593\times10^8}$$

$$= 21.19 \text{ rad.}$$

$$A_{max} = \frac{0.92\times0.92\times21.19\times36\times0.582}{1.841\times10\times10^3\times20\times10^{-6}}$$

$$= 102.1$$

7. An identical two-cavity Klystron amplifier operates at 4 GHz with $V_0 = 1$ KV, $I_0 = 22$ mA, cavity gap = 1 mm and drift space = 3 cm. If dc beam conductance and catcher cavity total equivalent conductance are 0.25 × 10^{-4} mhos and 0.3 × 10^{-4} mhos respectively. Calculate (a) beam loading coefficient, dc transit angle in the drift space and the input cavity voltage magnitude for maximum output voltage, (b) voltage gain and efficiency, neglecting the beam loading.

Ans: (a) dc beam velocity, $u_0 = 0.593 \times 10^6 \sqrt{V_0}$

$$= 0.59 \times 10^6 \sqrt{1}\times10^3$$

$$= 1.88 \times 10^7 \text{ m/s.}$$

Gap transit angle $\theta_g = \dfrac{\omega d}{u_0}$

$$= \frac{2\pi \times 4 \times 10^9 \times 1 \times 10^{-3}}{1.88 \times 10^7} \text{ rad.}$$

$= 1.337$ rad $= 76.6$ **degrees.**

The beam coupling coefficient

$$\beta_1 = \beta_2 = \frac{\sin\frac{\theta_g}{2}}{\frac{\theta_g}{2}} = \frac{\sin 38.3^\circ}{0.6685}$$

$= 0.927.$

dc transit angle in drift space

$$\theta_0 = \frac{\omega L}{u_0} = \frac{2\pi \times 4 \times 10^9 \times 3 \times 10^{-2}}{1.88 \times 10^7} \text{ rad.}$$

$= 40.11$ **rad.**

For maximum output voltage $X = 1.84$, $J_1(X) = 0.582$ so that the input cavity gap voltage magnitude,

$$V_1 = \frac{2V_o X}{\beta_1 \theta_0} = \frac{2 \times 10^3 \times 1.841}{0.927 \times 40.11} \text{ volt}$$

$= 99$ V.

(b) The voltage gain,

$$A_v = \frac{\beta^2 \theta_0 J_1(X) I_0}{X V_o G_{sh}} = \frac{0.927 \times 0.927 \times 40.11 \times 0.582 \times 10^{-3}}{1.841 \times 0.55 \times 10^{-4} \times 10^3}$$

$= 4.36 = 12.8$ dB,

Catcher voltage $V_2 = A_v \times V_1 = 4.36 \times 99 = 431.64$ V.

$$\text{Power efficiency } \eta = \frac{P_{RF}}{P_{dc}} = \frac{\beta_2 I_1 J_1(X) V_e}{I_o V_o} = \frac{\beta_2 J_1(X) V_2}{2V_o}$$

$$= \frac{0.927 \times 0.582 \times 431.6}{10^3}$$

$= 23.28\%$.

8. A helix travelling-wave tube operates and 4 GHz under a beam voltage of 10 KV and beam current of 500 mA. If the helix impedance is 250 ohms and the interaction length is 20 cm, Find the output power gain in dB.

Ans: $V_0 = 10$ KV; $I_0 = 500$ mA, $Z_0 = 25\ \Omega$, $f = 4$ GHz, $l = 20$ cm.

$$\therefore u_0 = 0.593 \times 10^6 . \sqrt{V_0} = 0.593 \times 10^6 (10 \times 10^3)^{1/2} = 0.593 \times 10^8 \text{ m/sec.}$$

$$N = \frac{l}{\lambda e} = \frac{l\omega}{2\pi u_0} = \frac{0.2 \times 2\pi \times 4 \times 10^9}{2\pi \times 0.593 \times 10^8} = 13.49$$

$$C = \left(\frac{I_0 Z_0}{4V_0}\right)^{1/3} = \left[\frac{500 \times 10^{-3} \times 25}{4 \times 10 \times 10^3}\right] = 0.068$$

Therefore $A_p = -9.45 + 47.3 \times 13.49 \times 0.068$

$= 33.85$ dB.

9. A pulsed cylindrical magnetron is operated with the following parameters:

Anode voltage = 25 KV ; Beam current = 25 A

Magnetic density = 0.34 Wb/m² ; Radius of cathode cylinder = 5 cm

Radius of anode cylinder = 10 cm.

Calculate (a) the angular frequency, (b) the cut-off voltage, (c) the cut-off magnetic flux density.

Ans: (a) Angular frequency $= eB_0/m = 1.759 \times 10^{11} \times 134$

$= 0.5981 \times 10^{11}$ radian.

(b) The cut-off voltage $= \left(eB_0^2 b^2 / 8m\right) (1 - a^2/b^2)^2$

$= 1/8 \times 1.759 \times 10^{11} \times 0.34^2 \times (10 \times 10^{-2})^2 \times (1 - 5^2/10^2)^2$

$= 142.97$ KV.

(c) The cut-off magnetic flux density $= \dfrac{(8V_0\, m/e)^{1/2}}{b\left(1 - a^2/b^2\right)}$

$$= \left(\frac{8 \times 25 \times 10^3 \times 1}{1.759 \times 1}\right)^1 [10 \times 10^{-2} (1 - 5^2/10^2)]^{-1}$$

$= 142.2$ mWb/m².

TWO MARKS QUESTIONS AND ANSWERS

PART A

1. Define a microwave junction?

Ans:

(a) The point of interconnection of two or more microwave devices is called microwave junction.

(b) Commonly used microwave junctions are E-plane Tee, H-plane Tee, Hybrid ring, directional coupler and circulator.

2. Why is a magic Tee referred to E-H tee?

Ans:

(a) The magic tee is a combination of the E-plane tee and H-plane tee.

(b) It's a four port hybrid circuit.

(c) It is also known as hybrid tee.

3. Define scattering matrix.

Ans:

(a) Scattering matrix is a square matrix which gives all the combination of power relationship between the various input and output of a microwave junction.

(b) It is also called as S-matrix.

4. What are scattering coefficients?

Ans:

(a) The elements of scattering matrix are called scattering coefficients or scattering parameters.

(b) The parameters which is used for representation are Z, Y, H, ABCD, etc.

5. What is a waveguide?

Ans: A waveguide is a hollow metal tube designed to carry microwave energy from one place to another.

6. What is H-plane tee?

Ans:

(a) An H-plane tee is a waveguide tee in which the axis of its side arm is shunting the E-field or parallel to the H-field of the main guide.

(b) It is also called as Shunt Tee.

7. What is E-plane Tee?

Ans:

(a) An E-plane Tee is a waveguide tee in which the axis of its side arm is parallel to the E-field of the main guide.

(b) It is also called as series tee.

8. Define Tee-junction.

Ans:

(a) In microwave circuits, a waveguide or co-axial line with three independent ports is commonly referred to as Tee-junction.

(b) The basic types are: (1) E-plane Tee (series), (2) H-plane Tee (shunt).

9. Name some uses of waveguide Tees.

Ans: It is used to connect a branch or section of the waveguide in series or parallel with the main waveguide transmission line for providing means of splitting and also of combining power in a waveguide system.

10. What are the types of waveguide tees?

Ans: The two basic types are:

(a) E-plane Tee (series) and (b) H-plane Tee (shunt).

11. Define difference arm.

Ans:

(a) In E-plane tee, the power port 3 of is proportional to the difference between instantaneous powers entering from port 1 and 2.

(b) Therefore, the third port is called difference arm.

12. What is sum arm?

Ans:

(a) In a H-plane Tee, if two input waves are fed into port 1 and port 2 of the collinear arm, the output wave at port 3 will be in phase and additive.

(b) Because of this, the third port is called as sum arm.

13. Write the applications of magic tee.

Ans: A magic tee has several applications:

(a) Measurement of impedance, (b) As duplexer,

(c) As mixer, (d) As an isolator.

14. What is directional coupler?

Ans:

(a) Directional coupler are transmission line device that couple together two circuits in one direction, while providing a great degree of isolation in the opposite direction.

(b) It is used to measure incident/reflected power, SWR values, provide a signal path to a receiver or to perform a desirable operations.

15. Define coupling factor (c).

Ans: The coupling factor of a directional copuler is defined as the ratio of the incident power, P_i to the forward power, P_f measured in dB.

$$\text{Coupling factor (db)} = 10 \log_{10} \frac{P_i}{P_f}$$

16. Define directivity of directional coupler.

Ans:

(a) The directivity of a directional coupler is defined as the ratio of forward power, P_f to the back power, P_b expressed in dB.

$$D(\text{dB}) = 10 \log_{10} \frac{P_f}{P_b}$$

(b) It is a measure of how directional coupler distinguishes between forward and reverse travelling powers.

17. What do you mean by isolation?

Ans: Isolation is defined as the ratio of the incident power, 'P_i' to the back power 'P_b' expressed in dB.

$$\text{Isolation (dB)} = 10 \log_{10} \frac{P_s}{P_b}$$

18. Define Isolator. (Nov./Dec.2016)

Ans: An isolator or uni line is a two port non-reciprocal device which produces a minimum attenuation to wave in one direction and very high attenuation in the opposite direction.

19. What is circulator?

Ans:

(a) A circulator is a multi-port junction in which the wave can travel from one port to next immediate port in one direction only.

(b) They are useful in parametric amplifiers, tunnel diode, amplifiers and duplexers in radar.

20. Mention the different types of directional couplers.

Ans: (1) Two-hole directional coupler, (2) Four-hole directional coupler, (3) Reverse-coupling directional coupler, (4) Bethe-hole directional coupler.

21. Write the properties of ferrites.

Ans: Properties of Ferrites

(a) Ferrites posses strong magnetic properties.

(b) Ferrites are most suitable for use in microwave devices in order to reduce the reflected power.

(c) Ferrites possess high resistivity, hence they can be used upto 100 GHz.

(d) Ferrites also exhibit non-reciprocal property.

22. Write the types of ferrite devices. **(April/May 2015)**

Ans: Three types of non-reciprocal ferrite devices which make use of faraday rotation or microwave systems are: (a) Gyrator, (b) Isolator and (c) Circulators.

23. What is gyrator? **(Nov./Dec. 2013)**

Ans: It is a two port device it has a relative phase difference of 180° for transmission from port 1 to port 2 and no phase shift for transmission from port 2 to port 1.

24. What do you meant by faraday rotation?

Ans: The rotation of the direction of E-field of a linearly polarized wave passing through a magnetized ferrite medium is known as faraday rotation.

25. Define Faraday rotation isolator.

Ans: Isolator can be made by inserting a ferrite rod along the axis of a rectangular waveguide. Here the isolator is called as Faraday-Rotation isolator.

26. Define ferrites. **(May/June 2014)**

Ans: Ferrites are non-metallic materials with resistivity (l) nearly 10^{14} times greater than metals and also the dielectric constants (ε_r) is in between 10-15 and relative permeability of the order of 1000.

27. What is transferred electron effect? **(Nov./Dec. 2012)**

Ans:

(a) Some materials like gaAs exhibit a negative differential mobility (i.e. a decrease in the carrier velocity with an increase in the electric field when biased above a threshold value of the electric field).

(b) The electrons in lower-energy band will be transferred into the higher-energy band.

(c) The behaviour is called transferred electron effect and the device is also called transferred electron device (TED) or Gunn diode.

28. What is the negative resistance in Gunn diode? **(May/June 2014, 2013)**

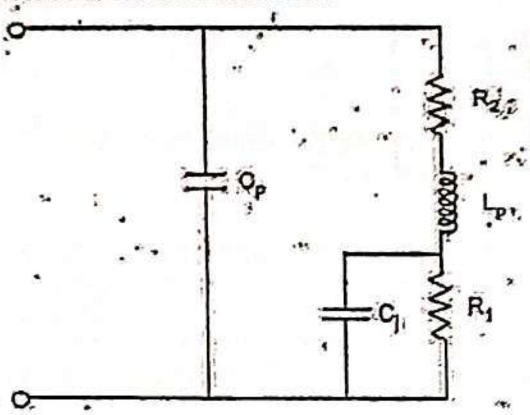
Ans:

(a) The carrier drift velocity is linearly increased from zero to maximum when the electric field is varied from zero to a threshold value.

(b) When the electric field is beyond the threshold value of 3000 V/cm, the drift velocity is decreased and the diode exhibits negative resistance.

29. Draw the equivalent circuit of Gunn diode.

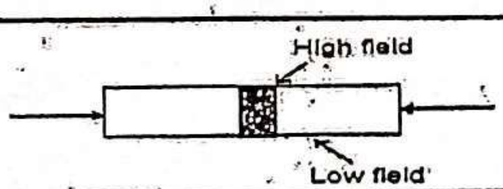
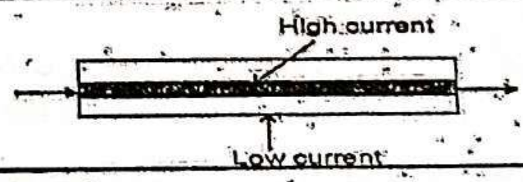
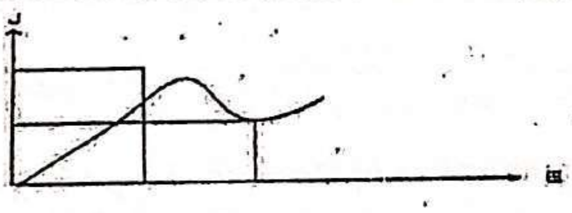
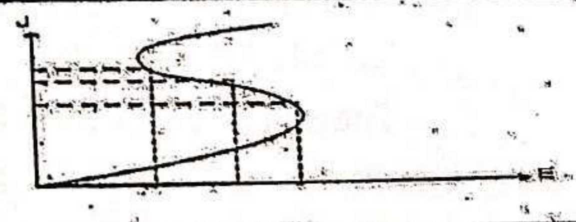
Ans:



30. What are the various modes of operation of Gunn diode?

Ans: (a) Gunn oscillation mode, (b) Stable amplification mode, (c) LSA oscillation mode, (d) Bias circuit oscillation mode.

31. Compare voltage and current controlled modes.

Ans: *Voltage Controlled Mode*	*Current Controlled Mode*
• The current density can be multi-valued.	The voltage density can be multi-valued.
• High field domains are formed, separating two-low field regions.	The splits the sample results in high current filaments running along the field directly.
	
	

32. What are the elements that exhibit Gunn effect? (May/June 2013)

Ans: The elements are:

(a) Gallium arsenide, (b) Indium Phosphide,

(c) Cadmium Telleride and Indium Arsenide.

33. What are the mode available in negative resistance device?

Ans: Two modes are available in the negative resistance devices:

(a) Voltage-controlled modes, (b) Current-controlled modes.

34. Write the disadvantage of source generation of solid state microwave device.

Ans: (a) Low efficiency at frequencies above 10 GHz,

(b) Small tuning range,

(c) Large dependence of frequency on temperature and

(d) High noise.

35. State the difference between micro wave transistors and transferred electron devices (TEDs).

Ans: *Transferred Electron Devices*	*Microwave Transistor*
TED's are bulk devices having no junction or gates.	Transistor operate with either junction or gates.
TED's operate with hot electrons whose energy is very much greater than thermal energy.	Transistors operate with warm electrons whose energy is much greater than thermal energy.

36. Define gunn oscillation mode.

Ans: This mode is defined in the region when the product of frequency multiplied by length is about 10^7 cm/s and the product of depending time length is between 10^{11} and 10^{12} cm^2.

37. Define LSA mode.

Ans: This mode is defined in the region where the product of frequency time length is about 10^7 cm/s and the quotient of doping divided by frequency is betwen 2×10^4 and 2×10^5.

38. Define inhibited mode.

Ans:

(a) When the transit time is chosen so that the domain collected white $E < E_{th}$. A nwe domain cannot form until the field rises above threshold again.

(b) The oscillation field is greater than transit time (i.e.,) $\tau_0 < \tau_1$. This delayed mode is called inhibited mode.

The efficiency is about 20%.

39. Define avalanche transit time devices.

Ans:

(a) Avalache transit-time devies are Pn-junction diodes with highly doped pn junction.

(b) They could produce a negative resistance at microwave frequencies by using a carrier impact ionization avalanche breakdown and carries drift in the high field intensity region under reverse tralpsed condition.

40. What are modes available in avalanche devices?

Ans: There are three modes of avalanche device.

(a) IMPATT - Impact Ionization Avalanche Transit Ionized Device.

(b) TRAPATT - Trapped Plasma Avalanche Triggered Transit Device.

(c) BARITT - Barrier Injected Transit Time Device.

41. Define Quality Factor Q.

Ans: The quality factor of a circuit is defined as:

$$Q = \omega \frac{\text{Maximum stored energy}}{\text{Average dissipated power}}$$

42. What are the factors that exhibit negative resistance in IMPATT? (May/June 2014)

Ans: The factors that exhibit negative resistance are:

(a) The impact ionization avalanche effect, which causes the carrier current $I_o(t)$ and AC voltage to be out of phase by 90°.

(b) The transit-time effect, which further delays the external current $I_e(t)$ relative to the AC voltage by 90°.

43. Mention the disadvantages of IMPATT diodes.

Ans: The major disadvantages are:

(a) DC power is drawn due to induced electron current in the external circuit, IMPATT diodes have low efficiency.

(b) Tend to be noisy due to the avalanche process and to the high level of operating current.

(c) A typical noise figure is 30 dB which is worse more than that of Gunn diodes.

44. Define the efficiency of IMPATT diode.

Ans: Efficiency, $\eta = \frac{\text{RF power output}}{\text{DC input power}} = \frac{P_{ac}}{P_{dc}} = \left(\frac{V_a}{V_d}\right)\left(\frac{I_a}{I_d}\right)$

V_a and I_a → AV voltage and current; V_d and I_d → DC voltage and current.

45. Mention the applications of IMPATT diodes.

Ans: (a) Micro wave generators, (b) Modulated output oscillators,

(c) Received local oscillators, (d) Parameters amplified pumps,

(e) Negative resistance amplification.

46. What are the composition of ferrite? (Nov./Dec. 2013)

Ans:

(a) Ferrites are prepared by synthesizing metallic oxides and they have a chemical formula $MeOFe_2O_3$ (i.e.,) mixture of metallic oxide and ferric oxide.

(b) MeO is divalent which represents metallic oxide such as ZnO, MgO, MNo, etc.

47. Draw the diagram of H-plane Tee junction? (Nov./Dec. 2012)

Ans:

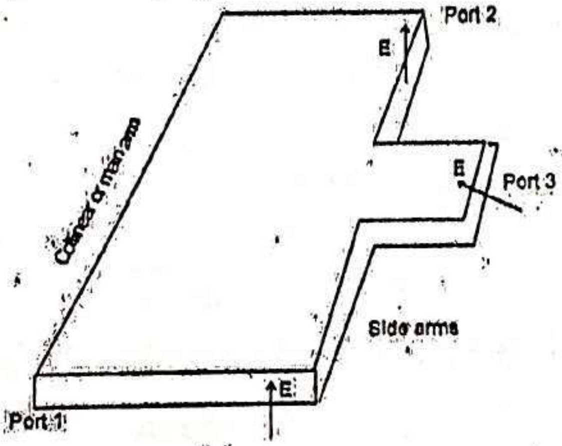


Fig.: H-Plane Tee

48. What is transit time?

Ans: The time taken by an electron to travel from the cathode to the anode plate of an electron tube is known as transit time.

The transit time in repeller space is given by:

$$T = n + \frac{3}{4}$$

where n = any integer.

49. What is drift space?

Ans: The separation between buncher and catcher grids is called as drift space.

50. What are the high frequency effects in conventional tubes? (Nov.2011), (Apr.2015)

Ans: The high frequency effects in conventional tubes are:

1. Circuit reactance

- Inter electrode capacitance,
- Lead inductance,
- Transit time effect,
- Cathode emission,
- Plate heat dissipation area,
- Power loss due to skin effect, radiation and dielectric loss,

51. What is the velocity modulation and bunching in Klystron amplifier?

Ans:

(a) The variation in electron velocity in the drift space is called velocity modulation.

(b) The electrons passing the first cavity gap at zeros of the gap voltage pass through with unchanged velocity those passing through the positive half cycles of the gap voltage undergo an increase in velocity, those passing through the negative half cycles of gap voltage undergo an decrease in velocity. As a result of these, electrons bunch together in drift space is called bunching.

52. What is the purpose of slow wave structures used in TWT amplifiers?

Ans: Slow wave structures are special circuits that are used in microwave tubes to reduces wave velocity in a certain direction so that the electron beam and the signal wave can interact. In TWT, since the beam can be accelerated only to velocities that are about a fraction of the velocity of light, slow wave structures are used.

53. What is hull cut off condition?

Ans: In a magnetron, the electron will just graze the anode and return towards the cathode depends on V_0 and β_0.

The hull cut off magnetic equation is $B_{oc} = \frac{(8V_0 m/e)^{1/2}}{V_o}$

The hull cut off voltage equation is $V_{oc} = \frac{e}{8m} B_o^2 b^2 (1 - a^2/b^2)$

If $B_0 > B_{oc}$ for given V_o the electron will not reach anode.

If $V_0 > V_{oc}$ for given B_o, the electron will not reach the anode.

54. How are spurious oscillations generated in TWT amplifier? State the method to suppress it.

Ans:

- In a TWT, adjacent turns of the helix are so close to each other and hence oscillations are likely to occur.
- To prevent these spurious signals some form of attenuator is placed near the input end of the tube which absorbs the oscillations.

55. What is BWO?

Ans: A backward wave oscillator (BWO) is a microwave CW oscillator with an enormous tuning and overall frequency coverage range.

BWO are used as oscillators sources in radar applications.

56. What is frequency pulling and frequency pushing in magnetron?

Ans:

- Frequency pulling is caused by changes in the load impedance reflected into the cavity resonators.
- Frequency pushing is due to the change in anode voltage which alters the orbital velocity of the electron clouds.

57. What is π mode of operation?

Ans:

- In this mode of operation, the phase difference between adjacent anode poles is π rad or 180° so that self constant oscillations exist. $Q_n = \pi$.
- The bunching action of magnetron occurs and their bunching is known as "Phase focussing effect".

58. State the applications of BWO.

Ans:

- It can be used as signal source in instruments and transmitters.
- It can be used as broad band noise source which is used to confuse energy radar.

59. State the applications of TWT.

Ans:

- Low power, low noise TWT is in radar and microwave receiver.
- Laboratory instruments.
- Drivers for more powerful tubes.
- Medium and high power CWTWT's are used for communication and radar.

60. State the four types of TWTs.

Ans:
- Broadband, low noise, low level amplifier.
- CW power TWT
- Pulsed TWT
- Dual mode TWT.

61. What is rising sun structures?

Ans: An anode block with a pair of cavity systems of quite dissimilar shape and resonant frequency is called rising sun structure.

62. State the applications of magnetrons.

Ans: 1. Pulse work in radar, 2. Linear particle accelerators.

63. Give the drawbacks of Klystron amplifiers.

Ans:

- As the oscillator frequency changes then resonator frequency also changes and the feedback path phase shift must be readjusted for a positive feedback.
- The multicavity Klystron amplifier suffer from the noise caused because bunching is never complete and electrons arrive randomly at catcher cavity. Hence it is not used in receivers.

64. What is the condition for oscillation in reflex Klystron?

Ans: The necessary condition for oscillation is that the magnitude of the negative real part of the elctronic admittance should not be less than the total conductance of the cavity circuit.

(i.e.,) $|-G_e| \geq G$ where $= G = G_c + G_b + G_l = \frac{1}{R_{sh}}$

$R_{sh} \rightarrow$ effective shunt resistance, $G_c \rightarrow$ copper losses of cavity,
$G_b \rightarrow$ beam loading conductance, $|G_l| = 1 \rightarrow$ load conductance.

65. What are the applications of reflex Klystron?

Ans:

- Signal source in microwave generator.
- Local oscillators in receviers.
- It is used in FM oscillator in low power microwave links.
- In parametric amplifier as pump source.

66. How the Klystron amplifier can act as Klystron oscillator?

Ans: When the Klystron amplifier is given as positive feedback such that the overalll phase shift becomes zero or 360 and $|\beta A_V| = 1$, then Klystron amplifier acts as an oscillator.

67. What are the applications of Klystron amplifier?

Ans: • UHF TV transmitters, • Long range radar, • Linear particle accelerator, • Troposcatter links • Earth station transmitter.

68. What is the effect of transit time?

Ans: There are the two effects.

- At low frequencies, the grid and anode signals are no longer 180 out of phase, thus causing design problems with feedback in oscillators.
- The grid begins to take power from the driving source and the power is absorbed even when the grid is negatively biased.

69. What are the types of magnetrons?

Ans:
- Magnetrons using hole and slot,
- Magnetrons using vane,
- Magnetrons using rising for cavities,
- Voltage tunable magnetrons,
- Frequency angle magnetrons,
- Coaxial magnetrons,
- Inverted magnetrons.

70. Define phase focussing effect?

Ans: The bunching of electrons is known as phase focussing effect. This effect is important because without it favoured electrons will fall behind the phase change of electric fied across the gaps. Such electrons are retarded at each interaction with the RF field in magnetron.

71. What is meant by strapping?

Ans: The magnetron has eight or more coupled cavity resonators and hence several modes of oscillation are possible. The oscillating frequency of different modes are not same and are quite close the each other which results in mode jumping.

- This results in oscillations of reduced power at wrong frequency, to prevent this strapping is used.

- It consists of two rings of heavy gauge wire connecting alternating node poles which provides phase difference of 2π radians.

72. What are the advantages of TWT?

Ans: (a) Bandwidth is large, (b) High reliability, (c) High gain, (d) Constant performance is space, (e) Higher duty cycle.

73. Draw the equivalent circuit of reflect Klystron.

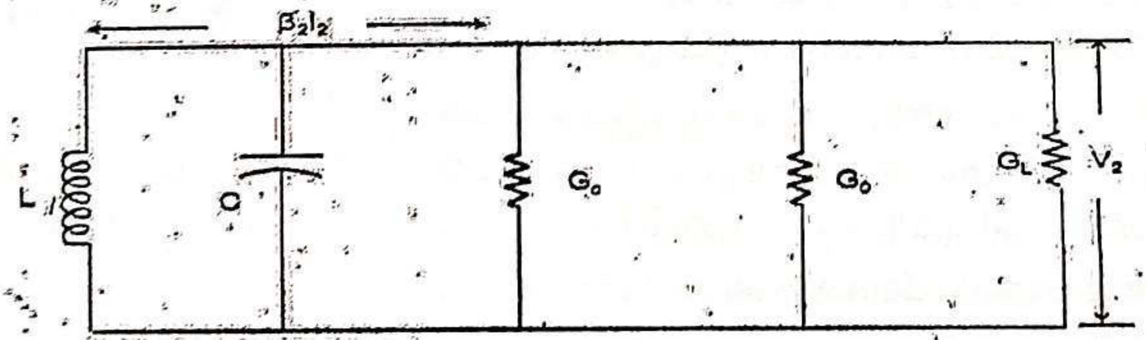


Fig.: Reflex Klystron

where L and C – energy storage element of cavity,

G_c – copper loss of cavity, G_B – beam loading conductance,

G_L – load conductance.

74. Draw the equivalent circuit of magnetron.

Ans:

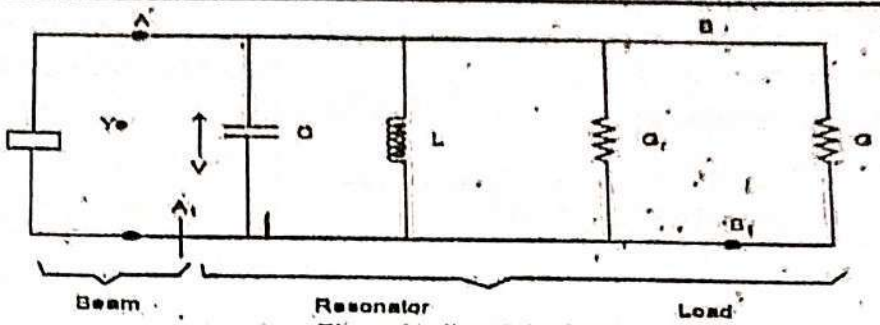


Fig. : Reflex Klystron

where γ_e – electron admittance,
V – RF voltage across the vane tips,
C – Capacitance at the vane tips,
L – Inductance of resonator.
G_r – Conductance of the resonator,
G_l – Load conductance per resonator.

75. Differentiate between TWT and Klystron Amplifier.

(Nov./Dec. 2013, 2014, 2011; April/May 2010)

Ans:

TWT	Klystron Amplifier
• The interaction of electron beam and RF beam in the TWT is continuous over the entire length of the circuit.	The interaction in Klystron amplifier occurs only in the gaps of few resonant cavities.
• The wave in TWT is propagating wave.	In Klystron amplifier, it is not a propagating wave.
• In coupled cavity TWT, there is coupling effect between the cavities.	Here each cavity in the Klystron operates independently.
• Wide band device.	Narrow band device.

76. Give some microwave sources.

Ans: (a) Klystron Amplifier,
(b) Reflex Klystron,
(c) Travelling wave tube,
(d) Magnetron.

77. Name some O-type tubes.

Ans: (a) Helix Travelling wave tube,
(b) Coupled cavity TWT,
(c) Forward wave amplifier,
(d) Backward wave amplifier,
(e) Backward wave oscillator.

78. Differentiate btewcen O-type tubes and M-type tubes. (Nov./Dec. 2012)

Ans:

O-Type Tubes	M-Type Tubes
• Linear beam tubes in which the accelerating electric field in same perpendicular to	Crossed field device where the static magnetic field is perpendicular to electric field.
• Electron beam travel in a straight line,	Electron beam travel in curved path.

79. Define Bunching.

Ans: The electrons passing the first cavity gap at zeros of the gap voltage pass through with unchanged velocity, these passing through positive half cycle of gap voltage under go an increase in velocity those passing through the negative half cycles of gap voltage under go an decrease in velocity. As a result of these, electrons bunch together in drift space. This is called bunching.

80. What are slow wave structure?

Ans: Slow wave structures are special circuits that are used in microwave tubes to reduce the wave velocity in a certain direction so that the electron beam and the signal wave can interact.

81. State the advantages of parametric amplifiers. (Nov./Dec. 2011, 2012)

Ans:

- Noise figure is very less because of minimum resistive elements.
- More stable.
- Bandwidth is small sue to tuned circuits and it can be increased by stagger tuning..

82. Compare PIN and PN diode. (Nov./Dec. 2016)

Ans:

PIN Diode	PN Diode
PIN diode is a heavily doped n-region separated by a layer	Doping is normal in both P and of high resistivity n sides.
Preferred semiconductors is silicon because of its power handling capacity.	Preferred semiconductors are germanium and silicon.

83. What is tetrodes and pentodes? (Nov./Dec. 2016)

Ans: Tetrodes contains cathode, two grids and an anode. Pentodes contain 5 elements, (i.e.,) cathode, 3 grids and anodes.

84. What is magnetron? (Nov./Dec. 2016)

Ans: Magnetron is a high power microwave oscillator. The magnetron magnetic field is used for producing oscillation at microwave frequencies. The magnetron is referred to as a crossed-field device.