Ch-6 - Multicavity Magnetron

Magnetron belongs to Cross-field tube type or M-type device. In Cross-field devices, the d.c magnetic field and d.c electric fields are perpendicular to each other. and the d.c magnetic field plays a direct role in the RF interaction process.

The electrons emitted by Cathode are accelerated by the electric field and gain velocity, but greater their velocity, the more their path is bent by the magnetic field.

Multicavity Magnetron :-

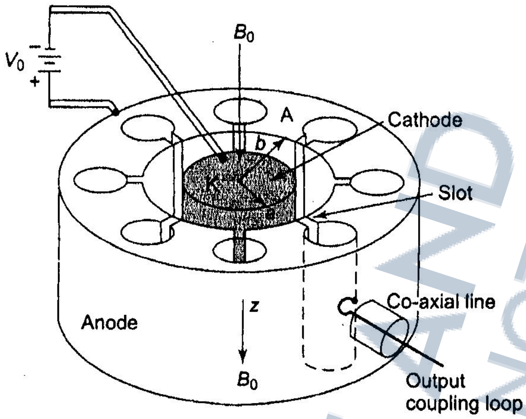
Magnetron is the first high power microwave source or oscillator. The multicavity magnetron (more generally magnetrons) are known as multicavity travelling wave magnetrons) are superior in performance and technically highly developed devices. The examples of different types of travelling-wave magnetrons are cylindrical magnetron, linear magnetron, Planar magnetron, Co-axial magnetron, voltage-tunable magnetron, inverted Co-axial magnetron etc.

→ Used to generate high MW power required in radar & Communication system.

→ Magnetron are Cross field tubes (M-type) in which the d.c magnetic field and d.c electric field are

Perpendicular to each other.

→ A high power microwave oscillator uses a traveling wave ~~tue~~ cylindrical magnetron tube as shown in fig 59 & 60.



59
Fig. 9.24 *Basic magnetron oscillator*

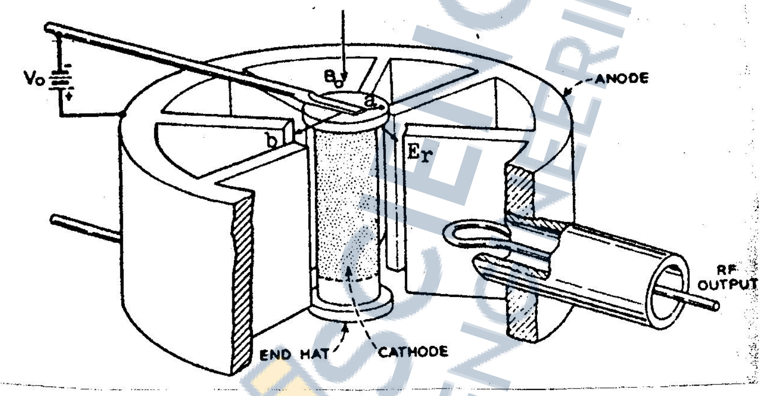


fig 60:- Interior view of magnetron

→ Magnetron consists of a cylindrical cathode 'K' of finite - length - radius 'a' at the center [fig 59] of surrounded by a cylindrical anode 'A' of radius 'b'.

The anode is a slow-wave structure consisting of several re-entrant cavities equispaced around the circumference and coupled together through the anode - cathode space by means of slots.

Radial electric field is established by d.c voltage

'V_0' in between the Cathode and the anode and an axial d.c magnetic flux density 'B_0' is maintained in the +ve Z- direction by means of a permanent magnet or an electromagnet.

Principle of operation:-

Magnetron theory of operation is based on the motion of electrons under the influence of combined electric and magnetic fields. In Fig 61, trajectories a', b', c', d' of the electrons are shown for different magnetic field strengths.

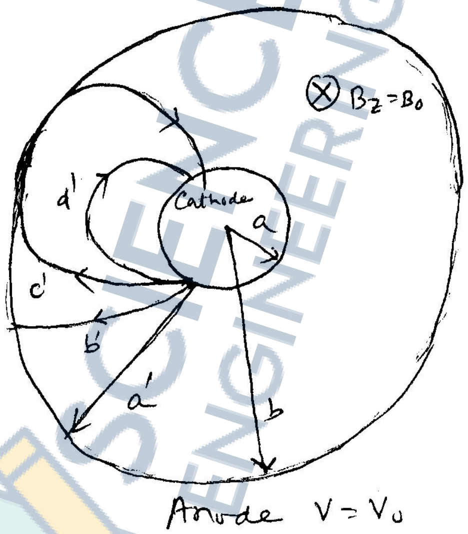


fig 61:- Electron trajectory

→ At zero magnetic field, the electron take the straight path a', by the influence of electric field only and collected by anode.

→ For a given 'V_0' if the magnetic field is increased, the electron take the curved path b' due to the force 'F' to reach the anode. [given by eqn (1)]

After emergence form the cathode with zero velocity (say), the electrons will acquire velocity 'v' having a tangential as well as radial components due to force 'F' exerted by cross fields E and H. ($B = \mu H$)

$$F = -eE - e(v \times B) \quad \text{(1)}$$

At a critical value of magnetic field B_c, (say), the electrons just graze the anode surface at radius 'b' and take the path c' to return to the cathode for a given voltage V_o. The value B_c is called cutoff magnetic field flux density. If the magnetic field is greater than B_c, all the electrons return to the cathode as shown by a typical path d' without reaching the anode.

Due to excitation of the anode cavities by RF noise voltage in the biasing circuit, RF field lines are fringed out of the cavity slot to the space between the anode and cathode. The accelerated electrons in the trajectory, when retarded by this RF field, transfer energy from the electron to the cavities to grow RF oscillations. When the system RF losses balance the RF oscillation energy, a stable oscillation is achieved. Output power is extracted through an external line coupled to the cavity.

Equations of Electron trajectory :-

The equations of motion for electrons in a cylindrical magnetron can be written with aid of eqn (2) & (3) as [In cylindrical co-ordinates (r, φ, z)]

$$\frac{d^2r}{dt^2} - r\left(\frac{d\phi}{dt}\right)^2 = \frac{e}{m}E_r - \frac{e}{m} r B_z \cdot \frac{d\phi}{dt} \quad (2)$$

$$\frac{1}{r}\left(\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right)\right) = \frac{e}{m} B_z \frac{dr}{dt} \quad (3)$$

where $\frac{e}{m} = 1.759 \times 10^{11} \frac{C}{kg}$ is the charge-to-mass ratio of the electron. and $B_0 = B_z$ is assumed in the +ve Z- direction.

Rearranging eqn (3),

$$\frac{d}{dt}\left(r^2\frac{d\phi}{dt}\right) = \frac{e}{m} B_z \cdot r \frac{dr}{dt} = \frac{1}{2} w_c \frac{dr^2}{dt} \quad (4)$$

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

where $\boxed{w_c = \frac{e}{m} B_z}$ — (4A), is the cyclotron angular frequency.

Integrating eqn (4), we have

$$\int d\left(r^2\frac{d\phi}{dt}\right) = \frac{1}{2} w_c \int d(r^2)$$

$$\Rightarrow \quad r^2 \frac{d\phi}{dt} = \frac{1}{2} \omega_c r^2 + \text{constant} \quad \text{--- (5)}$$

At $r = a$, where 'a' is the radius of the cathode cylinder, and $\frac{d\phi}{dt} = 0$.

Putting this condn in eqn (5), we have

$$\Rightarrow \quad 0 = \frac{1}{2} \omega_c a^2 + \text{Constant}$$

$$\Rightarrow \quad \text{Constant} = -\frac{1}{2} \omega_c a^2$$

$\therefore$ Eqn (5) becomes,

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

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

$\therefore$ Angular velocity is expressed as,

$$\boxed{\frac{d\phi}{dt} = \frac{1}{2} \omega_c \left(1 - \frac{a^2}{r^2}\right)} \quad \text{--- (6)}$$

The kinetic energy of the electron is given by,

$$\frac{1}{2} m v^2 = e V_0 \quad \text{--- (7)}$$

However, the electron velocity has r and ϕ components such as

$$v^2 = v_r^2 + v_\phi^2 = \left(\frac{dr}{dt}\right)^2 + \left(r \frac{d\phi}{dt}\right)^2 = \frac{2eV_0}{m} \quad \text{--- (8)}$$

At $r = b$, where 'b' is the radius from the centre of the cathode to the edge of the anode,

$\frac{dr}{dt} = 0$ (Radial velocity = 0), when the electrons just graze the anode.

$\therefore$ Eqn (6) & (8) becomes,

$$\frac{d\phi}{dt} = \frac{1}{2} \omega_c \left(1 - \frac{a^2}{b^2}\right) \quad \text{——— (9)}$$

$$b^2 \left(\frac{d\phi}{dt}\right)^2 = \frac{2eV_0}{m} \quad \text{——— (10)}$$

Substituting eqn (9) into eqn (10), we have

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

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

$$\Rightarrow \frac{1}{2} \omega_c \left(1 - \frac{a^2}{b^2}\right) = \sqrt{\frac{2eV_0}{b^2 m}}$$

$$\Rightarrow \omega_c = \frac{2\sqrt{\frac{2eV_0}{b^2 m}}}{\left(1 - \frac{a^2}{b^2}\right)}$$

$$\Rightarrow \sqrt{\frac{e}{m}}\, \cancel{\frac{e}{m}}\, B_z = \frac{2\sqrt{\frac{2eV_0}{b^2 m}}}{\left(1 - \frac{a^2}{b^2}\right)} = \frac{\sqrt{8} \cdot \cancel{\sqrt{\frac{e}{m}}} \cdot \frac{\sqrt{V_0}}{b}}{\left(1 - \frac{a^2}{b^2}\right)}$$

$\left(\because \omega_c = \frac{e}{m} B_z \text{ from eqn } 4(A)\right)$

$$\Rightarrow B_z = \frac{\sqrt{\frac{8 m V_0}{e}}}{b\left(1 - \frac{a^2}{b^2}\right)} \quad \text{——— (11)}$$

The electron will acquire a tangential as well as radial velocity. For a given V_0, The magnetic flux density for which electron will just graze the anode and return towards the Cathode [Curve c'' on fig 61] is known as cutoff magnetic flux density. The Hull cutoff magnetic eq^n obtained from eq^n (11) as

$$\boxed{B_{0c} = \frac{\left(8 V_0 \frac{m}{e}\right)^{\frac{1}{2}}}{b\left(1-\frac{a^2}{b^2}\right)}} \quad (12)$$

Conversely, for a given magnetic flux density B_0, the d.c voltage for which electron will just graze the anode and return towards the Cathode is known as cutoff voltage. The Hull cutoff voltage eq^n obtained from eq^n (11), as

$$\boxed{V_{0c} = \frac{e}{8m} B_0^2 b^2 \left(1-\frac{a^2}{b^2}\right)^2} \quad (13)$$

→ From eq^n (12), it is clear that if $B_0 > B_{0c}$, for a given V_0, the electron will not reach the anode and return to the Cathode [Curve d' on fig 61].

→ From eq^n (13), it is clear that if $V_0 < V_{0c}$ for a given B_0, the electron will not reach the anode.

Ex -1 Liao Book

An X-band pulsed cylindrical magnetron has the following operating parameters:

Anode voltage = 26 kV (V_0)

Beam current (I_0) = 27 A

Magnetic flux density (B_0) = 0.336 $\frac{Wb}{m^2}$

Radius of Cathode cylinder (a) = 5 cm

Radius of Vane edge to the center (b) = 10 cm

Compute

(a) Cyclotron angular freq

(b) The cutoff voltage for a fixed B_0

(c) The cutoff magnetic flux density for a fixed V_0

Ans :- From eqn 4(A), cyclotron angular freq

$$W_c = \frac{e}{m} B_0$$

$$= (1.759 \times 10^{11}) \times 0.336$$

(a) $$W_c = 5.91 \times 10^{10} \text{ rad}$$

(b) The cutoff voltage for a fixed B_0 is

$$V_{0c} = \frac{1}{8} \times \frac{e}{m} \times B_0^2 b^2 \left(1 - \frac{a^2}{b^2}\right)^2$$

$$= \frac{1}{8} \times 1.759 \times 10^{11} \times (0.336)^2 \times (10 \times 10^{-2})^2 \times \left(1 - \left(\frac{5}{10}\right)^2\right)^2$$

$$= \frac{1}{8} \times 1.759 \times (.336)^2 \times \frac{9}{16} \times 10^9$$

$\Rightarrow \quad V_0 = 139.62 \times 10^{-4} \times 10^{9}$

$\Rightarrow \quad \boxed{V_0 = 139.62 \times 10^{5}\ V}$

[Check the ans But in Book = 139.62 kV]

(c) The cutoff magnetic flux density for a fixed V_0 is

$$B_0 = \frac{\left(8 V_0 \frac{m}{e}\right)^{\frac{1}{2}}}{b\left(1 - \frac{a^2}{b^2}\right)}$$

$$\Rightarrow \quad B_0 = \frac{\sqrt{8 \times 26 \times 10^{3} \times \frac{1}{1.759 \times 10^{11}}}}{10 \times 10^{-2} \sqrt{\left(1 - \left(\frac{5}{10}\right)^2\right)}}$$

$$= \frac{\sqrt{118.24 \times 10^{-8}}}{10^{-1} \times \left(\frac{3}{4}\right)}$$

$$= \frac{10.87 \times 10^{-4} \times 4}{10^{-1} \times 3}$$

$B_0 = 14.498 \times 10^{-3}$

$\Rightarrow \quad \boxed{B_0 = 14.498\ \frac{mWb}{m^2}}$

Cyclotron Angular frequency:-

Since the magnetic field is normal to the motion of electrons that travel in a cycloidal path, the outward centrifugal force is equal to the pulling force. Hence

$$\frac{mv^2}{R} = evB$$

where R = radius of the cycloidal path.

v = tangential velocity of the electron.

The cyclotron angular freq of the circular motion of the electron is then given by,

$$\omega_c = \frac{v}{R} = \frac{eB}{m} \quad -(15) \qquad \left[\because \frac{mv^{\cancel{2}}}{R} = e\cancel{v}B \Rightarrow \frac{v}{R} = \frac{eB}{m} \right]$$

Resonant Modes in a Magnetron:-

The nature of field distribution in the magnetron cavities is such that the alternating RF magnetic flux lines pass through the cavities parallel to the cathode axis, and the alternating RF electric fields are concentrated across the slot and fringe out to the interaction space between the anode & cathode, in the transverse direction.

Since the slow-wave structure is closed on it self, the total phase shift around the internal periphery must be an integral multiple of '2π' for possible oscillations. The phase shift between two adjacent cavities is given by

$$\phi_n = \frac{2\pi}{N} n \quad \text{--- (16)}$$

N = No of cavities.

where $n = \pm 1, \pm 2, \pm 3, \ldots, \pm \frac{N}{2}$ indicates the n^{th} mode of oscillation.

Imp → Magnetrons are ordinarily operated on the π-mode.

ie

$$\phi_n = \pi \quad (\pi\text{-mode})$$

This occurs when $n = \frac{N}{2}$.

e.g if a magnetron having 8-cavities.

$N = 8$, $n = \frac{N}{2} = \frac{8}{2} = 4$.

$$\phi_n = \frac{2\pi}{8} \times 4 = \pi$$

Since the phase difference between two successive cavities is 'π', excitation is max^m in the cavities.

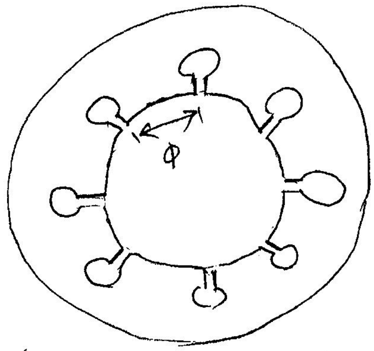


fig 6.2: Inside view of 8-cavity magnetron.

Note:- Net phase shift of 8 cavities = 8π, which is multiple of 2π.

Fig 63:- Shows the lines of force in the π-mode of an eight-cavity magnetron. It is evident that in the π-mode the excitation is large in the cavities, having opposite phase in successive cavities.

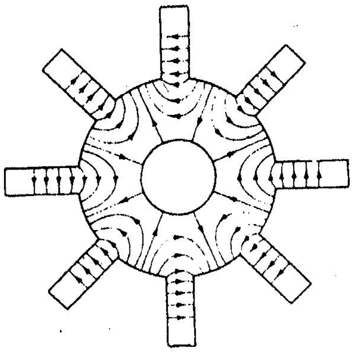


Figure ~~10-1-3~~ 63 Lines of force in π mode of eight-cavity magnetron.

→ The successive rise and fall of adjacent anode-cavity fields may be regarded as a travelling wave along the surface of the slow-wave structure. For the energy to be transferred from the moving electrons to the travelling field, the electrons must be deaccelerated by ~~flux~~ a retarding field when they pass through each anode cavity.

→ If 'L' is the mean separation between cavities, the phase constant of the fundamental mode field is given by

$$\beta_0 = \frac{2\pi n}{NL} \quad \text{—(17)}$$

{ Note:- In Transmission line we have $\tan \beta \ell$
$\therefore \beta \ell = \text{Angle}$
$\Rightarrow \beta = \frac{\text{Angle}}{\ell} = \frac{\phi}{L}$

Here $\phi = \frac{2\pi n}{N}$

...e traveling field of the fundamental mode ...avels around the structure with angular velocity

$$\frac{d\phi}{dt} = \frac{\omega}{\beta_0} \quad \text{--- (18)}$$

Note:— In Rectangular wave guide Phase velocity $u = \frac{\omega}{\beta}$

When the cyclotron frequency of ...e electrons is equals to the angular frequency ... the field, the interaction between the field and electron occures and energy is transferred.

$$\omega_c = \omega$$

$$\Rightarrow \boxed{\omega_c = \beta_0 \frac{d\phi}{dt}} \quad \text{--- (19)}$$

[From eqn 18]

where $\omega_c = \frac{eB}{m}$ from eqn (15)

...ower o/p & efficiency of Magnetron

A magnetron can deliver a peak power o/p up to 40 MW with d.c voltage of 50 KV ... 10 GHZ. The average power o/p is of ...e order of 800 KW.

The magnetron possesses a very high ~~frequency~~ efficiency ranging from 40 to 70%.

Magnetrons are commercially available for peak power output from 3 KW and higher.

Traveling - Wave Tubes (TWT) (Liao Book)

→ Kompfner invented helix TWT in 1944.

→ Broadband appln → Helix TWT used.

→ High-avg-power purpose such as radar transmitters Coupled-cavity TWT are used.

→ Comparison of operating principle of TWT & Klystron

→ In case of TWT, the MW ckt is non resonant and wave propagates with same speed as the electrons in the beam. The initial effect on the beam is a small amount of velocity modulation caused by weak electric fields associated with traveling wave.

But in case of Klystron, this velocity modulation later translates to current modulation, which then induces RF current in the ckt, causing amplification.

Major difference betn Klystron & TWT

1. The interaction of electron beam and RF field in the TWT is continuous over the entire length of the circuit, but the interaction in Klystron occures only at the gap of a few resonant cavities.

2. The wave in the TWT is a propagating wave; the wave in the Klystron is not propagating.

3. In the Coupled-cavity TWT there is a coupling

effect betn the cavities, where as each cavity in the klystron operates independently.

4. In case of TWT, the microwave circuit is non resonant, but in case klystron it is resonant.

Principle of operation :-

→ A helix TWT consist of an electron beam and a slow-wave-structure. The electron beam is focused by a constant magnetic field along the electron beam & the slow-wave structure. [see fig 64]

→ This is termed as O-type travelling-wave tube. The slow-wave structure is either helical type or folded-back line. The applied signal propagates around the turns of the helix and produces an electric field at the center of the helix, directed along the helix axis.

→ The axial electric field progresses with a velocity that is very close to the velocity of light multiplied by the ratio of helix pitch to helix circumference $\left(\frac{p}{\pi d}\right)$ when the electrons enter the helix tube, an interaction takes place between the moving axial electric field and the moving electrons.

→ On the average, the electrons transfer energy to the wave on the helix. This interaction causes the signal wave on the helix to become larger. The electrons entering the helix at zero field are not affected by the signal wave; those electrons entering the helix

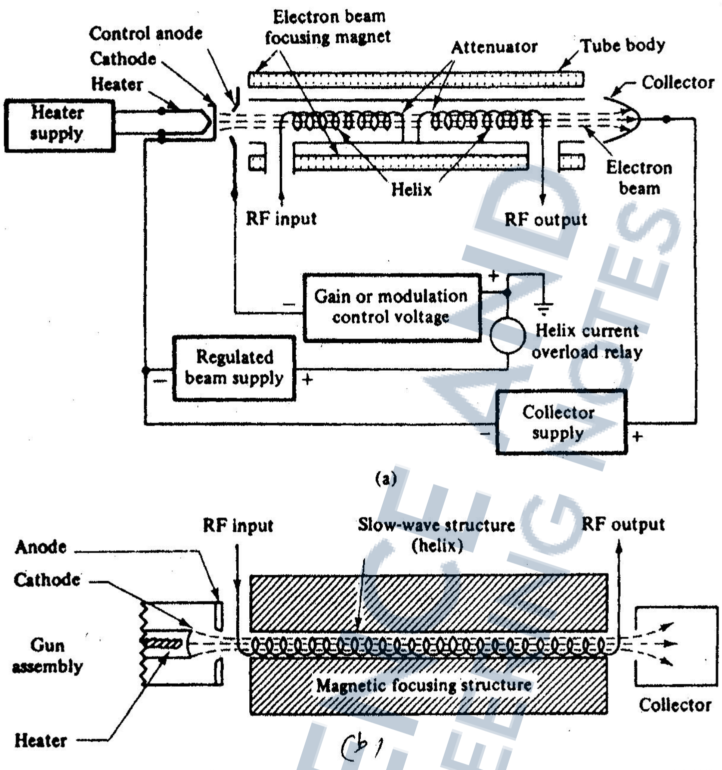


fig 64:- Diagram of helix TWT : (a) Schematic diagram of helix TWT
(b) simplified ckt.

→ at the accelerating field are accelerated [Fig 68] and those at the retarding field are deaccelerated

As the electrons travel further along the helix, they bunch at the collector end. [Fig 64]

→ The bunching shift the phase by $\frac{\pi}{2}$.

Each electrons in the bunch encounters a stronger retarding field. Then the MW energy of the electrons is delivered by the electron bunch to the wave on the helix. The amplification of the

Signal wave is accomplished.

Characteristics of TWT

Freq Range - 3 GHz and higher

Band width - about 0.8 GHz

Efficiency - 20 to 40 %

Power o/p - up to 10 kW average

Power gain - up to 60 dB.

Slow-Wave Structures

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. Different types of slow-wave structure is shown below.

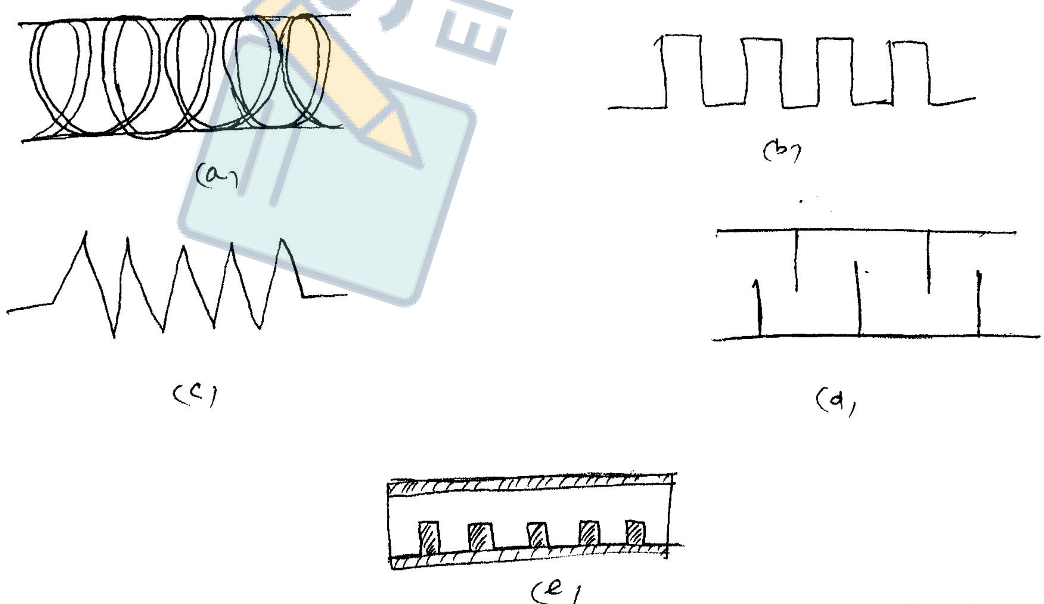
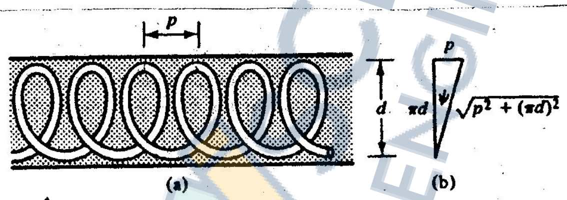


fig 65: Slow-wave structures (a) Helical type (b) Folded-back line (c) Zig-Zag line (d) Interdigital line (e) Corrugated waveguide.

The Phase velocity of the wave in ordinary waveguide is greater than the velocity of light in a vacuum. $\left[V_p = \frac{c}{\sqrt{1-(\frac{f_c}{f})^2}} \right]$

In the operation of travelling-wave and magnetron-type devices, the electron beam must keep in step with microwave signal. Since the electron beam can be accelerated only to to velocities that are about a fractions of the velocity of light, a slow-wave structure must be incorporated in the microwave devices so that the phase velocity of the MW signal ~~mus~~ can keep pace with that electron beam for effective interactions.

→ The commonly used slow-wave structure is a helical coil with a concentric conducting cylinder. [fig 6.6]



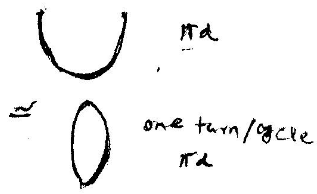


Figure 6.6 Helical slow-wave structure. (a) Helical coil. (b) One turn of helix.

→ It can be shown that the ratio of phase velocity V_p along the pitch to the phase velocity along the coil [Along the coil signal travels with velocity of light] is given by

$$\frac{V_p}{c} = \frac{p}{\sqrt{p^2+(\pi d)^2}} = \sin\psi \quad -(1)$$

$\because$ $\sin\psi = \frac{V_p}{c}$
and $\sin\psi = \frac{p}{\sqrt{p^2+(\pi d)^2}}$

where

c = 3×10^8 m/sec

p = helix pitch

d = diameter of the helix

ψ = pitch angle

→ In general, the helical core may be within a dielectric-filled cylinder. The phase velocity in the axial direction is expressed as,

$$V_{pe} = \frac{p}{\sqrt{\mu\epsilon\,[p^2+(\pi d)^2]}} \quad -(2)$$

$\because$ From eqn (1)
$v_p = \frac{p.c}{\sqrt{p^2+(\pi d)^2}}$
and $c = \frac{1}{\sqrt{\mu\epsilon}}$

→ If pitch angle is very small,

$$p << \pi d$$

$$p^2 << (\pi d)^2$$

The phase velocity along the ~~coil~~ pitch in free space is approximately represented by,

$$\frac{V_p}{c} \simeq \frac{p}{\pi d}$$

{ from eqn (1)
$\because p^2 << (\pi d)^2$

$$\Rightarrow V_p \simeq \frac{pc}{\pi d} = \frac{\omega}{\beta} \quad -(3)$$

($\because V_p = \frac{\omega}{\beta}$ As studied in rectangular wave guide)

V. imp Amplification Process :- (BPUT 2010, 2012)

A Schematic diagram of a helix-type traveling-wave tube is shown in fig 67.

→ Write Principle of operation in page 307.

→ The motion of electrons in the helix type TWT can

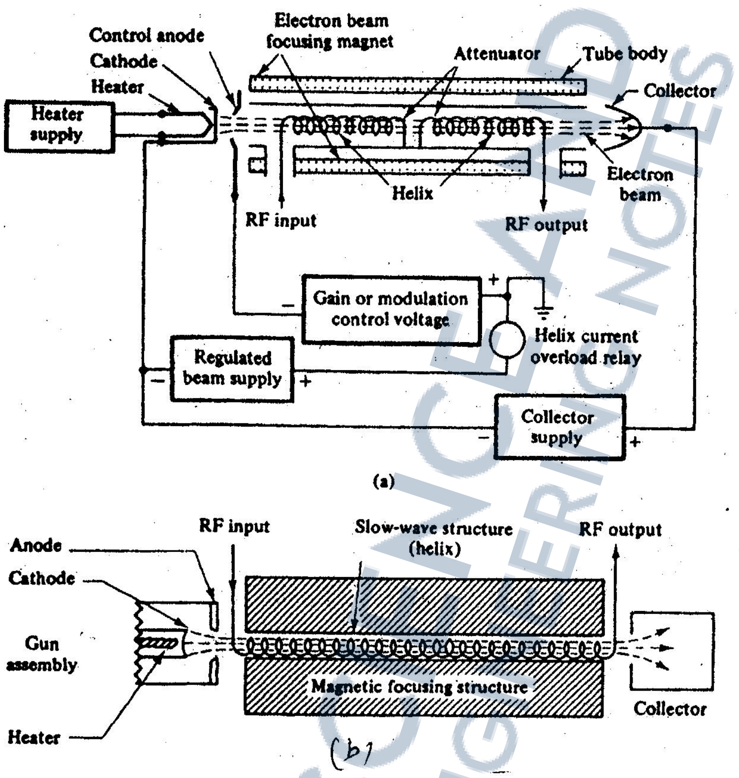


fig 67:- Diagram of helix TWT : (a) Schematic diagram of helix TWT (b) Simplified ckt.

be quantitatively analyzed in terms of the axial electric field. If the traveling wave is propagating in the Z-direction, the Z-component of the electric field can be expressed

$$E_z = E_1 \sin(\omega t - \beta_p z) \quad \text{——} \quad (4)$$

...re E_1 is the magnitude of the electric ...ld in the Z-direction. If $t = t_0$, at $z = 0$, the electric field is assumed maximum.

$\beta_p = \frac{\omega}{v_p}$ = is the axial phase constant of the microwave

v_p = axial phase velocity of the wave.

The axial electric field exerts a force on the electrons

$$F = (-e).E_z = (-e)\left[E_1 \sin(\omega t - \beta_p z)\right] \quad (5)$$

But

$$F = ma = m.\frac{dv}{dt} \quad (6)$$

Equating (5) & (6)

$$m\frac{dv}{dt} = -e E_1 \sin(\omega t - \beta_p z) \quad (7)$$

Assume that velocity of electron is

$$v = v_0 + v_e \cos(\omega_e t + \theta_e) \quad (8)$$

where

v_0 = d.c electron velocity

v_e = magnitude of velocity fluctuation in the velocity-modulated electron beam

ω_e = angular freq of velocity fluctuation.

θ_e = phase angle of the fluctuations.

Then

$$\frac{dv}{dt} = -v_e \omega_e \sin(\omega_e t + \theta_e) \quad (9)$$

Putting eqn (9) in eqn (7), we have

$$m.\left[-v_e \omega_e \sin(\omega_e t + \theta_e)\right] = -e E_1 \sin(\omega t - \beta_p z)$$

$$\Rightarrow m v_e \omega_e \sin(\omega_e t + \theta_e) = e E_1 \sin(\omega t - \beta_p z) \quad (10)$$

For interaction between electrons and the electric field, the velocity of the ~~electron~~ velocity-modulated electron beam must be approximately equal to the d.c electron velocity.

$$v \simeq v_0 \qquad \text{--- (11)}$$

Hence the distance z travelled by the electron is

$$z = v_0 (t - t_0) \qquad \text{--- (12)}$$

and eq^n (10) becomes,

$$m v_e w_e \sin(w_e t + \theta_e) = e E_1 \sin[wt - \beta_p (v_0 (t - t_0))]$$

$$\Rightarrow m v_e w_e \sin(w_e t + \theta_e) = e E_1 \sin[(w - \beta_p v_0)t + \beta_p v_0 t_0] \qquad \text{--- (13)}$$

Comparing left and right hand side of eq^n (13), we have

$$m v_e w_e = e E_1$$

$$\Rightarrow v_e = \frac{e E_1}{m w_e} \qquad \text{--- (14)}$$

$$w_e = w - \beta_p v_0 \qquad \text{--- (15)}$$

$$= \cancel{\beta_p v_p - \beta_p v_0} \qquad \left[\because \beta_p = \frac{w}{v_p}\right]$$

$$= \beta_p v_p - \beta_p v_0$$

$$\Rightarrow w_e = \beta_p (v_p - v_0) \qquad \text{--- (16)}$$

and

$$\theta_e = \beta_p v_0 t_0 \qquad \text{--- (17)}$$

It can be seen that the magnitude of velocity fluctuation (V_e) of the electron beam is directly proportional to the magnitude of the wave electric field.

Note :- The electrons entering the retarding field are deaccelerated and those in the accelerating field are accelerated. They begin forming a bunch

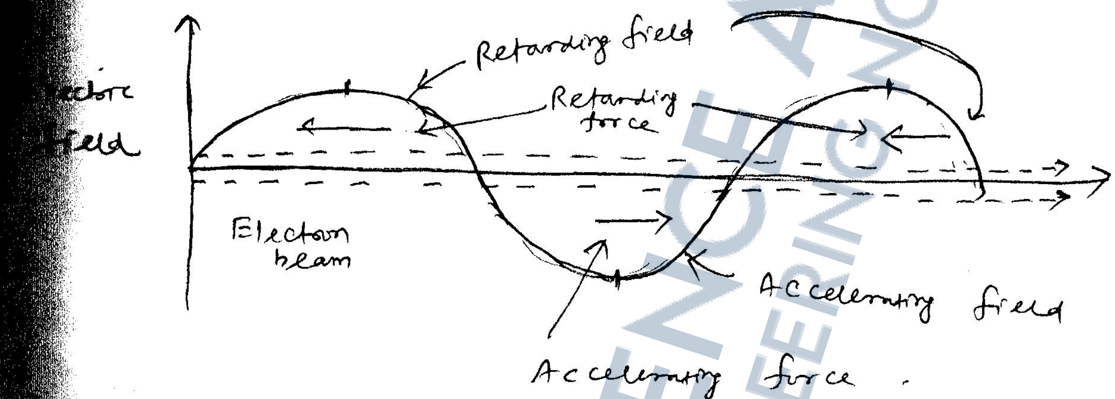


Fig 68 :- Interaction between electron beam & electric field

centered about those electrons that enter the helix during the zero field.

Since the d.c velocity of the electrons is slightly greater than the axial wave velocity, more electrons are on the retarding field than on the accelerating field and a great amount of energy is transferred from the beam to the e-m field.

The MW signal voltage is, in turn amplified by the amplified field. The bunch continues to become more compact and a larger amplification of the signal voltage occures at the end of the helix. The magnet produces an axial magnetic field to prevent spreading of the electron beam as it travels down the tube.

An attenuator placed near the center of the helix, to attenuate any reflected wave generated ~~during~~ due to impedance mismatch that could ~~cause~~ be fed back to the i/p to cause oscillations.

Klystron Amplifier	TWT Amplifier
1) Linear beam or 'O' type device	1) Linear beam or 'O' type device
2) Electric field is stationary only e-beam travels.	2) Electric field travels along the electron beam
3) Interaction of e-field & e-beam ~~is conti~~ takes place only at the gap of few resonant cavities.	3) The interaction of e-field & e-beam takes place over the entire length of the ckt.
4) The wave (i/p) is not propagating.	4) The wave (i/p) in TWT is propagating
5) Use resonant MW ckts	5) Use non-resonant MW ckts.
6) Narrowband device due to resonant cavities.	6) wideband device because of non-resonant wave circuits.

(Appl^n) of TWT :-

1) TWT amplifiers are used in medium-power (Satellite) and high-power satellite transponder ~~o/p~~ o/p.

2) Repeater amplifier in wideband Comm^n line.

3) ~~Ex~~ Used in Radar transmitter.

(For) Problems :-

The o/p Power gain in dB is defined as

$$\boxed{A_p} = 10 \log \left| \frac{\text{o/p voltage}}{\text{i/p voltage}} \right|^2 = \boxed{-9.54 + 47.3\,NC}$$

The first term -9.54 dB represents a loss. ~~due to the fact that~~

$$N = \frac{l}{\lambda_e}$$

l = length of slow-wave structure in meter.

N = circuit length in electronic wavelength. [N = How many multiple of λ_e]

$$\lambda_e = \frac{2\pi}{\beta_e}$$

$\beta_e = \frac{\omega}{u_0}$, $u_0 = \sqrt{\frac{2eV_0}{m}}$

The factor 'C' is the gain parameter of the circuit defined by

$$\boxed{C = \left(\frac{I_0 Z_0}{4 V_0}\right)^{\frac{1}{3}}}$$

I_0 = d.c beam current

V_0 = ~~s~~ d.c beam voltage

Z_0 = Characteristic impedance of the helix.

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Ex-1 :- A TWT has the following characteristics. Beam voltage $V_0 = 3\,kV$, Beam current $I_0 = 30\,mA$, $Z_0 = 10\,\Omega$, Circuit length $N = 50$, freq $(f) = 10\,GHz$.

Determine (a) The gain parameter (C)

(b) Power gain in dB.

Ans → (a) $C = \left(\dfrac{I_0 Z_0}{4V_0}\right)^{\frac{1}{3}}$

$$= \left(\frac{\cancel{30}^{10} \times 10^{-3} \times 10}{4 \times \cancel{3} \times 10^{3}}\right)^{\frac{1}{3}}$$

$$= (25)^{\frac{1}{3}} \times 10^{-2}$$

$$\boxed{C = 2.92 \times 10^{-2}}$$

(b) $A_p = -9.54 \cancel{NC} + 47.3\,N.C$

$$= -9.54 + (47.3)(50)(2.92) \times 10^{-2}$$

$$= -9.54 + 69.058$$

$$\boxed{A_p = 59.518\ dB}$$

— o —

be

e

p.

th